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of Science and Technology

AN INTERNATIONAL REFERENCE WORK

IN FIFTEEN VOLUMES INCLUDING AN INDEX

VOLUME 2 BAB CET



(LEFT) Alpha beta titanium water quenched from 1400°F Specimen was electrolytically polished then etched in a 1% hydrofluoric acid solution Magnification 100X *(photograph by W C Coons, Curtiss Wright Corp)* (RIGHT) The wake of a model propeller at best rate of climb *(photograph by F N M Brown)*

McGRAW HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY
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Suggestions to the Readers

The basic plan of the Encyclopedia is explained here in order to facilitate its use

The subject matter of the various disciplines or branches of science and technology is organized systematically a general article provides a broad survey of the field and a number of separate articles alphabetically arranged cover its main subdivisions and more specific aspects

Cross references guide the reader from the general articles to the other articles into which the subject is subdivided and from these to articles on more highly specialized phases of the subject The cross references—there are about 50 000 of them—are printed in small capital letters so that they can be easily recognized By means of the cross references a reader may find his way from ELECTRICAL ENGINEERING through ELECTRONICS and VACUUM TUBE to ELECTRON MOTION IN VACUUM or ELECTRON EMISSION Or following another line of cross references the reader would be led to ELECTRIC POWER SYSTEMS TRANSMISSION LINES ELECTROMAGNETIC WAVE and so on

In general, each article begins with a definition of the title that states its scope and coverage Usually only the scientific or technological sense is discussed Most of the articles after this statement go on to increasingly complex and detailed considerations A reader thus needs to proceed only as far as his inclinations and requirements dictate

The Index Volume 15 should be consulted to locate the discussion of topics covered in the Encyclopedia but not given in separate entries

Every phylum class and order in the plant and animal kingdoms is allotted a separate article Many of the more common families genera and species are covered either in one of the order articles or in a separate article under its own scientific or common name

The adjectives electric and electrical are used in the following senses Electric—containing producing arising from actuated by or carrying electricity or capable of doing so as for instance electric generator electric motor electric wiring Electrical—related to pertaining to or associated with electricity but not having its properties or characteristics as for example electrical code electrical engineering

Words used as titles are wherever possible given in the singular to permit a consistent alphabetic arrangement Titles are alphabetized by word and not by letter for example

Earth sciences
Earth tides
Earthmover
Earthquake

A word used as a noun precedes the same word used adjectivally thus

Mercury (element)
Mercury (planet)
Mercury battery

or

Circuit, electronic
Circuit breaker

Hyphened terms are alphabetized as single words for example

Animal virus
Animal-feed composition

Most of the longer articles contain bibliographies citing useful sources of further information For additional bibliographical citations the reader should refer to related articles (as indicated by the cross references in the article) Bibliographies are placed at the ends of articles or sometimes at the ends of major sections in long articles

A list of initials and names of the contributors to the Encyclopedia is to be found in Volume 15 This list will permit quick identification of a contributor's initials after an article Immediately following this list is a second list of encyclopedia contributors with their affiliations and the titles of articles each has written for the Encyclopedia

McGraw-Hill Encyclopedia of Science and Technology

Baboon

Any of several African monkeys of the family Cercopithecidae, characterized by doglike heads and quadrupedal gait, the fore and hind legs being of almost equal length Most baboons live in rocky areas, where troops of 12–50 individuals defend themselves against even the largest of the predatory animals. They are of vicious disposition and are



The baboon (*From P Martin Duncan, ed , Cassell's Natural History, Cassell & Company, Ltd , London*)

armed with large sharp canine teeth They are omnivorous and in some areas are highly destructive to farm crops Baboons vary greatly in color, from yellow or reddish gray to almost black Some species have an 18 in tail, others only a rudiment *See* PRIMATES [J D B]

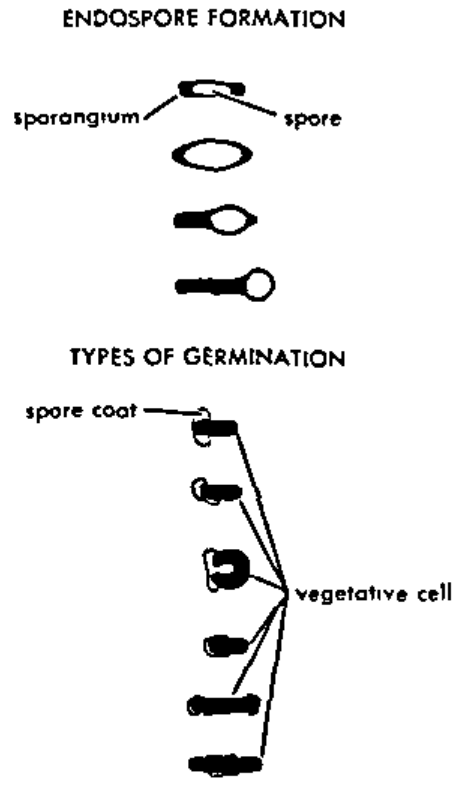
Bacillaceae

The family of the rod shaped, sporeforming bacteria in the order Eubacteriales Species in this family range from organisms used in retting flax to those pathogenic for animals and man, such as anthrax (*see* ANTHRAX) The special features of the group are largely associated with spore production The spore is formed within the vegetative cell and is therefore of the type known as an endospore Its outstanding property is a capacity to tolerate conditions which destroy the vegetative stage (*see* BACTERIAL ENDOSPORES) The Bacillaceae are divided into two genera, *Bacillus*, organisms capable of aerobic growth, and *Clostridium*, those that require anaerobic conditions

Sporulation. This usually occurs only at the end of a period of vegetative multiplication A vegetative cell produces only one spore As the spore matures, it becomes impermeable to aqueous dyes and may thus be recognized in a stained sporangium The shape and size of the spore and its position in the rod are characteristics of species When a spore has matured it is liberated by the dissolution of the remnant of its parent cell

Endospore properties. The endospore is distinguished from the vegetative cell by its much lower water content its greater refractive index, and its exceptional resistance to destructive agencies such as desiccation, heat, or disinfectants In heat resistance, there is a wide variation among species Some spores are destroyed in water at 90°C in a few minutes, the most resistant will survive at 100°C in water or steam for periods longer than 24 hours

Spore germination. Spore germination is provoked by a suitable food supply In this event the



Variations in the shape, size, and site of formation of endospores and in the germination into cells

spore absorbs water loses its refractile character becomes stainable with aqueous dyes and loses its heat resistance A vegetative rod then breaks out of the spore coat by one of the methods shown in the illustration and the young cell proceeds to multiply by fission In the case of several species single substances such as L alanine or glucose stimulate spore germination as effectively as a complete nutrient mixture Such germination stimulants have the remarkable effect of compelling the spore to germinate although the environment may be lethal to the vegetative form

Bacillus This genus comprises the organisms that grow aerobically Some of them are capable of anaerobic growth if they are supplied with a fermentable sugar or with nitrate The species show much diversity in temperature requirements some being thermophiles capable of growth above 70°C

Other characters by which the species may be recognized are the morphology at the time of spore formation and biochemical features such as action on proteins and ability to produce acid acid and gas or acetoin from sugars Organisms of this genus often come into prominence in the processing of foods where heat treatments eliminate nonsporing bacteria The spores of *B subtilis* and of the thermophile *B stearothermophilus* are extremely resistant to heat One species *B anthracis* is the causative agent of anthrax Other species are pathogenic for the larvae of the honeybee or other insects

Clostridium This genus comprises a group of strictly anaerobic species Their vegetative cells are easily killed by oxygen yet they frequently multiply in nature because aerobes afford them protection The species differ in microscopical character and temperature requirements (some being thermophiles) and they show wide variations in chemical activity Some ferment carbohydrates to a variety of products which in many cases include butyric acid Others digest proteins actively and ferment the amino acids so produced Still other species effect more specialized fermentations Among the useful activities of clostridia are the retting of flax and other fiber producing plants the acetone-butanol fermentation of *C acetobutylicum* and related organisms and the fixation of nitrogen by *C pasteurianum* On the other hand the action of these organisms on foods is invariably destructive and several species are pathogenic for man or animals For example *C botulinum* produces an exotoxin which is neurotoxic for man and animals if injected or if ingested in food

Ecology All Bacillaceae appear to have the same mode of life A large reserve of dormant spores occurs in nature principally in soil Many of the spores are possibly of great age especially in the case of organisms such as thermophiles which only rarely meet conditions suitable for growth If a spore is induced to germinate by the presence of food material rapid multiplication may occur When the food supply is exhausted spores may again be formed and they join the natural reserve The short multiplication phase becomes possible in the refuse of plant and animal life in foods in the bowel of the animal in the case of clostridia and in the tissues of animals in the case of pathogenic species *See* BLACKLEG BOTULISM TETANUS [T G]

Bacillary dysentery

A highly infectious disease of man localizing in the bowels The disease occurs sporadically or in epidemics under unsanitary conditions It is also called shigellosis from the generic name of the causative agent the dysentery bacilli *Shigella* (*see* SHIGELLA) The *Shigellae* enter the body with food or water contaminated by fecal matter unclean hands or flies

The incidence of bacillary dysentery is high the world over Reliable figures are not available because reporting even where prescribed by law is not complete In the United States 20 000–30 000 cases are reported annually but from other data it would appear that the true figure is at least in the order of 700 000 In countries with low standards of sanitation nearly everybody will experience dysenteric infection at some time of his life Devastating epidemics have been frequent in the past under conditions of crowding and poor sanitation such as in armies children's homes asylums and prisons The same is still true today wherever the conditions arise that favor the dissemination of infection

The leading symptom is watery watery mucoid or bloody diarrhea accompanied by fever dehydration and prostration Mortality varies but may be high A chronic disabling condition of the bowel with severe diarrhea may result Convalescent or healthy carriers are frequent

Effective therapy is available with sulfonamides and antibiotics Prevention can be achieved by sanitation (guarding water and food from contamination)

The main diagnostic tool is the isolation and identification of dysentery bacilli from feces and inculpated food *See* BACTERIOLOGY MEDICAL SALMONELLA [A J W]

Bacitracin

An antibiotic produced by *Bacillus licheniformis* (*B subtilis* strain Tracy) It is active against a wide variety of gram positive bacteria and only a few gram negative ones The use of bacitracin is almost entirely limited to topical (including local injection and oral dosage) application because of the toxicity shown after systemic administration It is therapeutically effective in the local treatment of a wide variety of infections such as furuncles abscesses infected wounds carbuncles and impetigo caused by staphylococci streptococci and certain other gram positive bacteria It is also used as a feed supplement for enhanced growth of chickens

and swine In 1956 the production of bacitracin in the United States was 2158 lb for medical uses and 21 104 lb for feed supplement *See* ANTIBIOTIC STAPHYLOCOCCUS STREPTOCOCCUS

Chemistry Bacitracin is normally marketed as a mixture of polypeptides (bacitracin A B C D E and F) The A component makes up the main part of the product with varying amounts of the other components The component amino acids (some of which are D amino acids) in these bacitracins are known and their sequence in the molecule has been worked out for some

Purified bacitracin is a white to light brown powder soluble in water and a variety of aqueous alcohols including *n* butanol and *sec* butanol Purified bacitracin has an activity of 60 units/mg with a molecular weight of about 1470 for bacitracin A

Assay The drug is assayed by a diffusion plate assay using *Micrococcus flavus* or by a turbidimetric assay using a sensitive organism such as a hemolytic streptococcus *See* BIOASSAY

Antimicrobial activity The antimicrobial activity resembles that of penicillin in that it is bacteriostatic for gram positive bacteria especially cocci and the gram negative gonococci meningococci and hemophilus type B Most of these sensitive organisms are inhibited at concentrations between 0 0009 and 5 0 μg/ml There is a synergistic action shown in combination with penicillin and even penicillin resistant strains may be inhibited by mixtures at levels which are well below the effective level for either drug alone Resistance to bacitracin does not appear to develop during therapy but can be developed in vitro *See* DRUG RESISTANCE GRAM NEGATIVE DIPLOCOCCI HEMOPHILIC BACTERIA

Pharmacology Bacitracin is essentially nontoxic when used locally as an ointment by instillation of solutions into the spine and skull or by oral administration In human therapy intramuscular or intravenous injection exhibits some degree of kidney toxicity in a high percentage of patients General allergic reactions to bacitracin are not encountered After oral administration no concentration in the blood can be demonstrated

Use Therapeutically effective results are obtained by local application of bacitracin as an ointment or by instillation as a solution in infections of the eye ear nose and throat or in infections of surgical and other wounds and in vulvovaginitis when caused by sensitive bacteria It can also be injected in small doses into locally infected tissues such as furuncles carbuncles and abscesses Its use in systemic infections is generally not recommended

Production Commercial production is carried out by means of fermentation with strains of *B licheniformis* selected for high bacitracin production for bacteriophage resistance and for a rough colony form (for ease in filtration) The inoculum is started from spores flask stages and an inoculum tank stage follow The final fermentation is conducted in 15 000–50 000 gal tanks on a medium composed of soybean meal or other high protein seed meal as a protein source a carbohydrate such as starch and calcium carbonate or calcium lactate The culture is vigorously aerated and may also be mechanically agitated Optimum titers of bacitracin at 48 hr fermentation may be 3–4 g/liter or higher

Recovery for medicinal use is by extraction of the filtered broth with butanol at pH 7 and back extraction into water with phosphoric acid at pH 2 3 After various purification steps the final concentrate may be spray dried or the bacitracin may be precipitated as a zinc salt Recovery for animal feed supplement is usually by evaporation of the whole broth to a syrup in a multiple effect evaporator followed by drum or spray drying [REB]

Bibliography A L. Baron *Handbook of Antibiotics* 1950 Federal Trade Commission *Economic Report on Antibiotics Manufacture* 1958 H S Goldberg *Antibiotics Their Chemistry and Non Medical Uses* 1959

Background count

The number of counts that must be subtracted from an observed number of counts in an experiment where atomic or nuclear particles coming from a source are being enumerated The background count may be due to cosmic rays to natural radioactivity in the air the walls of the room or in the counter itself or to the scattered radiation in the vicinity of a source of nuclear particles such as an accelerator or a nuclear reactor The background normally continues to give counts during the experiment To determine the background count the source of true counts is removed shielded or turned off and the number of counts during a given time is observed This number is then converted to a background counting rate which may be subtracted from the observed counting rate of the source to give the true counting rate [WBF]

Backing wind

A wind which changes direction in a counterclockwise sense for example a south wind changing to an east wind or an east wind changing to northerly At a particular place the wind gradually backs with time when a cyclone passes eastward on a path south of the observer s location The wind characteristically backs with increasing height on the west side of an extratropical cyclone The meaning in terms of changes of cardinal directions is reversed in the Southern Hemisphere This term is opposite in sense to veering wind [CWN]

Backward wave tube

A type of microwave traveling wave tube in which the phase velocity is in the opposite direction to the

tubes are useful as voltage tuned oscillators for signal generators power sources for quick tuning transmitters and local oscillators in receivers for the same kind of system Or if operated as regenerative amplifiers they are useful as narrow band amplifiers in wide range rapidly tunable receivers

O type backward wave oscillators The O type backward wave oscillator (or O carcinotron) may be similar in appearance to an ordinary forward wave traveling wave tube There is an electron gun producing an electron beam some mechanism for longitudinally focusing the beam throughout the length of the tube a slow wave circuit for the interaction and a collector of the beam The circuit may also be similar to those described for traveling wave tubes but it will usually be a periodic circuit in which a backward space harmonic is utilized Thus when phase velocity v_p is in the direction of the beam in Fig 1 as is required for continuous interaction the group velocity v_g or energy flow is backward toward the gun The output of the tube is then at the gun end as shown

Figure 2 shows a portion of frequency versus phase diagram for a periodic circuit The region BC represents a backward wave space harmonic for such a circuit since phase velocity (ω/β) is positive when group velocity $(d\omega/d\beta)$ is negative as contrasted to the space harmonic represented by AB where both are positive together Such a diagram shows that phase velocity must change with frequency on the backward harmonic portion therefore frequency must change as beam voltage is varied if beam and circuit waves are to keep in synchronism This is the origin of the voltage tuning feature of such tubes

The regenerative feature may be explained thus the beam is imagined to provide a forward flow of energy and the circuit a backward flow so that there is a succession of continuous feedback paths between the two Therefore when current becomes high enough the tube will break into oscillation with the voltage tuning feature already described This start oscillation current is a function of the length of the circuit the beam voltage and the interaction impedance (*see* TRAVELING WAVE TUBE) The current varies directly as voltage inversely as interaction impedance and inversely as the third power of the circuit length in numbers of wavelengths at the slow wave velocity Normal operation is at a current of the order of twice the start oscillation current Excessive currents will bring in higher order electronic modes that interfere with operation in the desired one

The most common circuit for backward wave oscillators as for forward wave traveling wave tubes is the helix However to obtain the backward wave use is made of the (-1) space harmonic of the helix which has oppositely directed phase and group velocities as required This harmonic has fields which are circumferentially varying and also which vary with radius in such a way that fields are

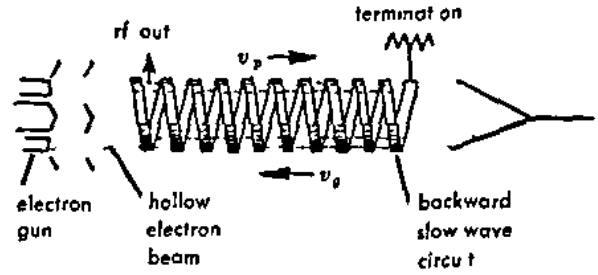


Fig 1 O type backward wave oscillator using helix as circuit

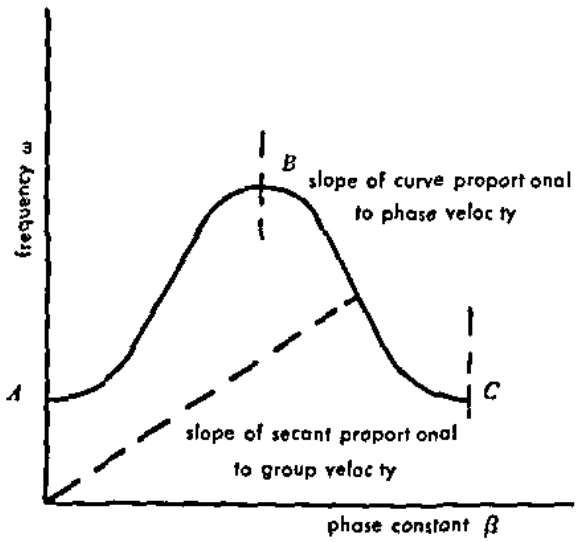


Fig 2 Frequency versus phase diagram for a periodic circuit illustrating forward and backward space harmonics

zero on the axis Thus the center of the beam is not active and it is advantageous to use a hollow electron beam in a helix type backward wave oscillator For very high powers the folded wave guide type of circuit may be better for power dissipation purposes For very high frequencies in the millimeter wavelength range the Karp circuit is larger than the helix and so easier to build Backward wave oscillators have been made with voltage tuning ranges of 10 1 but a typical design value is 2 1 Output can be quite constant over the band Powers may be from a few milliwatts to several hundred watts (continuous) Highest frequencies of operation have been for a wavelength of about 1 millimeter For further information on the circuits used *see* TRAVELING-WAVE TUBE

M type backward wave oscillator The M type backward wave oscillator (or M carcinotron) is similar in principle to the O type described above except that the magnetron type of focusing and interaction is used As illustrated in Fig 3 the transverse magnetic field and the dc electric field between sole and circuit act to confine the beam to the interaction space The circuit most commonly used is an interdigital circuit using a backward space harmonic of this Efficiency of the M type oscillator is somewhat better than that for the O type

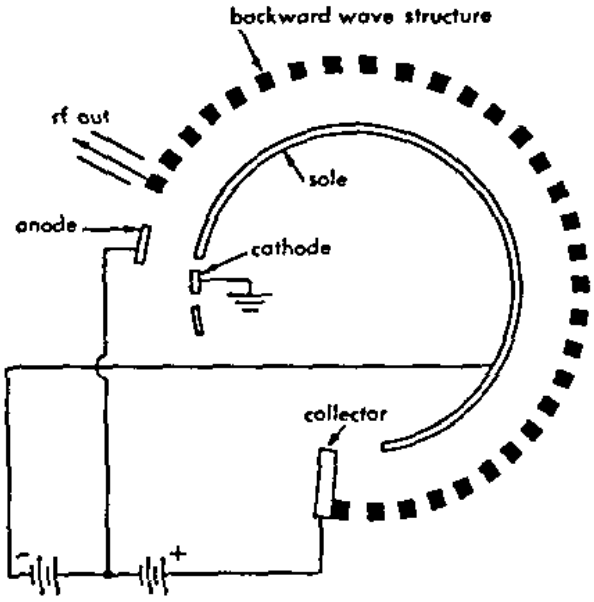


Fig 3 M type backward wave oscillator (M-carcinotron)

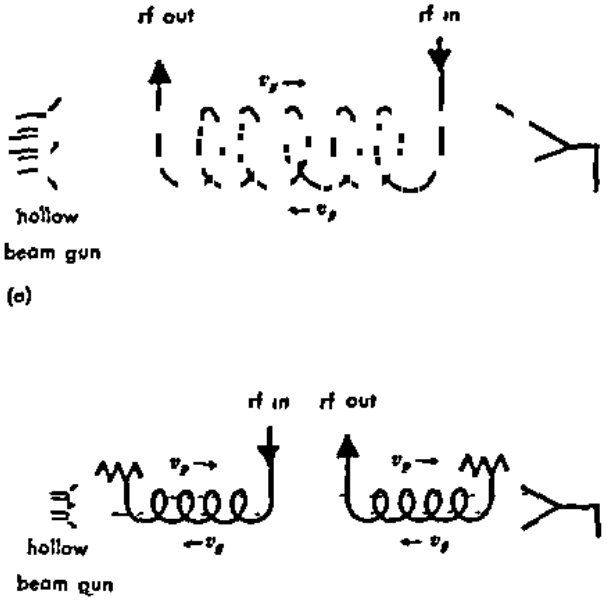


Fig 4 Backward wave amplifiers (a) Single-circuit type (b) Cascade type

but other characteristics are similar *See* MAGNETRON

Backward wave amplifiers If the backward wave tubes as described above are operated with currents less than the start oscillation value a narrow band regenerative amplification will be obtained which is also electrically tunable over a wide range by change of beam voltage As illustrated in Fig 4*a* input for this backward wave operation is at the collector end of the tube and output is at the gun end Bandwidth at a given voltage setting is typically a fraction of a per cent and tuning range is easily made 2 1 as in the backward wave oscillator Stability of a backward wave amplifier is increased by separating the circuit into two or more parts (Fig 4*b*) Such cascade backward wave amplifiers have stable gains greater than 30 decibels have bandwidths and tuning ranges similar to the above and have been made with noise figures as low as 3.5 decibels

For other microwave oscillators and amplifiers *see* MICROWAVE TUBE [J R WH]

Bibliography M R Currie and J R Whinnery The cascade backward wave amplifier *Proc IRE* 43 1617 1631 1955 R Kompfner and N T Williams Backward wave tubes *Proc IRE* 41 1602 1611 1953

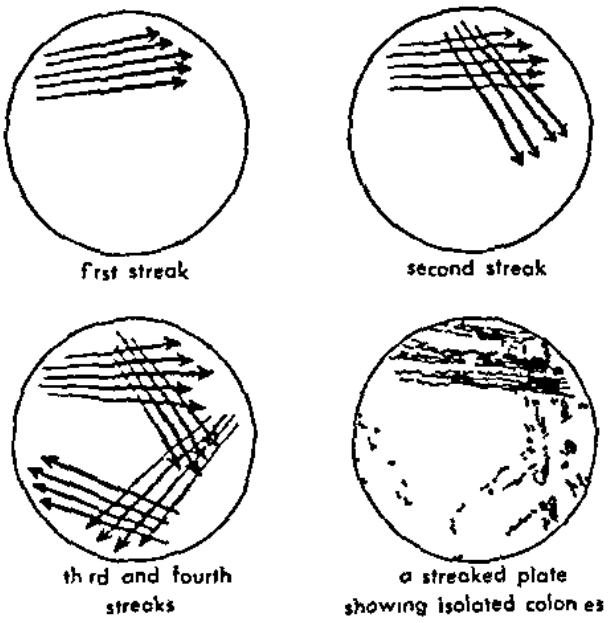
Bacteria

Extremely small—usually 0 3–2 0 microns (μ) in diameter—and relatively simple organisms in the class Schizomycetes the fission fungi (*see* SCHIZOMYCETES) Bacteria are found almost everywhere being abundant in soil water and the alimentary tracts of animals Each kind of bacterium is fitted physiologically to survive in one of the innumerable habitats created by various combinations of space food moisture light air temperature in history substances and accompanying organisms Dried but often still living bacteria can be carried into the air One of the few locations in which bacteria are not usually found is within the cells of other healthy organisms

Bacteria have a practical significance for man Some cause disease in man and domestic animals thereby affecting his health and economy (*see* BACTERIOLOGY MEDICAL ZOONOSES) Some bacteria are useful in industry while others particularly in the food petroleum and textile industries, are harmful (*see* FOOD ENGINEERING FOOD MICROBIOLOGY INDUSTRIAL MICROBIOLOGY) Some bacteria improve soil fertility (*see* SOIL MICROBIOLOGY)

As in higher forms of life each bacterial cell arises either by division of a preexisting cell with similar characteristics or through combination of two such cells in a sexual process (*see* REPRODUCTION ANIMAL) The earlier idea that full-fledged bacteria arise from nonliving material by spontaneous generation has been disproved by careful elimination of living bacteria from the nonliving material This does not eliminate the possibility that sometime during evolution of the universe life was derived from the nonliving (*see* LIFE ORIGIN OF) Separation of matter into living and nonliving is arbitrary though useful and unambiguous when transitional states are not under consideration

Pure cultures Descriptions of bacteria are preferably based on the studies of pure cultures since in mixed cultures it is uncertain which bacterium is responsible for observed effects Pure cultures are sometimes called axenic a term denoting that all cells had a common origin in being descendants of the same cell without implying exact similarity in all characteristics Pure cultures can be obtained by selecting single cells but indirect methods achieving the same result are more common



Streak plate technique

These involve separating the bacteria from each other and keeping their progeny separate This is done on a streak plate The nutrient culture medium is solidified with a gelling agent usually agar The tip of a fine sterile wire is dipped into a suspension of the mixed bacteria and streaked over the surface of gelled nutrient agar in a flat covered dish the petri plate During streaking the number of bacteria on the needle becomes so reduced (by rubbing off on the agar) that single bacteria are by chance left on the gel at considerable distances from all other cells Another method is to inoculate the suspension of mixed bacteria into melted nutrient medium which is cooled to just above the solidification temperature in order not to kill the inoculated cells the medium is then solidified *See* CULTURE PURE

With either method if conditions are suitable each bacterium grows and divides using food diffused through the gel and produces a mass of cells called a colony Colonies always develop until visible to the naked eye unless toxic products or deficient nutrients limit them to microscopic dimensions.

Since a colony might arise from more than one cell and thus from dissimilar cells it must be picked out diluted and subcultured This process is repeated until daughter colonies are alike and contain only one cell type as judged by microscopic examination Slight differences in the microscopic or submicroscopic structure of the individual bacterial cells often affect their appearance as a colony When the desired bacterium is so scarce that the chance of separating it from others is slight the colony containing it is transferred to an enrichment culture where environmental conditions better suited to the desired bacterium than to contaminants are provided *See* CULTURE ELECTIVE

Classification. The morphology that is the shape size arrangement and internal structures of bacteria can be distinguished microscopically and provides the basis for classifying the bacteria into major groups While stains are used to visualize bacterial structures otherwise not seen the stain reaction with Gram's stain provides another characteristic used in classifying bacteria

The submicroscopic differences that distinguish many bacterial genera and species are due to structures such as enzymes and genes that cannot be seen The nature of these structures is determined by studying the metabolic activities of the bacteria Data are accumulated on the temperatures and oxygen conditions under which the bacteria grow their response in fermentation tests their pathogenicity and their serological reactions *See* BACTERIA TAXONOMY OF

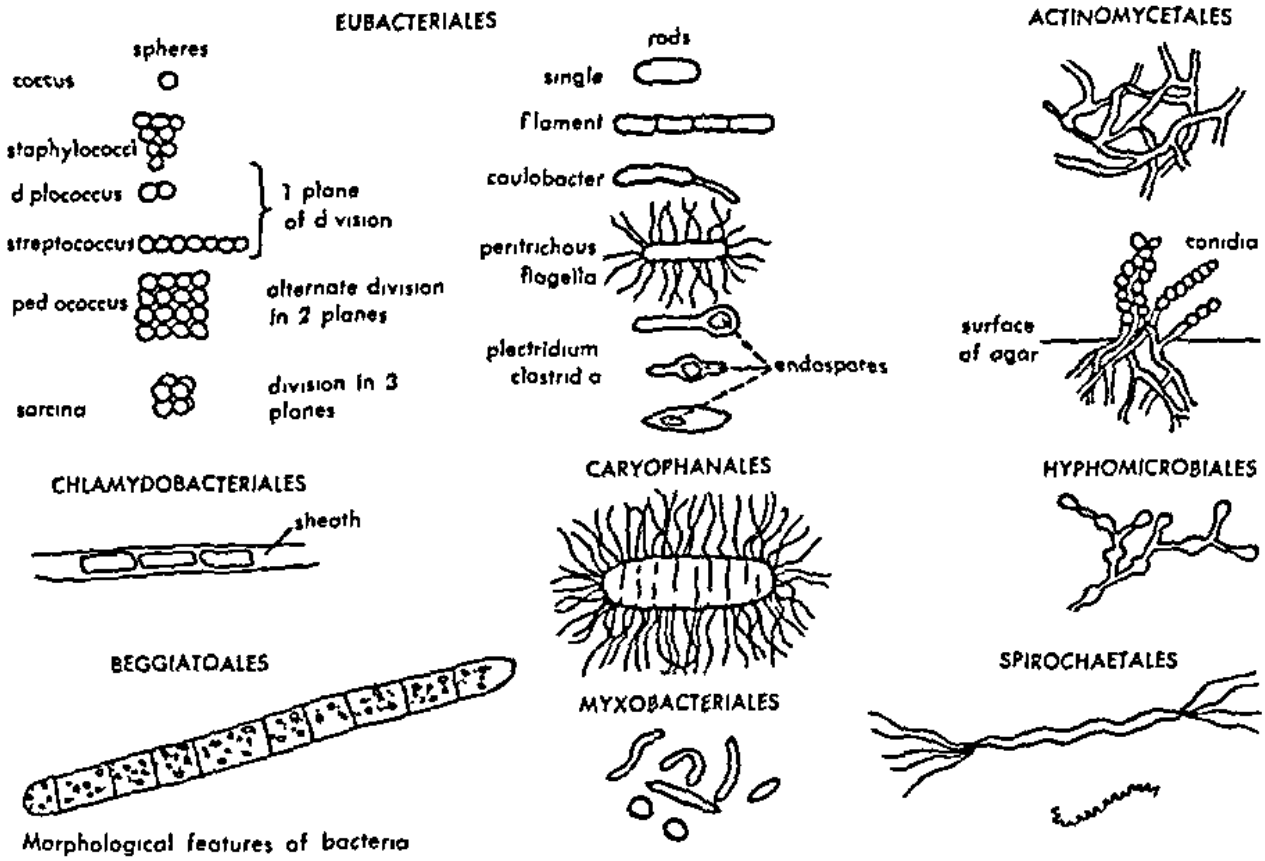
Stains and staining reactions Many bacterial structures not otherwise visible such as shape flagella and spores can be differentiated with various staining techniques The most common staining procedure is the Gram s stain in which crystal violet and iodine form a violet colored complex with cell material The complex is not extracted by alcohol and acetone from gram positive cells and these appear violet The complex is extracted from gram negative cells which stain red when the counter stain saffranin is added While gram negative organisms are constant in their reactions gram positive organisms may when they get older show variation in their response and appear gram negative *See* STAIN (MICROBIOLOGICAL)

Shape and arrangement Three principal shapes of bacteria exist spherical (coccus) rod shape (bacillus), and twisted rod (spirillum) The coccus may be arranged in chains of cocci as in *Streptococcus* or in tetrads of cocci as in *Sarcina* The rods may be single or in filaments

Motility Many bacteria are not motile Of the motile bacteria however some move by means of tiny whirling hairlike flagella extending from within the cell Others are motile without flagella and have a creeping or gliding motion Spiral forms are usually polarly flagellated that is with flagella at the end of the cell Cocci (spheres) are rarely flagellated Rod shaped bacteria may lack flagella or have polar or peritrichous (around the entire surface of the cell) flagella *See* BACTERIAL MOTILITY

Cell wall and endospore Many bacteria are enveloped in a capsule a transparent gelatinous or mucoid layer outside the cell wall Some chiefly rods in the family Bacillaceae form within the cell a heat and drought resistant spore called an endospore Endospores are spherical to oval in shape and sometimes develop to a size that swells the cell to a drumstick shape (plectridium) if the endospore is located terminally or to a spindle shape (clostridium) if it is located centrally Cytoplasmic structures such as reserve fat protein and volutin are occasionally visible within the bacterial cell *See* BACTERIAL ENDOSPORES

Nucleus In many species of bacteria a definite nucleus cannot be differentiated However when



Morphological features of bacteria

bacteria are subjected to nuclear dyes the entire cell becomes stained suggesting that the nuclear material may be diffuse The nucleus of bacteria contains linearly arranged hereditary units analogous and possibly homologous with the chromosomes and genes of higher forms of life During cell division and sexual reproduction these units are transmitted in an orderly way by orderly mechanisms as yet unelucidated *See* BACTERIAL GENETICS

Temperature relationships Bacteria are said to be psychrophilic if their optimum temperature is below 20°C mesophilic if it is 20 45°C and thermophilic if it is above 45°C Some bacteria can grow at temperatures as high as 75°C Others which are not killed but which cannot grow at high temperatures are called thermoduric

Oxygen relationships Bacteria are said to be aerobic if they require oxygen and grow best at a high oxygen tension usually 20% or more Microaerophilic bacteria need oxygen but grow best at or may even require reduced oxygen tensions that is less than 10% Anaerobic bacteria do not require oxygen for growth Obligatorily anaerobic bacteria can grow only in the complete absence of oxygen

Fermentation and respiration Fermentation is a term used to indicate processes in which foodstuffs are decomposed in the absence of oxygen Respiration is the comparable aerobic process in which oxygen is one of the foods Some oxygen utilizing microorganisms cannot completely oxidize the food to water and carbon dioxide and often form acids as a product of this type of aerobic food utilization These incomplete oxidative processes are sometimes called fermentations though they are actually examples of limited respiration As in all chemical rearrangements some of the available energy in both respiration and fermentation is dissipated as heat The remainder is stored in the form of the materials that make up living cells

In respiration as much as 50% of the food material and energy appear as bacterial cell material and the remainder as carbon dioxide water and heat In fermentation the lack of O_2 decreases the energy supply available through rearrangement of the food and less food (up to 8%) is converted to cells Less heat is dissipated and fermentation products are formed such as CO_2 hydrogen methane ethanol acetone glycerol and formic acetic, propionic butyric lactic and succinic acids These products when combined with oxygen by aerobes to form water and carbon dioxide yield energy equal to the difference between the energy available in respiration and in fermentation

Fermentation tests Fermentation tests which use liquid media each medium containing a different nutrient aid in classifying bacteria Gas or acids or both are always formed when carbohydrates are fermented Acid is detected by including an indicator of acidity in the culture medium, a small inverted tube is used to trap any gas emitted Other useful tests measure the acidity (pH) developing during fermentation and the range of acidity permitting growth *See* FERMENTATION

Fermentation of proteins yields products similar to those from carbohydrates plus large quantities

of nitrogenous products such as ammonia and amines Since ammonia and amines are weak bases a protein fermentation causes alkalinity instead of acidity The ability of an organism to ferment carbohydrate or protein is tested by inoculating the organism into milk containing litmus indicator called litmus milk The culture is incubated and then examined for color changes denoting acidity or alkalinity

Digestion tests Tests for digestion of protein starch fats cellulose pectin and many other insoluble materials disclose other physiological characteristics useful in classification Ability to digest protein (peptonization) is often tested by examining litmus milk cultures for an increase in transparency caused by digestion of casein the protein responsible for the white opacity of milk The digestion of gelatin another protein may be detected by liquefaction

Other metabolic reactions of bacteria include the oxidation of ammonia to nitrate by nitrifying bacteria (*see* NITROBACTERACEAE) oxidation of sulfur to sulfates by sulfur bacteria (*see* THIOBACTERIACEAE) and oxidation of ferrous to ferric iron by iron bacteria (*see* CHLAMYDOBACTERIALES) Some of the products formed within the cell in these oxidations react with carbon from carbon dioxide with hydrogen from water and with other elements to form new cells

The purple sulfur bacteria and the green sulfur bacteria also form new cells from inorganic compounds but the hydrogen is obtained by splitting water with light (photolysis) instead of with chemical energy These bacteria form an oxidized substance as the second product of the photolysis of water as do green plants But the former cannot convert this to oxygen which the latter do hence the photosynthetic bacteria can photosynthesize only if an oxidizable compound such as hydrogen (H_2) hydrogen sulfide (H_2S) or a suitable organic substance is present with which the oxidized moiety is continually reduced See RHODOBACTERIINEAE

Some bacteria obtain energy from the oxidation of reduced substances with compounds other than oxygen (O_2) The sulfate reducers use sulfate the denitrifiers nitrate or nitrite and the methanogenic bacteria carbon dioxide as the oxidizing agents producing H_2S nitrogen (N_2) and methane (CH_4) respectively as reduction products

Pathogenicity Pathogenicity the ability to cause disease is another property used in establishing the relationship between various groups of bacteria Some bacteria produce disease only in certain species for example *Neisseria gonorrhoeae* will cause gonorrhea only in man Some bacteria cause only one while others may cause several diseases An example of the former is *Corynebacterium diphtheriae* which causes diphtheria *Staphylococcus aureus* belongs to the latter category and may cause boils osteomyelitis and pneumonia

Serological reactions Serological reactions are most useful in distinguishing closely related bacteria If two bacteria A and B differ some of their proteins and other complex molecules also differ When cells of A are injected into an experimental animal such as a rabbit some of their constituent molecules (especially proteins) cause production in the rabbit's blood of special proteins called antibodies Each of these can combine specifically with the molecular species that caused its production If after a suitable incubation period blood is drawn from the animal (in the case of a rabbit usually from an ear vein) and allowed to clot a clear yellow liquid (blood serum) is extruded as the clot shrinks It contains antibodies against each protein in the injected A cells If B cells in excess are added to this antiserum each B protein occurring also in A reacts with its corresponding antibody thereby removing from the serum all antibodies against proteins common to both A and B Addition of A cells gives a further reaction if A contains proteins not found in B With reciprocal absorption of B antiserum with A cells and testing with B cells for antibodies restricted to B any differences in the A and B cells can be detected *See* ANTIGEN ANTIBODY REACTION

Natural defenses against bacterial infections These depend in part on serological mechanisms When bacteria enter animal hosts containing antibodies against them the bacteria become coated with antibodies and are then susceptible to engulfment and digestion (phagocytosis) by host cells Chicks mice and rats aseptically removed from the shell or uterus can be reared bacteria free These axenic animals when mature are highly susceptible to infection by bacterial types harmless to normal animals Antibodies carried over from the mother protect very young animals and by the time maternal antibodies are depleted normally reared offspring have developed their own The isolation of axenic animals deprives them of the bacterial antigens necessary for development of protective antibodies *See* GERMFREE VERTEBRATE

Every ancestor of living organisms survived bacterial attacks to reach maturity The resistance selected in this manner is the factor most commonly concerned in defense against infections

Bacterial variation Variation in the characteristics of a single cell occurs during cell division but since cells in a culture divide at different times unless artificially synchronized the average for the entire cell population is constant as long as the environment is constant A change in any limiting factor in the environment causes a change in the population In nature environmental changes are often cyclic and bacteria undergo accompanying changes in morphology interpreted by some as a life cycle The applicability of this term to bacteria has been disputed

An extremely small proportion of living organisms undergo sudden genetic changes usually involving only one characteristic of the cell which are transmitted through many generations (*see* MUTATION) Because of the tremendous number of bacteria (1 ml of a culture may contain as many bacteria as there are humans on earth) their mutations are common in cultures as well as in nature

If in a given environment a mutation enables its possessor to grow and divide more rapidly than the type from which it arose the mutants ultimately predominate The characteristics of the population are changed by the environment through selection of cells most fitted to survive rather than by a direct action on all cells as discussed in the preceding paragraph

Dissociation Bacterial pathogens have been observed that form a protective capsule which may belong to one of several different serological types Noncapsulated mutant cells occasionally arise In the animal they are destroyed by phagocytes but on artificial media they survive and produce colonies with a rough surface Such strains are called rough or *R* forms to distinguish them from the capsulated smooth or *S* types Heavy inoculation of an *R* strain into a susceptible animal causes a change to an *S* strain since any reverse mutant (that is a mutation from *R* to *S* cell can multiply whereas the *R* cells are consumed by phagocytes Pretreatment of the injected *R* cells with an extract of *S* cells or growing *R* cells in a medium with an extract of *S* cells induces reversion to an *S* strain serologically identical with the one used to prepare the extract *See* BACTERIA LYSOGENIC PNEUMOCOCCUS

Interrelationship between bacteria and other organisms Such interrelationships may be close and may involve particular species Examples are the parasitic association of many bacteria with plant and animal hosts and the mutualistic association of nitrogen fixing bacteria with leguminous plants of cellulolytic bacteria with grazing animals and of luminous bacteria with certain deep sea fishes *See* ECOLOGIC INTERACTIONS

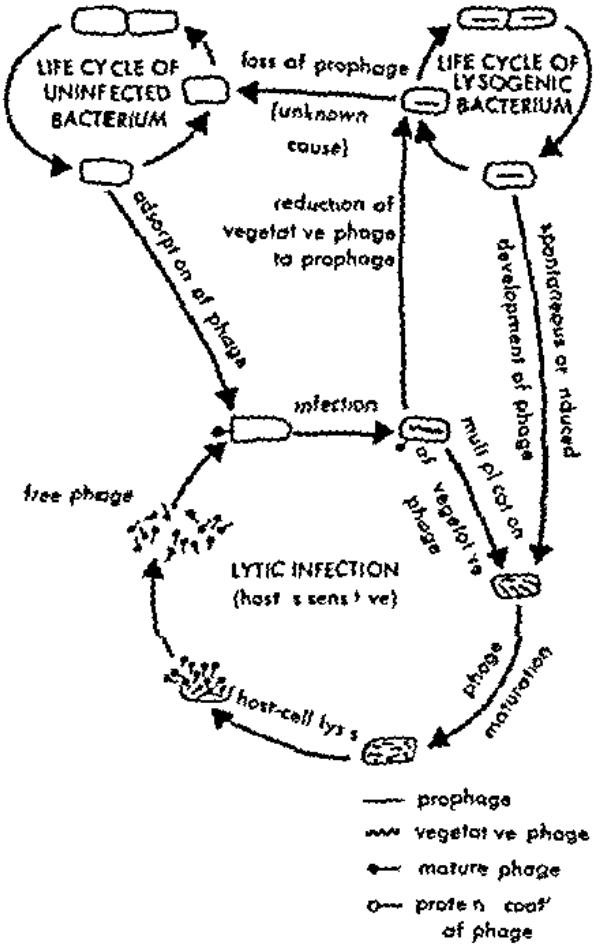
Bacteria are also active in other less intimate but no less important, natural interrelationships Bacterial decomposition of the dead bodies of animals and especially plants releases for reuse by living plants the carbon dioxide needed in photosynthesis Many other chemical activities relate bacteria to other organisms through the world pool of materials essential to life to which all organisms contribute and from which they draw their food [R E H]

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Bacteria, lysogenic

Those bacteria which carry a bacteriophage or rather its prophage (a noninfectious self reproducing form of bacteriophage) without showing any signs of infection Phages from which this latent type of infection may develop are called temperate as opposed to virulent phages, which always cause a lytic infection

For some reason the DNA (deoxyribonucleic acid) of a temperate phage may fail to initiate the usual vegetative (multiplying) phase of the life cycle and instead incorporates itself into the cell's genetic mechanism in a form called prophage (see



Life cycles of phage and host (E Jawetz J L Melnick and E A Adelberg *Review of Medical Microbiology* 2d ed 1956)

NUCLEIC ACID) As such it is transmitted from cell to cell at the time of division existing in a completely masked form These lysogenic bacteria appear perfectly normal as does the lysogenic culture which they comprise During the growth of a lysogenic culture however some disturbance of metabolism occurs in an occasional cell and the prophage escapes from its bound form and redirects the cell's synthetic activity into the production of phages This cell subsequently lyses and frees infectious phage particles into the medium Since lysogenic bacteria are immune to the virus whose precursors they carry this new phage merely accumulates in the culture and its presence is made known only when it comes in contact with susceptible cells When only one cell in a population of millions or billions converts in this way to phage production the phenomenon may be missed completely and the latent infection never suspected

With certain lysogenic cultures it is possible to induce phage production in many or all cells by exposure to ultraviolet radiation or to certain chemicals *See* INFECTION LYTIC

It seems probable that the lysogenic state is of importance in the natural history of bacteria and bacterial viruses and evidence suggests that a similar condition may exist in other virus-host systems *See* BACTERIOPHAGE COLIPHAGE [P B C]

Bacteria, taxonomy of

The arrangement or classification of bacteria as distinct from nomenclature which deals with the naming of microorganisms The bacteria are classified in the class Schizomycetes *See* SCHIZOMYCETES

To classify is to compare the characteristics of microorganisms for the purpose of grouping like organisms together into taxonomic groups The unit of classification is the species Like species are grouped into a genus like genera into a tribe like tribes into a family like families into an order like orders into a class like classes into a division and like divisions into a kingdom There are but two kingdoms—the plant and the animal The bacteria are generally regarded as belonging to the plant kingdom *See* PLANT KINGDOM PROTOPHYTA

Formation of species Ideally each bacterium is separated from its fellows and maintained in pure culture Each pure culture is described and each one with a different combination of characters is called a strain (*see* BACTERIA CULTURE PURE) If a strain is sufficiently different from other strains it may be designated as a species and given a specific name and a generic name It is undesirable that all strains be made into species first because it would suggest a basic genetic difference between them which may not exist and second because it would clutter the scientific literature with such a large number of species that the primary purpose

Where strains are found to have a number of characters in common but differ from each other in other respects they may be regarded as a single taxonomic group—in this case a species—whose characters are those which are common to all strains included in the species

In the creation of a species the characters which describe the species are chosen for their constancy and for their constant correlation with other characters for example the constant production of acid from glucose maltose and sucrose does not constitute sufficient cause for grouping two strains together if in one instance these properties are correlated with a rod shape and a gram negative stain and in the other with a coccal shape and a gram positive stain Selection on the basis of correlated features is the nearest approach which can be made to a natural classification in the absence of direct evidence of genetic relationships *See* GRAM'S STAIN

The designation of a species after the careful investigation of a large number of cultures is the ideal procedure Some species however have been described from a single strain and in several instances such as in the iron bacteria *Pasteuria Blastocaulis* and others on microscopic descriptions only

As new strains are added to an existing species the number of strains may become so large that a new pattern of [illegible]nships between strains in the species may emerge necessitating a reconsideration of the species description or even a division into two or more species The danger inherent in such development is that the original species if based solely on the characteristics common to its component strains will lose its identity In order to avoid this the concept of the type culture has developed A single strain of the species is selected and designated as the type culture of the species and the species description is based on the characteristics of the type culture Should any subsequent division of the species be desirable at least one of these subdivisions must then retain the characteristics of the type culture of the original species and a new type culture be designated for newly created species

A species of bacterium thus becomes the type culture together with all other cultures considered to be sufficiently like the type culture to be grouped with it

The type culture may be the original culture a strain selected and designated as the type culture by international agreement or in the absence of a culture the original description of the culture

Formation of genera A genus is a group of related species Ideally its formation should follow the same pattern as that involved in the creation of a species the comparisons being drawn between the characteristics of species with emphasis on the correlation of these characteristics As with the species the creation of a genus is largely a matter of personal opinion but it is further complicated by the existence of considerably fewer characteristics upon which a decision can be made To preserve the identity of a genus it has become necessary to define it in terms of a type species The type species is the species to which the name of the genus will always remain attached If a genus is subdivided the subdivision which contains the original type species retains the original generic name while a new type species must be designated for the newly created genus

A few among the many bacterial genera contain but a single species Such a species is considered to differ so markedly from other described species that it cannot be grouped with them in the same genus Since every bacterial species must bear a generic as well as a specific name a separate genus must be created for the species in question

In the grouping of genera into tribes tribes into families families into orders and orders into classes the higher the rank the fewer the criteria upon which comparisons can be based With some species indeed the dominating feature of the rank may be lacking but on the basis of correlation of the lesser features a species has been assigned to that rank A good example is *Mycobacterium phlei* which rarely if ever branches but is nonetheless placed in the order Actinomycetales whose two dominant features are the occurrence of branched rods and a gram positive staining reaction The reason is that *M. phlei* is acid fast and this property is encountered only among the Actinomycetales all of which are gram positive though not

necessarily acid fast *Mycoplana* which does form branched rods is excluded from the Actinomycetales because it is gram negative and possesses other characteristics which more closely ally it with genera of the order Pseudomonadales *See* ACID FAST STAIN

Classification is desirable because it systematizes one's thinking and because it helps to determine the way in which the microorganisms have evolved in nature In a more tangible practical manner it also helps to predict the behavior of groups of microorganisms under various conditions Sensitivity to penicillin for example is characteristic of most gram positive species

To confirm the true natural relationship between living things it is necessary to study their genetic constitution In plants this is comparatively simple since the nucleus which contains the chromosomes with their character determining genes is easy to demonstrate and sexual reproduction makes it possible to determine genetic similarity Study of the genetic constitution of bacteria is still in its infancy Chromosomal bodies have been demonstrated in many bacteria but evidence for sexual reproduction is of an indirect type and the existence of true mitotic division in asexual reproduction is still a matter of controversy

Until such time as the so-called natural classification of bacteria based as it is on correlation of observable characteristics is confirmed by genetical studies it is wise to regard bacterial genera as form genera and to treat with great reserve the suggested groupings into higher ranks

Artificial keys Classification—the orderly arrangement of bacteria into species genera and higher ranks—has been discussed It is a slow process which evolves with the development of science In the course of development new cultures of bacteria are being isolated or microscopically defined Before they can be considered as additions to the existing list of bacteria they must be compared with known species—in other words an attempt must be made to identify them If it can be shown that a newly isolated strain has the same characteristics as an established one it automatically becomes identifiable with the established species If it cannot be exactly matched its possible relationship to existing species is examined By this process of comparison it assumes a definite position in the existing scheme as a new strain within an existing species or a new species within a genus or it may possibly become the sole representative species of a new genus

Artificial keys such as those proposed by C B van Niel and compiled by V B D Skerman are prepared from information about known species and designed primarily to assist in identification that is they match the unknown against the known If it is found that the match cannot be made the primary purpose of such keys has been fulfilled and the worker is obliged to classify the new organism The artificial key will not classify but it will give a clear indication of the possible relationship of the new organism

Artificial keys differ from the so called natural keys in that they do not permit any speculation about inherent but undefined characteristics such as the possible branching of *Mycobacterium phlei* They are based solely on observable or determinable features

To use an artificial key the characteristics of the organism must first be determined The key poses a series of numbered paired questions the answer to *one of which indicates the next numbered* pair in the series to be consulted Finally a number is replaced by a name Skerman's keys are limited at the present time to determining the genus to which the organism belongs Bergey's Manual contains many similar keys to species within each genus

Classification The partial outline of the orders suborders and families of the Schizomycetes given here follows that developed for *Bergey's Manual of Determinative Bacteriology* (7th ed) For information on the class orders and further subgroups see individual articles by these titles

Pseudomonadales (order)
- Rhodobacteriineae (suborder)
- Pseudomonadineae
  - Nitrobacteraceae (family)
  - Methanomonadaceae
  - Thiobacteriaceae
  - Pseudomonadaceae
  - Caulobacteraceae
  - Siderocapsaceae
  - Spirillaceae

Chlamydobacteriales

Hyphomicrobiales

Eubacteriales
- Azotobacteraceae
- Rhizobiaceae
- Achromobacteraceae
- Enterobacteriaceae
- Brucellaceae
- Bacteroidaceae
- Micrococcaceae
- Brevibacteriaceae
- Lactobacillaceae
- Neisseraceae
- Proprionibacteriaceae
- Corynebacteriaceae
- Bacillaceae

Actinomycetales
- Mycobacteriaceae
- Actinomycetaceae
- Streptomycetaceae
- *Actinoplanaceae*

Caryophanales

Beggiatoales

Myxobacterales

Mycoplasmatales

Spirochaetales

[V B D S]

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Bacterial cell chemistry

That branch of bacteriology concerned with the description of the various components of the cell in chemical terms

Chemical composition In common with cells of higher plants and animals the bacterial cell composed of proteins nucleic acids carbohydr

and lipids The water and mineral contents are also similar to those of other living organisms On a weight basis bacteria contain 70–90% water, and the mineral content is 1–10% Much of the mineral matter is accounted for by potassium sodium calcium magnesium and phosphorus Proteins and nucleic acids are the major organic constituents of bacteria and they are present in more constant amounts than other organic compounds such as the lipids and carbohydrates Protein contents determined by the percentage nitrogen account for 40–60% of the dry weight of the bacterial cell The nucleic acid content is 10–20% The amounts of carbohydrate and lipid vary widely and are dependent on the growth conditions Carbohydrate content is 10–30% and that of lipids 1 50% *See* CARBOHYDRATE LIPID NUCLEIC ACID PROTEIN

Proteins Most of the cellular proteins formed by bacteria are similar in amino acid composition to those of other organisms However bacteria produce a number of peptides (substances that are chemically related to the proteins) containing the D isomers of certain amino acids instead of the usual L isomers found in the majority of proteins D and L forms of amino acids exist because of the asymmetric nature of constituent carbon atoms (*see* OPTICAL ACTIVITY) The substance forming a thick viscid layer or capsule surrounding the cells of *Bacillus anthracis* is a polymer of D-glutamic acid A number of bacteria contain D alanine and D glutamic acid in cell wall peptides and related intracellular substances The amino acid diaminopimelic acid was first detected and isolated from the bacterium *Corynebacterium diphtheriae* in 1950 It is present in many bacteria and several blue green algae but is absent from other algae fungi protozoa and viruses Diaminopimelic acid is localized in the bacterial cell wall

Nucleic acids Bacteria contain both types of nucleic acid known to occur in cells of higher organisms Ribose is the sugar component of one type of nucleic acid ribosenucleic acid (RNA) and deoxyribose is the sugar in deoxyribonucleic acid (DNA) The Feulgen reaction is given by DNA and forms the basis of the cytochemical technique used for the demonstration of the bacterial nucleus

Carbohydrates A great variety of carbohydrates occur as the result of bacterial metabolism They range from simple polymers of glucose such as the cellulose produced by *Acetobacter xylinum* to complex substances composed of a number of sugar units such as glucose galactose rhamnose and amino sugars Unusual features of certain bacterial carbohydrates include the presence of the D isomer of arabinose in some the occurrence of heptose sugars and the detection of new amino sugars such as muramic acid and fucosamine Neuraminic acid an important constituent of carbohydrate protein complexes of animal cells and tissues has been reported in polymeric form in cultures of *Escherichia coli*

Lipids Bacteria produce a variety of lipid materials waxes and fats but no sterols have been found in bacterial cells Phosphatidic acid is the typical phospholipid of some bacteria and it occurs in the protoplasmic membrane An unusual lipid first found in *Bacillus megaterium* is a polymer of β hydroxybutyric acid It is present in the form of granules that may be stained with the fat soluble dye Sudan black Recently it has been found in many different kinds of bacteria

Chemical anatomy of bacterial cell Anatomy, the science of bodily and cellular structure has been applied to the bacterial cell The major structural elements of bacteria have been isolated and chemically characterized This method of studying the chemical anatomy of the bacterial cell avoids the difficulties of applying cytochemical tests such as the Feulgen reaction to such small cells as bacteria

Flagella The filamentous locomotive appendages of bacteria are composed of flagellin a protein related chemically and physically to the hairlike proteins of other organisms *See* BACTERIAL MOTILITY

Capsules The thick mucous envelope or capsule may be composed of polypeptide or carbohydrate material The viscous capsular carbohydrates may be composed of a variety of sugars including hexoses pentoses methylpentoses uronic acids and amino sugars

Cell walls Bacteria possess a rigid wall structure that is responsible for the shape of each cell The cell walls of many bacteria are composed entirely of mucocomplex material which gives on acid hydrolysis a mixture of three or four amino acids and amino sugars including the new substance muramic acid In walls of some species sugars are also present Alanine and glutamic acid are invariably present and diaminopimelic acid is characteristic of some walls For other bacteria the mucocomplex component accounts for only 10–20% of the wall and the remainder of the wall is composed of protein lipid and carbohydrate constituents

Protoplasmic membrane This is composed largely of lipid and protein together with a small amount of carbohydrate

Action of enzymes on bacterial structures Enzymes have been used for the selective removal of surface slime capsular polysaccharides and the bacterial cell wall (*see* ENZYME) Lysozyme an enzyme obtained from egg white specifically degrades the cell wall of some species When the bacterial wall is digested with lysozyme in a sucrose medium the bacterial protoplast is liberated The protoplast can be further degraded with proteolytic and lipolytic enzymes *See* BACTERIAL PHYSIOLOGY

[M R J S]

Bacterial coenzyme

Organic molecules that participate directly in a bacterial enzymatic reaction and may be chemically altered during the reaction Although many enzymes do not need specific cofactors the majority of bacterial endoenzymes do These cofactors may be simple inorganic cations such as magnesium

manganese or calcium which are commonly referred to as activators or more complex organic molecules The latter are referred to as coenzymes

Coenzymes are the functional units also called prosthetic or active groups of an enzyme Their catalytic activity depends on their association with a protein moiety, the apoenzyme or carrier which is responsible for the high degree of specificity of the complex or holoenzyme Many of these combinations are readily dissociable

$$\text{Holoenzyme} \rightleftharpoons \text{Coenzyme} + \text{Apoenzyme}$$

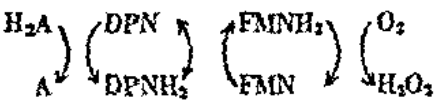
Good examples of such enzymes are the pyridine nucleotide and flavin nucleotide enzymes whose coenzymes are di and triphosphopyridine nucleotide (DPN and TPN) and flavin mononucleotide and flavin dinucleotide (FMN and FAD) respectively The coenzymes act as hydrogen acceptors and can in combination with a wide variety of specific apoenzymes catalyze the dehydrogenation of a large number of substrates

Some holoenzymes particularly the iron porphyrin enzymes such as catalases peroxidases and cytochromes can be dissociated only by drastic means their coenzymes are far more firmly bound to the protein This is in keeping with the much more restricted range of their activity which appears to be limited to specific reactions that are common to the majority of bacteria and other living organisms See BACTERIAL ENZYME DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN) ENZYME

Coenzymes and growth factors The universal occurrence in the metabolism of all living organisms of hydrogenations dehydrogenations transhydrogenations aminations deaminations transaminations and various other general reaction types implies that the coenzymes for these processes must be present in the cells Since 1940 this has cast a new light on the often encountered special nutrient requirements especially for vitamins of the B group The latter are now recognized as substances that are structurally closely allied to coenzymes Thus the ability of a particular bacterium to develop only if supplied with a certain B vitamin can be readily interpreted to mean that the organism cannot synthesize the corresponding coenzyme from other substances For example *Hemophilus influenzae* cannot synthesize DPN, and must consequently be supplied with the intact coenzyme before it can grow Other organisms can synthesize the pyridine nucleotides if they are provided with simpler building blocks such as nicotinic acid amide or nicotinic acid If a bacterium can grow in a medium devoid of such building blocks the implication is that it can perform the synthesis of the coenzyme from still more remote and often quite simple ingredients Where this has been experimentally tested the results have been uniformly positive

Various obligatory parasites which in their normal habitat find an adequate supply of such vitamins or coenzymes appear to have adjusted to this situation by losing the ability to synthesize these substances themselves This has been the basis for the development of current ideas on physiological specialization and evolution See VITAMIN

Function The mode of action of coenzymes generally involves their role as temporary acceptors for particular atoms or atom groups derived from a substrate and subsequently as donors of the same entities to another kind of acceptor under the influence of specific apoenzymes For example the role of pyridine and flavin nucleotide coenzymes in hydrogen transfer may thus be represented by the diagram



Some organic coenzymes and prosthetic groups of enzymes

Coenzyme	Function	Related nutritional factor or vitamin
Adenosinetriphosphate (ATP)	Transphosphorylation	None
Diphosphopyridine nucleotide (DPN)	Hydrogen acceptor in dehydrogenases	Nicotinic acid amide
Triphosphopyridine nucleotide (TPN)	Hydrogen acceptor in dehydrogenases	Nicotinic acid amide
Flavin mononucleotide (FMN)	Hydrogen acceptor in dehydrogenases	Riboflavin
Flavin adenine dinucleotide (FAD)	Hydrogen acceptor in dehydrogenases	Riboflavin
Coenzyme A (CoA)	Condensing enzymes	Pantothenic acid
Pyridoxal phosphate	Transaminases amino acid decarboxylases	Pyridoxine pyridoxal pyridoxamine
Thiamine pyrophosphate	Decarboxylase	Thiamine
Tetrahydrofolic acid	Transformylation	Folic acid
6 8 Dithio-*n*-octanoic acid (Lipoic acid)	Oxidative decarboxylation	Required by some microorganisms
Iron porphyrin	In catalase peroxidase cytochromes	Protoporphyrin
Glucose 1 6-diphosphate	Phosphoglucotransferase	None

where H_2A represents an appropriate oxidizable substrate and A its oxidation product

Similar diagrams can be constructed to illustrate the role of adenosinetriphosphate (ATP) as a phosphorylating agent with the production of adenosinediphosphate (ADP) and the subsequent reformation of ATP from ADP with phosphate groups produced in special positions during metabolism of thiamin pyrophosphate as the coenzyme of certain decarboxylations of pyridoxal phosphate in amino group transfer of tetrahydrofolic acid in the transfer of formyl groups and of coenzyme A in the transfer of acyl groups In the last mentioned case acetyl groups derived from the oxidation of alcohol lactic pyruvic or fatty acids may be transferred to oxaloacetate with the production of citrate which in turn is subject to further oxidation by way of the so called tricarboxylic acid or Krebs cycle See ADENOSINEDIPHOSPHATE (ADP) ADENOSINETRIPHOSPHATE (ATP) BACTERIAL METABOLISM KREBS CYCLE TRANSAMINATION

Reaction specificity As already mentioned a particular coenzyme may act in concert with any one of a large number of substrate specific apoenzymes The nature of the coenzyme then determines the general type of reaction that the holoenzymes can catalyze Some of the more common ones are listed in the table [QNM WAV]

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Bacterial endospores

Resistant bodies produced by bacteria Endospores (spores) enable the bacteria to withstand extremes of temperature and humidity Endospores are produced by species of both the anaerobic *Clostridium* and the aerobic *Bacillus* and appear as highly refractile bodies inside a mother cell or sporangium (Fig 1) Each cell usually produces one endospore with a size shape and position in the cell which is characteristic of the species

Endospore structure and constituents The structure of the endospore includes a two-layer cell wall an outer thin coat (exosporium) of low refractive index a striated cortex comprising 50 80% of cell volume between the cell wall and the cytoplasmic membrane and a dense cytoplasm with a terminal nucleus The chemical analysis of endospores shows that compared to vegetative cells they have less water free amino acids sulfhydryl groups lipid phosphorus and β hydroxybutyric lipid However they contain higher amounts of p-amino acids heavy metals and phosphoprotein Dipicolinic acid is unique to endospores amounting to as much as 10 15% of dry weight Endospores contain fewer active enzymes than do vegetative cells Several are active in intact endospores while others called dormant enzymes are observed only after activation of the endospore by heat or chemical agents



Fig 1 Sporulating cells of *Bacillus cereus* N grosin a r mount (*Photomicrograph by M D Fitzjames*)

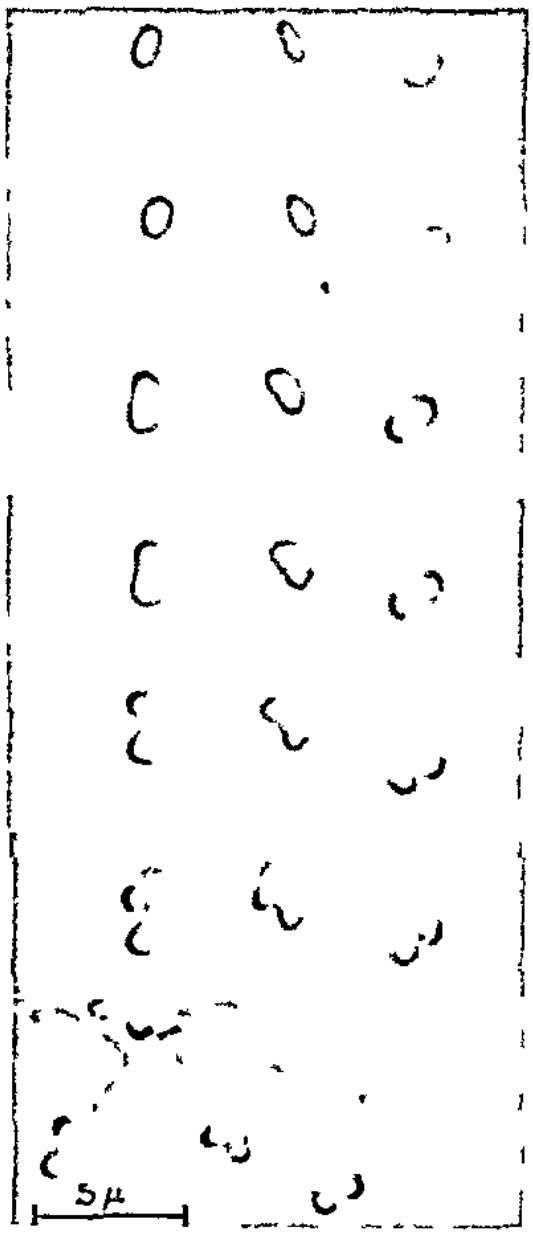


Fig 2 Germination of spores of *Bacillus subtilis* Three hour time lapse from beginning to end of germination (*Photomicrograph by C F Robinow*)

Endospore formation While this characteristic can be lost and occasionally regained it is a very stable property in a majority of spore forming bacteria The conditions necessary for endospore formation are not well understood the process

requires active metabolism and can be initiated by various conditions (deficiencies) which retard vegetative growth Sporulation involves several phases (1) the formation of a refractile pre spore (2) dipicolinic acid synthesis and finally (3) the development of the thermostable endospore The genus *Bacillus* has a higher oxygen requirement for the onset of sporulation than for maintaining vegetative growth Calcium is necessary for the formation of thermostable spores

Germination Germination is usually regarded as the loss of heat resistance while outgrowth refers to the subsequent developments leading to mature vegetative cells The breaking of dormancy of endospores requires heat activation or aging and the addition of species-specific germination stimulants which are usually either an amino acid or a carbohydrate and a nucleoside The process is not understood although endospores can metabolize the germinating agents

The breaking of dormancy is characterized by an imbibition of water by increased permeability and by losses in refractility heat resistance and the dry weight with decreases in peptides amino acids and calcium dipicolinate Increased permeability and loss in dry weight are attributed to a lytic enzyme Later the endospore coat breaks and a new germ cell emerges from the spore coat The germ cell eventually matures into a vegetative form in which the cell wall is derived from the cytoplasmic membrane of the endospore (Fig 2) Chromatin differentiation and changes in nucleic acids metaphosphate and enzymes occur during the entire transition *See* BACTERIAL CELL CHEMISTRY BACTERIAL METABOLISM BACTERIAL PHYSIOLOGY

[H O H]

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Bacterial enzyme

A term for a group of catalysts produced by bacteria A list of bacterial enzymes would include most of the enzymes found in mammalian tissues In addition bacteria contain many enzymes not found or as yet not reported to occur in higher forms of life The great adaptability of the bacterial cell to metabolize a wide variety of substances as well as to control to some extent the environment in which the cell lives is reflected in the ability to form adaptive enzymes A majority of bacterial enzymes requires cofactors for activity These may be inorganic cations or organic molecules called coenzymes *See* BACTERIA COENZYME ENZYME

Classification Bacterial enzymes may be classified as either constitutive enzymes or adaptive enzymes the latter are more properly designated as induced enzymes Constitutive enzymes are defined as those enzymes formed by the bacterial cell under any or all conditions of growth whereas adaptive enzymes are formed by the bacterial cell only in response to an inducer In nature the inducer is usually the substrate for the specific adaptive enzyme involved However in the laboratory it is possible to use inducers which are not substrates provided the molecular configurations are similar to those of true substrates An example of an adaptive enzyme might be galactokinase an enzyme necessary for the phosphorylation of galactose it is formed only if the cell is grown on a medium containing D-galactose as a carbon source If a culture of bacteria grown on galactose were subsequently transferred to a galactose free medium the enzyme galactokinase would no longer be synthesized by the bacterial cell Although bacteria vary considerably in their ability to adapt to various substrates most bacteria are versatile in their abilities to form adaptive enzymes

Bacterial enzymes may also be subdivided into those enzymes remaining within the cell (endoenzymes) which are necessary for the energy yielding degradation reactions and the energy requiring formation of cell constituents as differentiated from the hydrolytic enzymes secreted by the cell (exoenzymes) into the surrounding medium

Endoenzymes Endoenzymes are generally characterized by a high degree of specificity and often catalyze a reaction of only a single substrate

Some of the common reaction types catalyzed by endoenzymes are listed in Tables 1 and 2 the reactions mentioned under Example illustrate either a general or a specific case

Many endoenzymes are recognized as composed of a protein moiety also called carrier or apoenzyme and a small molecular species the coenzyme also known as the prosthetic or "active

Table 1 Reactions involving carbohydrates

Enzyme type	Type of reaction catalyzed	Example
Kinases	Phosphorylation of substrate	CHO | HCOH | HOCH | HCOH | HCOH | CH_2OH Glucose + ATP $\xrightarrow{\text{Glucok nase}}$ CHO | HCOH | HOCH | HCOH | HCOH | $CH_2OPO_3H_2$ Gluc hosph + ADP

Table 1 Reactions involving carbohydrates (Cont.)

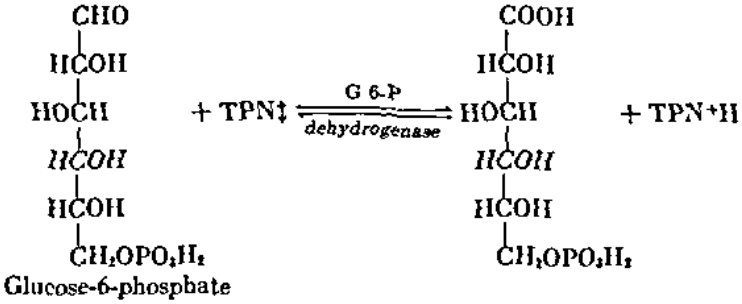
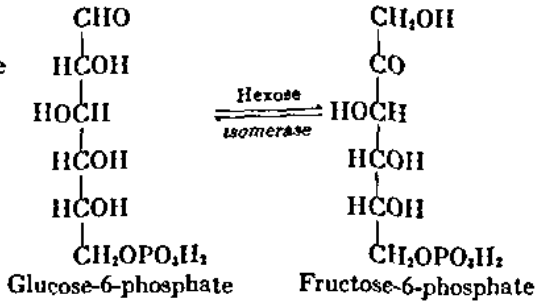
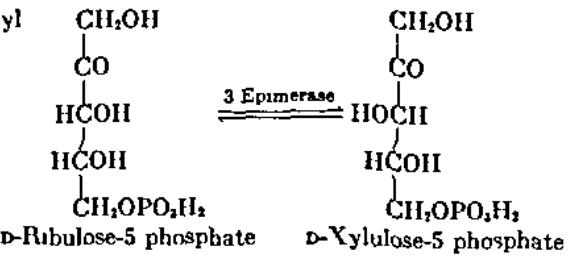
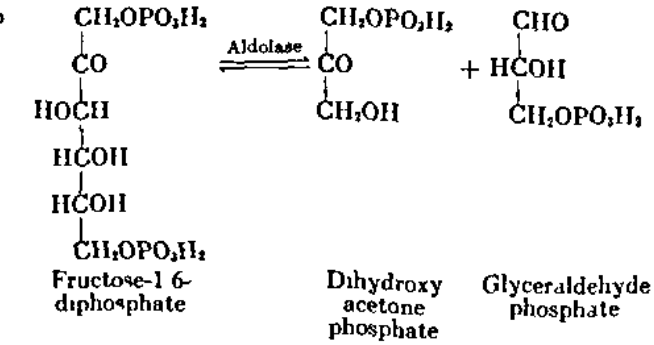
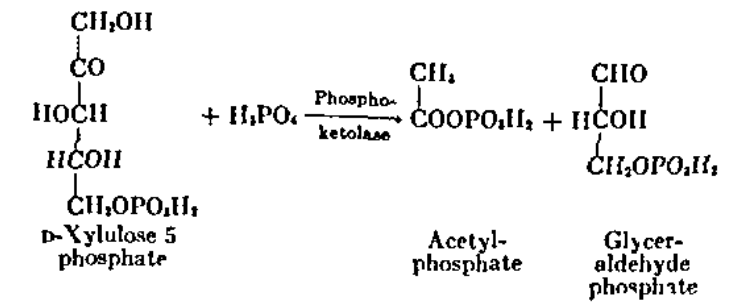
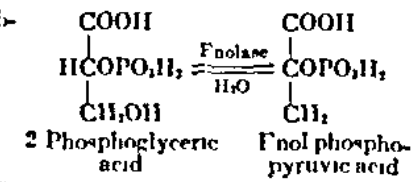
Enzyme type	Type of reaction catalyzed	Example
Dehydrogenases	Oxidation or reduction of substrate	
Isomerases	Molecular rearrangement of substrate to form ketose from aldose or aldose from ketose	
Epimerases	Rearrangement of hydroxyl groups on substrate	
Aldolases	Cleavage of substrate into two molecules	
Ketolases	Cleavage of substrate at position of carbonyl carbon	
Enolase	Convert keto form of substrate to enol form by addition of H_2O	

Table 1 Reactions involving carbohydrates (Cont)

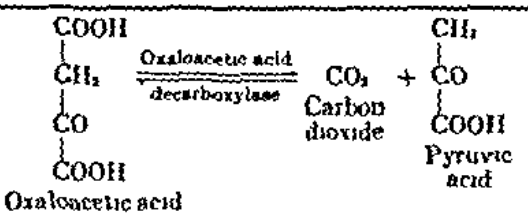
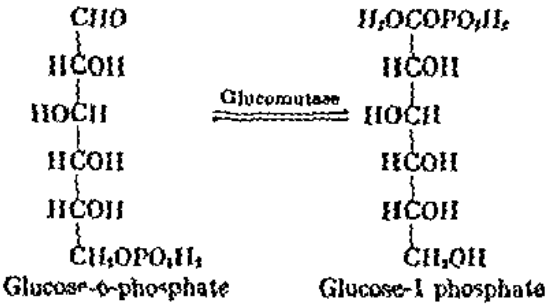
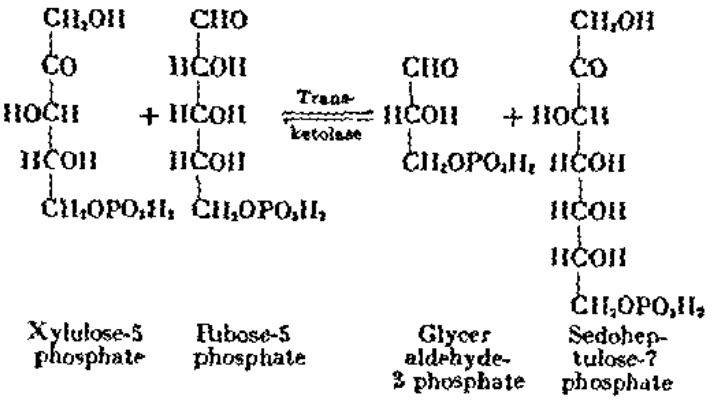
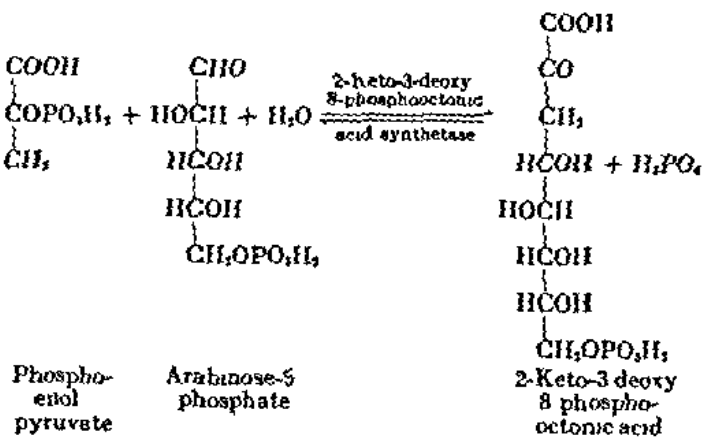
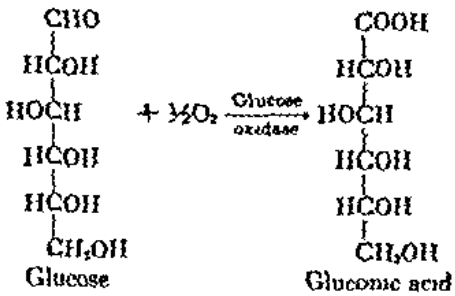
Enzyme type	Type of reaction catalyzed	Example
Decarboxylases	Remove carboxyl carbon from substrate	
Mutases	Result in transposing phosphate from one carbon of substrate to a different carbon atom of same substrate molecule	
Transketolase	Similar to ketolase except 2-carbon fragment must be transported by the enzyme to an acceptor compound to form a new compound	
Synthetase	Condensation of phosphoenol pyruvate with CO_2 or other phosphorylated carbohydrates each synthetase is specific for one condensation	
Oxidases	Yield same over-all result as dehydrogenases however no coenzyme is involved and molecular oxygen is required	

Table 1 Reactions involving carbohydrates (Cont)

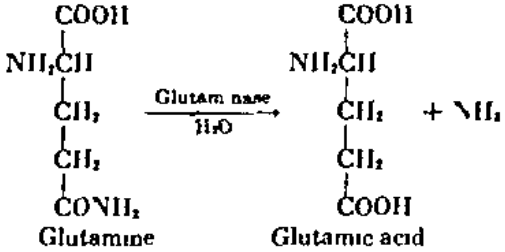
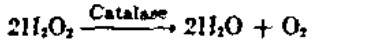
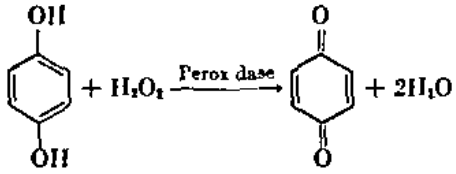
Enzyme type	Type of reaction catalyzed	Example
Phosphorylases	Condenses smaller phosphorylated sugars into polysaccharides	$H_2OCOPO_3H_2$ (HCOH)(HOCH)(HCOH)(HCOH)CH_2OH Glucose 1-phosphate $\xrightarrow{\text{Phosphorylase}}$ Starch + H_3PO_4
Phosphatases	Remove phosphate from aldehyde or acid substrate	CHO(HCOH)(HOCH)(HCOH)(HCOH)$CH_2OPO_3H_2$ Glucose 6-phosphate $\xrightarrow[+H_2O]{\text{Phosphatase}}$ CHO(HCOH)(HOCH)(HCOH)(HCOH)CH_2OH Glucose + H_3PO_4

* Adenosinetriphosphate
† Adenosinediphosphate
‡ Triphosphopyridine nucleotide

2 Enzymes involving amino acid metabolism

Enzyme type	Type of reaction catalyzed	Example
Amino acid deaminases	Remove amino group from amino acid different deaminases may carry out a reductive or oxidative deamination members of genus *Clostridium* carry out an anaerobic dismutative deamination referred to as the Stickland reaction it represents a combination of the two kinds	Reductive $RCH(NH_2)COOH \xrightarrow[+2H]{\text{Deaminase}} RCH_2COOH + NH_3$ Oxidative $RCH(NH_2)COOH \xrightarrow{\text{Deaminase}} RCOCOOH + NH_3 + 2H$ Stickland reaction $RCH(NH_2)COOH + XCH(NH_2)COOH \xrightarrow{+H_2O}$ $RCOCOOH + XCH_2COOH + 2NH_3$
Amino acid transaminases	Removes amino group from one amino acid and carries it to an α keto acid to form a new amino acid and a new α keto acid	$CH(NH_2)(CH_2)(CH_2)COOH$ Glutamic acid + $CH_3COCOOH$ Pyruvic acid $\xrightarrow{\text{Transaminase}}$ $CH_3CH(NH_2)COOH$ Alanine + $CO(CH_2)(CH_2)COOH$ α Keto-glutaric acid
Amino acid decarboxylases	Remove carboxyl group leaving basic amine	$RCH(NH_2)COOH \rightarrow RCH_2NH_2 + CO_2$ Amino acid → Amine
Amino acid oxidases	Same as oxidative deaminases (see amino acid deaminases above)	

Table 2 Enzymes involving amino acid metabolism (Cont.)

Enzyme type	Type of reaction catalyzed	Example
Amidases	Remove amide group from some amino acids	
Miscellaneous		
Catalase	Iron-containing enzyme which oxidizes hydrogen peroxide	
Peroxidases	Oxidizes large number of phenols and aromatic amines in presence of H_2O_2	

group Neither component acts as a catalyst by itself only the combination or holoenzyme does The coenzyme is responsible for the particular type of catalytic activity displayed by the holoenzyme such as the dehydrogenation of an alcohol to an aldehyde of an aldehyde to a carboxyl group or the transfer of an amino group from one molecule to another The apoenzyme on the other hand confers on the holoenzyme its pronounced specificity Thus a single kind of coenzyme can act in combination with any one of a large variety of apoenzymes so that each of the combinations is functional in the conversion of one specific substrate (*see* BACTERIAL COENZYME)

Exoenzymes In addition to the enzymes of bacteria which participate directly in the metabolic cycles of the cell there are numerous enzymes which function as depolymerizing enzymes making micromolecules available to the cell The most common examples include the cellulases which degrade cellulose to cellobiose amylases which degrade starch to dextrins and maltose and the proteinases which hydrolyze proteins to polypeptides and amino acids The ability of any given organism to use a particular substance of high molecular weight depends upon its ability to produce hydrolytic enzymes that are capable of attacking the substance in question The exoenzymes are generally referred to as hydrolases because they catalyze the hydrolytic breakdown of their substrates Examples of this group of bacterial enzymes are presented in Table 3 *See* AMYLASE

Adaptive exoenzymes Many exoenzymes are constitutive Nevertheless their production may be enhanced by cultivation of the appropriate bacteria in the presence of the corresponding di oligo or polysaccharides hemicelluloses and proteins In some cases exoenzymes are formed only in response to the presence in the medium of the specific substrate

Medical importance Many pathogenic microorganisms excrete enzymes which probably play an important role in pathogenesis in some cases The α toxin (lecithinase) of *Clostridium perfringens* illustrates a highly active enzyme which is responsible for the necrotizing action associated with gas gangrene infections due to this microorganism (*see* GANGRENE GAS) *Streptococcus pyogenes* excretes hyaluronidase which degrades ground substance (polymer of hyaluronic acid) streptodornase which splits deoxyribonucleic acid and streptokinase which activates plasmin resulting in a system that lyses fibrin Other examples include coagulase of the *Staphylococcus* which activates clotting of

Table 3 Extracellular bacterial enzymes

Organism	Enzyme	Substrate	End products
Clostridium	Cellulase	Cellulose	Cellobiose
Beneckea	Chitinase	Chitin	N Acetyl glucosamine derivatives
Erwinia	Pectinase	Pectin	Galacturonic acid derivatives
Bacillus	Amylase	Starch Amylose Glycogen	Limit dextrins maltose
Bacillus	Proteinase Lipases (esterases)	Protein Fats	Polypeptides Glycerol and fatty acids

Table 4 Enzymes excreted by microorganisms of medical importance

Organism	Enzyme	Substrate	End products
Clostridium	Lecithinase	Lecithin	Diglyceride phosphoryl choline
Clostridium	Collagenase	Collagen	?
Streptococcus	Hyaluronidase	Hyaluronic acid polymer	Hyaluronic acid
Streptococcus	Streptodornase	Deoxyribonucleic acid	Nucleotides
Streptococcus	Streptokinase	Activates plasminogen to plasmin	Results in lysis of fibrin clots
Staphylococcus	Coagulase	Coagulase reacting factor	Results in coagulation of plasma
Proteus	Urease	Urea	Ammonia and carbon dioxide

plasma urease of *Proteus vulgaris* which splits urea to ammonia and carbon dioxide and collagenase of *Clostridium* which hydrolyzes collagen A summary of the more common enzymes excreted by pathogenic microorganisms is presented in Table 4 *See* HYALURONIDASE STAPHYLOCOCCUS

Penicillinase is an enzyme that hydrolyzes penicillin to penicilloic acid which has no antibiotic activity The enzyme is often produced inductively for example by *Bacillus species*

The development of penicillin resistance in *Staphylococcus* cultures has been associated with the appearance of mutants that can form penicillinase *See* BACTERIAL GENETICS MUTATION

Even penicillinase producing bacteria are vulnerable to penicillin in high enough concentrations In that case the inactivation of the antibiotic lags behind its inhibitory effects *See* PENICILLIN

Autolytic enzymes Autolytic enzymes form a class of enzymes which are located in the cell wall of bacteria but are held in check by a battery of enzyme inhibitors However in many bacteria the autolytic enzyme system is readily activated following injury or death of the cell resulting in a rapid degradation of the cell wall to soluble moieties with disintegration of the protoplast The notable example is the treatment of *Diplococcus pneumoniae* with sodium deoxycholate or surface active agents which results in a rapid autolysis of the cells *See* BACTERIAL COENZYME BACTERIAL METABOLISM PNEUMOCOCCUS [O N M W A V]

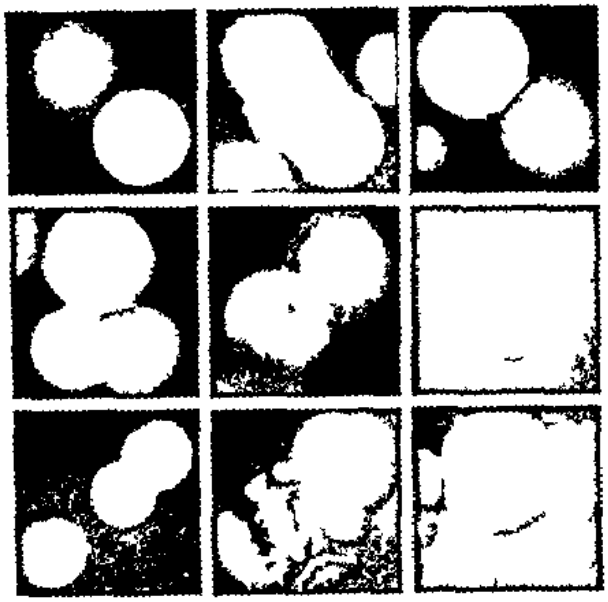
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Bacterial genetics

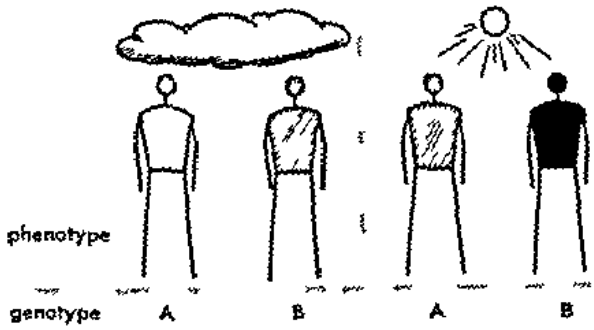
The study of the variability and inheritance of characteristics of bacteria The information derived from bacterial genetics has provided bacteriologists with a better means for controlling or producing such economically important bacterial characteristics as fermentative capabilities virulence and capacity to immunize It has also furnished geneticists with extremely useful model systems for the study of principles of heredity or genetic principles These principles have proved to be comparable in higher and lower organisms even though sexual processes of reproduction seem to be relatively rare among bacteria and where they occur appear less highly developed than in higher forms since in all known cases one of the two participating parents contributes only a small portion of its total set of hereditary determinants

Mutation and population change As a rule bacteria multiply asexually by simple fission They undergo such fissions as frequently as every 15 min *and thus can attain enormously large population* sizes for example 1 000 000 000 or 10^9 organisms per milliliter within relatively short periods of time As in higher organisms the determinants of hereditary bacterial characteristics are likely to change spontaneously that is mutate at rates that can differ for different determinants or genes Roughly there is one determinant for each heritable and independently variable characteristic (*see* GENE MUTATION) Thus depending upon the gene involved mutation rates may be as low as 1 affected bacterium per 10^{10} organisms per generation or as high as 1 in 10^3 per generation The constant occurrence of such spontaneous mutations in growing bacterial populations provides a source of genetically different cells or mutants with new characteristics Whenever the properties of these few altered bacteria are better suited to the existing environmental conditions than those of their parental cells the mutated bacteria will outgrow often quite rapidly the parent type cells Population changes thus result

Genotypic and phenotypic changes Genotypic changes are the relatively stable alterations of individual genes of gene assortments and of the characteristics they control caused by either mutation *by sexlike processes* or by lysogenic conversion Genes however merely control the reaction range of a cell the specific expression of a given characteristic is subject to considerable temporary modification by environmental conditions For example certain bacteria possess the genetic potential to form a certain pigment the actual amount of pigment produced by the individual bacterium however is influenced by the nutritional conditions and the hydrogen ion concentration of the environment Such environment dependent variability in



Bacter al mutants d ffering in the morphology of their colon es The colon es here shown are all formed by closely related members of the species Bacter um tula rense the causat ve agent of rabb t fever (W Braun J Bacter ol 61 557–569 1951)



D agram illustrat ng phenotyp c change The expres s on of sk n p gmentat on a gene controlled charac teristic, is dependent on the environment (W Braun Bacter al Genet cs Saunders 1953)

the expression of the gene-controlled characteris t cs is known as phenotypic variability and the resulting changes are called phenotypic changes

Role of deoxyribonucleic acid (DNA) As in higher organisms the site of most bacterial deter minants of hered tary traits is within the nucleus an intracellular structure rich in DNA In the parlance of the geneticists the transfer of the genetic "information is presumably accomplished by the capabil ty of DNA the chemical controller of specific cellular processes to produce more of its own kind DNA exists in the form of highly com plex molecules whose nucleotide components can occur in an extremely large number of arrangements or sequences It is believed that the specificity of DNA resides in its nucleotide se quence Such DNA is transmitted to the daughter cells during nuclear division which precedes cellu lar division The chemical processes that control the structure and function of a cell are all under the direct or indirect control of enzymes which are proteins and it is believed that the formation of specific enzymes is controlled by specific genes

The existence of bacterial chromosomes the presumed sites of the genes is suspected but re mains to be confirmed The relative instability of the genes which are subject to mutation under normally existing conditions can be increased greatly but relatively unspecifically by certain en vironmental agents referred to as mutagenic agents or mutagens Examples of these are x rays ultra violet rays (UV) nitrogen mustard peroxide and many of the tumor inducing (carcinogenic) sub stances Most m tagens evoking induced muta tions are extremely toxic but the killing and mu tation enhancing effects are not necessarily identi cal This is demonstrated by the phenomenon of photoreactivation or photorecovery which is the capability of visible light to overcome the muta genic and killing effects of UV after exposure of bacteria to h gh intensities of UV only the killing but not the mutagenic effects can be reversed

Sexlike mechanisms In a number of bacterial species sexlike mechanisms have been demon strated These lead to an alteration in the set of genes of one cell by a process of exchange of determinants that are contributed by another cell which is genetically d fferent though related De pend ng upon the size of the contribut on from the second cell three types of sexlike mechanisms can be distinguished

Transformation This was first demonstrated among bacteria causing pneumonia Transforma tion involves the transfer of single genetic determi nants from one bacterium to another via DNA The DNA is either extracted chemically from the donor cell or is released from it by lysis

Transduction This was shown to occur among bacteria belonging to the group causing typhoid fe ver Transduction involves the transfer of single or occasionally two determinants from one bacterial cell to another via bacterial viruses which are also called bacteriophages these viruses p ck up the bacterial gene or genes in the course of their mul tiplication in the virus-sensitive host bacterium The host is destroyed as a result of the virus infection (see INFECTION LYTIC) Subsequently these vi ruses may infect related bacteria that are more resistant to them The virus will then coexist in such a bacterium in a so called state of lysogen icity or lysogeny and can contribute the set of determinants picked up in its prior susceptible host to the determinants of the new host (see C TERIA LYSOGENIC)

Recombination This is a process t mong colon bacilli and which re ely the sexual phenomena of m

ganisms Two competent bacteria enter into direct physical contact or conjugation One contributes the major portion of its set of determinants, an exchange between determinants of the donor and the *recipient* cells occurs during which new combinations of genes may result if the parents differed in their determinants However the total number of determinants does not increase since surplus determinants are later lost from the recombinant bacterium or from its offspring

In some bacteria the presence of specific bacterial viruses or more precisely of prophage within the bacterial cell can alter specific bacterial characteristics This phenomenon of lysogenic conversion is illustrated by the fact that virus free cells of the diphtheria organism are harmless to their mammalian host whereas lysogenic cells produce a disease causing toxin

Application to biological problems Studies with certain types of bacterial mutants have contributed much to the understanding of the control of biochemical processes in the cell by genes The particular mutants involved are cells that have lost the capacity to manufacture certain substances or metabolites indispensable for growth which their parent cells were able to synthesize To support multiplication the growth medium of this class of biochemical mutants which are called auxotrophs must be supplemented with the specific substance they fail to synthesize With the aid of a variety of different auxotrophic mutants intermediates in the various complicated pathways leading to the production of essential metabolites or of end products of the cell s metabolic activities have been identified (*see* BACTERIAL METABOLISM)

Other bacterial mutants namely those that spontaneously have become resistant to a given antibiotic have contributed much to the recognition of the mode of action of specific antibiotics and thereby contributed to the improvement of therapeutic procedures (*see* ANTIBIOTIC CHEMOTHERAPY) Thus mutations endowing bacterial cells with resistance to one antibiotic like penicillin occur independently of mutations causing resistance to another antibiotic like streptomycin Since each one of these mutational events is rare on the order of 1 in 10^9 cells a simultaneous change within one cell which endows it with resistance to both antibiotics at the same time is a highly improbable event likely to occur in only 1 of 10^{18} cells This fact underlies the practice of combined antibiotic therapy which reduces the chances for occurrence of doubly resistant forms in patients under treatment High resistance to most antibiotics is attained by a series of independent mutational events in one cell and its progeny with each mutational step leading to only a slight increase in resistance However high resistance to some antibiotics like streptomycin also can be attained by one mutational event that is in one step Numerous experiments have indicated that such changes can occur independently of the presence of the antibiotic Resistance like most other genetic changes of bacteria and higher organisms can therefore occur independently of any specific inducing or directing influences of the environment

Mutants with decreased or otherwise altered virulence characteristics derived from disease causing (pathogenic) bacterial strains have aided in the elucidation of problems of disease development both in individuals (pathogenesis) and in populations (epidemiology) Still other types of mutants for example those capable of producing larger amounts of an antibiotic or possessing unusual or more effective fermentative capacities than those of their parents have become of considerable economic importance in industrial procedures

In any growing bacterial population initially consisting of one particular type mutant cells initially represent only a minor fraction of the population Many different environmental and genetic factors can contribute to the progressive replacement of the original bacterial type by mutant cells The identification of factors that control such population changes has become of value to a number of biological problems Among such problems are the maintenance of stock cultures used for vaccine production and an understanding of phenomena contributing to infectious disease processes Another problem is the recognition of competitive interactions among different cell types interactions that may contribute to processes of normal (developmental) and abnormal (for example neoplastic) differentiation in higher forms Representative factors influencing competition and natural selection in bacterial cell populations are specific metabolites which may be produced by one cell type and which may affect the growth of mutant cell types cellular breakdown products which can possess selective toxicity for specific types of cells, exhaustion of nutrients which may affect one type of bacterium (such as the parent) more than another (for example the mutant) Identification and control of such factors has improved the ability either to prevent undesirable population changes in bacterial cultures or to enhance such changes at will Such population studies also contribute to a better understanding of mechanisms of mutation and selection that have influenced processes of evolution

[W PR]

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Bacterial growth

Two related but distinct processes increase in the mass of bacteria and increase in the number of bacteria The increase in the number nearly always occurs by simple binary fission an exception is found in the Hyphomicrobiales which multiply by a

kind of budding process (*see* HYPHOMICROBIALES) To measure bacterial growth, either the cells can be counted or the cell mass can be weighed

The growth curve of a typical bacterium is shown in Fig 1 In the lower portion of the figure the culture density (number of cells or cell mass per milliliter) is plotted against time in the upper portion, the logarithm of the density is similarly plotted The curve may be divided into three major phases, connected by two transitional zones The three phases are the lag phase the exponential growth phase and the stationary phase

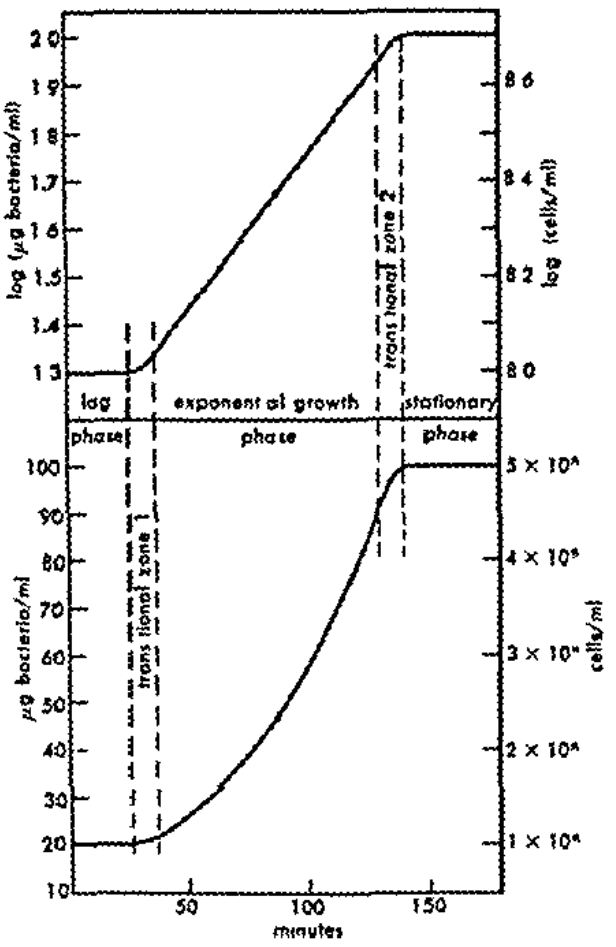


Fig 1 The bacterial growth curve Lower portion the increase in the mass of bacteria and the number of bacteria with time Upper portion the increase in the logarithms of bacterial mass and number with time log phase 25 min doubling time t_d 45 min specific growth rate μ 0 154 min $^{-1}$

Lag phase When a culture that has reached the stationary growth phase is inoculated into fresh medium there is a period during which growth can not be detected This is the lag phase The length of the lag phase depends on the bacterium the medium and the length of time the inoculum had been in the stationary phase If an exponentially growing culture is transferred to fresh medium there is no lag phase

A culture growing exponentially in one medium will often show a lag when transferred to a different medium In some cases this has been attributed to the time required for the cells to synthesize the enzymes required for growth in the second medium but which were not formed in the first medium These enzymes are called induced enzymes and they are formed only in the presence of their substrates The adjustment which stationary phase cells undergo during the lag phase probably also involves enzyme synthesis

Exponential growth phase This is the period during which the logarithm of the culture density increases linearly with time During this phase the composition and metabolic activities of the bacteria remain constant Hence the biochemical machinery of each newly formed cell is identical with that of its parent This results in exponential growth and it may be seen from the following considerations Every newly synthesized cell continues to form more cellular material at the same rate its parent did This rate is the rate of synthesis of new cell material per unit mass of bacteria and is called the specific growth rate μ It is a constant whose value depends on the particular bacterium and on the conditions of growth

$$\mu = \frac{dB}{dt} \times \frac{1}{B} = \frac{d \ln B}{dt} \tag{1}$$

where B is the culture density ln is the logarithm to base e and t is time The total rate of new cell synthesis at any time is the specific rate times the amount of bacteria present at that time

$$\frac{dB}{dt} = \mu B \tag{2}$$

Integration of Eq (2) between the limits $B = B_0$ and $B = B$ where B_0 is the cell density at time zero and B_t is the cell density at time t yields

$$B_t = B_0 e^{\mu t} \tag{3}$$

and taking logarithms of both sides of Eq (3) one obtains

$$\ln B_t = \ln B_0 + \mu t \tag{4}$$

This is the most useful form of the equation for exponential growth

The specific growth rate constant is often expressed in terms of generation time or doubling time t_d This is the time it takes for the cell concentration to double that is for B to become $2B$ From Eq (4) one obtains

$$\begin{aligned} \ln 2B_0 &= \ln B_0 + \mu t \\ t_d &= \frac{\ln 2}{\mu} = \frac{0\,69}{\mu} \end{aligned} \tag{5}$$

Balanced growth During exponential growth the ratios of all cell components to one another are constant This is called balanced growth In general a change from balanced to unbalanced growth results in a change in some property of the culture

Unbalanced growth may result from the selective inhibition of the synthesis of one particular cell component If growth continues long enough the imbalance can become so extreme that the cell dies This may be the cause of cell death by some lethal agents which cause no gross structural dam age

Individual cell growth A culture usually con tains from 10^6 to 10^9 cells per milliliter Therefore even very large variations in the properties or be-havior of individual cells are not ordinarily observ able If a property is distributed normally that is follows the curve of normal distribution then the behavior of the population with respect to the prop erty may be taken as an indication of the behavior of individual cells An example is the generation times of individual cells which are broadly dis tributed around a mean generation time equal to the populational generation time

However not all the cells of a population need be identical and the distribution of a property is not always continuous or normal Some properties for example the formation of certain induced enzymes are distributed discontinuously That is only a fraction of the population possesses this property In an all or none situation like this the behavior of the populational average under differ ent conditions is a very misleading indication of the behavior of individual cells

Growth end point and stationary phase Ex ponential growth cannot continue indefinitely be cause the medium becomes unsuitable for further growth either by the accumulation of toxic prod ucts or by exhaustion of an essential nutrient As a result of either the culture enters the stationary phase

An analysis of the limitation of growth by ex haustion of the medium follows Any bacterium has certain minimal requirements for growth In a minimal medium which supplies only these require ments growth stops when any one of the nutrients is exhausted This is the limiting nutrient The relationship between growth and the amount of two different limiting nutrients is shown in Fig 2 The two curves follow the equation

$$Y = \frac{B_n}{S_0} \tag{6}$$

where B_n is net growth that is the final growth minus the inoculum S_0 is the amount of limiting nutrient supplied and Y is the yield constant

Environment and growth rate The growth rate of a bacterium is markedly affected by the environ ment Temperature pH oxidation potential and osmotic and hydrostatic pressure can all influence the growth rate The growth rate is also dependent on the type of nutrients supplied in the medium Also the specific growth rate depends on the con centration of the limiting nutrient in a minimal medium according to the equation

$$\mu_s = \mu_m \left(\frac{S}{S + K_m} \right) \tag{7}$$

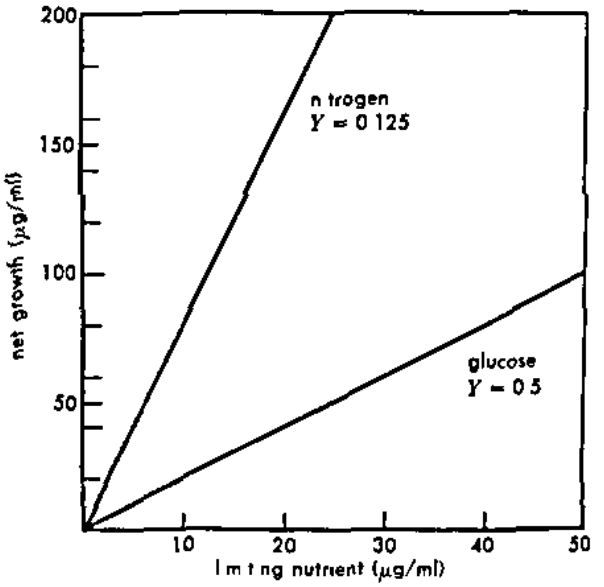


Fig 2 Dependence of growth on the amount of a limiting nutrient

This equation states that as the substrate con centration S is increased the growth rate μ_s in creases eventually the growth rate attains a maxi mum value μ_m and is then not changed by a further increase in S In other words at substrate concen trations greater than some limiting concentration the growth rate is independent of substrate concen tration In Eq (7) K_m is a constant which depends on the nature of the substrate and on the bacterium K_m is numerically equal to the substrate concen tration at which μ_s is one half μ_m It is important to realize that at low values of S the cells are growing exponentially although the specific growth rate is less than maximal With most sub strates K_m is very small in the case of *Escherichia coli* growing in a medium with glucose as the limit ing nutrient K_m is about 10^{-3} g/liter Thus if the initial glucose concentration is 0 1% the culture will reach nearly its maximum amount of growth before the specific growth rate declines

Continuous culture In the usual type of cul ture the conditions of growth are constantly chang ing For many experiments it is desirable to main tain an exponentially growing culture at a constant cell density and in a constant environment There are two devices by which this can be done These are the turbidostat and the bactogen or chemostat In both the culture is kept at a constant volume in a growth tube by allowing fresh medium to enter the growth tube as fast as the culture is removed

Turbidostat By means of a photocell and appro priate electrical connections the turbidostat main tains a constant culture density by adjusting the flow rate of fresh medium into the growth tube The dilution rate that is the rate of flow of fresh me dium into the culture divided by the volume of the culture is equal to the specific growth rate which depends only on the medium

Chemostat The chemostat operates on a different principle It uses a minimal medium with one limit

ing nutrient If the dilution rate is less than the growth rate the density of the culture will increase and the concentration of the limiting nutrient in the growth tube will decrease Eventually the concentration will become so low that the specific growth rate of the culture becomes equal to the dilution rate as seen in Eq (7) and the culture then stabilizes itself The density at which the culture stabilizes will depend only on the concentration of the limiting nutrient in the fresh medium the growth rate can be varied simply by changing the dilution rate *See* BACTERIAL METABOLISM BACTERIAL NUTRITION CHEMOSTAT [W R S]

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Bacterial luminescence

A light producing phenomenon exhibited by certain bacteria Most luminous bacteria are found in the sea They may be classified as parasitic causing infection of various animals saprophytic living on dead matter such as fish or meat or symbiotic living in the luminous organs of fish or squid Most will grow on ordinary nutrient agar with 3% sodium chloride and glycerol The two forms of luminous bacteria which have been studied most extensively are *Achromobacter fischeri* and *Photobacterium phosphoreum* The intensity of bacterial light emission is extremely high The emission of 7 5 ergs of radiant energy per second from a milliliter suspension has been measured The color of the light is usually a blue green with an emission peak at approximately 480 millimicrons (4800 angstrom units)

By R DuBois's definition luciferin luciferase and oxygen are the three components essential for light emission Luciferin is an oxidizable substance and luciferase is an enzyme or catalyst which accelerates the combination of luciferin with oxygen The energy liberated in this oxidation excites the luciferin for light emission There are many luminous organisms and the luciferin and luciferases are different for each In bacteria reduced flavin mononucleotide (FMN) a riboflavin derivative may be the luciferin A luciferase obtained from bacteria catalyzes the oxidation of reduced FMN in the presence of a long-chain aldehyde and oxygen Any aldehyde with a chain length of 6–16 carbons is effective During the reaction one of the luciferin molecules becomes excited and emits light The mechanism of this chemical reaction is unknown However the light emitted in the test tube is identical to that observed in the whole (living) cell

When luminous bacteria are deprived of oxygen light emission ceases and reduced FMN accumulates Upon the readmission of air a brilliant flash occurs The intensity of the flash appears to depend upon the accumulation of reduced FMN

Genetic changes (mutations) in luminous bacteria have been obtained which affect the light emitting system As a result mutant organisms requiring aldehyde for luminescence have been isolated Mutations that prevent the synthesis of luciferase have also been observed The biochemical work clearly implicated the luminescent system as an accessory electron or hydrogen transport process in the living organism It is highly doubtful that light emission is of any importance to the bacterial cell It is merely an indicator of excited states normally occurring during electron transport processes *See* BACTERIAL METABOLISM BIOLUMINESCENCE [W D M]

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Bacterial metabolism

The sum total of the chemical changes carried out by living bacteria Metabolism also implies an orderliness an integration of a very large number of enzymatically catalyzed chemical reactions to fulfill one or more functions in the cell Even though extracts and preparations of disrupted bacterial cells can be obtained which display a moderately large number of enzymatic reactions perhaps simulating what goes on in the intact cell this is not regarded as metabolism Particular sequences of biochemical reactions are known as biochemical or metabolic pathways Such pathways may be concerned with catabolism the attack on and the conversion of a foodstuff for the procurement of chemical building blocks for biosynthesis, and of chemically stored energy By products may be produced and heat invariably is produced also The fabrication of more complex substances especially cellular constituents forms the building blocks and with the energy derived from catabolism comprises anabolism In essence catabolism denotes the oxidative degradation activities of an organism whereas anabolism denotes the reductive synthetic activities Metabolism also embraces the chemical and energetic aspects of permeability osmotic work reproduction motility photo- and chemotaxis luminescence adaptation cellular and subcellular differentiation and maintenance of preexisting form and structure in the absence of growth *See* BACTERIAL CELL CHEMISTRY BACTERIAL GROWTH BACTERIAL LUMINESCENCE

The innumerable different metabolic pathways have many features in common The enzymatically catalyzed reactions are simple intelligible one step chemical changes involving relatively few basic types of reactions Most pathways are slight variations of other pathways they employ the same kinds of inorganic and organic coenzymes and frequently they employ the same intermediates or precursors They produce and are powered by a very few common energy storage coenzymes It is common for pathways to exhibit some form of cyclic pattern whereby a product formed in the end of a reaction sequence reenters the sequence at an earlier stage For these reasons individual pathways are in close relation and even in equilibrium with other pathways so that in some circumstances the

same result may be obtained by alternative pathways It is probably impossible to affect specifically one pathway and only one without directly or indirectly affecting several others The integration of metabolic reactions is achieved in a variety of ways enzyme competition for common substrates inhibition of enzyme synthesis or activity at an early step by the products of a reaction sequence (feedback control) predominance of coupled reactions and the architectural proximity of the enzymes responsible for sequential reactions in discrete physical subcellular structures For example the protein synthesizing enzymes are associated with cytoplasmic granules containing nucleoprotein and oxidative enzymes of respiration are mostly located on the bacterial cell membrane *See* BACTERIAL COENZYME BACTERIAL ENZYME

One of the most important developments in bacterial metabolism is the doctrine of comparative biochemistry which states that biochemical pathways consist of a relatively small number of simple types of enzymatically catalyzed chemical reactions that are the same in microbial plant and animal cells and that the steps in the pathways elucidated in one bacterial species may be expected in other bacterial species as well as in plant and animal tissues which carry out the corresponding transformation In essence bacterial metabolism is a model from which the results are likely to be applicable to plants and animals The greater convenience of working with bacteria as experimental material gives them a favored position for general biochemical studies *See* METABOLISM

BACTERIAL CATABOLISM

Bacterial catabolism comprises the biochemical activities concerned with the net breakdown of complex substances to simpler substances by living cells Substances with a high energy level are converted to substances of low energy content and the organism utilizes a portion of the released energy for cellular processes

Endogenous and exogenous catabolism Endogenous catabolism relates to the slow breakdown of nonvital intracellular constituents to secure energy and replacement building blocks for the maintenance of the structural and functional integrity of the cell This ordinarily occurs in the absence of an external supply of food Exogenous catabolism refers to the degradation of externally available food The principal reactions employed are dehydrogenation or oxygenation (either represents biological oxidation) hydrolysis hydration decarboxylation and intermolecular transfer and substitution The complete catabolism of organic substances results in the formation of carbon dioxide water and other inorganic compounds and is known as mineralization Catabolic processes may degrade a substance only part way The resulting intermediate compounds may be reutilized in biosynthetic processes or they may accumulate intra or extracellularly The degree of breakdown depends on the genetic constitution of the particular bacteria and also can be markedly influenced by environmental conditions Catabolism also implies a conversion of the chemical energy into a relatively few energy rich compounds or "bonds" in which form it is biologically useful, also part of the chemical energy is lost as heat

Intermediary metabolism Bacterial intermediary metabolism relates to the chemical steps involved in metabolism between the starting substrates and the final product Normally these intermediates or precursors of subsequent products do not accumulate inside or outside the bacterial cell in significant amounts being transformed serially as rapidly as they are formed The identification of such compounds the establishment of the coenzymes and enzymes catalyzing the individual reaction steps the identity of active forms of the intermediates and other details of the reaction mechanisms are the objectives of a study of bacterial intermediary metabolism

Intermediary metabolism methodology Usually the objective is to interrupt the normal reaction sequence artificially so that the formation of one or more intermediates from their precursors continues Since the intermediates cannot then be further transformed they accumulate Intermediates may be detected qualitatively and quantitated by fairly specific procedures In some cases they are isolated in pure form and identified A number of chemical biological and physical methods are applied to this kind of study and usually are complementary Frequently it is desirable to simulate the reaction and study it with enzymes extracted from the living cell The respiratory quotient RQ (moles CO_2 produced/moles O_2 consumed) provides a rough index of the chemical nature (relative state of reduction) of a material being oxidized by a population of live bacteria By comparison with the theoretical values for complete oxidation valuable information relative to the extent of oxidation may be obtained The instrument universally employed for measuring the gas exchange on a micro scale is the Warburg respirometer Changes in pressure of CO_2 and O_2 are measured at constant gas volume and temperature in individual manometers attached to vessels containing substrate and suspensions of cells Uniform physicochemical environment is ensured by constant shaking in a constant temperature water bath Chemical or enzymatic reactions in which any gas is formed or consumed can also be studied kinetically and quantitatively

The Thunburg technique is used to study oxidation of a substrate occurring by dehydrogenation reactions A reversibly oxidizable indicator methylene blue substitutes for molecular oxygen as the ultimate hydrogen acceptor (oxidant) becoming reduced to the colorless leuco form Rigorous exclusion of gaseous oxygen is essential

Triphenyl tetrazolium compounds can be used instead of methylene blue The oxidized form is colorless, the reduced form is a red formazan Tetrazolium indicators have the advantage over

methylene blue that they are reoxidized by air only very slowly hence anaerobic conditions are not essential

Metabolite utilization determines the probable involvement of a supposed intermediate in a metabolic pathway If the hypothetical intermediate is metabolized it must be examined further However negative results may only indicate the failure of an intermediate to penetrate the permeable membrane of the cell In this event cell free enzyme preparations of the bacteria are helpful

Metabolite replacement by analogs or antimetabolites, chemicals structurally related to the natural intermediates is a method for interfering fairly specifically with a given reaction or pathway Usually a degree of inhibition of a reaction can be achieved and the effect on the formation of an end product or of a function studied

Inhibition of a specific reaction on a pathway by any of a number of means including metabolite analogs or nonspecific poisons frequently results in the accumulation of a precursor at the blocked reaction The accumulation may be intra or extracellular or both *See* Poison

Isolation and determination of identity of the accumulated intermediates is then possible whereas normally intermediates exist in unisolable concentrations

Paper vapor phase and column chromatographic techniques are invaluable physical procedures for the separation purification isolation and sometimes identification of compounds from multicomponent mixtures such as extracts of bacterial cells or cultural filtrates Tracer techniques employ metabolites labeled uniformly or in particular atoms with radioactive or stable isotopes The metabolic path of the metabolite is traced by following the distribution and fate of the labeled elements usually in various other metabolites with suitable instruments Concentrations of intermediates below the sensitivity of chemical isolation or detection procedures can readily be studied with tracers *See* Chromatography Radioisotope (biology)

Biochemical mutation is a tool for securing an inheritable block in a metabolic pathway A gene controlling the synthesis or function of a specific enzyme is permanently altered *mutationally* usually via irradiation or treatment with nitrogen mustard gas This alteration implies that the corresponding enzyme does not function in the mutated cell Since each of the steps in a metabolic chain reaction is mediated by its own specific enzyme the result is that the chain is interrupted If for example a biochemical process normally proceeds by a consecutive conversion of substance S_1 to product S_n via the steps

$$S_1 \xrightarrow[E]{} S_2 \xrightarrow[E_1]{} S_3 \xrightarrow[E_2]{} S_4 \xrightarrow[E_3]{} S_5 \xrightarrow[E_4]{} S_6 \xrightarrow[E_5]{} \qquad \xrightarrow[E_{n-1}]{} S_n$$

and the individual step reactions involve the enzymes E_1 E_2 E_3 E_4 E_5 E_{n-1} respectively then a mutated cell lacking a functioning E_4 can convert S_1 only as far as S_4 Hence this substance now no longer subject to conversion to S_5 tends to accumulate often in sufficient quantity to permit its isolation and hence identification as an intermediate product in a reaction chain *See* Bacterial genetics Mutation

Adaptive or induced enzymes are synthesized by the bacterial cell only in the presence of a specific inducing substance The product of the action of the first induced enzyme in turn functions as an inducer of a second enzyme and so on until the original substrate is converted to products acted on by the central constitutive enzymatic machinery of the cell If the hypothetical intermediate is utilized nonadaptively by a bacterium preadapted to a given substrate that is if the cell is simultaneously adapted to attack it this is taken as presumptive evidence that the postulated intermediate is on the pathway of utilization of the original substrate

Coenzyme action can be deduced by determining the biochemical or metabolic abnormalities caused in bacteria by affecting the function of specific enzymes through interference with the participation of essential inorganic or organic coenzymes This may be done by creating a deficiency by limiting the amount of coenzyme furnished as exogenous nutrients or through vitamin or coenzyme analogs In cell free extracts the coenzyme deficiency may be obtained by means of dialysis

CATABOLISM OXIDATIVE METABOLISM

Bacterial oxidative metabolism is manifested by the decomposition of a tremendous number of different substances by one or another species of bacteria Virtually any naturally occurring substance theoretically capable of yielding energy through oxidation is utilized for that purpose by some bacterial organism or other Some bacteria are extremely versatile and can utilize any one of a great number of different organic substrates as sources of energy and carbon for growth Other bacteria attack limited numbers of compounds and some are extremely specific for a single compound or for very few compounds Some are obligately linked to the oxidation of the reduced forms of a single inorganic element In the great majority of cases the substance or substrate undergoing oxidative attack is converted for the most part to bacterial cells carbon dioxide and complex mucoid substances The accumulation in appreciable yields of incomplete oxidation or degradation products by aerobic bacteria is not common although several instances are known In terms of substrate utilized the energy requirements of bacteria are considerably in excess of the carbon requirements for cell synthesis and so it is characteristic of bacterial oxidations that relatively large amounts of substrates are oxidized in relation to the amount of cellular material synthesized The more completely a substrate is decomposed by bacteria the less of it needs to be oxidized to yield a given amount of bacterial growth

Aerobic oxidations Aerobic oxidations are reactions in which the substrate is oxidized with con

comitant reduction of oxygen to water The oxidizable substrate may be represented by the generalized symbol H_2A Most bacterial oxidations take place via dehydrogenation of the hydrogen donors This occurs by transfer of two electrons (e) and two protons resulting in the formation of the oxidized product A

$$\underset{\text{Hydrogen donor (substrate)}}{H_2A} \xrightarrow[\text{(oxidation)}]{\text{Dehydrogenation}} A + 2H^+ + 2e$$

The dehydrogenation reaction will proceed only when the equilibrium is shifted to the right by removal of one or more products of the reaction This is done by hydrogen acceptors or oxidants which take up the protons and electrons thereby becoming reduced The oxidant may be denoted by the symbol B and its reduction by the equation

$$\underset{\text{Hydrogen acceptor (oxidant)}}{B} + 2H^+ + 2e \xrightarrow[\text{(reduction)}]{\text{Hydrogenation}} H_2B$$

Coupling the two reactions the net transformation for the bacterial oxidation of any substance may be represented as the sum of these reactions

$$H_2A + B \rightarrow A + H_2B + \text{energy}$$

The transfer of protons (active hydrogen) and electrons is mediated by a series of carriers present in catalytic concentrations and the equation merely represents the over all transformation by which all bacteria secure energy

Another less common mechanism of bacterial oxidation is oxygenation the direct incorporation of molecular oxygen in certain substrates in the initial oxidative step These reactions are catalyzed by oxidases and may be represented by the generalized equations

$$\underset{\text{Substrate}}{A} + O_2 \rightarrow \underset{\text{Oxidized substrate}}{AO_2}$$

$$\underset{\text{Substrate}}{AH_2} + 2[H] + O_2 \rightarrow \underset{\text{Oxidized substrate}}{AOH_2} + H_2O$$

Depending on the bacterial species or even strain and the environmental conditions H A may be any one of a great variety of organic and a lesser number of inorganic substances

Different organisms are capable of employing different hydrogen acceptors or oxidants for the oxidation of a substrate and this provides a basis for classification of the bacteria as well as for distinguishing types of bacterial oxidations Most bacteria utilize molecular oxygen as the ultimate hydrogen acceptor these are accordingly aerobic bacteria or aerobes In the absence of oxygen that is under anaerobic conditions they can use other hydrogen acceptors in lieu of O such as methylene blue or tetrazolium compounds Some of them can also use nitrate nitrite or nitrous oxide (N_2O) in that capacity Some bacteria that cannot live in the presence of oxygen (anaerobic bacteria) use sulfate or carbon dioxide as hydrogen acceptors (oxidants) As in the case of oxygen which yields H_2O the reduced forms of these oxidants accumulate as the result of the bacterial transformations each plays the role of B under appropriate conditions in the following reaction *See* BIOLOGICAL OXIDATION FERMENTATION

$$\underset{\text{Hydrogen acceptor (oxidant)}}{B} + 2H^+ + 2e \xrightarrow[\text{(reduction)}]{\text{Hydrogenation}} H_2B$$

Metabolism of inorganic substances When the oxidation of the reduced forms of inorganic substances is utilized as the sole source of energy for growth at the expense of carbon dioxide as the sole source of carbon the process is known as autotrophy The use of organic substances for energy and carbon assimilation is known as heterotrophy

1 Molecular hydrogen Molecular hydrogen is used autotrophically by certain bacteria all of which are capable of growing either autotrophically or heterotrophically they are facultative autotrophs The growth supporting reaction (sometimes called the Knallgasreaktion that is explosive gas reaction) they carry out is

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$$

The best known hydrogen bacteria belong to the genera *Hydrogenomonas* and *Mycobacterium* Many heterotrophic bacteria can also carry out the previous reaction but they are incapable of growing at the expense of the energy derived from that reaction exclusively *See* METHANOMONADACEAE

2 Iron compounds Iron may occur in nature in the form of salts and complexes of organic compounds Bacteria that decompose the organic moiety will therefore cause the formation of ferric carbonate or hydroxide Such organisms have often been designated as iron bacteria because their activities lead to the precipitation of $Fe(OH)_3$

Nevertheless this term was first proposed for the members of a special physiological group of bacteria characterized by their ability to oxidize ferrous to ferric ion and to live at the expense of the energy liberated in this oxidation they can therefore grow as strict autotrophs Thus far this ability has been definitely established for only one bacterial species *Ferrobacillus ferrooxidans* and made probable for another *Gallionella ferruginea* Still others like the filamentous sheathed bacteria known as *Leptothrix ochracea* and related species that regularly occur along with *Gallionella* in localities where ferrous ion containing seepage water runs into an oxygen rich environment and $Fe(OH)_3$ precipitates may also belong to this physiological group However the *Leptothrix* species are now recognized as special environmental forms of *Sphaerotilus* species which can also thrive in media not containing ferrous iron where they grow at the expense of the oxidation of organic substances

See CAULOBACTERACEAE CHLAMYDOBACTERIALES SIDEROCAPSACEAE

The oxidation of ferrous to ferric iron may be represented by the equation

$$4FeCO_3 + O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + 4CO_2 + \text{Energy}$$

3 Reduced sulfur compounds Inorganic sulfur compounds at various levels of reduction such as sulfite tetrathionate thiosulfate elementary sulfur, and hydrogen sulfide can be used as oxidizable substrates by many kinds of bacteria Generally the oxidation yields sulfate as the end product if H_2S *is the substrate it is oxidized initially to elemen* tary sulfur In the case of the relatively large representatives such as species of *Beggiatoa Thiothrix Thiovulum Chromatium* and so on this sulfur accumulates in the bacterial cells in the form of characteristic highly refractile droplets which apparently can serve as a reserve source of substrate and disappear if the supply of H_2S dwindles to too low a level

$$2H_2S + O_2 \rightarrow 2S + 2H_2O + \text{Energy}$$
$$2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4 + \text{Energy}$$
$$Na_2S_2O_3 + 2O_2 + H_2O \rightarrow Na_2SO_4 + H_2SO_4 + \text{Energy}$$

Sodium thiosulfate

Many sulfur bacteria are obligately autotrophic Physiologically the best known are the small rod shaped *Thiobacillus* species (*see* THIOBACTERIACEAE) *T thioparus* thrives in neutral *T thiooxidans* in acid media the latter can still grow in solutions containing as much as 5% sulfuric acid *T novellus* is a facultatively autotrophic thiosulfate oxidizer

The oxidation of sulfide is postulated to proceed via sulfur (hydrate) sulfoxylic acid and sulfurous acid that of thiosulfate via tetrathionate trithionate and sulfite

4 Nitrogen compounds (nitrification) The best known bacteria which oxidize reduced inorganic nitrogen compounds are the members of the obligately autotrophic rods comprising two genera *Nitrosomonas* and *Nitrobacter Nitrosomonas europaea* oxidizes ammonia to nitrous acid via hydroxylamine nitroxyl (NOH) has been postulated as the subsequent intermediate oxidation stage

$$NH_4OH + 1\tfrac{1}{2}O_2 \rightarrow NH_2OH + H_2O + \text{Calories}$$

Ammonia (hydrate) — Hydroxyl amine

$$NH_2OH + O_2 \rightarrow HNO_2 + H_2O + \text{Calories}$$

Hydroxyl amine — Nitrous acid

Nitrosobacter winogradskii oxidizes nitrite to nitrate

$$HNO_2 + 1\tfrac{1}{2}O_2 \rightarrow HNO_3 + \text{Energy}$$

Nitrous acid — Nitric acid

Nitrogen free aliphatic compounds Although the number of oxidizable compounds and bacteria capable of effecting their oxidation are almost infinitely large patterns of oxidation common to particular types of substrates appear to be the rule In general the oxidation pathways shape the substrate so that it can feed into the central terminal oxidation mechanisms almost universal in bacteria In the main the product entering the terminal oxidation cycle is active acetate that is acetyl coenzyme A (acetyl SCoA) Thus the special pathways for the decomposition of the diverse organic substrates in reality are mechanisms for their conversion to acetic acid Most of the carbon assimilated by the bacterial cell is drained from the oxi *dation pathway at or subsequent to the acetate* stage

1 Hydrocarbons A variety of bacteria especially in the genera *Mycobacterium* and *Nocardia* oxidatively attack paraffinic and olefinic hydrocarbons including gases liquids and solids The available information indicates that paraffinic hydrocarbons are oxidized monoterminally probably via the addition of molecular oxygen to form the hydroperoxide which in turn yields the corresponding primary alcohol

$$RCH_2CH_3 + O_2 \rightarrow RCH_2CH_2\text{OOH} \xrightarrow{+2H} RCH_2CH_2OH + H_2O$$

Aliphatic *paraffinic* hydrocarbon — Hydroperoxide — RCH_2CH_2OH

The gaseous alkanes can also be oxidized subterminally in that case they yield methyl ketones The proposed mechanism is

$$RCH_2CH_3 + O_2 \rightarrow RCHCH_3 \xrightarrow{+2H} RCHOHCH_3 \xrightarrow{-2H} RCOCH_3$$

OOH — Secondary alcohol — Methyl ketone

Palmitate waxes (esters) are produced by certain bacteria during growth on long chain liquid alkanes The alcohol moiety of the ester corresponds to the substrate hydrocarbon

2 *Alcohols Primary low* molecular weight alcohols are oxidized by many bacteria the first stage being the corresponding aldehyde The enzyme alcohol dehydrogenase is responsible

$$RCH_2OH \xrightarrow{-2H} RCHO$$

Primary alcohol — Aldehyde

The aldehyde is almost invariably rapidly oxidized to the corresponding carboxylic acid by hydration and dehydrogenation

$$RCHO \xrightarrow{+HOH} RC(H)(OH)OH \xrightarrow{-2H} RC(=O)OH$$

Aldehyde — Aldehyde hydrate — Carboxylic acid

comitant reduction of oxygen to water The oxidizable substrate may be represented by the generalized symbol H_2A Most bacterial oxidations take place via dehydrogenation of the hydrogen donors This occurs by transfer of two electrons (e) and two protons resulting in the formation of the oxidized product A

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attacks short chain fatty acids is a copper enzyme the one attacking longer chains may be an iron enzyme The addition of the elements of water to the double bond is accomplished by a hydrase specifically crotonase This enzyme has no known coenzyme and it also provides a means of reversible conversion of $\beta\gamma$ unsaturated acids to $\alpha\beta$ unsaturated acids via a common β hydroxy acid intermediate

$$RCH{=}CHCH_2CO{-}SCoA \xrightleftharpoons{HOH} RCH_2CHOHCH_2CO{-}SCoA \xrightleftharpoons{HOH} RCH_2CH{=}CHCO{-}SCoA$$

The β hydroxy acyl CoA is oxidized by the diphosphopyridine nucleotide (DPN)-containing enzyme β hydroxy acyl CoA dehydrogenase All acids containing 4–12 carbon atoms (C_4 to C_{12}) are oxidized at approximately the same rate Only the *d* isomer is oxidized the *l* isomer is inert (*see* OPTICAL ACTIVITY) The β ketoacyl CoA is then cleaved by a β ketothiolase (acetyl CoA transacetylase) between the α and β carbons with the concomitant uptake of 1 mole of CoA The original CoA remains on the two-carbon cleavage fragment as acetyl CoA The thiolase reaction adds the second CoA molecule to the remaining carbon chain at the carbonyl group forming an acyl CoA chain shorter by two carbons than the original fatty acid

This shorter acyl CoA moiety is further oxidized by the same general mechanism Hence the fatty acids that contain an even number of carbon atoms and have the general composition $C_{2n-1}H_{4n-1}COOH$ eventually yield a corresponding number n of acetyl CoA molecules The fatty acids with an odd number of carbon atoms $C_{2n}H_{4n-1}COOH$ yield one molecule of propionyl CoA in addition to $n-1$ molecules of acetyl CoA

Acetyl CoA is further oxidized via the citric acid or glyoxylic acid cycle discussed later in this article It is probable that propionyl CoA is degraded by an initial carboxylation to methyl malonyl CoA which is next converted to succinyl CoA

$$CH_3{-}CH_2{-}CO{-}SCoA + CO_2 \rightarrow CH_3{-}\underset{\displaystyle COOH}{\overset{\displaystyle H}{\underset{|}{\overset{|}{C}}}}{-}CO{-}SCoA \rightarrow HOOC{-}CH_2{-}CH_2{-}CO{-}SCoA$$

The succinate can then be oxidized to acetate via fumarate malate and oxaloacetate

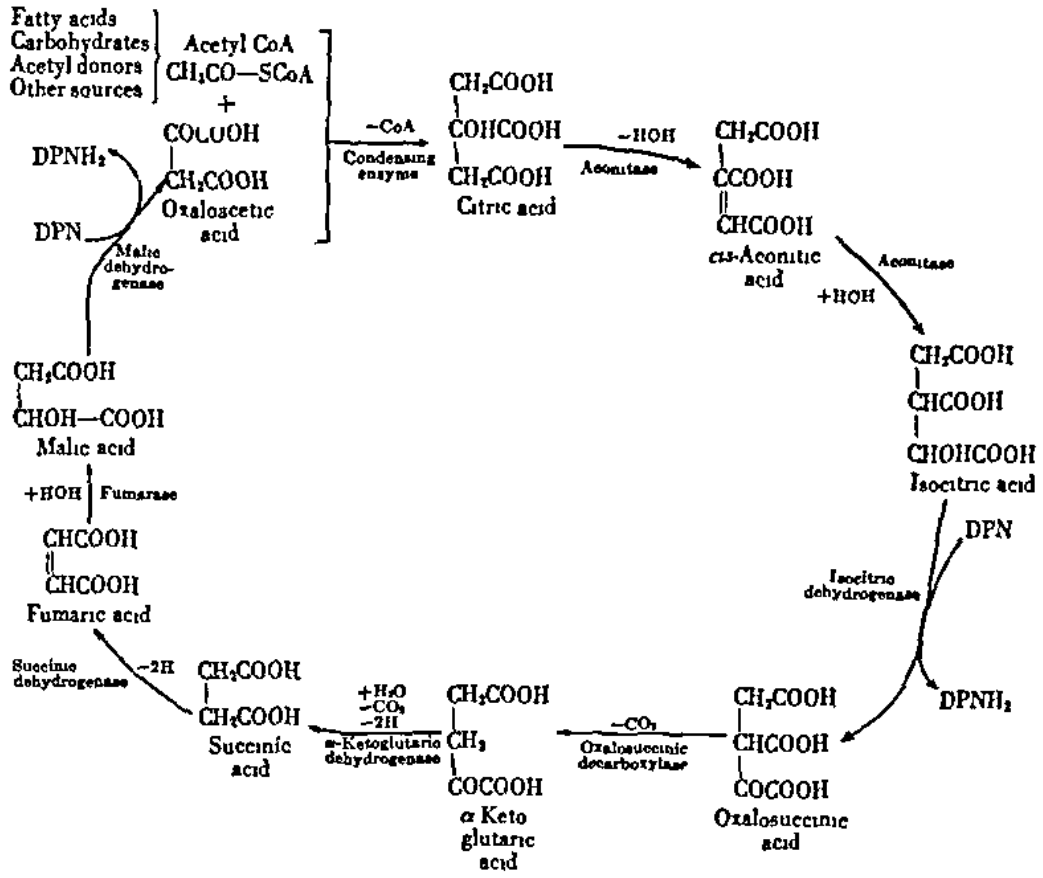
Certain bacteria produce acetyl phosphate apparently as an energy reservoir Acetyl phosphate is readily converted to acetyl CoA by the enzyme phosphotransacetylase

$$CH_3CO{-}OPO_3^{-} + HSCoA \xrightarrow{\text{Phosphotransacetylase}} CH_3CO{-}SCoA + HOPO_3^{-}$$

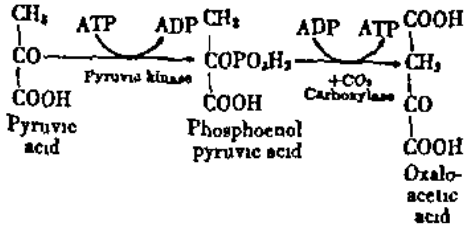
As in biological oxidations in general the pattern of bacterial oxidations is to chip large and more complex substrates into small carbon chain fragments As a rule these fragments are then broken down in stepwise fashion via fairly complex cyclic systems to CO_2 water and energy in a process known as terminal oxidation

The Krebs tricarboxylic acid (TCA) system is the most common cyclic mechanism of terminal oxidation in biological systems It was conceived and clarified by H A Krebs a British biochemist who received the Nobel Prize for this contribution The mechanism appears to be identical in bacteria and other microorganisms and in plant and animal cells Minor modifications or adaptations of the Krebs cycle are known The TCA system is a cyclic pathway for the oxidation of acetyl CoA derived from fatty acid or carbohydrate breakdown from acetyl donors or from other types of metabolism to CO_2 and water producing high energy bonds In the presence of assimilable nitrogen and mineral salts various components are drained off from the cycle to serve as precursors of amino acid and other cellular components Under resting cell conditions the substrate may be oxidized completely via the citric acid cycle or variable amounts may be drained off and converted to products of oxidative assimilation The oxidative formation of acetyl CoA from pyruvic acid will be discussed later under triose pathway in connection with carbohydrate oxidation Oxaloacetic acid is the key component of the cycle it functions as the initial acceptor of acetate into the cycle A transfer of acetate is effected by a specific enzyme oxaloacetate transacetylase better known as citrate condensing enzyme which links the methyl carbon of the acetyl group with the carbonyl carbon of oxaloacetate splits out CoA and forms citric acid

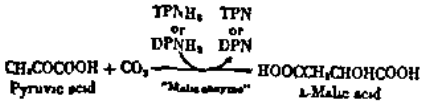
In the next step the elements of water are removed from citrate by the enzyme aconitase leaving the asymmetrical unsaturated *cis* aconitic acid The elements of water are then added back to the double bond carbons but in the reverse positions forming isocitric acid There is some evidence for two different aconitases effecting the dehydration and the hydration The simultaneous dehydrogenation of isocitrate at the carbinol group and decarboxylation of the tertiary carboxylic group is believed to be catalyzed simultaneously by a DPN dependent enzyme isocitric dehydrogenase and oxalosuccinic decarboxylase The product α ketoglutaric acid is oxidatively decarboxylated to succinic acid The coenzymes diphosphothiamine lipoic acid and CoA are sequentially involved in this over all transformation which comprises three intermediate enzymatic steps This system is similar to that which oxidatively decarboxylates pyruvic acid and which is discussed below Succinyl CoA is the immediate precursor of the succinic acid the acid is liberated by succinyl CoA deacylase Succinic acid is then oxidized to fumaric acid by succinic dehydrogenase a flavin dependent enzyme The fumarate is next hydrated by fumarase forming L malic acid which in turn regenerates oxaloacetate after its oxidation by means of the DPN dependent malic dehydrogenase The hydrogens or electrons are converted stepwise to water via the terminal electron transport system High energy phosphate bonds are thereby generated at various stages



Krebs tricarboxylic acid cycle



Wood Werkman reaction



Reduction and carboxylation of pyruvic acid to malic acid

their formation constitutes oxidative phosphorylation

In the living cell, where the keto acid components are siphoned off for the synthesis of amino acids, the cycle would quickly run down because there would no longer be a continuous supply of oxaloacetic acid In addition, this substance itself can be readily decarboxylated to carbon dioxide and pyruvic acid which constitutes an additional drain The level of oxaloacetate can however, be maintained by a carboxylation of pyruvic acid derived from other sources, mainly carbohydrate One such reaction is the so-called Wood Werkman reaction in which pyruvic acid is converted to phosphoenolpyruvic acid the actual acceptor of CO_2 The fixation is coupled with the regeneration of an energy rich pyrophosphate bond, either ADP or inosine diphosphate functions as the phosphate acceptor The second carboxylation reaction is that accomplished by the malic enzyme, it represents a simultaneous reduction and carboxylation of pyruvic acid to malic acid by a DPN dependent enzyme

It has been recognized, however, that these carboxylation reactions are inadequate to generate sufficient oxaloacetate particularly in those cases where acetate is the main or only oxidizable substrate This has long presented a problem which has now been solved by the discovery of the glyoxylic acid cycle which permits the formation of oxaloacetate and hence also of citrate, from two carbon fragments exclusively The cycle comprises a condensation of acetyl CoA with glyoxylic acid to malic acid under the influence of the enzyme malate synthetase

$$\underset{\text{Glyoxylic acid}}{HOOCCHO} + \underset{\text{Acetyl CoA}}{CH_3CO{-}SCoA} \xrightarrow[\text{Malate synthetase}]{-CoA} \underset{\text{Malic acid}}{HOOCCHOHCH_2COOH}$$

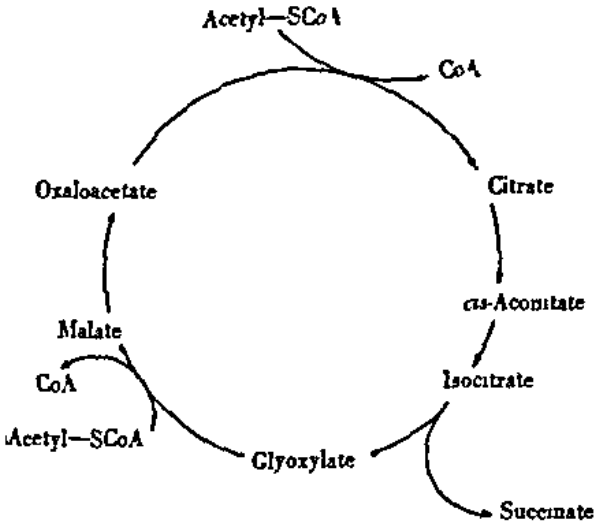
The malate is then oxidized to oxaloacetate

A continuous supply of glyoxylic acid is ensured by a conversion of isocitrate other than its oxidation

to oxalosuccinate It is a cleavage under the influence of the enzyme isocitratase to glyoxylate and succinate according to the equation

$$\begin{array}{l} CH_2COOH \\ | \\ CHCOOH \\ | \\ CHOHCOOH \\ \text{Isocitric acid} \end{array} \xrightarrow{\text{Isocitratase}} \begin{array}{l} CH_2COOH \\ | \\ CH_2COOH \\ + \\ CHOCOOH \end{array} \quad \begin{array}{l} \text{Succinic acid} \\ \\ \text{Glyoxylic acid} \end{array}$$

The cycle is schematically represented as follows



The net change in one turn of the glyoxylic acid cycle is

$$2 \text{ Acetate} + \tfrac{1}{2}O_2 \rightarrow \text{Succinate}$$

The succinate is metabolized via the Krebs cycle or other pathways *See* KREBS CYCLE

5 Hydroxy acids The β hydroxy monocarboxylic acids are discussed under fatty acids The α hydroxy acids are oxidized to the corresponding α keto acid by zinc containing dehydrogenases Lactate dehydrogenase acts on everal α-hydroxy acids The enzymes are stereospecific for the L forms Three lactic dehydrogenases are known which differ in their coenzyme requirements One utilizes DPN a second uses flavin nucleotide and the third cytochrome c the last one is oxygen linked

$$\underset{\text{L Lactic acid}}{CH_3CHOHCOOH} \xrightarrow[\text{dehydrogenase}]{-2H,\ \text{Lactic}} \underset{\text{Pyruvic acid}}{CH_3COCOOH}$$

6 Keto acids The most important keto acids are the α and β ketomonocarboxylic acids The α keto acids may be successively decarboxylated to the next smaller aldehyde by a diphosphothiamine decarboxylase and then oxidized

$$RCOCOOH \xrightarrow[\text{Decarboxylase}]{-CO_2} RCHO \xrightarrow[+H_2O]{\text{DPN or TPN, DPNH}_2 \text{ or TPNH}_2} RCOOH$$

Aldehyde

The oxidative decarboxylation of pyruvic acid involves a series of coenzymes as shown on the following page

For β ketomonocarboxylic acids oxidation see the discussion of fatty acids for β ketoadipic acid oxidation see the section on aromatic compounds

7 Carbohydrates The oxidation of carbohydrates occurs by different routes all of which may occur in any one bacterial species However one or more may be lacking in some bacteria *See* CARBOHYDRATE

The triose pathway is responsible for the production of pyruvic acid by the Embden Meyerhof mechanism of glycolysis described later in this article The pyruvic acid is oxidatively decarboxylated to acetyl SCoA as described above which in turn is oxidized by the citric acid cycle

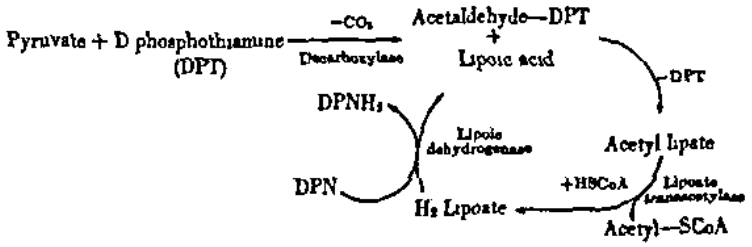
In aerobic bacteria the rupture of the carbon chain of glucose occurs after oxidation to 6 phosphogluconate This compound may be oxidatively decarboxylated to ribulose-5 phosphate which is further metabolized via the pentose phosphate pathway described later Alternatively the 6-phosphogluconate may be dehydrated at carbon atoms two and three forming 2 keto 3-deoxy 6 phosphogluconic acid This pathway is also described later (Entner Doudoroff)

The net effect of six turns of the hexosemonophosphate cycle is the complete oxidation of one molecule of glucose

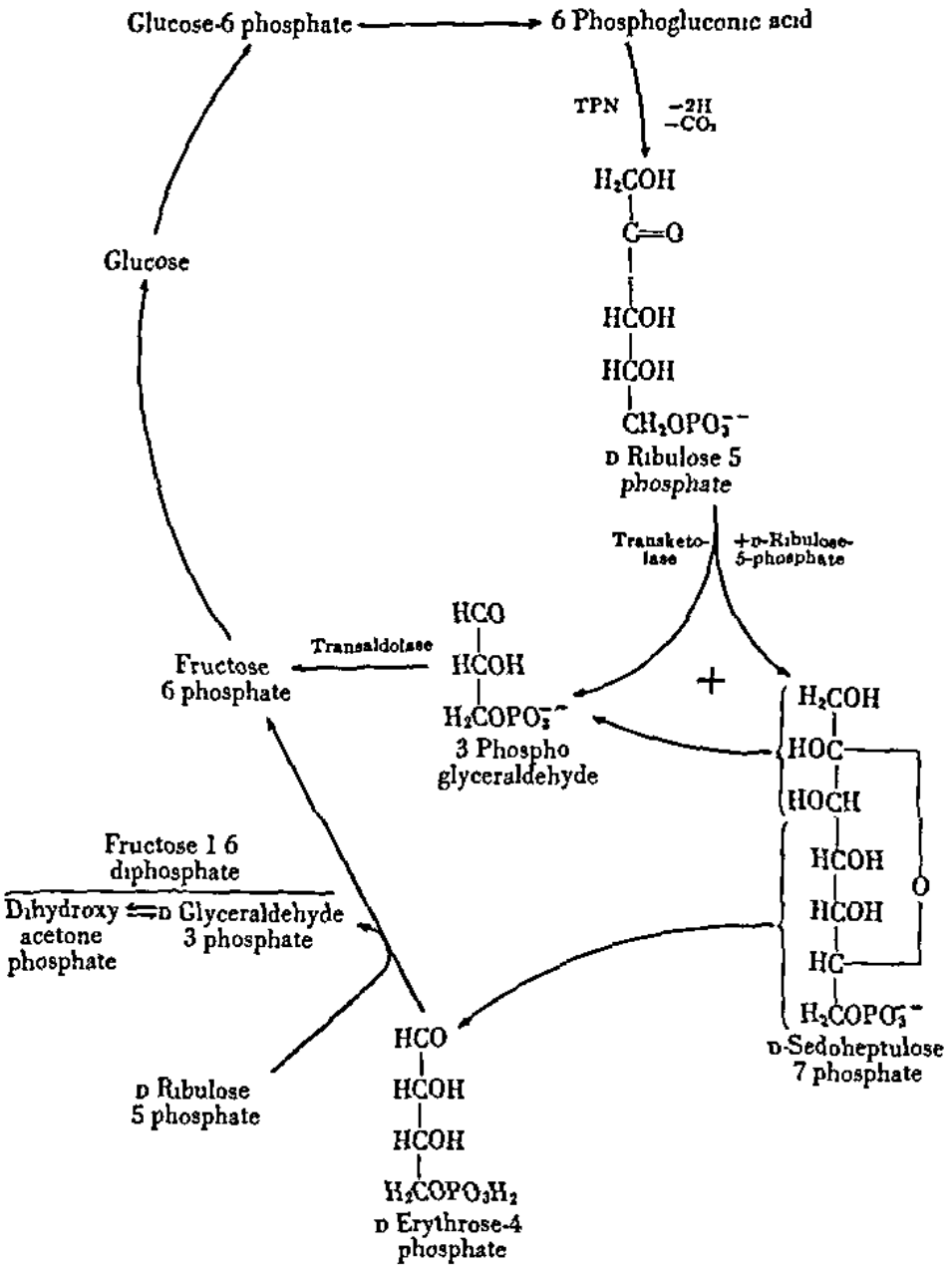
$$6 \text{ Glucose} + 6O_2 \rightarrow 5 \text{ Glucose} + 6H_2O + 6CO_2$$
$$\text{Net Glucose} + 6O_2 \rightarrow 6H_2O + 6CO_2$$

The oxidative steps are those between glucose and ribulose 5 phosphate (RP) Glucose is regenerated from RP by interconversion of five six and seven carbon sugar phosphate esters The terminal two carbons of one RP are transferred by transketolase (a diphosphothiamine enzyme) to a second RP forming a seven carbon sugar (D sedulose 7 phosphate) and leaving glyceraldehyde 3-phosphate (G-3-P) By transaldolase the terminal three carbons of the sedoheptulose are condensed with the G-3-P to produce fructose-6-phosphate The tetrose remaining from the 7 carbon sugar is condensed with a terminal two carbon fragment from another RP forming fructose-6 phosphate and leaving G 3 P The latter is converted to an equilibrium mixture with dihydroxyacetonephosphate by triose phosphate isomerase These trioses are then condensed to hexose diphosphate by the action of aldolase

Oxidation of aromatic compounds This property is found mainly in aerobic bacteria belonging to the genera *Pseudomonas Vibrio* and *Mycobacterium* As a rule the aromatic compounds are converted to a benzene ring compound containing two adjacent carboxyls The catechol and the protocatechuic acid pathways are the best known both eventuating in β ketoadipic acid (β KAA) Mandelic acid tryptophan and indoleacetic acid are converted to catechol via the following sequences



Oxidative decarboxylation of pyruvic acid



Carbohydrate oxidation in aerobic bacteria

D(−) Mandelic acid $\xrightleftharpoons[\text{Racemase}]{}$

L(+) Mandelic acid $\xrightarrow[\text{L-Mandelic dehydrogenase}]{-2H}$

Benzoylformic acid $\xrightarrow[\text{Benzoylformic carboxylase}]{-CO_2}$

Benzaldehyde $\xrightarrow[\text{Benzaldehyde dehydrogenase}]{+H_2O_2\ -2H}$

Benzoic acid → Catechol

Tryptophan $\xrightarrow[\text{Tryptophan peroxidase}]{O_2,\ H_2O}$ Formylkynurenine $\xrightarrow[\text{Formylase}]{H_2O}$

Kynurenine $\xrightarrow[\text{Kynureninase}]{-\text{Alanine}}$ Anthranilic acid → Catechol

Indoleacetic acid → Skatole → Indoxyl →
Salicylic acid → Catechol

Phenol is oxidized directly to catechol
The protocatechuic acid pathway follows

p Nitrobenzoic acid → *p* Aminobenzoic acid
↓
p Cresol → *p* Hydroxybenzyl alcohol →
p Hydroxybenzoic acid → Protocatechuic acid

The dihydroxy ring structures are then cleaved between the adjacent hydroxyls to form aliphatic dicarboxylic acids The two pathways converge at β ketoadipic acid as shown on the following page Beta ketoadipic acid is split to acetyl CoA and succinyl CoA This reaction sequence is shown on the following page

The latter activates β KAA and the process is a cyclic one whereby the net products are acetyl CoA and succinic acid which are then oxidized via the citric acid cycle

The oxidative degradation of the amino acids phenylalanine and tyrosine proceeds by a different pathway

Phenylalanine $\xrightarrow[\text{Phenylalanine hydroxylase}]{}$ Tyrosine $\xrightarrow[\text{L-Amino acid oxidase}]{+H_2O\ -2H\ -NH_3}$

p Hydroxyphenylpyruvic acid $\xrightarrow[\text{Oxidase}]{+O_2\ \ CO_2}$

Homogentisic acid $\xrightarrow[\text{Oxidase}]{O_2}$

4 Maleylacetoacetic acid $\xrightarrow[\text{Isomerase}]{}$

4 Fumarylacetoacetic acid $\xrightarrow[\beta\text{-D ketonase}]{H_2O}$

Fumaric acid + Acetoacetic acid

Polycyclic aromatic hydrocarbons are oxidized by certain bacteria by routes which have not been clarified enzymatically As a rule *o* hydroxycarboxylic acids containing one ring less than the starting compound have been isolated and these are considered to be intermediate breakdown products

Nitrogen containing organic substances The complete breakdown of this class of substances ordinarily results in release of all of the nitrogen as ammonia

1 Amino acids Enzymes are specific for L and D-amino acids The ka
of amm
tion are
the amino acid and the bacterial species

Amino acid oxidases are flavoproteins which attack a number of different amino acids according to the following reaction

RCHNH$_2$COOH (α Amino acid) $\xrightarrow[\text{Amino acid oxidase}]{-2H}$ RC=NHCOOH (Imino acid) $\xrightarrow{H_2O}$
RCOCOOH (α Keto acid) + NH$_3$ (Ammonia)

The imino acid hydrolyzes spontaneously The flavoprotein is linked to oxygen and produces hydrogen peroxide Glycine oxidase is a separate specific amino acid oxidase

Glutamic and alanine dehydrogenase are DPN or TPN linked enzymes which convert the substrates to α ketoglutaric acid and pyruvic acid respectively with the liberation of ammonia Oxygen is not essential

Aspartase catalyzes the deamination of aspartic acid to fumaric acid and ammonia

Beta substituted amino acids that is serine threonine and cysteine are dehydrated

RCHOHCHNH$_2$COOH (β Substituted α amino acid) $\xrightarrow[\text{Dehydrase}]{-H_2O}$

(RCH=CNH$_2$COOH) → RCH$_2$C=NHCOOH (Imino acid) $\xrightarrow{H_2O}$
RCH$_2$COCOOH (α Keto acid) + NH$_3$ (Ammonia)

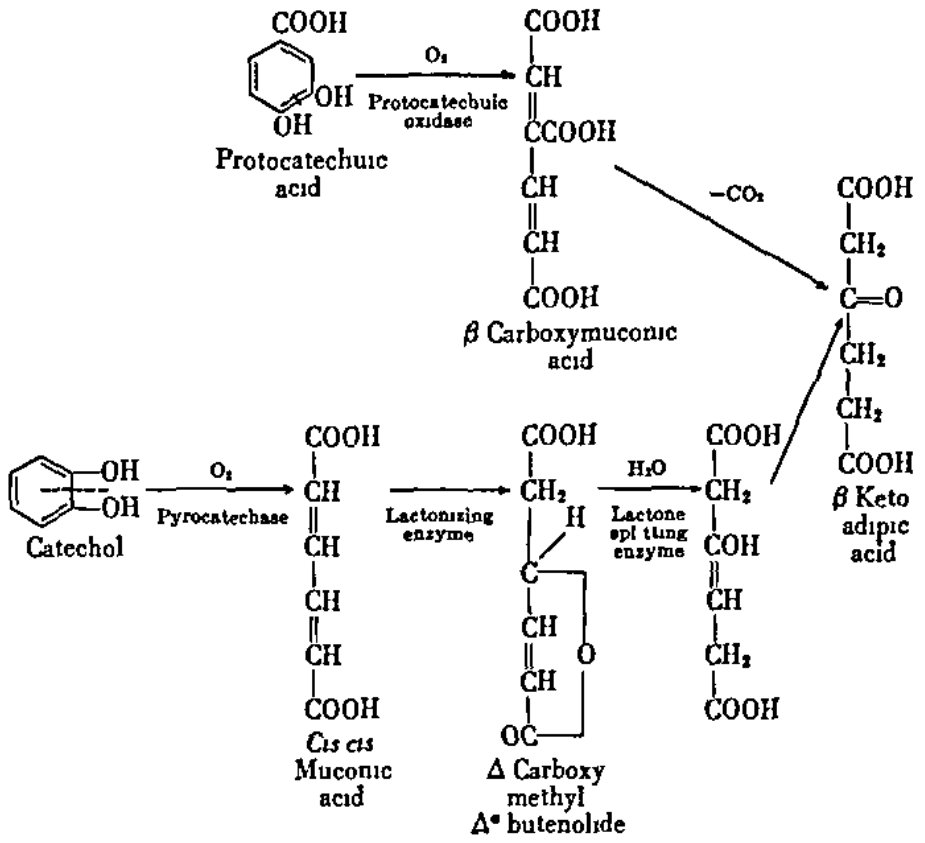
Histidine and hydroxy L-proline are oxidized as follows

Histidine $\xrightarrow[\text{Deamination}]{-NH_3}$ Urocanic acid $\xrightarrow[\text{Urocanase}]{HOH}$

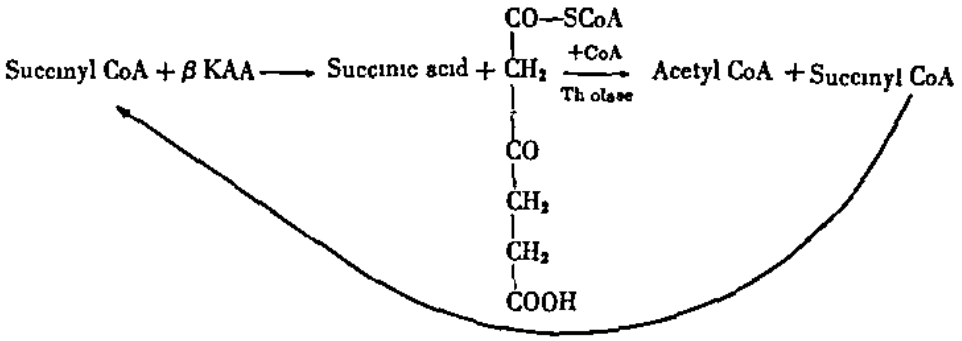
Formiminoglutamic acid → Glutamic + Formylgl
Formiminoglutamic acid → Glutamic + Formic acid

Hydroxyl L-pr
Δ^1 4 Hyd
(2 Keto-4

2 Purines
purines is best



Cleavage of dihydroxy ring structure in protocatechuic acid and catechol



Formation of acetyl CoA and succinyl CoA from ketoadipic acid

Uric acid $\xrightarrow{+O\ H_2O}$ Hydroxyacetylene →
Allantoin $\xrightarrow{+H_2O}$ Allantoic acid →
2 Urea + Glyoxylic acid → CO_2 + Formic acid

The formic acid and CO produced from glyoxylic acid are derived from the carboxyl and α carbons respectively

The initial step in pyrimidine degradation is a reduction

Pyrimidine $\xrightarrow{+2H}$ Dihydropyrimidine →
β Carbamylamino acid → β Amino acid + CO_2 + NH_3

From uracil the intermediates are β carbamylamin opropionic acid and β aminopropionic acid respec tively from thymine they are β carbamylaminoiso butyric acid and β aminoisobutyric acid The fol lowing oxidase pathway has been described in a species of *Mycobacterium*

Uracil $\xrightarrow[\text{Ox dase}]{+O}$ Barbituric acid $\xrightarrow[\text{Barb turase}]{+H\ O}$
Urea + Malonic acid
↓
Acetic acid + CO_2

Thymine $\xrightarrow[\text{Ox dase}]{+O}$ 5 Methylbarbitur c acid

3 Pyridines The scanty information on the mechanism of degradation of pyridine compounds is limited to the oxidation of pyridoxine (vitamin B_6) nicotinic acid and nicotine These appear to be oxidized as follows

Pyridoxine → Isopyridoxal → 5 Pyridoxic acid →
a Hydroxymethyl *a* (*N* acetylaminomethylene)
succinic acid

Nicotinic acid $\xrightarrow{H_2O}$
6 Hydroxynicotinic acid $\xrightarrow{-CO_2\ +O_2}$
2 5 Dihydroxynicotine → Fumaric acid + Formic acid

Nicotine → 3 (4 methylaminobutyryl) pyridine →
3 Succinyl-6 hydroxypyridine → ?

4 Proteins Proteins are hydrolytically broken down to the constituent amino acids by means of proteolytic enzymes and peptidases Polypeptides of gradually diminishing size are produced free amino acids are ultimately liberated These are oxidized as described above *See* PROTEIN

Anaerobic oxidations A number of different bacteria are capable of utilizing inorganic oxidants as alternatives to oxygen or organic substances as the ultimate electron or hydrogen acceptors The nature of the oxidant and the change it undergoes distinguish the various kinds of anaerobic oxidations The reduction of the oxidant is part of the energy liberating process as contrasted to reduction for purposes of assimilation as a nutrient In the former case the amount of oxidant that is reduced per unit of growth is very large and the reduced product accumulates extracellularly

Nitrate reduction A great many aerobic bacteria including species belonging to a variety of different genera can facultatively utilize nitrate in the absence of oxygen The enzyme nitrate reductase is a molybdenum dependent flavin linked inducible enzyme Usually the specific substrates that an organism can oxidize with nitrate as the ultimate oxidant are the same as those it can oxidize with oxygen The nitrate is reduced to nitrite which may accumulate or may be further reduced to ammonia by the way of hydroxylamine Nitrite reductase and hydroxylamine reductase are also flavoproteins Cytochrome c appears to mediate *the flow of the electrons to nitrite*

Denitrification The reduction of nitrate or nitrite to gaseous products constitutes denitrification Nitrogen gas is the most common product although nitrous oxide (N_2O) and nitric oxide (NO) are also formed under some conditions The latter two may be further reduced to N_2 but they are not obligatory intermediates in the denitrification Nitrite is reduced to nitric oxide by a flavoprotein that requires copper and iron All of the enzymes in denitrification are capable of receiving electrons from pyridine nucleotide enzymes

Sulfate reduction The bacteria effecting sulfate reduction belong to the genus *Desulfovibrio D desulfuricans* being the most common species *Clostridium nigrificans* also is a sulfate reducer The organisms are obligate anaerobes which reduce sulfate to hydrogen sulfide during oxidation of various substrates Blackening of the medium results from the interaction of the H_2S with iron Sulfate reduction is mediated by a cytochrome linked enzyme and the active form of sulfate that undergoes reduction is adenosine 3 phosphate 5 phosphosulfate Sulfate reducing bacteria cause corrosion of iron because by creating a strongly reduced environment they locally create anodic conditions relative to the more oxidized surroundings thus producing a corrosion cell

Carbonate reduction Two different types distinguishable by the nature of the reduction products are known They are

1 CO_2 reduction to acetic acid This is performed by certain obligately anaerobic sporeforming bacteria that use CO as the hydrogen acceptor for the oxidation of various substrates *Clostridium aceticum* thus produces acetic acid from molecular hydrogen and CO_2

$$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O$$

and like *C thermoaceticum* oxidatively decarboxylates *pyruvic acid with a concomitant reduction* of CO_2 to acetic acid

$$\begin{aligned} 4[CH_3COCOOH + H_2O &\rightarrow CH_3COOH + CO_2 + 2[H]] \\ 2CO_2 + 8[H] &\rightarrow CH_3COOH + 2H_2O \\ \hline 4CH_3COCOOH + 2H_2O &\rightarrow 5CH_3COOH + 2CO_2 \end{aligned}$$

These organisms decompose sugar in accordance with the equation

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH$$

and tracer studies with *C thermoaceticum* have shown that this conversion proceeds by an initial decomposition of the sugar via pyruvic acid

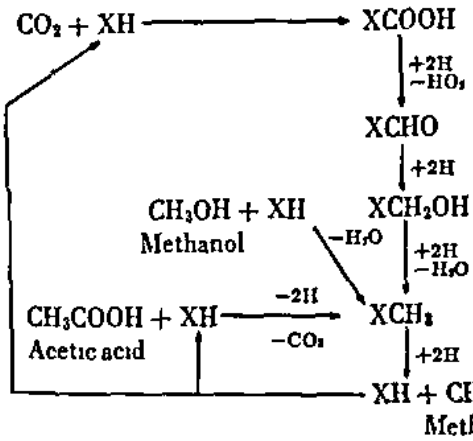
$$\begin{aligned} C_6H_{12}O_6 &\rightarrow 2CH_3COCOOH + 4[H] \\ 2CH_3COCOOH &\rightarrow 2CH_3COOH + 4[H] + 2CO_2 \\ 2CO_2 + 8[H] &\rightarrow CH_3COOH \\ \hline C_6H_{12}O_6 &\rightarrow 3CH_3COOH \end{aligned}$$

C acidi urici carries out an anaerobic degradation of purines in which the oxidation of the substrate is likewise coupled with the reduction of CO to acetic acid

2 CO reduction to methane The anaerobic decomposition of organic matter by complex microbial populations invariably results in the production of methane from CO by the activities of the so-called methane bacteria One stage in the disposal of sewage is marked by an intense methane fermentation The lower primary and secondary alcohols as well as organic acids are the most common substrates whose oxidation is linked to the reduction of CO_2 to methane Hydrogen and carbon monoxide also undergo a methane fermentation In some cases it has been found that carbon monoxide formic acid formaldehyde and methanol are not intermediates in the bacterial reduction of CO_2 to methane The bacteria that carry out this process are strict anaerobes and are dependent on CO_2 Four genera are known *Methanobacillus Methanobacterium Methanosarcina* and *Methanococcus* In addition to morphological di
the bacteria display substrate specifici

types do produce methane by reduction of methanol or from the methyl group of acetate proving that a mechanism independent of CO_2 reduction exists for formation of methane Experiments with deuterium labeled acetate have shown that the methane evolved may comprise the intact methyl groups suggesting a reductive demethylation of acetate

The following scheme represents a possible mechanism of the methane fermentation XH refers



to a hypothetical intracellular reduced carrier or coenzyme [J W F]

CATABOLISM FERMENTATIVE METABOLISM

Many bacteria are able to decompose organic compounds and to grow in the absence of oxygen gas Such anaerobic bacteria obtain energy and certain organic compounds needed for growth by a process of fermentation This consists of an oxidation of a suitable organic compound using another organic compound as an oxidizing agent in place of molecular oxygen In most fermentations both the compounds oxidized and the compounds reduced (used as an oxidizing agent) are derived from a single fermentable substrate In other fermentations one substrate is oxidized and another is reduced Different bacteria ferment different substrates Many bacteria are able to ferment carbohydrates such as glucose and sucrose polyalcohols such as mannitol and salts of organic acids such as pyruvate and lactate Other compounds such as cellulose amino acids and purines are fermented by some bacteria

Bacterial fermentations are rather arbitrarily classified according to either the nature of the substrate or the nature of the characteristic product These two types of classification are not mutually exclusive and lead to different associations of genera and species catalyzing fermentative reactions In the following discussion the primary classification is based upon the nature of the substrate

drate fermentations is based largely on the nature of the characteristic fermentation product

Bacterial carbohydrate fermentations Some of the characteristic products of bacterial carbohydrate fermentations are ethyl alcohol lactic acid acetic acid propionic acid butyric acid butyl alcohol acetone and butanediol Because certain microorganisms form predominantly one or another of these compounds the name of the product has come to be associated with the type of fermentation In this way such terms as alcoholic fermentation lactic acid fermentation and propionic acid fermentation have become established Sometimes these names have more historical than scientific value

Alcoholic fermentation Alcoholic fermentation is the process by which certain yeasts decompose sugars in the absence of oxygen to form ethanol and carbon dioxide according to the equation

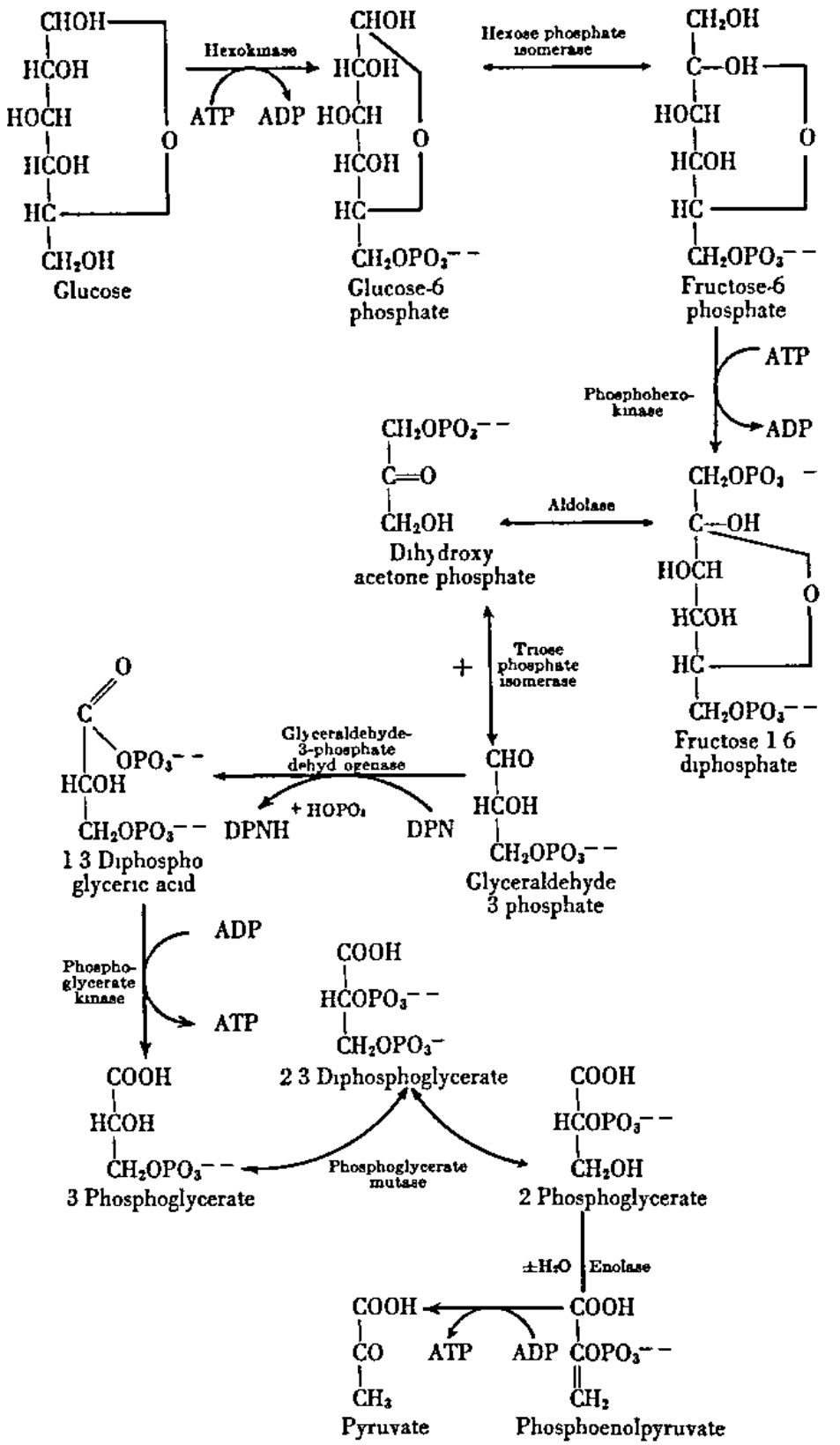
$$\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow 2\underset{\text{Ethanol}}{CH_3CH_2OH} + 2\underset{\text{Carbon dioxide}}{CO_2}$$

This fermentation provides the basis for the commercial production of ethanol and alcoholic beverages *such as wine and beer*

The conversion of glucose to ethanol and carbon dioxide is a complex enzymatic process involving many chemical steps The main features of this process are the phosphorylation of the hexose (6 carbon) sugar to form a hexose diphosphate a cleavage of this compound to two molecules of triose (3 carbon) phosphate the oxidation of the latter and its further conversion of pyruvate the decarboxylation of pyruvate to carbon dioxide and acetaldehyde and the reduction of the latter to ethanol An essential feature of this process is a coupled conversion of inorganic orthophosphate to a high energy phosphate group in ATP Two moles of phosphate are converted in this way for each mole of glucose fermented The resulting ATP is used to provide energy for the biosynthesis of essential cellular components

Glycolysis is the conversion of glucose to lactic acid Glycolysis and alcoholic fermentation by yeast involve the same chemical steps from glucose to pyruvate This sequence of enzymatic reactions also known as the Embden Meyerhof pathway is shown in the accompanying diagram The first step is a transfer of a phosphate group from ATP to glucose to form glucose 6 phosphate This is rearranged to form fructose 6 phosphate which reacts with ATP to form fructose 1 6 diphosphate This compound is cleaved by the enzyme aldolase into 1 mole each of dihydroxyacetone phosphate and D-glyceraldehyde 3-phosphate The enzyme triose phosphate isomerase interconverts the two triose phosphates After these preparatory reactions glyceraldehyde 3 phosphate is oxidized and DPN is reduced This oxidation reduction reaction catalyzed by the enzyme glyceraldehyde phosphate

dehydrogenase requires the presence of orthophosphate During the reaction orthophosphate disappears and 1 3 diphosphoglyceric acid is formed The phosphate group attached to carbon atom 1 of this compound is transferred to adenosinediphosphate (ADP) to form 3-phosphoglyceric acid and



Embden Meyerhof pathway of glycolysis and alcoholic fermentation

ATP The enzyme phosphoglyceromutase transfers the phosphate group from the 3 to the 2 position of glyceric acid in a reaction involving 2 3 diphos phoglyceric acid Enolase dehydrates 2 phospho-glyceric acid to phosphoenol pyruvic acid a com pound containing a 'high energy phosphate group Finally the phosphate group is transferred to ADP to yield pyruvic acid and ATP The conversion of 1 mole of glucose to 2 moles of pyruvic acid is accompanied by an uptake of 2 moles of orthophos phate (P_i and a net formation of 2 moles of ATP according to the following equation

$$C_6H_{12}O_6 + 2DPN + 2ADP + 2P_i \rightarrow 2CH_3COCOOH + 2ATP + 2DPNH$$

In glycolysis by muscle tissue the reduced diphos phopyridine nucleotide (DPNH) is reoxidized back to the oxidized form (DPN) by a reaction in which pyruvic acid is simultaneously reduced to lactic acid

$$CH_3COCOOH + DPNH + H^+ \rightarrow CH_3CHOHCOOH + DPN^+$$

Pyruvate — Lactate

In alcoholic fermentation by yeast enzymes the DPNH is reoxidized by acetaldehyde which is formed in the decarboxylation of pyruvic acid

$$CH_3COCOOH \rightarrow CH_3CHO + CO_2$$

$$CH_3CHO + DPNH + H^+ \rightarrow CH_3CH_2OH + DPN^+$$

Acetalde hyde — Ethanol

The over all reaction is then

$$C_6H_{12}O_6 + 2ADP + 2P_i \rightarrow 2CH_3CH_2OH + 2CO_2 + 2ATP$$

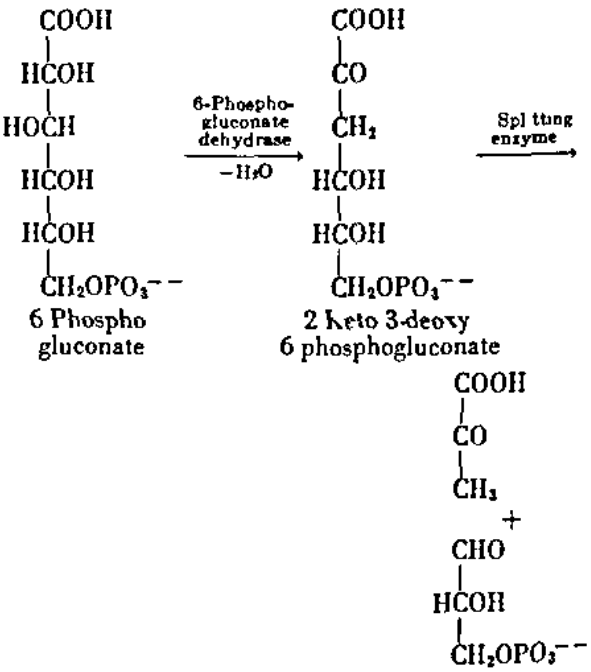
In living yeast the ATP (present in catalytic amounts) is used in various biosynthetic reactions In cell free yeast extract in which conditions are not favorable for the occurrence of many biosyn thetic reactions ATP is used mainly to phos phorylate excess glucose Both types of reaction continuously regenerate ADP which is essential for the oxidation of glyceraldehyde phosphate

The pentose phosphate pathway of glucose de composition involves hexose monophosphates and pentose monophosphates but not fructose diphos phate This pathway is used by some anaerobic bacteria It is shown on the opposite page

The first step is the same as in glycolysis the conversion of glucose to glucose 6 phosphate The latter compound is oxidized by a dehydrogenase to 6 phosphoglucono Δ lactone the oxidizing agent is TPN The lactone is hydrolyzed to 6 phospho gluconic acid which is then oxidized by TPN and a specific dehydrogenase to ribulose 5 phosphate and carbon dioxide A rearrangement at carbon atom 3 under the influence of an epimerase results in the formation of xylulose 5 phosphate This com pound is cleaved between carbon atoms 2 and 3 in an enzymatic reaction that consumes orthophos-

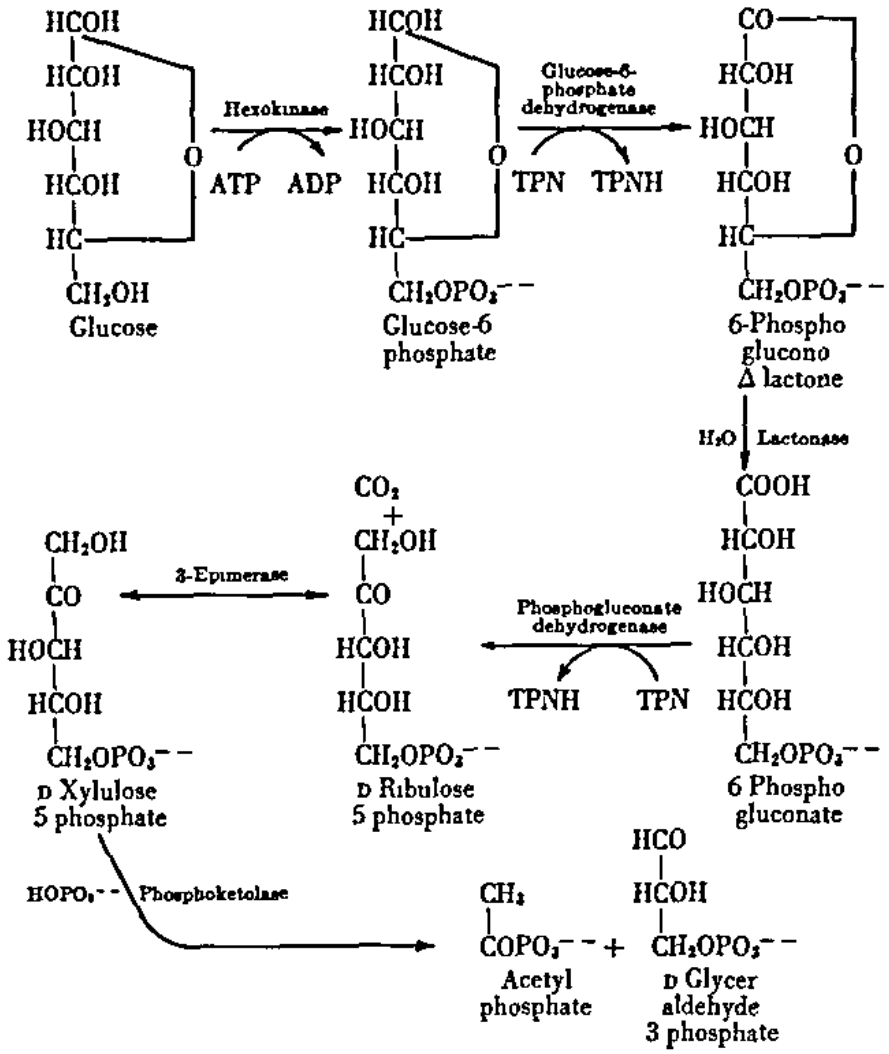
Meyerhof pathway to pyruvate The further fate of pyruvate and acetyl phosphate depends upon the enzymatic make up of the organism using this metabolic path

The 2 keto-3-deoxy 6-phosphogluconate (Entner Doudoroff) pathway represents another method of degrading glucose with the liberation of energy This pathway has been studied mainly in an aero bic organism *Pseudomonas saccharophila*, but it probably also functions in some anaerobic bac teria The distinguishing feature of the Entner Doudoroff pathway of glucose metabolism is pre sented in the following diagram



The initial steps from glucose to 6 phosphoglu conate are the same as in the pentose phosphate pathway The 6 phosphogluconate is then dehy drated and rearranged under the influence of a dehydrase to form the characteristic compound of this pathway 2 keto 3-deoxy 6 phosphogluconate A "splitting enzyme cleaves this compound between carbon atoms 3 and 4 to yield pyruvate from glu cose carbon atoms 1 3 and glyceraldehyde 3-phos phate from carbon atoms 4–6 The conversion of the triose phosphate to a second mole of pyruvate follows the Embden Meyerhof pathway The fur ther reactions of pyruvate vary with the organism

Alcoholic fermentation by bacteria is relatively uncommon *Ps lindneri* (*Zymononas mobilis*), a bacterium found in pulque ferments glucose or fructose to 45% carbon dioxide 45% ethanol and 7% lactic acid The fermentation appears to follow the Entner Doudoroff pathway This is indicated by the fact that the carbon dioxide is derived from glu cose carbon atoms 1 and 4 and the primary alcohol group of ethanol is derived from glucose carbon atoms 2 and 5 In alcoholic fermentation by yeast



A pentose phosphate pathway in bacteria

carbon dioxide is derived from glucose carbon atoms 3 and 4, and the alcohol group of ethanol is derived from glucose carbon atoms 2 and 5

Glucose	*Yeast*	*Ps lindneri*
^1CHO	$^1CH_3$	$^1CO_2$
^2CHOH	$^2CH_2OH$	+
^3CHOH	+	$^2CH_2OH$
^4CHOH	$^3CO_2$	$^3CH_3$
^5CHOH	+	+
$^6CH_2OH$	$^4CO_2$	$^4CO_2$
	+	+
	$^5CH_2OH$	$^5CH_2OH$
	$^6CH_3$	$^6CH_3$

Lactic acid fermentation Lactic acid fermentations are processes by which glucose and some other carbohydrates are converted to lactic acid and sometimes other products These fermentations are caused by species of *Streptococcus, Leuconostoc, Lactobacillus,* and some other genera These bacteria are responsible for the souring of milk and cream for the preservation of silage and for some types of food spoilage *See* FOOD SPOILAGE, MILK

Lactic acid fermentations may be divided into two types the homolactic and heterolactic fermentations

Homolactic fermentations caused mainly by *Streptococcus* and certain *Lactobacillus* species convert sugar almost entirely to lactic acid Only when the fermentations occur in an alkaline me

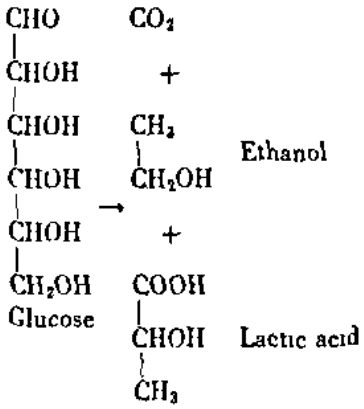
$$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH$$

dium do other products such as formate, acetate, and ethanol accumulate in considerable amounts *Streptococcus* species usually form L(+) lactic acid, the isomer metabolized most readily by man *Lactobacillus* species may form either L(+), D(−), or racemic lactic acid Homolactic fermentations occur by the glycolytic (Embden [illegible] hof) pathway The pyruvic acid is reduced to

acid by reduced diphosphopyridine nucleotide (DPNH) under the influence of the enzyme lactic dehydrogenase

$$CH_3COCOOH + DPNH + H^+ \rightarrow \underset{\text{Pyruvic acid}}{} \qquad \underset{\text{Lactic acid}}{CH_3CHOHCOOH} + DPN^+$$

Heterolactic fermentations caused mainly by *Leuconostoc* and certain *Lactobacillus* species produce lactic acid in smaller yield and convert a considerable part of the sugar to carbon dioxide and other products such as ethanol acetic acid glycerol and mannitol *Leuc mesenteroides* ferments glucose according to the following equation



The glycolytic pathway of sugar decomposition cannot account for the formation of equimolar amounts of the three products The origin of the carbon atoms of the products established by experiments with C^{14} labeled glucose is consistent with the occurrence of the pentose phosphate pathway The acetyl phosphate produced in this sequence is reduced first to acetaldehyde and then to ethanol using reducing agents (TPNH and DPNH) produced during the oxidation of glucose to acetyl phosphate pyruvate and carbon dioxide Apparently all typical heterolactic fermentations involve the pentose phosphate pathway Heterolactic fermentations of fructose but not glucose characteristically produce mannitol in good yield

Several homolactic and heterolactic species are able to ferment the pentose sugars xylose arabinose and ribose The products of pentose fermentation by both types of lactic acid bacteria are lactic and acetic acids

$$\underset{\text{Pentose}}{C_5H_{10}O_5} \rightarrow \underset{\text{Lactic acid}}{CH_3CHOHCOOH} + \underset{\text{Acetic acid}}{CH_3COOH}$$

Propionic acid fermentation The propionic acid fermentation converts sugars polyalcohols salts of organic acids such as lactate and pyruvate and some amino acids such as alanine and serine to propionic acid and often other products including acetate succinate propanol and carbon dioxide Most of the bacteria that cause the propionic acid fermentation are species of *Propionibacterium* A few other bacteria including *Clostridium propionicum* and *Micrococcus lactilyticus*, cause a similar fermentation

The simplest propionic acid fermentation is that of glycerol, 90% of the substrate may be converted to propionic acid

$$\underset{\text{Glycerol}}{CH_2OHCHOHCH_2OH} \rightarrow \underset{\text{Propionic acid}}{CH_3CH_2COOH} + H_2O$$

When the medium contains a considerable concentration of carbon dioxide, succinic acid is also formed and the yield of propionic acid is reduced For each mole of succinate accumulating 1 mole of carbon dioxide is consumed Experiments with C^{14} labeled carbon dioxide show that carbon dioxide carbon is incorporated into the carboxyl groups of both propionic and succinic acids There is considerable evidence that succinic acid and succinyl coenzyme A are intermediates in the formation of propionic acid Propionic acid is probably formed from glycerol by the sequence of reactions shown on the following page

The acetyl CoA required for the formation of succinyl CoA is probably formed by the following reaction

$$CH_3COOH + ATP + CoA \rightarrow \underset{}{} \qquad CH_3CO{-}CoA + AMP + PP$$

Lactate a favorite substrate of propionic acid bacteria is fermented approximately according to the equation

$$3CH_3CHOHCOOH \rightarrow \underset{}{} \qquad 2CH_3CH_2COOH + CH_3COOH + CO_2 + H_2O$$

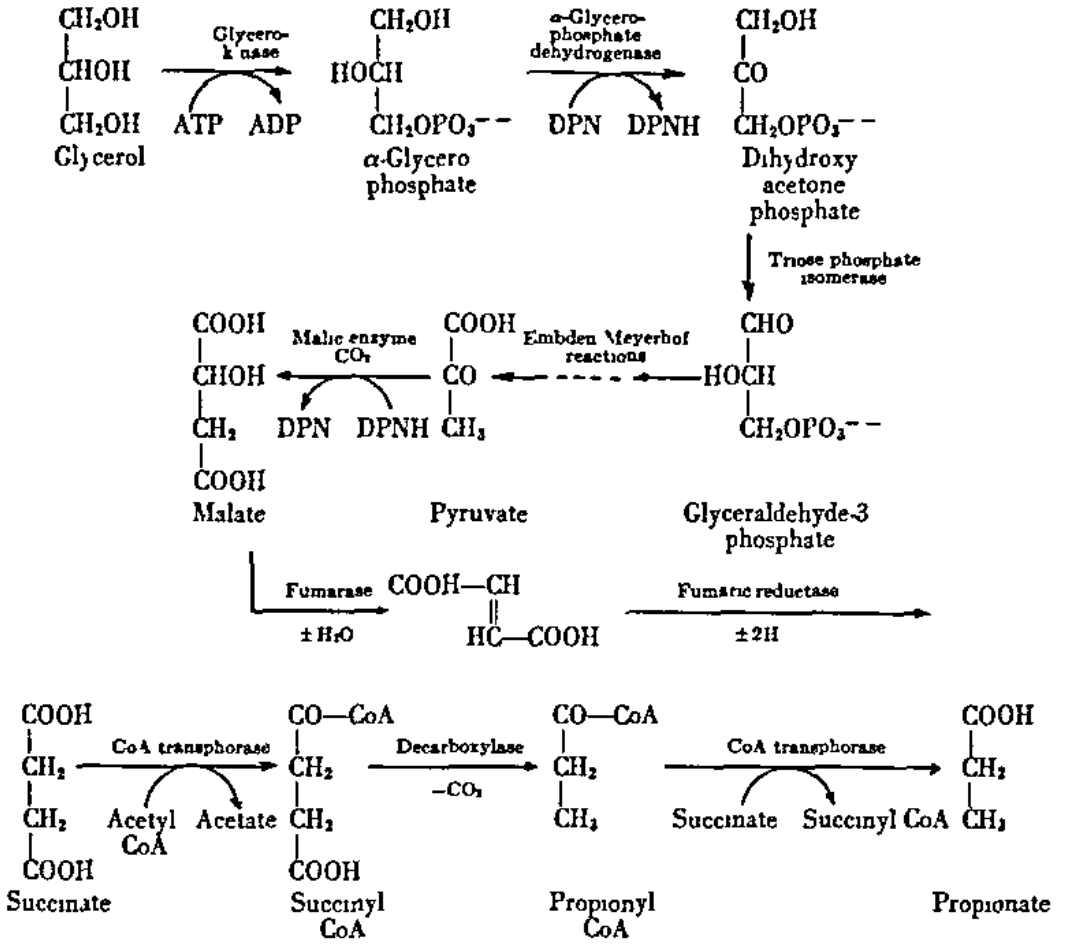
A little succinic acid is also formed Hexose and pentose sugars are converted to the same products

The propionic acid fermentation is essential for the preparation of Swiss cheese The characteristic flavor is partially attributable to propionic acid and the holes in the cheese are caused by carbon dioxide formed by the propionic acid bacteria *See* CHEESE

Butyric acid fermentation The butyric acid fermentation results in the formation of butyric acid and usually other products which may include hydrogen carbon dioxide acetic acid and caproic acid This type of fermentation is usually caused by anaerobic sporeforming bacteria such as *Clostridium butyricum* and *C kluyveri* A few nonsporulating bacteria such as *Butyribacterium rettgeri* and *Sarcina maxima* also produce butyric acid Suitable substrates for the butyric acid fermentation are hexose and pentose sugars polyalcohols polysaccharides salts of organic acids (tartrate lactate) and occasionally ethanol plus a short chain fatty acid

The simplest butyric acid fermentation is caused by *C kluyveri* which converts ethanol and acetate to caproic acid The fermentation involves two stages in the first stage butyric acid is formed and in the second stage it is converted to caproic acid

$$\underset{\text{Ethanol}}{CH_3CH_2OH} + \underset{\text{Acetic acid}}{CH_3COOH} \rightarrow \underset{\text{Butyric acid}}{CH_3CH_2CH_2COOH} + H_2O$$



Steps in the propionic acid fermentation

$$CH_3CH_2OH + CH_3CH_2CH_2COOH \rightarrow$$
Ethanol Butyric acid

$$CH_3CH_2CH_2CH_2CH_2COOH + H_2O$$
Caproic acid

These reactions provide the energy needed by the bacteria

The conversion of ethanol and acetate to butyrate like all fermentations is a relatively complex process The individual enzymatic steps are shown in the reaction sequence shown on the following page

Caproic acid is formed by a similar sequence of reactions in which a molecule of acetyl CoA is replaced by butyryl CoA in the β ketothiolase reaction Elongation of the carbon chain occurs by addition of two carbon moieties onto the carboxyl carbon of butyric acid

Similar reactions occur in the butyric acid fermentation of glucose The sugar appears to be converted to pyruvate by the Embden Meyerhof pathway Pyruvate is then oxidized to acetyl CoA with the simultaneous formation of carbon dioxide and hydrogen according to the equation

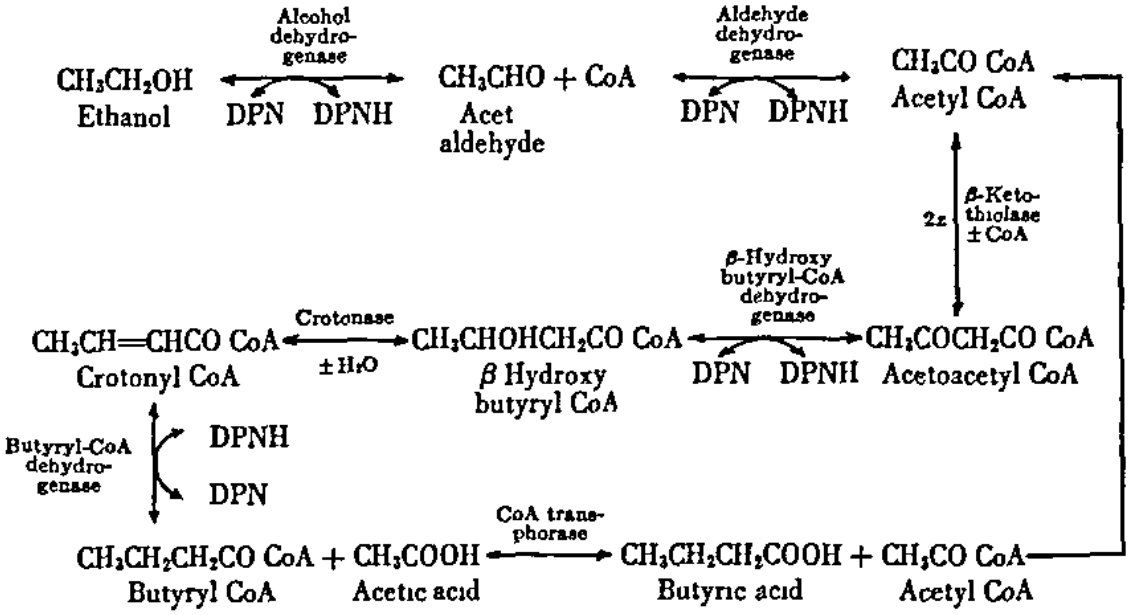
$$CH\ COCOOH + CoA \rightarrow$$
$$CH\ CO{-}CoA + CO_2 + H_2$$

As a consequence of this reaction 2 moles of carbon dioxide and 2 moles of hydrogen are formed per mole of glucose fermented The acetyl CoA is converted to butyric acid with the aid of reduced diphosphopyridine nucleotide (DPNH) produced during the oxidation of triose phosphate

Butanol acetone fermentation The butanol acetone fermentation yields considerable amounts of the solvents butanol and acetone and smaller amounts of acetic and butyric acids along with the gases hydrogen and carbon dioxide This fermentation catalyzed by *C acetobutylicum* has been extensively used for the commercial production of butanol and acetone from starch and sugars

The butanol acetone fermentation results from a small modification of the chemistry of the butyric acid fermentation of carbohydrates Initially the same products mainly butyric and acetic acids carbon dioxide and hydrogen are formed in both fermentations Then if the medium is permitted to become acid a leak develops in the sequence of reactions for converting acetyl CoA to butyrate This leak develops as a result of the formation of an enzyme system that converts acetoacetyl CoA to acetoacetate and then decarboxylates the latter to acetone

$$CH_3COCH_2CO{-}CoA \rightarrow$$
$$CoA + CH_3COCH\text{-}COOH \xrightarrow{\text{Acetoacetate decarboxylase}}$$



Conversion of ethanol and acetate to butyrate

The destruction of acetoacetyl CoA both causes the accumulation of acetone and prevents the further formation of butyrate The reducing agents initially used to reduce acetoacetyl CoA to butyryl CoA are then used for the reduction of butyryl CoA via butyraldehyde to *n* butanol as shown on the opposite page

Consequently acetone and butanol are formed simultaneously During the solvent producing stage of the fermentation a large increase in the formation of carbon dioxide relative to hydrogen occurs as a result of the decarboxylation of acetoacetic acid

Clostridium butylicum a species closely related to *C acetobutylicum* forms an additional product isopropanol This branched chain secondary alcohol is formed by reduction of acetone

$$\underset{\text{Acetone}}{CH_3COCH_3} + 2H \rightarrow \underset{\text{Isopropanol}}{CH_3CHOHCH_3}$$

Only a few species of *Clostridia* catalyze this reaction

Ethanol acetone fermentation The ethanol acetone fermentation of carbohydrates is catalyzed by *Aerobacillus macerans* This species forms ethanol acetone acetic and formic acids carbon dioxide and hydrogen from glucose or starch The chemistry of the fermentation has not been studied extensively but is probably similar to that of the butanol acetone fermentation except for the absence of reactions from acetoacetyl CoA to butyrate The acetone is formed by decarboxylation of acetoacetic acid and the ethanol, a major product originates by reduction of acetyl CoA via acetaldehyde a reaction analogous to the reduction of butyryl CoA to butanol by *C acetobutylicum*

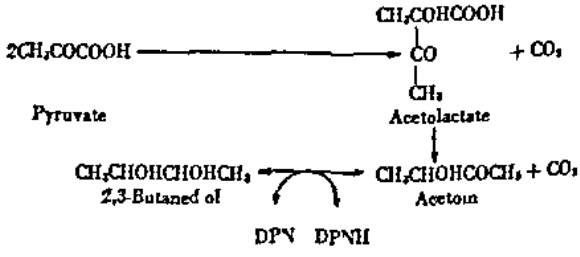
The 2 3-butanediol fermentation of carbohydrates is caused by *Aerobacter* and *Serratia* species *Aerobacillus polymyxa* and some strains of *Bacillus subtilis* This type of fermentation produces large yields of carbon dioxide ethanol and 2 3-butanediol moderate yields of formate and hydrogen and small yields of acetate lactate and succinate In *Aerobacter* species the conversion of glucose to pyruvate appears to follow the Embden Meyerhof pathway Some of the pyruvate undergoes a cleavage reaction involving coenzyme A with formation of acetyl CoA and formate The acetyl CoA is partly converted to acetate and partly reduced via acetaldehyde

$$\underset{\text{Pyruvate}}{CH_3COCOOH} + CoA \rightarrow \underset{\text{Acetyl CoA}}{CH_3CO{-}CoA} + \underset{\text{Formate}}{HCOOH}$$

to ethanol The formate is partly broken down by the formic hydrogenlyase enzyme system to carbon dioxide and hydrogen

$$HCOOH \rightarrow CO_2 + H_2$$

The remainder of the pyruvate is mostly converted to acetolactate and carbon dioxide



The acetolactate is rapidly decarboxylated by a specific enzyme to acetoin The latter compound is an effective oxidizing agent under anaerobic conditions it is readily reduced under the influence of



Reduction of butyryl CoA to butanol

a specific dehydrogenase to 2 3-butanediol Under aerobic conditions some bacteria can slowly oxidize acetoin to diacetyl a slightly volatile compound that is responsible for the characteristic odor of butter

$$CH_3CHOHCOCH_3 + \tfrac{1}{2}O_2 \rightarrow CH_3COCOCH_3 + H_2O$$
Acetoin Diacetyl

Fermentations of nitrogen compounds Under anaerobic conditions bacteria are able to decompose many organic nitrogenous compounds including amino acids and various heterocyclic compounds such as the purines Fermentations of such compounds are described as putrefactive because they frequently result in the formation of substances having unpleasant odors The bacteria that ferment nitrogenous compounds are mostly species of *Clostridium* (*C botulinum C perfringens C spotogenes C tetani C tetanomorphum*) but several species belonging to the genera *Fusobacterium Diplococcus* and *Micrococcus* are known

Amino acid fermentation Amino acid fermentations involve either the anaerobic decomposition of a single substrate or the coupled decomposition of two or more substrates The latter type of decomposition is known after its discoverer as the Stickland reaction

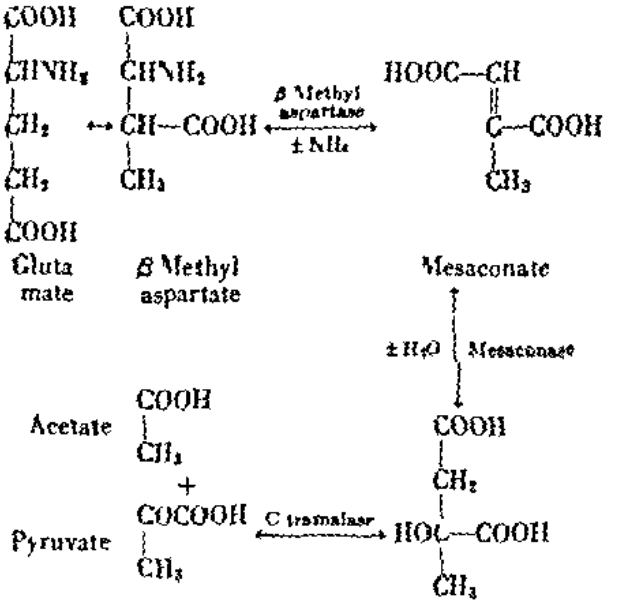
Most of the common amino acids can be fermented singly by certain anaerobic bacteria Alanine cysteine glutamate glycine histidine serine and threonine are some of the amino acids known to be fermented The products usually include one or more of the short chain fatty acids (acetic propionic butyric) carbon dioxide hydrogen and ammonia

The decomposition of alanine by *C propionicum* is one of the simpler amino acid fermentations The process described by the following equation

$$3CH_3CHNH_2COOH + 2H_2O \rightarrow$$
Alanine
$$2CH_3CH_2COOH + CH_3COOH + CO_2 + 3NH_3$$
Propionate Acetate

is similar to the propionic acid fermentation of lactate by the same organism except for the additional formation of ammonia The chemical steps in the fermentation of alanine have not been completely elucidated but they include an oxidation of 1 mole of alanine to acetate carbon dioxide and ammonia via pyruvate and a reduction of 2 moles of alanine to propionate and ammonia probably via the coenzyme A derivative of acrylate

The fermentation of glutamate by *C tetanomorphum* results in the formation of ammonia acetate butyrate carbon dioxide, and hydrogen This modified butyric acid fermentation involves the transient formation of several branched chain dicarboxylic acids shown in the following scheme



These reactions result in the conversion of glutamate to acetate and pyruvate The latter compound undergoes oxidative decarboxylation to form an acetyl compound which is converted partly to acetate and partly to butyrate Energy for synthetic reactions is produced during the fermentation of pyruvate as in other butyric acid fermentations

The aerobic decomposition of the sulfur containing amino acid cysteine by *Proteus vulgaris* and other bacteria results in the formation of hydrogen sulfide (H_2S) ammonia and pyruvate

$$CH_2CHCOOH + H_2O \rightarrow H_2S + NH_3 + CH_3COCOOH$$
SH NH2
Cysteine Pyruvate

By an analogous reaction another sulfur containing amino acid methionine gives methylmercaptan (CH_3SH) ammonia and α ketobutyrate

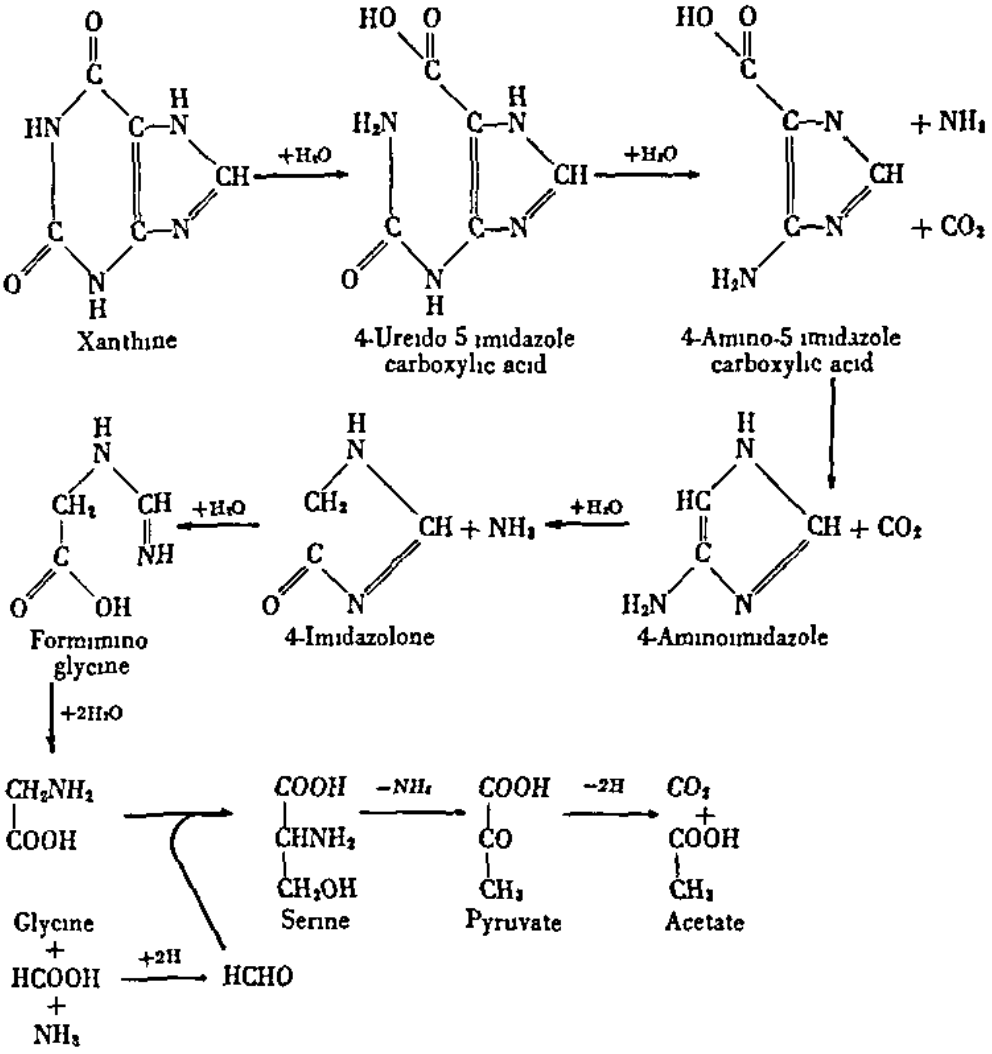
$$CH_3S—CH_2CH_2CHNH_2COOH + H_2O \rightarrow$$
Methionine
$$CH_3SH + NH_3 + CH_3CH_2COCOOH$$
α ketobutyrate

Both hydrogen sulfide and methylmercaptan contribute to the putrefactive odor of decomposing proteins The two keto acids are further fermented to fatty acids and carbon dioxide

A decarboxylation of certain amino acids according to the equation

$$RCHNH\ COOH \rightarrow RCH_2NH_2 + CO_2$$

is catalyzed by a number of bacteria The amino acids most commonly decarboxylated are histidine



Fermentation of xanthine by *C acidi-urici*

tyrosine arginine ornithine lysine tryptophan and glutamate The decarboxylation of lysine for example produces cadaverine a basic substance having a very unpleasant odor

$$NH_2(CH_2)_4CHNH_2COOH \rightarrow NH_2(CH_2)_4CH_2NH_2 + CO_2$$

Lysine → Cadaverine

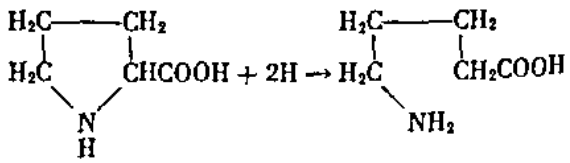
The decarboxylation reaction occurs mainly in bacteria exposed to a relatively acidic medium Because the products of decarboxylation are more basic than the amino acids the reaction helps to maintain a neutral environment

whereas the other is reduced The simplest example is the coupled decomposition of alanine and glycine according to the reaction

$$CH_3CHNH_2COOH + 2CH_2NH_2COOH + 2H_2O \rightarrow 3NH_3 + 3CH_3COOH + CO_2$$

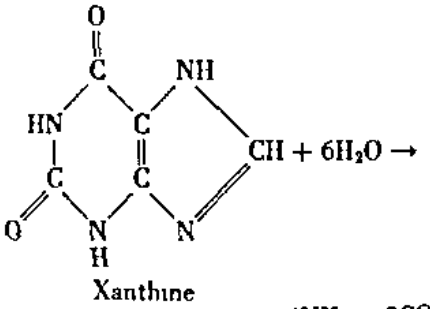
Alanine + Glycine → Acetate

In this process the oxidation of 1 mole of alanine to acetate carbon dioxide and ammonia is coupled with the reduction of 2 moles of glycine to acetate and ammonia Other amino acids that are oxidized include leucine isoleucine valine and histidine The products are always ammonia carbon dioxide and a carboxylic acid with one less carbon atom Other amino acids that are reduced include proline hydroxyproline ornithine and tryptophan The reduction of proline (or hydroxyproline) converts a ring compound to a straight chain compound without formation of ammonia



With ornithine or tryptophan as with glycine the α amino group is removed by a reductive deamination

Purine fermentation Purine fermentations are caused by a few *Clostridium* and *Micrococcus* species *C acidi urici* for example rapidly ferments uric acid xanthine and certain other purines to ammonia carbon dioxide acetate and very small amounts of glycine and formate The fermentation of xanthine is approximately described by the equation



Xanthine

$$4NH_3 + 3CO_2 + CH_3COOH$$

Other purines are converted to xanthine before the ring system is ruptured Chemical steps in the fermentation of xanthine are shown in the scheme on the preceding page

The fermentation involves first a destruction of the six membered ring followed by a conversion of the imidazolone ring to the straight chain compound formiminoglycine The latter is converted to glycine ammonia and activated formic acid actually a derivative of tetrahydrofolic acid The activated formic acid is reduced to the formaldehyde level of oxidation and condensed with glycine to form serine This amino acid is deaminated and rearranged to form pyruvate which is oxidized to acetate and carbon dioxide High energy phosphate is probably formed during the oxidation of pyruvate and stored as ATP for use in biosynthetic reactions [H A B]

BACTERIAL ANABOLISM

Bacterial anabolism comprises the biochemical activities concerned with the synthesis and organization of the multifarious chemical constituents of the bacterial cell The build up starts with a relatively small number of low molecular weight building blocks which are assimilated directly from the environment or produced by catabolism By sequential reactions they are fashioned into different products mostly of high molecular weight for example lipids polysaccharides proteins and nucleic acid Other typical anabolic products include pigments vitamins and antibiotics The enzymes responsible for the sequential reactions in any one biosynthetic pathway are usually located on cellular structures and thus are in physical proximity to the preceding and succeeding enzymes Anabolism also connotes the transport of building blocks to the reaction sites their energetic activation and the transfer and fixation of the finished product to its ultimate site in the cell

Energy relations in metabolism During the metabolism of a substrate bacteria perform numerous biochemical transformations whose overall effect is the liberation of energy in the form of heat This can be illustrated by the spectacular rise in temperature accompanying the microbial decomposition of a large mass of plant material that is well enough insulated to prevent a rapid exchange of heat with the environment The temperature in such a mass may go up to 80°C or more in a matter of hours Similarly in the large culture vats in which microbes are grown for example for the commercial production of alcohol or antibiotics heat production is usually so intense that the contents must be continuously cooled to keep the temperature within the physiologically tolerable range This is done by the use of cooled brine *See* ANTIBIOTIC ETHYL ALCOHOL

Prior to 1930 it was customary to attribute the energy liberation exclusively to those metabolic processes that were collectively called catabolism The anabolic reactions were grouped together in a separate category because they could all be considered as processes involving the uptake of energy

Reactions that release energy and thus can proceed spontaneously are called exergonic Here the sum of the chemical (free) energy of the reactants is greater than that of the products Reactions in which the total free energy of the products exceeds that of the reactants are called endergonic They can occur only if enough energy is supplied to compensate for the difference If a proper mechanism exists whereby the energy released in an exergonic reaction can be transferred to an endergonic one the former can drive the latter and in this case the two processes are said to be energetically coupled

The sharp distinction between catabolic and anabolic processes in bacterial metabolism could be justified on this basis For example the degradation of a fatty acid to the corresponding number of acetic acid molecules is an energy yielding process Its opposite the formation of fatty acids from acetate which is quite common in bacterial metabolism must therefore require energy This kind of argument could also be applied to practically every aspect of anabolism Anabolism is an immensely complex phenomenon This is clear from the fact that many bacteria can live and multiply in a simple inorganic medium supplied with but a single organic substrate such as acetate This implies that these organisms can synthesize all of their cell constituents—carbohydrates fats proteins enzymes nucleic acids and so on—from the substrate So bewildering are the number and diversity of the components of a bacterial cell that it seemed hopeless to attempt an explanation of the manner in which the necessary syntheses are accomplished The best that could be done was to recognize the principle of energetic [illegible] which could be expressed in the form [illegible] eral equations

$$\text{Substrate} \xrightarrow{\text{Catabolism}} \text{Breakdown products} + \text{Energy}$$

$$\text{Substrate} + \text{Energy} \xrightarrow{\text{Anabolism}} \text{Products of synthesis}$$

These equations show that catabolic reactions may occur without concomitant anabolic ones while the reverse is obviously impossible anabolism is dependent on catabolism After 1930 however when a sound beginning had been made with a more detailed analysis of catabolic processes it gradually became clear that anabolic reactions might be amenable to this same approach and since 1950 enormous strides have been made in understanding the mechanism by which they proceed It is now universally accepted that anabolic processes can also be interpreted as being composed of series of simple consecutive step reactions and that each of these can be represented by a reaction equation that is fundamentally similar to the one given earlier in this article as a general expression of catabolic step reactions

$$H_2A + B \rightarrow A + H_2B$$

This significant change in outlook which has led to a progressively refined understanding of the mechanism of biosynthetic reactions began with the recognition that certain step reactions in such a process need not be regarded as endergonic The seeming contradiction of this statement with the argument presented earlier can be readily explained It has been learned that the actual reactants in a biosynthetic reaction the building blocks are not the simple substances like the substrate molecules previously considered but rather are derivatives of the latter in which they occur combined with a reactive moiety As a result of this combination they become more reactive this can also be expressed by saying that the substrate molecules have thus been lifted to a higher energy level Consequently they can then participate in spontaneous reactions for which the unchanged substrate molecules are unfit

Such reactive derivatives can be formed in either of two ways

1 They may originate directly as intermediate products during a breakdown process This happens if a substrate remains tied to the coenzyme that mediates its decomposition (*see* BACTERIAL COENZYME) In that event the catabolic product first emerges as a coenzyme bound substance

2 They may also be formed by a reaction in which a general energy storage product such as adenosinetriphosphate (ATP) is used to transfer an energy rich (reactive) fragment to a substrate molecule and so to raise the reaction potentials of the latter

The example of the degradation and synthesis of fatty acids can again serve to illustrate these two aspects In the section on fermentative metabolism it has been mentioned that the breakdown proceeds under the influence of enyzmes in association with coenzyme A The fatty acid first becomes attached to the latter as an acyl CoA compound from which after dehydrogenation two carbon fragments are split off as acetyl CoA This substance is far more reactive than acetate itself and two molecules can readily be synthesized without additional energy supply to acetoacetyl CoA On the other hand acetoacetic acid cannot be so formed from acetate this is an endergonic process Thus the reaction

$$\text{Fatty acid–CoA complex} \xrightarrow{\text{Dehydrogenation}} \text{Acetyl CoA}$$

illustrates the direct catabolic formation of a reactive entity that can function as a reactant in a synthesis that does not require an input of energy

The second type of mechanism is illustrated by the spontaneous enzyme mediated reaction between acetate and ATP which yields acetyl phosphate and adenosinediphosphate (ADP) Acetyl phosphate as a mixed anhydride comparable to acetyl chloride is an unstable substance on the same energy level as acetyl CoA and its acetyl group can be enzymatically transferred without extra energy supply to CoA yielding the genuine building block for the synthesis of the long chain fatty acids

$$\text{Acetate} + \text{ATP} \rightarrow \text{Acetyl phosphate} + \text{ADP}$$
$$\text{Acetyl phosphate} + \text{CoA} \rightarrow \text{Acetyl CoA} + \text{Phosphate}$$

The formation of acetyl phosphate from acetate represents an activation of the latter it is one instance of many similar processes by which a relatively stable that is unreactive substance can be converted into an unstable reactive one Owing to this activation the substance can then participate in a spontaneously occurring synthetic process the unactivated one cannot

This is the fundamental principle of the mechanism by which the energy liberating catabolic processes can be coupled to the energy requiring anabolic reactions

Role of phosphorylated compounds The above paragraphs have shown that ATP by transfer of one of its terminal phosphate groups to another substance can be used to raise the energy level of the latter Such reactions are quite common in the metabolism of bacteria as well as in that of other microbes plants and animals In fact most phosphorylations are accomplished in this manner and in earlier parts of this article many examples have been given This kind of reaction is possible because ATP itself is an unstable substance which contains two energy rich (commonly called high energy) phosphate bonds Upon hydrolytic cleavage each of these can release an amount of energy of the order of magnitude of 10 000 cal/mole If such a phosphate group is transferred to a metabolically unreactive molecule the latter acquires the bond energy which is thus not lost as heat This fundamental notion of the preservation of bond energy was first formulated by F Lipmann in 1939

However not all phosphorylations at the expense of ATP are equally effective in preserving bond energy In addition to the energy rich compounds of which acetyl phosphate is an example there are

other types of phosphorylated substances in which the energy of the phosphate bond is only of the order of magnitude of 3 000 cal/mole as shown by the amount of heat liberated during their hydrolysis These are the phosphate esters such as glycerophosphate glucose 6-phosphate and fructose 1 6 diphosphate all of which can be formed by transfer of a phosphate group from ATP according to the equation

$$R{-}CH\,OH + ATP \xrightarrow[\text{kinase}]{\text{Specific}} R{-}CH_2O{-}PO_3H_2 + ADP$$

The transfer of phosphate groups from ATP to substrate molecules is mediated by enzymes that are called kinases They are specific for a particular substrate and are correspondingly named glycerokinase glucokinase phosphofructokinase and acetate kinase

Because the phosphate bond energy in the esters is far less than that in ATP the esterification reactions involve the loss of a large proportion of the chemical energy as heat Nevertheless the esterifications are metabolically significant for they also yield compounds with potentialities greater than those possessed by nonphosphorylated substances The synthesis of polysaccharides and of sucrose provides a good example

In 1937 it was discovered that animal tissue extracts can depolymerize glycogen in the presence of orthophosphate to glucose-1 phosphate (G 1 P) This represents a phosphorolysis rather than a hydrolysis with phosphate instead of water being added to the glucosidic bond In 1939 this reaction was found to be reversible and the first enzymatic synthesis of a polysaccharide was thus accomplished A year later the reversible phosphorolysis of starch was demonstrated with extracts of plant tissues

$$\text{Glycogen or starch} + \text{Orthophosphate} \rightleftharpoons G\,1\,P$$

The ester phosphate linkage represents a bond energy of the same order of magnitude as that of the glucosidic bond in the polysaccharides On the basis of the principle of bond energy preservation it is therefore understandable that the transfer of a glucose moiety from starch or glycogen to phosphate does not require an input of energy and that this type of reaction is readily reversible

Sucrose too can be similarly split and synthesized This was shown with an enzyme extract of the bacterium *Pseudomonas saccharophila* which contains a phosphorylase catalyzing the reversible reaction

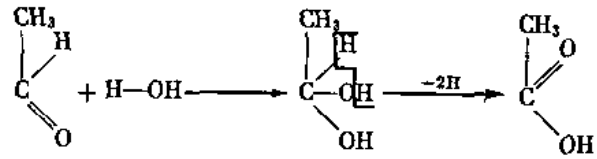
$$\text{Sucrose} + \text{Phosphate} \rightleftharpoons G\,1\,P + \text{Fructose}$$

These developments suggested that the conspicuous formation of polysaccharides from sucrose by various bacteria should be explained in like manner For example *Leuconostoc dextranicus* produces copious amounts of dextran a glucose polymer and *Streptococcus salivarius* as well as several species of *Pseudomonas* and *Bacillus* can synthesize levan a fructose polymer specifically from sucrose It has however been found that in these syntheses hexose moieties are not first transferred to phosphate but directly to a sugar molecule which acts as acceptor Such transfer reactions are mediated by enzymes known as dextran and levan sucrase respectively In spite of the difference in the phosphorylase reactions these polysaccharide forming processes nevertheless conform to the principle of bond energy preservation Thus the above examples show that this principle also applies to the (low energy) ester bonds *See* DEXTRAN

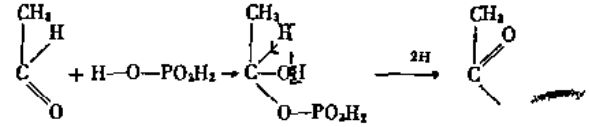
In this connection it is significant to note that carbohydrates are generally stored in the form of polysaccharide reserve products and in plants and certain animals are transported as disaccharides such as sucrose and trehalose The formation of these substances from intermediate products of metabolism the universal hexose phosphates implies that the phosphate bond energy is preserved Thus the subsequent conversions of the di and polysaccharides can start with the formation of phosphate esters from inorganic phosphate through the action of phosphorylases eliminating the waste of ATP for the initial phosphorylation

In the activation of substrate molecules by transphosphorylation from ATP the latter is consumed and it will be evident that in a metabolizing cell the stock of this material must be continuously replenished This is accomplished by the catabolic formation of high energy phosphate bonds including ATP itself It may occur in a number of different ways

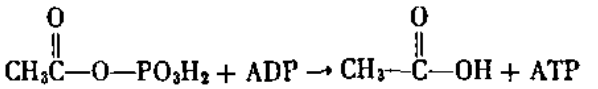
A simple example is the formation of acetyl phosphate during the bacterial oxidation of acetaldehyde This oxidation was once depicted as involving first a hydration of the aldehyde group and then a dehydrogenation of the hydrate



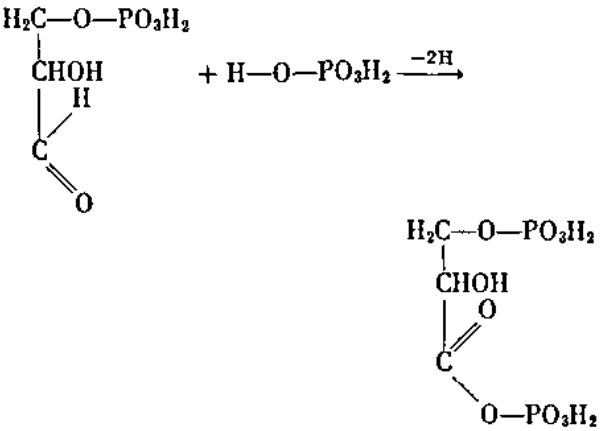
The discovery that inorganic (ortho)phosphate was involved in this reaction and emerged as a phosphate group combined with the organic oxidation product suggested that in the first step inorganic phosphate instead of water was attached to the carbonyl group and that the resulting phosphorylated aldehyde was then dehydrogenated to acetyl phosphate



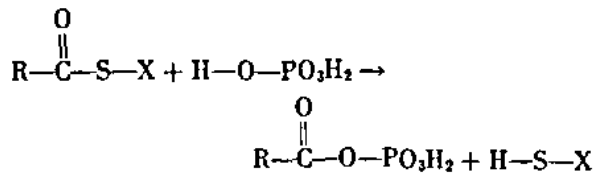
This process can be paraphrased by saying that the orthophosphate is smuggled into the reactive group of the aldehyde molecule in a reaction that does not require energy After the oxidation it is then left dangling in the form of the highly reactive mixed anhydride group The net result is that part of the energy that could have been liberated as heat by the dehydrogenation reaction is retained in the oxidized molecule as a high energy phosphate group From here the phosphate group can be transferred without additional energy supply to ADP with the formation of ATP



An essentially identical mechanism is encoun tered in the biological oxidation of 3 phosphoglyc eraldehyde to 1 3-diphosphoglyceric acid which also involves the transformation of orthophosphate into a high energy phosphate group



The similarity to the acetaldehyde oxidation is obvious It has however been found that the mechanism whereby the phosphate is introduced is somewhat more complicated than it has there *been represented* and *that the* primary reaction leads to the formation of a compound of the alde hyde not with phosphate but with a coenzyme containing a sulfhydryl group This compound is then dehydrogenated to a thiol compound which also has a mixed anhydride configuration and therefore contains an energy rich bond Thus it can spontaneously react with orthophosphate whereby the initial coenzyme is regenerated and acetyl phosphate produced

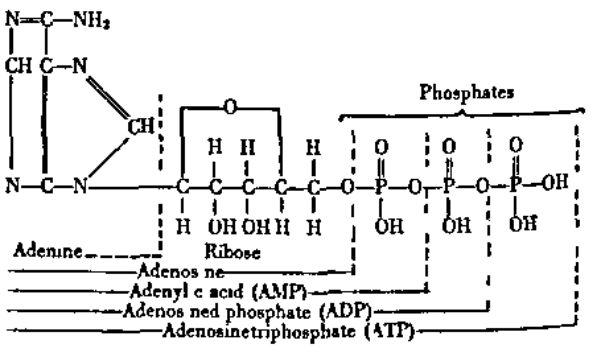


Thus the bond energy of the anhydride is pre served and the energy rich phosphate group can be transferred to ADP with the formation of ATP

These examples show how ATP can be generated through catabolic reactions, involved in the early stages of sugar degradation, which are common in many bacterial fermentation processes In fer mentative metabolism the yield of ATP per mole of sugar fermented is small, in the alcoholic and lactic acid fermentations the net gain is only 2 moles per mole of glucose This is of course, in line with the small free energy change in these processes In oxidative metabolism ATP formation is very much larger because here additional ATP generating mechanisms play a part They occur during the transfer of hydrogen atoms and elec trons from the substrate to oxygen by means of a series of enzyme systems principally including the di and triphosphopyridine nucleotides flavin nu cleotides and the various components of the cyto chrome system A pair of hydrogen atoms or elec trons so transferred can yield 3 molecules of ATP from ADP and orthophosphate and the complete oxidation of 1 mole of glucose to CO_2 and H_2O can generate about 36 moles of ATP The mechanism of this process designated as oxidative phosphory lation is not yet understood

A variant known as photosynthetic phosphoryla tion occurs in chlorophyll containing bacteria and in green plants These can form ATP from ADP and orthophosphate by converting the radiant en ergy absorbed by the photosynthetically active pig ments into the chemical energy of the high energy phosphate bond This process too appears to in volve an electron transport with pyridine and flavin nucleotides and cytochromes as mediators Thus the mechanism of this type of phosphorylation may well be the same as that operating in oxidative phosphorylation, the manner in which the electron flow originates is however different

Adenosinephosphates Three adenosinephos phates derivatives of the glucoside adenine ribo side or adenosine are known They are (1) adeno sinemonophosphate (AMP) also referred to as adenylic acid, (2) adenosinediphosphate (ADP), and *(3)* adenosinetriphosphate *(ATP)* The struc tures and relations of these substances are shown in the following diagram



It will be seen that the phosphate group of AMP is attached to adenosine by an ester (low energy) linkage while the additional phosphate groups of ADP and ATP represent anhydride (high energy) bonds Consequently ADP and ATP, but not

AMP can act as high energy phosphate donors and AMP and ADP are both high energy phosphate acceptors

Although ADP and particularly ATP are undoubtedly the most common high energy phosphate donors in bacterial metabolism there are others such as the previously mentioned acetyl phosphate phosphoenolpyruvic acid and 1 3-diphosphoglyceric acid The last two are known only as intermediate metabolic products while ADP and ATP generally are and acetyl phosphate occasionally may be high energy phosphate storage products as well This also applies to guanosine and inosine di and triphosphates (GDP GTP IDP ITP) which play a role in the Krebs or tricarboxylic acid cycle Nor are these the only ones in some organisms especially vertebrates creatine phosphate is an important high-energy phosphate storage product while arginine phosphate plays this role in invertebrate animals In these two substances the phosphate is not present in an anhydride linkage here the reactivity stems from an unstable phosphate to-nitrogen bond

Apart from being a high energy phosphate donor ATP can also participate in anabolic processes in another way It can transfer the adenyl (AMP) moiety to a substrate molecule with the formation of an adenylate and pyrophosphate (PP) The andenylates too represent activated substrates and are as will be seen later the genuine reactants in certain biosynthetic processes The significance of such adenylations has been sought in the concomitant formation of pyrophosphate which is readily hydrolyzed to orthophosphate by the enzyme pyrophosphatase In a situation where the equilibrium of the adenylase reaction is highly in favor of the starting materials (indicated by $\longleftarrow\!\!\!\!\rightarrow$) and thus adenylate would be formed in only extremely low concentration the removal of the pyrophospate in a subsequent reaction would cause a shift in the equilibrium with a larger concentration of adenylate being formed

$$\text{Substrate} + \text{ATP} \xleftrightarrow{\text{Transadenylase}} \text{Substrate adenylate} + \text{PP}$$

$$\text{PP} + \text{H}_2\text{O} \xrightarrow{\text{Pyrophosphatase}} \text{Orthophosphate}$$

Energy rich coenzyme substrate complexes The adenylation reactions mediated by enzymes known as transadenylases are a special instance of a more general type of substrate activation which yields an energy rich substrate enzyme complex Such complexes may be formed in one of two ways

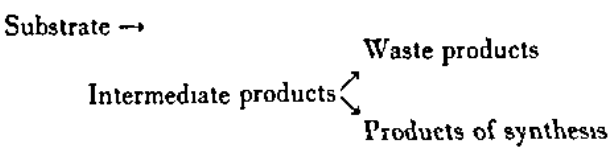
1 They may arise directly from the metabolic conversion of a substrate coenzyme compound that does not initially contain an energy rich bond This manner of origin is illustrated by the previously discussed formation of the coenzyme complex of 3-phosphoglyceric acid with its high energy bond from the addition product of 3 phosphoglyceraldhehyde and the sulfhydryl containing coenzyme by dehydrogenation

2 Alternatively they may result from the transfer of a moiety from an already activated to a non activated substance Examples of this mode of formation are the above mentioned transadenylations and the transacetylation by which the acetyl group of acetyl phosphate is transferred to coenzyme A with the formation of acetyl CoA and orthophosphate The former represent cases where the energy rich bond initially resides in the coenzyme ATP rather than in the substrate the second exemplifies the reverse situation

In all such reactions the principle of the preservation of bond energy is manifest The same principle is further illustrated by those processes in which a metabolic waste product originates in a coenzyme bound form with an energy rich bond If the waste product were split off from the complex by hydrolysis the bond energy would be lost as heat Generally however it is not so released but rather through the transfer of the coenzyme moiety to a substrate molecule which thereby becomes activated The reaction sequence in the propionic acid fermentation discussed under this heading in the section on fermentative metabolism of this article provides a good example The propionic acid originates as propionyl CoA and it can react for example with succinic acid to yield the fermentation end product along with the activated substrate succinyl CoA

$$\text{CH}_2\text{CH}_2\text{CO—S—CoA} + \text{HOOCCH}_2\text{CH}_2\text{COOH} \rightarrow \text{CH}_3\text{CH}_2\text{COOH} + \text{HOOCCH}_2\text{CH}_2\text{CO—S—CoA}$$

Catabolism and anabolism The metabolic significance of the energy rich coenzyme substrate complexes is that they represent the genuine building blocks that take part in the spontaneous biosynthetic reactions As shown in the preceding sections these complexes are formed directly or indirectly as a result of processes by which substrates are degraded Hence it now becomes possible to present a general picture of the connection between the catabolic and anabolic aspects of metabolism that is much more revealing than the earlier invoked concept of energetic coupling However useful this concept may have been at a time when nothing was known about the mechanism of energy transfer it was unsatisfactory precisely because it avoided this major problem Now that the general principles of that mechanism have been elucidated the notion of energetic coupling has lost its element of mystery At the same time it has become evident that the two aspects of metabolism that had formerly been sharply distinguished need no longer be viewed in this manner On the contrary the connection between them can now be interpreted far more adequately by considering the breakdown of a substrate as the means by which the genuine building blocks for the synthetic processes are manufactured This can be expressed by the diagram



which emphasizes the common origin of waste products and of products of synthesis from the same intermediate products rather than the energy relations

Essential for these advances in the understanding of metabolic processes has been the recognition that many of the enzyme controlled biochemical reactions are reversible and that the same intermediate products required as building blocks for the synthesis of different classes of compounds are produced during the metabolism of a wide variety of substrates This has been amply documented in the sections on oxidative and fermentative catabolism of this article

The reversibility of enzymatic reactions calls for an additional comment The equilibrium of such processes is determined by the free energy changes involved Thus if for a reaction of the type

$$A + B \rightleftharpoons C + D$$

the total free energy of A and B is greater than that of C and D the equilibrium will be in favor of the latter The greater the difference the farther will the reaction proceed to the right But if this system were combined with one representing an even greater free energy change

$$A + E \rightleftharpoons F + G$$

the removal of A by this reaction may bring about an increased formation of B from C and D This situation has been touched upon in discussing the adenylation of substrates by the reaction

$$\text{Substrate} + \text{ATP} \rightleftharpoons \text{Substrate-adenylate} + \text{PP}$$

There it was suggested that the subsequent hydrolysis of pyro to orthophosphate by pyrophosphatase could drive the adenylase reaction to the right The reason is that pyrophosphate contains an anhydride (that is high energy) bond whose energy is released as heat during hydrolysis This makes the pyrophosphatase reaction for all practical purposes irreversible so that its inclusion in a complex of enzymatic processes can be an effective method of energetic coupling by a simple mechanism

Oxidative and fermentative assimilation In a growing bacterial culture the number and diversity of synthetic processes comprising the formation of all cell constituents are so vast that a detailed analysis of the mechanism by which any one of them is formed is virtually impossible This requires a simpler situation which can be realized by using suspensions of bacteria in a medium in which they cannot multiply because it lacks some ingredient such as a nitrogen source necessary for the synthesis of a quantitively important cell material If a small amount of an oxidizable or fermentable substrate is added to such a suspension it will be quickly and completely metabolized At this point the quantity of carbon that disappeared as substrate is however much greater than that recoverable as CO_2 or fermentation products and the missing fraction is found as reserve material in the cells, it may amount to 20–80% of the substrate carbon Thus the metabolism entails a partial conversion of the substrate into assimilation products, this is referred to as oxidative or fermentative assimilation depending upon whether it occurred during an oxidative or fermentative decomposition of the substrate

In the presence of substances such as 2 4-dinitrophenol or sodium azide which prevent the metabolic generation of ATP the substrate is entirely converted into metabolic waste products The absence of assimilation under these conditions indicates that the assimilatory processes involve transphosphorylations This conclusion is entirely consistent with current knowledge of biosynthetic mechanisms

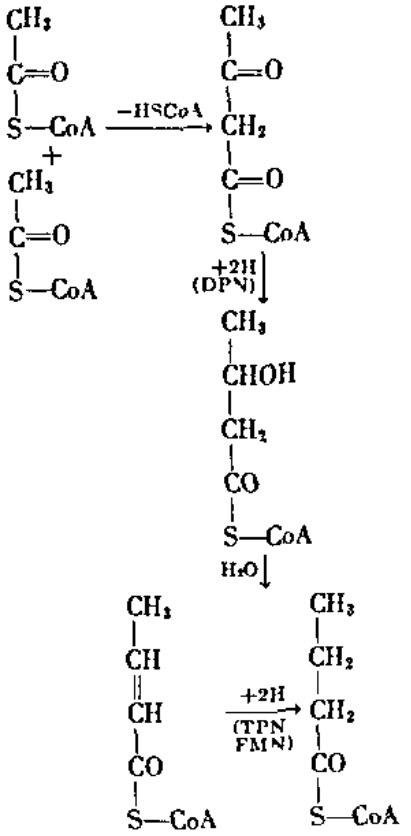
The nature of the assimilation product depends on the organism as well as on the substrate For example *Pseudomonas saccharophila* produces mainly poly β hydroxybutyric acid a fatlike reserve material from acetate butyrate and glucose *Rhodospirillum rubrum* also forms this polymer from acetate and butyrate but forms a glycogen like polysaccharide when metabolizing propionate pyruvate succinate or malate

Group transfer In the preceding sections several examples have been given of reactions in which smaller or larger groups of atoms are transferred from one molecule to another In this manner special building blocks arising as intermediate products during the metabolism of a particular substrate can be used in biosynthetic processes for the modification of other compounds and thus *aid in the eventual* synthesis of cellular *constituents* many of which bear little or no resemblance to the substrates from which they can be manufactured

The groups in question range from a pair of hydrogen atoms used for the reduction of some intermediate product and generally donated by reduced pyridine nucleotides to sulfhydryl sulfate amino methyl carbamyl formyl acetyl succinyl glucosyl fructosyl and even entire amino acid groups

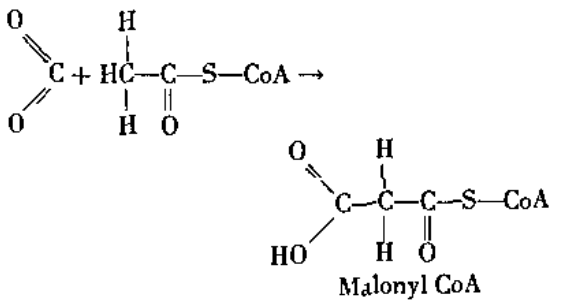
Specific biosyntheses The following account of some specific biosynthetic processes contains several examples of the principle of group transfer

Fatty acids and lipids Acetyl CoA is the universal building block from which fatty acids are synthesized by a consecutive series of reactions comprising coupling reduction dehydration and reduction respectively The first stage leading to a four carbon acid can be represented as follows the reductions are accomplished with reduced di and tripyridine nucleotide



Further coupling of the butyryl CoA with an additional molecule of acetyl CoA leads to the formation of a six carbon straight chain acyl CoA and in this manner the short chain even numbered fatty acids are built up

Recent discoveries reveal that the synthesis of long chain fatty acids by subcellular enzyme preparations is dependent on the presence of CO_2 and the B vitamin biotin The biotin combines with CO and in the presence of ATP and manganous ions mediates the carboxylation of acetyl CoA to malonyl CoA

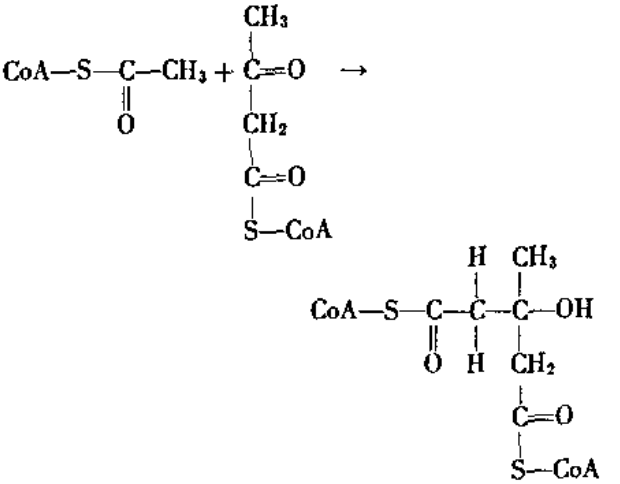


Malonyl CoA

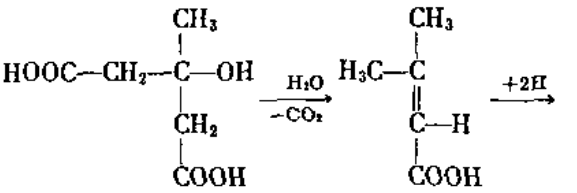
Malonyl CoA donates its acetyl CoA fragment to an acceptor acyl CoA the condensation being accompanied by the release of molecules of CoA and CO_2 originally derived from the acyl acceptor and CO_2 respectively The mono unsaturated fatty acids such as oleic acid are formed from saturated fatty acids through the action of an oxygenase

Molecular oxygen is required for this conversion Through lipase (esterase) action exchange is catalyzed between free fatty acids and the fatty acids in ester linkage with glycerol especially those in the 1 and 3 positions

Acetyl CoA can also be condensed directly with acetoacetyl CoA to the branched chain compound β hydroxy β methyl glutaryl CoA in the following way

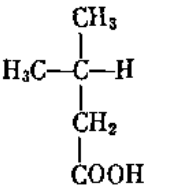


The latter can be converted by dehydration and decarboxylation to β methyl crotonyl CoA which in turn can be reduced to iso valeryl CoA thus branched chain fatty acids can be synthesized from acetyl CoA



β OH β Methyl glutaric acid

β Methyl crotonic acid

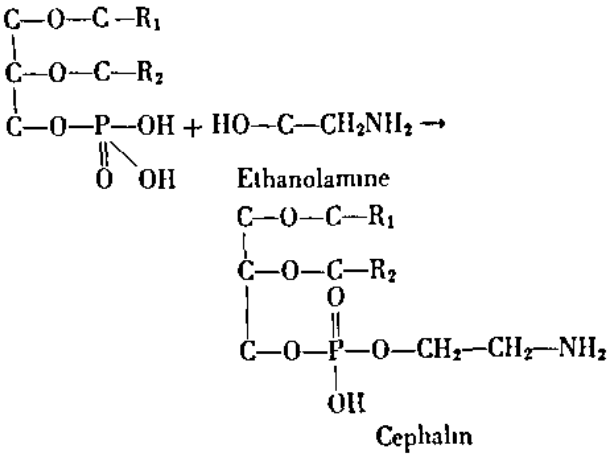


i Valeric acid

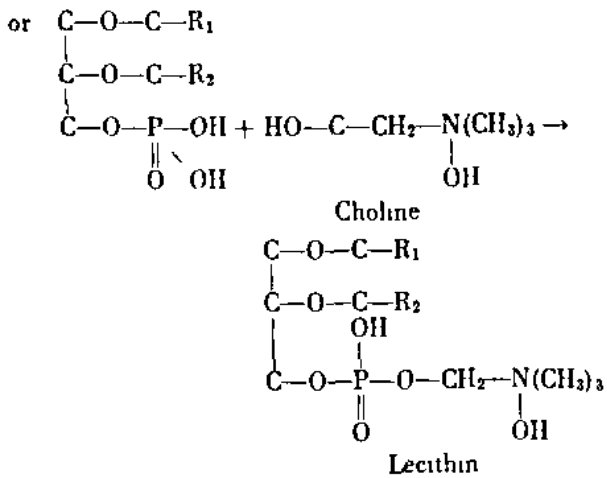
Bacteria like other organisms do not contain fatty acids as major cellular constituents in the free form but rather as lipids that is glycerol esters These can be synthesized directly from glycerophosphate and the CoA acylates Free fatty acids may also exchange with esterified ones in a glyceride particularly in the terminal positions under the influence of lipase a fat hydrolyzing enzyme of the group of esterases

Phospholipids or phosphatides are similarly formed by the esterification of the free hydroxyl groups of α glycerophosphate The resulting phosphatidic acid can then further react with certain

organic bases, such as ethanolamine or choline to form cephalin and lecithin respectively

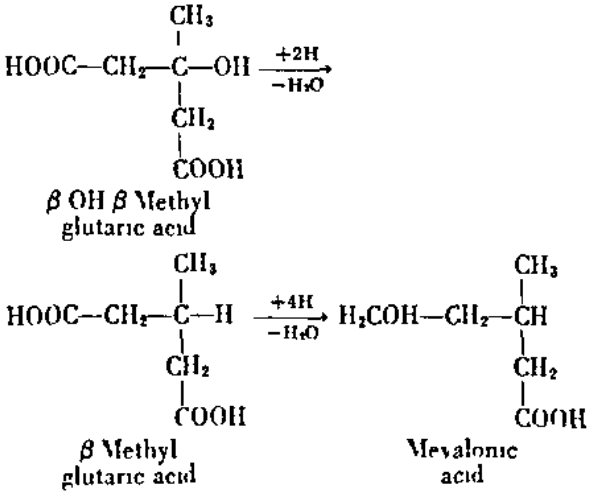


or

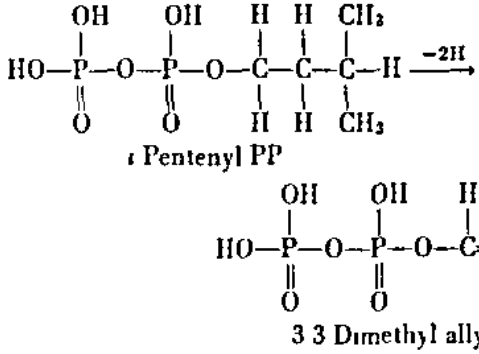


The organic bases participate in this reaction in the form of activated cytidyl phosphate compounds which mediate the group transfer

Steroids and carotenoids Another conversion of β hydroxy β methyl glutaric acid which has gained prominence in biosyntheses is its consecutive reduction to β methyl glutaric and to mevalonic acid



Soon after its discovery in 1956 mevalonic acid was recognized as a potential building block for the synthesis of steroids carotenoids and terpenes This has since been substantiated and the steps involved in the biosynthesis of steroids have been well worked out They are known to include phosphorylations with ATP and decarboxylation to iso pentenyl pyrophosphate (PP) and dehydrogenation of the latter to 3 3 dimethyl allyl pyrophosphate



From this derivative steroids are formed by consecutive condensations to squalene and lanosterol the synthesis of carotenoids leads by still unknown reactions to the colorless compound phytoene which has the branched 40 carbon chain characteristic of the carotenoid skeleton It is partially unsaturated but the number of conjugated double bonds is too small to cause light absorption in the visible range of the spectrum, hence it shows an absorption spectrum resembling that of carotenoids

colored carotenoids in the sequence

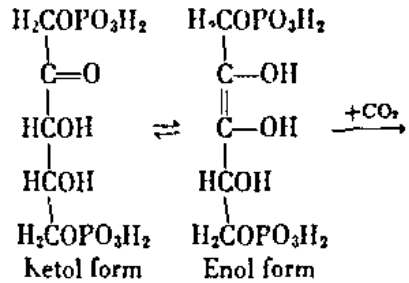
Phytoene → Phytofluene → ζ Carotene →
Neurosporene → Lycopene → Spirilloxanthin

This sequence was experimentally established in studies on the synthesis of carotenoids by purple bacteria The conversion to spirilloxanthin involves additional methylations *See* CAROTENOID, STEROID TERPENE

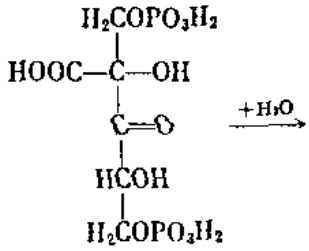
Carbohydrates One of the most significant biochemical processes in nature is the total synthesis of organic matter from carbon dioxide It closes the carbon cycle and provides a perpetual supply of food for all animals *See* PHOTOSYNTHESIS

The process is accomplished by plants and photosynthetic bacteria in the light and by chemoautotrophic bacteria in darkness Present evidence indicates that the major organic product synthesized by these organisms is initially carbohydrate from which numerous other organic substances can be derived by common metabolic pathways This conclusion has been reached as a result of studies in which the fate of the assimilated carbon dioxide has been determined with the aid of tracer techniques These have also revealed that the fundamental mechanism of carbon dioxide assimilation is identical in all organisms thus far investigated comprising higher plants algae photosynthetic bacteria and members of the chemoautotrophic bacterial genera *Thiobacillus* and *Hydrogenomonas*

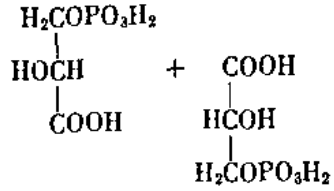
The key reaction is the addition of carbon dioxide to ribulose 1 5 diphosphate and the subsequent cleavage of the product to two molecules of 3-phosphoglyceric acid (PGA)



Ribulose 1 5-diphosphate



Carboxydismutase system



3 Phosphoglyceric acid (2 molecules)

Reduction of the PGA yields triosephosphate which can be condensed to fructose 1 6 diphosphate or can participate in the various reactions of the pentose cycle that have been described in more detail in the section on oxidative catabolism of this article This cycle in turn produces ribulose phosphate so that the assimilation of carbon dioxide can be continuously maintained in operation

The reductant for converting PGA into triose phosphate is derived from a photochemical decomposition of water mediated by the photochemical apparatus of the photosynthetic organisms or from the oxidation of appropriate inorganic substrates in the case of the chemoautotrophic bacteria The over all result of the primary processes involved in this assimilatory mechanism are expressed by the equations

$$3 \text{ Ribulose 1 5 diphosphate} + 3CO_2 \rightarrow 6\text{PGA}$$

$$6\text{PGA} + 12[H] \rightarrow 6 \text{ Triosephosphate}$$

$$5 \text{ Triosephosphate} \rightarrow 3 \text{ Ribulose diphosphate}$$

$$\text{Net} \quad 3CO_2 + 12[H] \rightarrow 1 \text{ Triosephosphate}$$

The photosynthetic bacteria comprise three distinct groups (1) the green sulfur bacteria most of which are strict autotrophs, these have not yet been studied in detail from the viewpoint of the mechanism of carbon dioxide assimilation, (2) the purple sulfur bacteria or Thiorhodaceae most of which can live either as photoauto or as photoheterotrophs and (3) the nonsulfur purple bacteria or Athiorhodacea which occur mainly as photoheterotrophs although some and perhaps all can also live as photoautotrophs if supplied with molecular hydrogen All of these bacteria can grow in the absence of oxygen when supplied with radiant energy of appropriate wavelength and with an oxidizable substrate the nature of the latter varying with the species of bacteria They do not produce oxygen in light as the green plants do, instead they cause the oxidation of the substrate without an oxidant other than carbon dioxide *See* RHODOBACTERIINEAE

These facts led in 1935 to the hypothesis that the primary photochemical reaction in all photosynthetic organisms consists in the photodecomposition of water (H O) to a reducing and an oxidizing moiety indicated as [H] and [OH] respectively In all cases the reducing moiety would be used for the reductive assimilation of carbon dioxide now more specifically identifiable as the reduction of PGA The oxidizing entity would be decomposed to H_2O and O_2 by green plants while the photosynthetic bacteria would use it for the oxidation of the inorganic or organic substrate

D I Arnon in 1959 has formulated a different hypothesis to account for the activities of the photosynthetic bacteria The sole photochemical process carried out by these organisms is considered to be the generation of an electron current leading from bacteriochlorophyll through phosphopyridine and flavin nucleotides and cytochromes back to the chlorophyll during which electron transfer reactions the absorbed radiant energy which causes the electron current to flow is transformed into chemical energy represented by ATP formation As mentioned earlier in this article photosynthetic phosphorylation has been established to occur in both green plants and photosynthetic bacteria

Although Arnon s hypothesis has many attractive features it is not yet clear how it can account for at least one phenomenon that has been established since the hypothesis was published It has been shown that photosynthetic bacteria in the light but in the absence of oxygen can oxidize certain substrates such as benzoic acid that have been found to be degraded by other bacteria only as a result of a direct oxygenation If the same mechanism of oxidation were operative in the photosynthetic bacteria it would seem that this requires the photochemical formation of an oxidant on the level of molecular oxygen rather than of ATP alone This dilemma will have to be resolved by future experiments

In 1940 J W Foster established that certain of the Athiorhodaceae in light but in the absence of oxygen can oxidize secondary alcohols corresponding ketones with the conc

assimilation of carbon dioxide according to the equation

$$4R_1\text{—}CHOH\text{—}R_2 + CO_2 \rightarrow 4R_1\text{—}CO\text{—}R_2 + (CH_2O) + H_2O$$

This showed that an organic substrate can be used exclusively as a hydrogen donor for carbon dioxide assimilation The studies of M Doudoroff and R Y Stanier in 1959 have shown conclusively however that substrates such as acetate and butyrate can be converted directly into poly β hydroxybutyric acid in a process that does not involve an appreciable carbon dioxide assimilation

It is also known that photosynthetic bacteria can produce substances other than sugar from carbon dioxide For example H Larsen found in 1951 that the green sulfur bacterium *Chlorobium thiosulfatophilum* can produce succinate from propionate and CO_2 in a photochemical reaction in accordance with the equation

$$CH_3CH_2\text{—}COOH + CO_2 \rightarrow HOOC\text{—}CH_2\text{—}CH_2\text{—}COOH$$

The succinate is not further used by the organisms and is the only detectable product of the reaction Experiments with labeled CO_2 have shown that this appears exclusively in the carboxyl group of the succinate

Another example of the primary incorporation of the carbon dioxide carbon atom in nonsugar compounds is provided by studies with the obligately chemoautotrophic bacterium *Thiobacillus denitrificans* Studies on the fate of labeled CO_2 with this organism have shown that although approximately 80–90% of the assimilated CO_2 is primarily converted into carbohydrate by way of the pentose cycle additional reactions occur which lead directly to the formation of amino acids This indicates that keto acids too are produced by the direct incorporation of CO_2 probably by the reversal of one or more steps in the Krebs cycle Such processes are not restricted to the autotrophic mode of life and are encountered also in heterotrophic metabolism

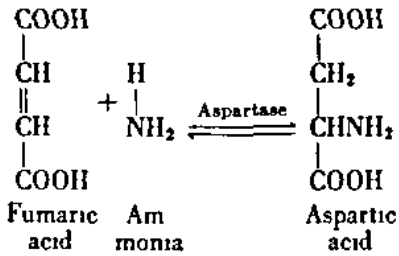
From the triosephosphate which appears to be the major primary product of genuine CO_2 assimilation other carbohydrates can readily be formed by reactions known to occur in the pentose cycle

condensations to di oligo and polysaccharides by reactions discussed earlier in this article

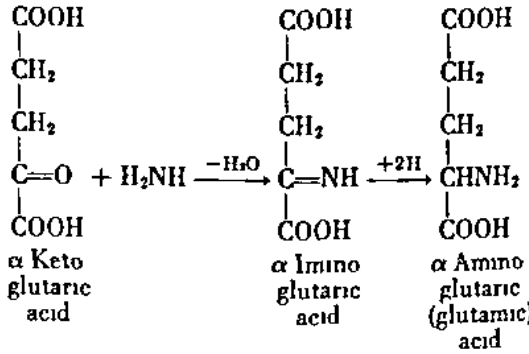
Heterotrophic nonphotosynthetic bacteria can synthesize carbohydrates from a large variety of substrates Only one general mechanism by which this occurs is known at present this involves the formation of PGA as an intermediate product and its reduction to triosephosphate Hence it resembles the photosynthetic carbohydrate synthesis although it generally does not include the aspect of CO_2 assimilation

Amino acids Many bacteria can synthesize all the amino acids found in their proteins from nitrogenfree organic substances and inorganic nitrogen compounds If the latter are provided in a form more oxidized than ammonia for example as nitrate or nitrite they are first reduced The fundamental reactions start from ammonia

The simplest known synthetic mechanism that leads to amino acid formation is the production of aspartic acid from fumaric acid and ammonia by addition of the latter to the double bond



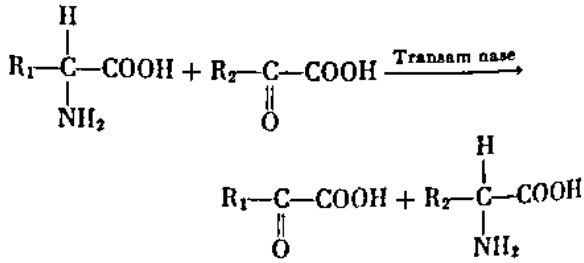
Another slightly more complex but probably more significant process leads to the production of glutamic acid from α ketoglutaric acid ammonia and a reducing agent The first step in this synthesis is the substitution of an imino group for the oxygen atom of the keto group the imino acid is next reduced with hydrogen donated by reduced pyridine nucleotide



Because both fumaric and α ketoglutaric acid are intermediate products in the Krebs cycle it will be clear that the synthesis of these amino acids causes a drain on this process

It is probable that glycine may be similarly formed from glyoxylic acid and ammonia as has been mentioned earlier glyoxylic acid originates by a direct fission of iso-citric acid

Other amino acids are synthesized by transamination reactions in which the amino group of an amino acid is transferred to the carbonyl group of a keto acid



The transfer is mediated by the coenzyme pyridoxal phosphate which is a derivative of vitamin B_6

Glutamic acid is generally the amino group donor in this type of reaction and the keto acid into which it is transformed can therefore be used over again for amino acid synthesis from ammonia as described above

In addition to these aminations and transaminations the synthesis of particular amino acids may require further modifications For example methionine is formed by an additional methylation sulfur containing amino acids such as cysteine are produced by the introduction of sulfhydryl groups the synthesis of citrulline and arginine is accomplished by condensation of ornithine with carbamyl phosphate *See* AMINO ACIDS TRANSAMINATION

Aromatic compounds Most bacteria can also synthesize aromatic compounds for example the amino acids phenyl alanine and tyrosine from aliphatic building blocks Studies with bacterial mutants have shown that a requirement for these amino acids can be satisfied by shikimic acid thus implicating this substance as a precursor in their synthesis Subsequent studies with bacteria have elucidated the manner in which shikimic acid is formed The first step is a condensation of phosphoenol pyruvic acid and erythrose 4-phosphate both intermediate products of sugar metabolism The condensation yields 2 keto-3-deoxy 7 phospho D glucoheptonic acid This is converted by ring closure to 5 dehydro-shikimic acid which is reduced to shikimic acid as shown in the equation on the following page

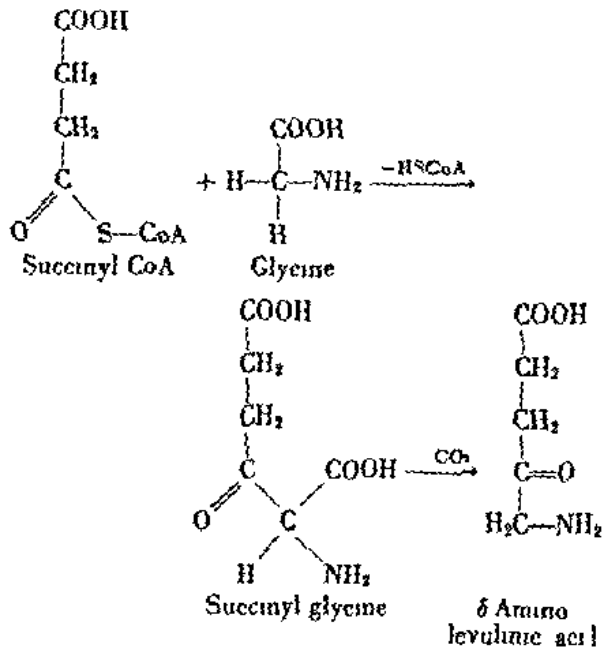
In principle the shikimic acid ring can be converted into an aromatic one by the elimination of two molecules of water and the formation of *p*-hydroxy and *p* amino benzoic acids from shikimic acid has been established

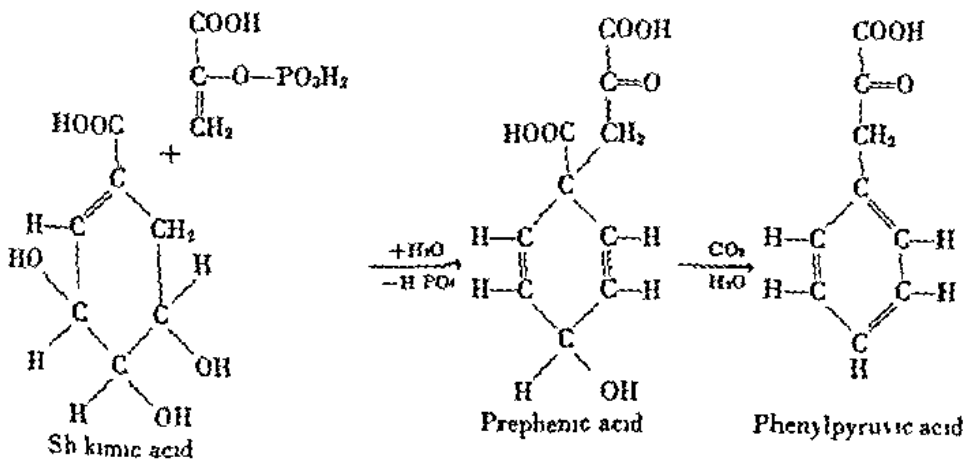
Phenylalanine is formed from shikimic acid by a primary condensation with pyruvic acid This yields prephenic acid which is decarboxylated to phenylpyruvic acid The latter can then be used for the synthesis of phenylalanine by the usual transamination reaction

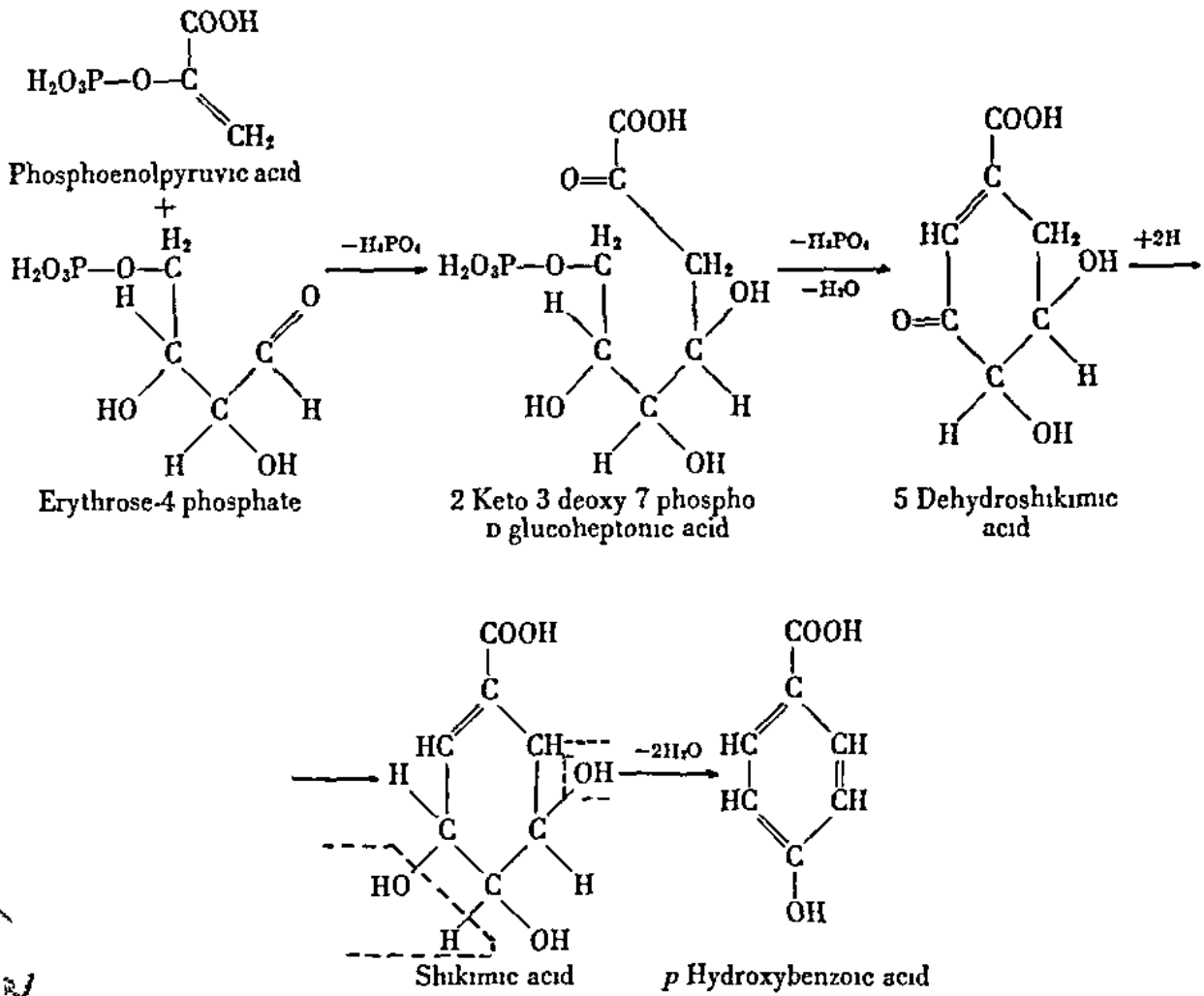
Tyrosine is also synthesized from shikimic via prephenic acid probably by direct oxidation of phenyl alanine

Pyrroles Nearly all bacteria contain cytochromes and many also contain catalase the photosynthetic species possess chlorophylls besides All of these substances are tetrapyrrole derivatives Because microbes, with rare exceptions do not require pyrroles or porphyrins for growth it follows that they must be able to synthesize these compounds from other ingredients

The first studies on the mechanism of pyrrole synthesis were conducted with red blood cells later various bacteria and other microorganisms were used as well The available evidence indicates that all organisms perform the synthesis in the same manner and that the first step is a condensation of succinyl CoA with (activated) glycine to succinyl glycine This condensation is fully analogous to the one by which acetoacetic acid and citric acid are produced The succinyl glycine is decarboxylated to δ amino levulinic acid



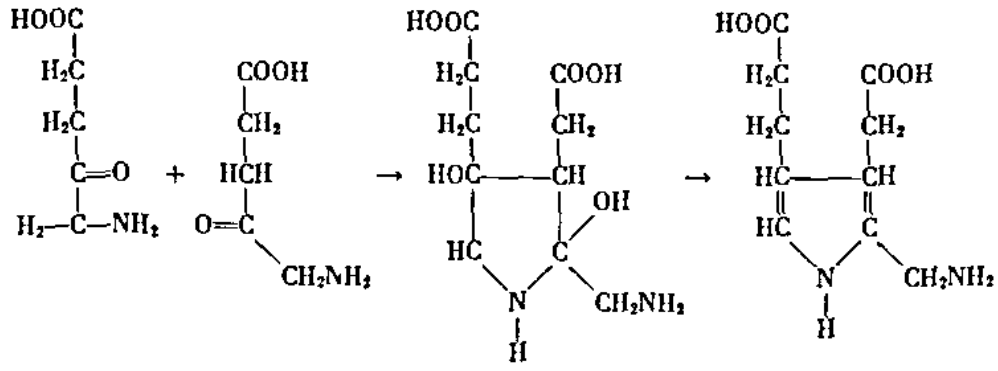




Formation of shikimic acid from phosphoenolpyruvic acid

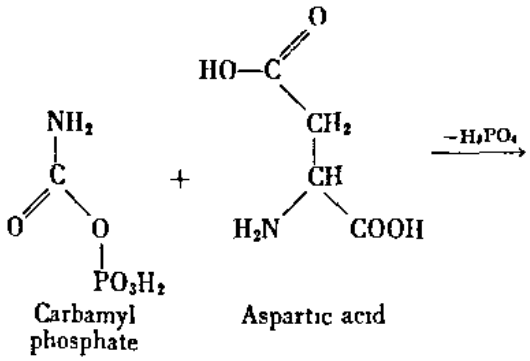
The product of this reaction is the immediate building block for the formation of the pyrrole ring which involves the condensation of two molecules of δ amino levulinic acid so that the carbonyl group of one reacts with the amino group of the other while the latter's carbonyl group reacts with *the β methylene group of the former*

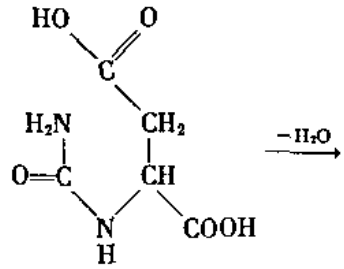
The resulting pyrrole porphobilinogen is characterized by the propionic and acetic acid substituent groups on the carbon atoms not bridged by the nitrogen atom The significance of this is that these same groups are found in identical positions on each of the four pyrrole rings of those porphyrins which on the basis of genetic studies are

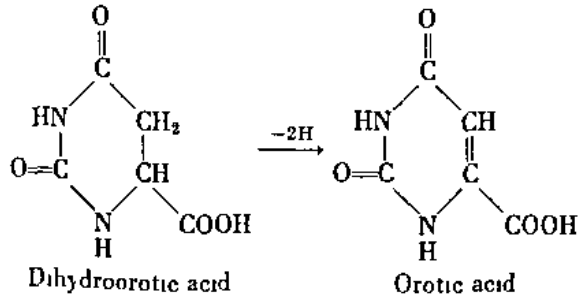


considered to be the precursors from which all other porphyrins as well as chlorophylls are derived The consensus is, therefore that the porphyrin synthesis itself takes place by a linkage of four porphobilinogen units At present the details of the mechanism by which this is accomplished are however still under debate and investigation *See* CHLOROPHYLL, HEMOGLOBIN, PORPHYRIN

Pyrimidines The biosynthesis of these essential constituents of nucleic acids involves the consecutive formation of two peptide bonds The first results from the coupling of aspartic acid and carbamyl phosphate which can be formed either by synthesis from carbon dioxide ammonia and ATP, or during the degradation of the amino acid citrulline The carbamyl moiety is transferred to the amino group of aspartic acid yielding carbamyl aspartic acid Its amino group is next joined to the δ-carboxyl group of the aspartic acid moiety with the production of dihydroorotic acid and the latter dehydrogenated to orotic acid with DPN



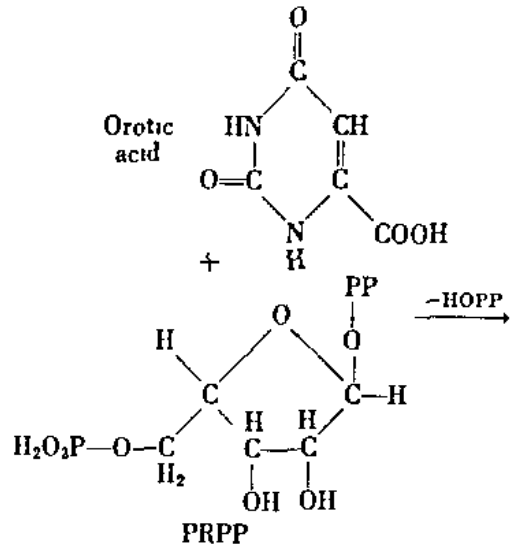


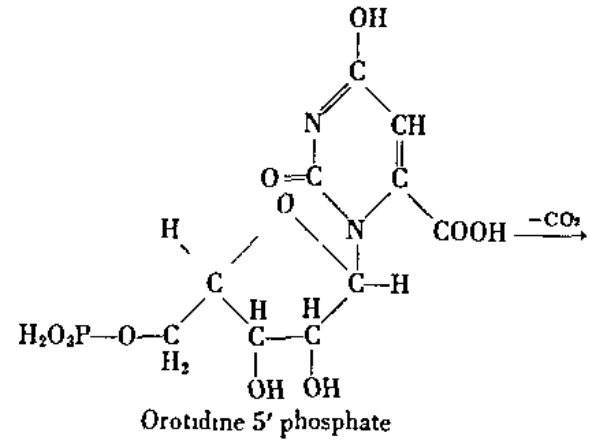


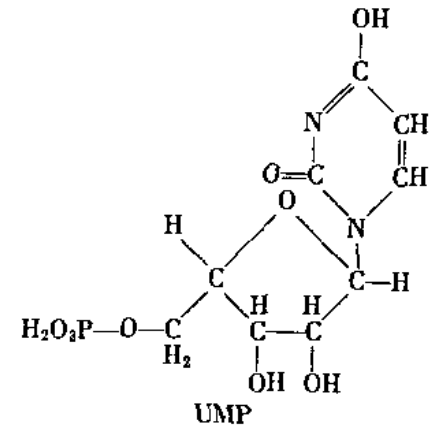
Orotic acid is the starting point for the synthesis of a riboside by condensation with 5 phosphoribosyl pyrophosphate (PRPP) itself the product of pyrophosphate transfer from ATP

Ribose 5 phosphate + ATP → PRPP + AMP

The ribose 5 phosphate moiety of the active PRPP can then be transferred to orotic acid, and the resulting orotidine 5′ phosphate decarboxylated to uridine monophosphate (UMP)







The equilibrium of the first of these step reactions is highly in favor of orotic acid and PRPP, this

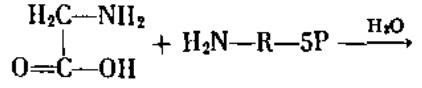
carboxylation reaction

UMP can be readily converted to cytidine-5′ phosphate by transamination and to th· phosphate by methylation

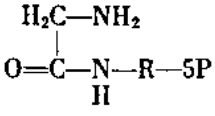
The ribose nucleotides are components of the ribonucleic acids (RNA) they can be reduced to deoxyribose nucleotides which are constituents of deoxyribonucleic acids (DNA)

Purines The biosynthesis of these nucleic acid building blocks starts with the construction of a five membered ring essentially from glycine ammonia and a one carbon fragment The first step is the amination of 5 phospho ribosyl pyrophosphate (PRPP) for which glutamine rather than glutamic acid acts as the amino group donor The resulting 5 phosphoribosylamine then undergoes a condensation with glycine by which glycinamide ribotide is formed In the following equations R represents ribose P phosphate

5 PRPP + Glutamine →
5—P—R—NH_2 + PP + Glutamic acid

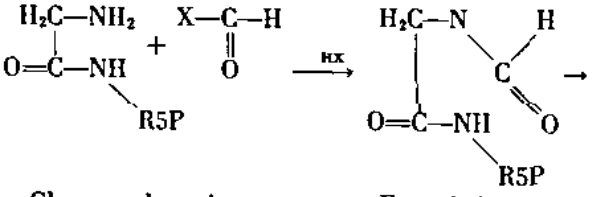


Glycine 5 Ribosylamine

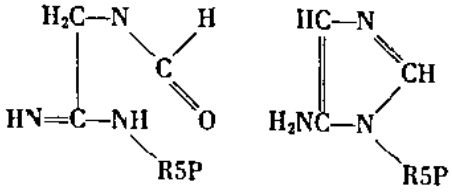


Glycinamide ribotide

The extra carbon atom is introduced as a formyl group transferred from a folic acid derivative it attaches to the original amino group of the glycine moiety The latter s carbonyl group is next converted into an imino group again by transfer from glutamine whereupon ring closure yields the substituted 5 membered ring in the form of 5 amino imidazole ribosylphosphate



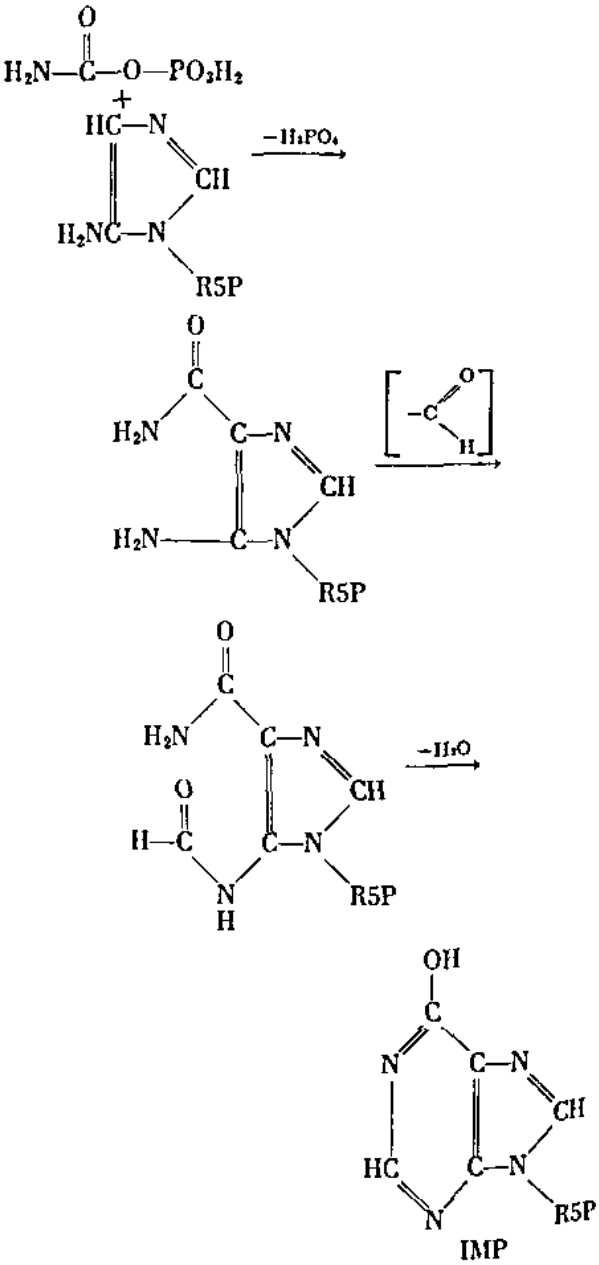
Glycinamide ribotide Active formyl Formyl glycinamide ribosyl phosphate



5 Amino imidazole ribosylphosphate

[illegible] that showed blocks in their purine synthesis machinery

The construction of the second ring involves first the addition of a carbamyl and next of a formyl group to the methene and amino groups of the two carbon chain respectively Ring closure then causes the formation of the purine ribotide inosinic acid or inosinemonophosphate (IMP)



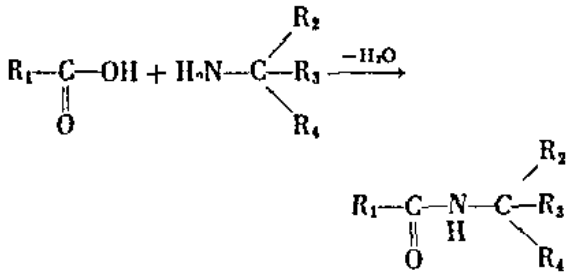
IMP

IMP can be further modified to adenylic acid as well as to xanthosine-5 phosphate and thence to guanylic acid

Biosynthesis of complex substances The section on specific biosyntheses in bacteria has dealt largely with the mechanisms involved in the manufacture of the relatively small units that are either cell constituents themselves or building blocks for larger entities The mode of formation of some of the latter such as the lipids and polysaccharides has also been briefly discussed This leaves the problem as to how the members of the two largest classes of compounds the proteins

and nucleic acids are synthesized It is only since 1953–1955 *that significant advances have been* made in this area these will be summarized in the next paragraphs

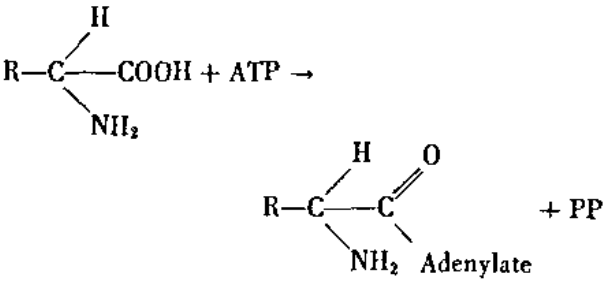
Proteins In the proteins the amino acids are joined together by peptide bonds resulting from the interaction of the amino group of one with the carboxyl group of another amino acid In a general manner this can be represented by the equation



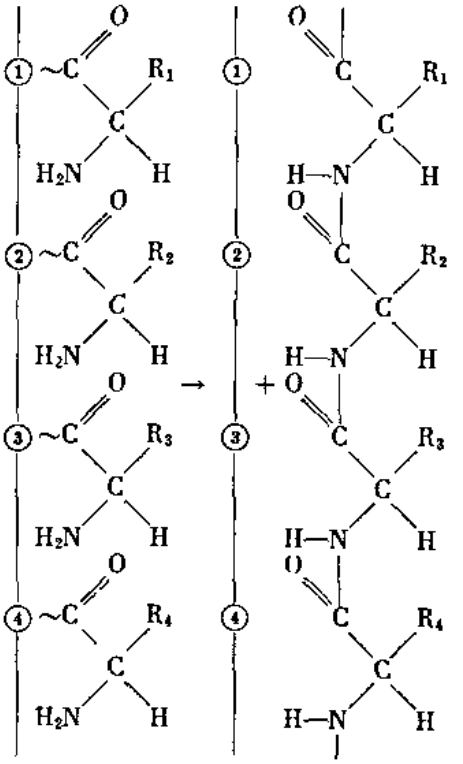
The nature of the component amino acids and the order in which they are linked determine the properties of the protein Because of the extraordinary specificity of these complex substances as revealed particularly by the behavior of enzymes and the obvious ability of an organism to duplicate exactly the many different proteins it contains it has for some time been evident that their biosynthesis must be regulated in a correspondingly delicate and specific manner This led to the idea that they would be assembled on templates each one of which possessed a fine structure which fitted in detail that of a particular protein or of an essential part of one Gradually it was recognized that nucleoproteins might fulfill the function of such templates and in 1953 E F Gale and J P Folkes in studies with fragmented bacterial cells clearly demonstrated that nucleoproteins specifically of the RNA type play a fundamental role in protein synthesis

Two essentially different mechanisms can be postulated by which the long amino acid chains may originate The first envisages the consecutive addition of a single amino acid or of a small peptide unit to a previously formed peptide so that the protein molecule will be built up gradually This notion is however inconsistent with the fact that a bacterium which lacks the ability to synthesize a particular amino acid does not in the absence of this substance synthesize protein or even smaller complex peptides even if all the other amino acids are provided It is thus more probable that the second mechanism operates which postulates that the synthesis of a protein occurs in such a way that all the component amino acids after first having been lined up in proper sequence are strung together in a single final operation

In this connection the involvement of nucleic acids is of particular interest Constituent units of these substances such as the adenosine and guanosine phosphates are known to participate in the activation of many substances When it was shown that amino acid incorporation into protein required amino acid activation and that this was accomplished by the initial formation of amino acid adenylates *from ATP according to the equation*



it was therefore reasonable to propose that the nucleic acids would provide the means for assembling the amino acids in the requisite order and in active form Thus they could act as both templates and catalysts Their specific configuration would confer upon them the template characteristics and their constituent nucleotides the catalytic properties The amino acids would come into close proximity with the amino group of one adjacent to the activated carboxyl group of the next As a result of the subsequent peptide bond formations the attachment of the amino acids to the nucleic acid chain would be severed the protein would become detached and the nucleic acid would be free to begin anew its function of assembly line if all the spaces available were filled up with the corresponding protein building blocks This concept can be represented by the following diagram in which the enzymatically active sites on the nucleic acid chain are indicated by circles The different numbers in the latter are intended to show that they are specific for the corresponding amino acids differentiated by like numbers of the substituent chains R and the high energy bonds by which the amino acids are attached are represented by ~



Nucleic acids The constituent units of these substances are as has been discussed in the section on the biosynthesis of pyrimidines and purines formed in such a way that the ribose group phosphorylated in the 5 position is already an integral part of these building blocks the synthesis directly yields 5 nucleotides rather than the simple bases that is the free pyrimidines and purines

In 1955 M Gruenberg Manago and S Ochoa discovered that bacteria produce enzymes which reversibly synthesize polyribonucleotides from 5 nucleoside diphosphates according to the equation

$$n\text{X Rib PP} \rightleftharpoons (\text{X Rib P})_n + n\text{P}$$

This reaction catalyzed by polynucleotide phosphorylase can be depicted by the diagram at the bottom of the page showing synthesis of polyribonucleotides from 5 nucleoside diphosphates Thus the phosphate in the 5 position of the ribose moiety is first activated by the addition of a second phosphate group to form the high energy pyrophosphate linkage the activated phosphate can then form an ester bond with the hydroxyl group in the 3 position of the ribose of the next nucleotide

The deoxyribonucleic acids are formed in an analogous manner as was shown in 1957 by A Kornberg and associates However in this case the active form from which the synthesis starts is not the di but the triphosphate derivative of the nucleotides and the linkage of the units proceeds with the elimination of pyrophosphate according to the equation

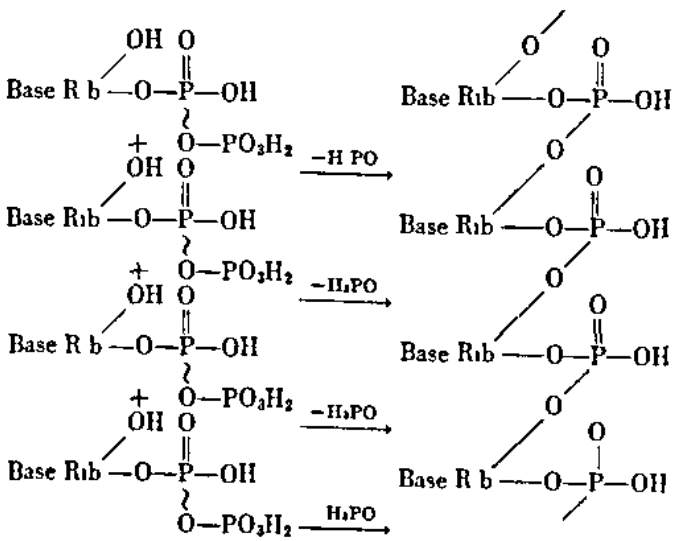
$$n\text{X deoxyribose PPP} \rightarrow (\text{X deoxyribose P})_n + n\text{PP}$$

in which X represents pyrimidine and purine bases

A more striking difference is that the de novo synthesis of DNA requires that all pyrimidine and purine triphosphates be present

ent for the synthesis to proceed It acts as a primer and the synthesized product appears to be indistinguishable from the primer This attests to a synthetic mechanism that is as specific as that involved in protein synthesis which is consistent with the fact that the deoxyribonucleoproteins are now considered to represent the genetic determinants of a cell so that their exact duplication is required to ensure genetic continuity Such an accurate duplication can at present be readily understood on the basis of the DNA model proposed by J D Watson and F H C Crick in 1953 This pictures the structure of DNA as composed of two polynucleotide chains coiled around each other and running in opposite directions They are linked by hydrogen bonds which join the pyrimidines of one to the purines of the opposite strand Such a double helix can admirably serve as a template strand I reproducing its opposite strand II and vice versa *See* NUCLEIC ACID

Cell organization and permeases The specificity of the proteins and nucleic acids has been attributed to their particular structural organization which represents a differentiation on a molecular level In a bacterial cell however there also exists an organizational pattern on a much larger scale (*see* BACTERIA) Many of the microscopically discrete structures are now recognized as units endowed with a multiplicity of enzymatic activity As has been remarked earlier in this article such structures can therefore serve to bring about a close proximity of the product of one enzymatic reaction with another enzyme for which it is a substrate They can therefore be viewed as assembly belts of greater size and complexity than the nucleic acids themselves Such structures are often associated with the cell membrane and thus appear to be eminently suited for mediating a contact between the cell interior and the external environment They may therefore play a role in facilitating the entrance of substrates into the cell



It has now been shown with many different kinds of bacteria that they can very rapidly absorb substances from the medium so that within 1 min the internal concentration vastly exceeds the external one Accumulations of this sort have been observed only in cases where the cells carry on an active metabolism The mechanism whereby this is achieved has therefore been termed active transport

Because bacteria grown in the absence of a particular substance often do not absorb the latter except after having been exposed to it for a fairly prolonged period of time and because they do not develop an active transport mechanism for that substance under conditions where protein synthesis has been excluded the phenomenon of active transport has been attributed to the activity of a special group of enzymes designated as permeases or transportases Some of these are considered to be inducible

It seems entirely possible that comparable mechanisms may operate not only between the outside and inside of a bacterium but also between different parts of the interior and thus aid in the construction of the final product the cell with its enormous diversity of specific properties a truly and amazingly organized unit [C B V N]

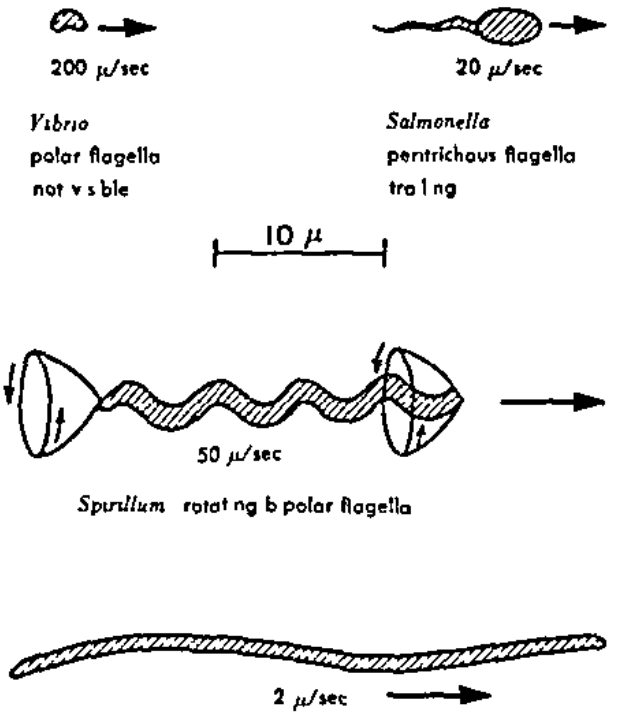
Bibliography H A Barker *Bacterial Fermentations* 1957, E F Gale *Synthesis and Organisation in the Bacterial Cell* 1959 H A Krebs and H L Kornberg Energy transformation in living matter *Ergeb Physiol.*, 49 212 298 1957 E L Oginsky and W W Umbreit *An Introduction to Bacterial Physiology* 2d ed 1959

Bacterial motility

Self propulsion in bacteria Two types of motility have been observed a swimming motion and a creeping or gliding motion The swimming motion is observed in bacteria with flagella These are hair like appendages less than 0 1 μ thick and several microns long which are inserted singly or in tufts at one or more points on the bacterium The gliding motion is found among the myxobacteria (Myxobacterales) and some filamentous forms such as *Beggiatoa* all of which lack flagella (*see* BEGGIATOALES MYXOBACTERIALES) The gliding motion at about 2 μ/sec is slower than the swimming motion of 200 μ/sec of *Vibrio comma* a flagellated form

Bacterial flagellum The flagellum is composed chiefly of contractile fibrous protein It originates in the cytoplasm of the cell and extends through the cell wall The external contours of the flagellum as seen with the electron microscope vaguely suggest the shape of two fibrils intertwined to form a double helix and covered by a membrane

Individual flagella cannot be seen with the light microscope unless their diameter is increased by deposition of a mordant. *See* STAIN (MICROBIOLOGICAL) The mordant combines with the stain to form an insoluble compound which is fixed to the bacteria With living active bacteria bundles of flagella can thus be seen if dark field illumination and a brilliant source of light are employed The use of a viscous medium which slows the movement of these bundles facilitates their observation

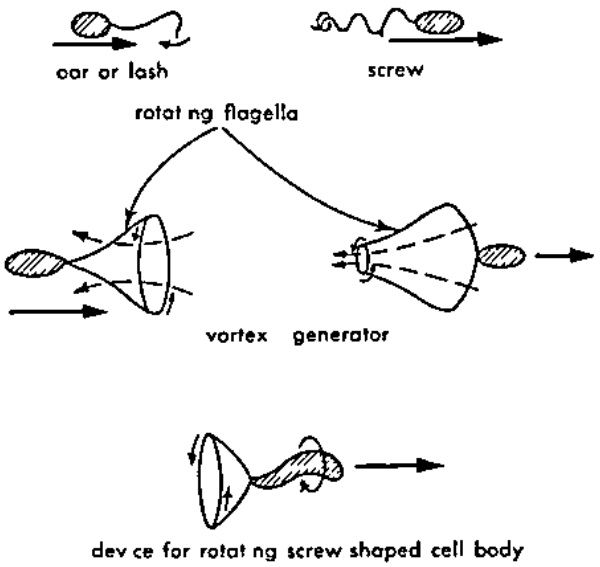


Four types of motile bacteria Speeds of swimming are approximate

Bacteria exhibit various numbers of flagella and modes of insertion In *Bacillus* and *Salmonella* among others the entire cell surface bears numerous flagella (peritrichous flagellation) Ellipsoidal bacteria commonly bear flagella at one or both poles (monopolar and bipolar flagellation) these occur singly (monotrichous) or in tufts (cephalotrichous) Flagellation of the corkscrew shaped spirilla is characteristically bipolar

Types of motility In bacteria these encompass the vigorous straight runs and reversals of the spirilla the rapid darting and tumbling of small polarly flagellated cells such as *Vibrio* the more stately sailing of the peritrichously flagellated bacteria and the slow gliding of the myxobacteria and the filamentous types

Mechanisms for motility While in most cases the action of the flagella cannot be discerned clearly their role as organs of locomotion has only been proven for the spirilla The flagella of *Spirillum serpens* rotate typically at a rate of 2400 rpm while the body rotates at 800 rpm In peritrichously flagellated bacteria on the other hand the flagella entwine into an apparently inert bundle which trails behind the cell Here motility could be effected by individual flagella not entwined in the visible bundle Alternatively the localized secretion of a surface active agent could propel the cell as a bit of soap drives a toy boat The cell could also swim by undulating its body as an eel swims This idea



Poss ble mechan sms for the act on of flagella

advanced by A Pijper as the basis for nearly all bacterial motility has been opposed because it implies that flagella are not functional and because the bacterial cell wall appears to be too rigid to allow such movements The preponderant opinion is that flagella where they occur are locomotor organs

Flagella could drive a bacterium by acting as an oar or lash as a screw as a vortex generator or by causing the cell body to rotate like a screw All of these mechanisms probably occur in nature The rapid rotation or lashing of a bundle of flagella could result from the coordinated sequential contraction of its component fibrils In the spirilla there is evidence that the flagellar activities at each end of the cell are coordinated by a central agency The mechanism of gliding motility is unknown

Tactic responses In bacteria there are sudden movements or responses induced by changes in the environment In spirilla the response is a reversal in swimming direction other forms jump back

ing its direction of swimming This phototaxis enables the cells to congregate in regions of greater illumination (*see* RHODOBACTERIINEAE) Most motile aerobes exhibit aerotaxis a response to a change in oxygen concentration Tactic responses are also elicited by changes in temperature (thermotaxis) by chemicals (chemotaxis) and by mechanical contact (thigmotaxis) Where tactic responses cause cells to congregate it can be inferred that motility is present In this way feeble motility can be distinguished from the random agitation caused by Brownian movement *See* TAXIS

The usual result of taxis is to move the organism to an environment which affords a more rapid energy yielding metabolism Motility is also related to energy yielding metabolism photosynthetic bacteria cease swimming in darkness and aerobes come to rest in the absence of air Thus the action of chemicals in eliciting tactic responses or in affecting motility can provide insight into bacterial metabolism *See* BACTERIAL CELL CHEMISTRY BACTERIAL PHYSIOLOGY [R K C]

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Bacterial nutrition

Like all other forms of life bacteria require food or nutrients for maintenance growth and multiplication Bacteria utilize a great and unique diversity of nutrients ranging from such simple substances as inorganic salts and carbon dioxide to complex mixtures of blood and extracts of heart liver brain and other tissues Probably every naturally occurring organic compound is usable by some bacterium Water which is essential for the growth of all bacteria is also part of the food supply The nutrients furnish the carbon nitrogen minerals and growth factors necessary for the synthesis of the carbohydrates lipids proteins nucleic acids and other basic constituents of the cell protoplasm They supply also the energy for these transformations and for locomotion intake of food and other life processes

Energy Most bacteria obtain their energy from the oxidation or fermentation of a large variety of organic compounds—sugars acids alcohols and others These organisms are known as heterotrophic bacteria A more limited group called chemoautotrophic bacteria is unique among plants and animals in that its members derive utilizable energy from the oxidation of inorganic substances Thus *Nitrosomonas* obtains energy from the oxidation of ammonia to nitrite *Nitrobacter* from the oxidation of nitrite to nitrate *Thiobacillus thiooxidans* from the oxidation of elemental sulfur or thiosulfate to sulfate and *Thiobacillus ferrooxidans* from the oxidation of iron from the ferrous to the ferric state There are also photosynthetic bacteria for example the purple and green sulfur bacteria which contain a pigment related to chlorophyll and are able therefore to utilize the energy of light for their metabolic activities somewhat as higher green plants do Some chemoautotrophic and photosynthetic bacteria are versatile in that they can obtain energy from the oxidation of organic compounds as well as from inorganic compounds and light

Carbon Although all heterotrophic bacteria require small amounts of carbon dioxide for growth they cannot use it as the sole source of carbon They obtain carbon for the formation of protoplasm from the same large variety of organic compounds that serve them as sources of energy These organic materials therefore have a dual function In contrast to the heterotrophic both chemoautotrophic and photosynthetic bacteria utilize carbon dioxide as the sole carbon supply In fact strict chemoautotrophs cannot use organic matter for either carbon or energy Some species however are

facultative and grow with both carbon dioxide and organic carbon

Nitrogen This element is needed by bacteria for the synthesis of proteins nucleic acids and other essential nitrogenous constituents of the cell Combined inorganic nitrogen in the form of ammonium and nitrate salts is suitable for the growth of most bacteria Also organic nitrogen containing substances such as peptides amino acids amines and amides can be utilized by many bacteria The suitability of these different nitrogen compounds varies with the individual bacterial strain Elemental or molecular nitrogen N_2 can be utilized by a limited number of genera including *Azotobacter Clostridium* and *Rhodospirillum* and also *Rhizobium* in symbiosis with plants These nitrogen fixing bacteria are of importance in the transfer of N_2 from the atmosphere to the soil where eventually it becomes available for the growth of plants *See* NITROGEN CYCLE

Minerals These are required by bacteria because they are structural units of essential compounds involved for example in the transfer of energy in the cell and in various enzymatic reactions Usually small amounts are adequate for optimum growth All bacteria require phosphorus and sulfur and these are usually supplied in the medium as phosphates and sulfates Many bacteria need potassium magnesium manganese and iron and some need calcium zinc copper and molybdenum Other inorganic elements are probably also required but conclusive evidence for this is lacking

Oxygen Molecular oxygen O is necessary for the growth of bacteria known as aerobes They use it to oxidize the nutrients in order to liberate energy and also to make compounds for synthesis of protoplasm In contrast other bacteria known as anaerobes cannot grow unless all traces of oxygen are removed from their environment A number of bacteria are facultative that is will develop either in the presence or absence of molecular oxygen Other bacteria are microaerophilic and will grow in the presence of minute quantities of oxygen

Growth factors Among the basic components of bacterial cells and indeed all living systems are the amino acids vitamins purines pyrimidines and certain other organic molecules Some bacteria are able to manufacture all of these essential substances from such simple nutrients as sugar and mineral salts However other bacteria for example the lactic acid bacteria and staphylococci are unable to synthesize several of these essential organic materials because of defects in their metabolism For the growth of these bacteria the amino acids vitamins or other compounds that cannot by synthesized must be supplied as nutrients in the culture medium Such required organic compounds are known as growth factors They include the vitamins thiamin niacin pyridoxin riboflavin biotin and others The vitamins are components of enzyme systems and are needed in minute amounts usually 1 part per 10 000 000 parts of medium or less

Also amino acids such as tryptophan serine leucine valine and histidine are essential growth factors for some bacteria These bacteria may require a single amino acid or as many as 17 different amino acids Another important group of growth factors is made up of the purines and pyrimidines (adenine guanine uracil thymine) These are needed for the synthesis of nucleic acids Also other compounds such as asparagine glutamine fatty acids spermidine and mevalonic acid are required by some bacteria Future research will undoubtedly disclose the need for additional growth factors since theoretically any essential organic compound of a bacterial cell may be required preformed in the medium by some organism that is unable to synthesize it *See* BACTERIAL METABOLISM BACTERIAL PHYSIOLOGY NUCLEIC ACID [J L S]

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Bacterial physiology

Any information which contributes to an understanding of the behavior of the living bacterial cell Matters relating to growth reproduction metabolism and death of the organism denote the grosser aspects and connote function of the organism The regulation of such behavior and the influence of cellular and biological factors and of extracellular physical and chemical factors on them are the principal concern of the bacterial physiologist Ultimately all biological behavior is resolvable to prime chemical and physical laws These fundamentals become physiological when they are adapted to account for function in the living cells Thus the laws of thermodynamics the mechanism of an enzymatic reaction or the kinetics of diffusion are foundations of bacterial physiology but not as independent isolated phenomena A dividing line between biochemistry and physiology frequently is undiscernible but when the emphasis is on chemical activity of structure in relation to the cell the division is clear

In the 1950s there was a strong trend to the study of bacterial physiology through the various structural parts of the bacterial cell Modern techniques permit the physical separation purification and concentration of almost any anatomical part of the bacterial cell Study as isolated entities of the chemical constitution the physical characteristics and arrangements of these parts has been one of the major approaches of the physiologist in elucidating the role of these parts in the functioning of the intact cell Consequently bacterial cytology and anatomy as well as electron microscopy which frequently reveals macromolecular order in subcellular structures are very much a part of modern bacterial physiology

Other major areas of modern bacterial physiology include cellular respiration genetics biosynthesis

nutrition ecology photosynthesis chemical inhibition bacteriophage infection toxin formation and other mechanisms of virulence enzyme synthesis and transformation of complex and pure individual chemical substances by bacterial action Each aspect has its own routine its specialized and sophisticated techniques of study and experimentation Perhaps the one experimental rationale that applies to most physiological studies involves the exposure of replicate cultures or suspensions or populations of bacterial cells to an environment that is constant in all aspects except the one variable that is under study A variable may be one that is qualitative or quantitative between the different replicates The response that the enclosed variable elicits from the organism is determined On a professional level physiology almost always necessitates an accurate measurement of the response and quantitation is consequently an indispensable arm of bacterial physiology Growth oxygen consumption and chemical or biological analysis for the amount of a substance biosynthesized degraded or transformed are the most common types of analyses conducted in bacterial physiology *See* BACTERIA BACTERIA LYSOGENIC BACTERIA TAXONOMY OF BACTERIAL CELL CHEMISTRY BACTERIAL COENZYME BACTERIAL ENDOSPORES BACTERIAL ENZYME BACTERIAL GENETICS BACTERIAL GROWTH BACTERIAL LUMINESCENCE BACTERIAL METABOLISM BACTERIAL MOTILITY BACTERIAL NUTRITION

[J W F]

Bacteriology

The science and study of bacteria and hence a specialized branch of microbiology (*see* MICROBIOLOGY) It deals with the nature and properties of the bacteria as living entities their morphology and developmental history ecology physiology and biochemistry genetics and classification *See* BACTERIA

Bacteria were discovered by Antony van Leeuwenhoek in 1676 when he examined under his microscope an infusion of ground pepper in water sealed in a glass tube and left standing for a few days This experiment has been repeated by many persons over a period of many decades The results have shown that invariably only bacteria develop in the pepper infusions prepared in this manner This the conclusion is unavoidable that the little animals which Leeuwenhoek described were indeed bacteria

The term *Bacterium* was introduced by C G Ehrenberg in 1828 as a generic name for some representatives it is derived from the Greek word meaning a small rodlet

The major subjects that have consecutively occupied the forefront of bacteriological research have been the origin of bacteria the constancy or variability of their properties their role as causative agents of disease and of spoilage of foods their significance in the cycle of matter their classification and their physiological biochemical and genetic features

Origin The very smallness of bacteria combined with their regular occurrence in infusions of plant and animal materials suggested that they might arise spontaneously from dead organic matter abiogenesis This view was defended for example by J T Needham G L de Buffon F A Pouchet and Charlton Bastian Others like Antony van Leeuwenhoek Lazaro Spallanzani Louis Pasteur and John Tyndall disputed it and claimed that bacterial growth occurred only by the multiplication of living germs that had either escaped being killed during the preparation of the infusions or gained entrance to them afterwards (biogenesis) Particularly the studies of Pasteur and Tyndall have been responsible for the currently held belief that bacteria are not generated spontaneously This does not mean that life cannot have originated in this manner there is now a strong tendency to accept this as a distinct possibility *See* LIFE ORIGIN OF

Constancy and variability Early studies with bacterial cultures indicated that the shape and size of the organisms as well as their activities were extremely variable However it was soon recognized that the observations supporting this idea could also be attributed to the simultaneous presence in one and the same culture of many different kinds of bacteria each one exhibiting a high degree of constancy Changes in the relative proportions of these various types as a result of exposure to different environmental conditions could then equally well account for the observed facts This led to the introduction of methods for the study of pure cultures that is cultures derived from only one single type (*see* CULTURE PURE) Studies of this sort have tended to discredit the notion of a pronounced morphological variability known as pleomorphism and have supported monomorphism the concept of morphological constancy At present the evidence is decisively in favor of the latter view though not in its extreme form some morphological variability in response to environmental conditions and age of a culture has been convincingly demonstrated In addition bacterial cultures are subject to spontaneous changes due to mutations *See* MUTATION

Agents of disease and spoilage One of the early and epoch making bacteriological discoveries was that bacteria can cause diseases of higher plants and animals This eminently practical aspect with its attendant implications for the cure and prevention of diseases has meant that for many years bacteriologists have concentrated their studies on pathogenic bacteria and bacteriology has become largely an adjunct to medicine *See* BACTERIOLOGY MEDICAL

Bacteria can also cause spoilage of foods The desire to restrict or prevent this has led to the development of a branch of food bacteriology which deals with the detection in foods of spoilage organisms and with their elimination *See* FOOD MICROBIOLOGY MILK

The cycle of matter Some early students of the bacteria such as Pasteur Ferdinand Cohn Sergei

Winogradsky and M W Beijerinck recognized their role as agents causing mineralization the decomposition of complex materials produced by higher plants and animals to simple inorganic substances This activity permits the continuous recirculation of matter generally known as the cycle of matter for the use by consecutive generations The great importance of the bacteria in perpetuating this cycle follows from computations showing that the activities of these organisms account for more than 90% of the transformations of organic to inorganic materials Many different types of bacteria are involved in these transformations Much has been learned about the specific activities of particular kinds by ecological studies notably with the aid of the elective culture techniques (*see* CULTURE ELECTIVE) Since the major part of these activities takes place in soil and in bodies of water for further details *see* SOIL MICROBIOLOGY WATER MICROBIOLOGY

Some bacteria produce substances that are useful to man Examples are alcohols various acids solvents and numerous biochemically important compounds Lately it is especially the antibiotic substances that have come into prominence Such organisms are therefore of industrial importance and are used on a large scale for the manufacture of the particular substances *See* ANTIBIOTIC INDUSTRIAL MICROBIOLOGY

Classification Only after the controversy about pleo versus monomorphism had been satisfactorily resolved in favor of the latter did it become possible to differentiate the various types of bacteria on the basis of their shape and size and to develop a system of classification for these organisms At first it was felt that differences in physiological properties should not be admitted for this purpose but as knowledge increased it was found that many kinds of bacteria that are morphologically indistinguishable nevertheless display widely divergent physiological characteristics and that these are just as constant as the morphological ones This has gradually led to the inclusion of physiological properties for the establishment of more adequately circumscribed systematic units and to a classification that has become increasingly more complex The multiplication of differential characters has also raised problems concerning their relative significance for taxonomic purposes and specialists in different fields have thus far failed to reach general agreement on questions of this sort Finally the frequent and uncontrollable occurrence of mutations in bacterial cultures has emphasized the inadequacy of certain criteria for the establishment of systematic units On the other hand there has developed a healthy interest in matters of bacterial classification and the field is presently under active study in various laboratories *See* BACTERIA TAXONOMY OF SCHIZOMYCETES

Physiology and biochemistry Bacteria have come gradually into prominence as extremely useful tools for the study of various biochemical and physiological problems This can be attributed to the enormous diversity and versatility of these organisms no other group of living beings displays so wide a variety of physiological and biochemical properties as do the bacteria In addition these organisms can be studied under rigorously controlled conditions far more easily than the higher plants and animals and many of them possess a striking ability to carry out highly specialized reactions almost to the exclusion of all others This greatly simplifies the profound study of such reactions

The strongest impetus to the use of bacteria as biochemical tools has come from the studies of A J Kluyver and his school These studies have revealed an astounding unity in the biochemical behavior of all living organisms and they resulted in the enunciation during the period 1926–1930 of the fundamental principles of biochemical processes Subsequently the studies of numerous details of biochemical reactions with the aid of bacteria have helped to elucidate the detailed mechanisms of the breakdown and synthesis of most of the important groups of substances to analyze the mode of action of vitamins and to discover new growth factors and their roles in nutrition At present the field of bacterial biochemistry is one of the most active in the area of general biochemistry *See* BACTERIAL PHYSIOLOGY BIOCHEMISTRY

Genetics The ease with which bacteria can be grown under fully controlled conditions their versatility the possibility of handling enormous numbers of individuals in a relatively small space and the general applicability of the results to other forms of life have caused a rapid development of the science of bacterial genetics which deals with the nature and transmission of hereditary characters

One of the first accomplishments in this area was the discovery of mutants that express themselves through changed biochemical properties This has provided the basis for the current concepts relating gene action to specific biochemical catalysts or enzymes Other advances of far reaching importance have been made possible by J Lederberg and E L Tatum's discovery that particular bacterial strains can be made to transmit hereditary characters to other strains by a process that is somewhat analogous to the hybridization of plants and animals

An additional advantage of the use of bacteria for genetic investigations is their very short generation time often of the order of magnitude of 30 min This implies that numerous generations can be obtained and examined in a single day From these beginnings scarcely two decades ago bacterial genetics has developed into a field of intensive and very fruitful research *See* BACTERIAL GENETICS [C B V N]

Bacteriology, medical

The study of a small number of the known genera of bacteria including the pathogenic bacteria those species which are similar to or found with pathogenic species and those that are part of the normal

bacterial flora of the body without causing infection The medical bacteriologist considers the entire infective process concentrating however on the properties of bacteria as related to infection Identification of pathogenic bacteria is also the concern of medical bacteriology because such identification is a large factor in the diagnosis of infectious disease The study of *the relation between bacteria* and infectious disease led to current concepts of infection in general because bacteria were shown to cause infection more readily than other microorganisms For example the protozoa were once confusingly mixed with other microorganisms the viruses were once invisible, and the yeasts and molds are still not easy to relate to the infectious process

Pasteur's and Koch's contributions Louis Pasteur s studies of fermentation of wines and beer led to a study of *bacteria When the thought* arose that a process akin to fermentation within the living human animal or plant might be responsible for certain diseases now known as infections searches revealed microscopically visible bacteria For example bacteria are not normally found in the blood but the infectious agent of anthrax (*Bacillus anthracis*) is found in large numbers in the blood of a sheep that has anthrax Not only was the cause and effect relationship for infectious disease established but also since bacteria obviously could *grow in kegs and bottles the cultivation of bacteria* was introduced early in the history of bacteriology Medical bacteriology is a contributor to bacteriology in its own right because of its study of infections due to bacteria such as diphtheria typhoid fever scarlet fever and boils It also contributed rules governing bacteria which could be applied to infections with other microorganisms less easily studied Pasteur led the way to the concept of infective bacteria and Robert Koch was perhaps the leading discoverer of bacteria responsible for infections many of the discoveries occurring in the decade from 1880–1890 It was at the turn of this decade that bacter al tox ns

fluid

nus

present but which could still cause disease Thus the cultivation and study of bacteria apart from in *fection* usually in pure culture with no other microorganisms present led to studies of the characteristics of bacteria which make them infective or pathogenic

Study of specific properties Normally medical *bacteriologists consider the entire infective* process since the life of a pathogenic microorganism is lived within or on the human body Veterinarians do likewise for diseases of animals and plant pa*thologists for diseases of plants* The emphasis however is on the properties of the microorganisms the pathologic effects produced are viewed primarily in their relationships to the bacteria con*cerned* \ few species of bacteria for example may produce exotoxins like those of diphtheria or tetanus responsible for some or all of the symptoms of the disease It was an early discovery that these exotoxins when introduced into animals or man, stimulate the production of corresponding antitoxins in the blood serum of the inoculated person or animal Bacteria also contain endotoxins which do not stimulate the production of neutralizing substances Bacteria sometimes produce an abnormal *sensitization as in tuberculosis* this is a part of the dynamics of the infective process Some other known specific properties seem to be related to infection as the production of coagulase or fibrinolysin by some bacteria affecting coagulation of blood plasma

Virulence Besides a gradually accumulating knowledge of specific properties related to infection a set of undesignated properties is grouped in the concept of virulent bacteria avirulent strains or those of reduced virulence (attenuated) Isola*tion of one type of bacteria from the infective* process implies that they are virulent and this can often be proved on laboratory animals or by the fact that infection is transmitted to other persons Continued cultivation of such isolated virulent strains of bacteria often leads to strains which lack the power to infect (avirulent) Likewise strains are often isolated which in every demonstrable way are members of pathogenic species yet lack the power to infect

Immunity The concept of immunity broadly *the response of the person to infection* originated specifically in 1798 with vaccination for smallpox an infection due to a virus Pasteur gave the concept profound impetus with his early studies of bacteria He was the first to use a culture low in virulence a deliberately attenuated strain for a vaccine (anthrax) In subsequent studies of the process of infection with bacteria much time has been devoted to the study of vaccines or other phases of immunity against bacterial infection with rather poor success Unquestionably the infective process and the reaction to it (immunity or susceptibility) are distinctive and complex for each infection

Identification of pathogenic bacteria Medical bacteriology also emphasizes the identification of pathogenic bacteria to help establish the specific infective nature of the disease Clinical and public health laboratories devote much of their time to such an identification as an aid in diagnosis and as confirmation of phases of epidemics Such identifications usually though not always require the isolation of pure cultures and a study of a minimum number of characteristics which will identify *them* with members of pathogenic species The characteristics fall into four general categories (1) morphologic features including the study of colonies of bacteria grown in cultures (2) metabolic features such as the specific fermentation of carbohydrates (3) pathogenicity or the ability to infect laboratory animals and (4) antigenicity

The antigenicity of bacteria refers to the proteins or protein complexes which are intrinsic parts of all bacteria or cells in general All bacteria have

sets of antigens on or in them, and hence any of them, pathogenic or not, can be identified serologically Specific sets of antigens occur regularly on or in the cells of each species When these antigens are injected into an animal, or are present as the result of infection in the animal or human, corresponding antibodies occur in the serum of the blood (antiserum) for each antigen, and these react demonstrably with the antigens Thus an antiserum and the corresponding bacteria react specifically, using extracts of bacteria (precipitation), suspensions of bacteria (clumping or agglutination, also fixation of complement) filtrates of bacteria (neutralization of toxins) or microscopic preparations (swelling of bacterial capsules) The study of these reactions between antigens and antibodies is known as serology, which came into being through studies of pathogenic species and is most commonly used in medical bacteriology The process can be inverted by mixing the patient's blood serum with known bacteria thus identifying unknown antibodies rather than identifying unknown bacteria Serologic reactions are commonly supposed to explain much of immunity but they do so only in a very few instances

Thus medical bacteriology was and still is a pioneer field in the study of the infective process

logic products

For disease entities caused by specific bacteria *see* ANTHRAX, BLACKLEG, BOTULISM, BRUCELLOSIS, CARRION'S DISEASE, CHOLERA VIBRIO *DIPHTHERIA* GANGRENE GAS, GLANDERS, GRANULOMA INGUINALE HEMORRHAGIC SEPTICEMIA JOHNE'S DISEASE, LEPROSY, LISTERIOSIS MELIOIDOSIS PLAGUE, PSEUDOTUBERCULOSIS, TETANUS TUBERCULOSIS, TULAREMIA

For disease entities caused by more than one microorganism *see* CYSTITIS, ENDOCARDITIS *FOOD POISONING BACTERIAL*, INFANT DIARRHEA MENINGITIS, PNEUMONIA

For groups of disease producing bacteria *see* ENTERIC BACILLI, GRAM NEGATIVE DIPLOCOCCI HEMOPHILIC BACTERIA LEPTOSPIRA PLEUROPNEUMONIA LIKE ORGANISM (PPLO), PNEUMOCOCCUS SPIROCHETE STAPHYLOCOCCUS, STREPTOCOCCUS *See also* BACTERIOLOGY, IMMUNOLOGY, QUELLUNG REACTION, SEPTICEMIA, SEROLOGY [M S M]

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Bacteriophage

A virus that infects bacterial cells It is usually spoken of as a "phage" for example coliphage, a phage able to infect the bacterium *Escherichia coli* Occasionally the action of phages is called the Twort d Herelle phenomenon after its discoverers *See* COLIPHAGE

In the 1920s, soon after bacteriophages were discovered, it was believed that they held much promise as therapeutic agents, but the tendency of bacteria to develop phage-resistant mutants has prevented effective use of this potentiality Recent interest in bacteriophages has been directed chiefly towards their use as life cycle models for understanding the growth of other kinds of viruses including the application of phage techniques to the study of these viruses, their value in general genetic studies involving problems of replication and recombination, their involvement in the transfer of genetic properties of bacteria from one culture to another (transduction), their use in the epidemiology of infectious disease as agents for typing bacteria to determine the source of an outbreak, and their threat to such industrial fermentations as the manufacture of cheese and the production of antibiotics where the infection of the starter cultures with phages (in the latter case actinophage) may ruin the process entirely or result in the production of an inferior product

Bacteriophages have been found for most of the common bacteria and are easily obtained from soils feces and even from bacterial cultures themselves Phages are usually species specific although occasionally they may affect closely related species Furthermore many different phages may exist for a single species and these will show selective action for the strains of that species that is some will be active over a broad host range and infect most strains others over a much narrower range It is probable that this specificity or lack of it is as much dependent upon the bacterial culture as it is upon the phage

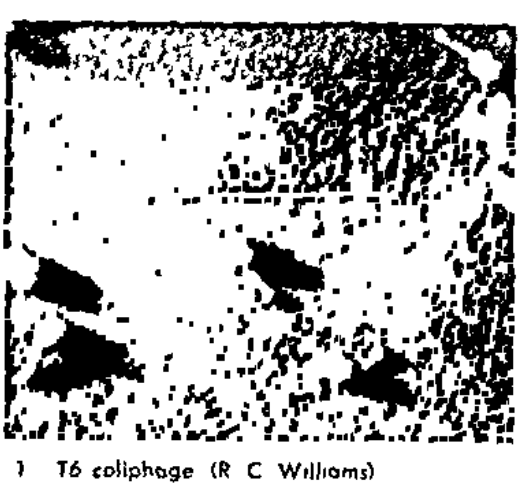


Fig 1 T6 coliphage (R C Williams)

Under the electron microscope phages appear as sperm like objects with a prismatic head 50–100 millimicrons (mμ) in diameter and tails up to 200 mμ in length Studies of photographs show that the phages are adsorbed by means of their tail to receptor spots on the bacterial cell surface

The presence of a phage is most dramatically shown by its ability to clear a cloudy culture of bacteria growing in broth and to produce plaques in a solid medium Both phenomena are the result

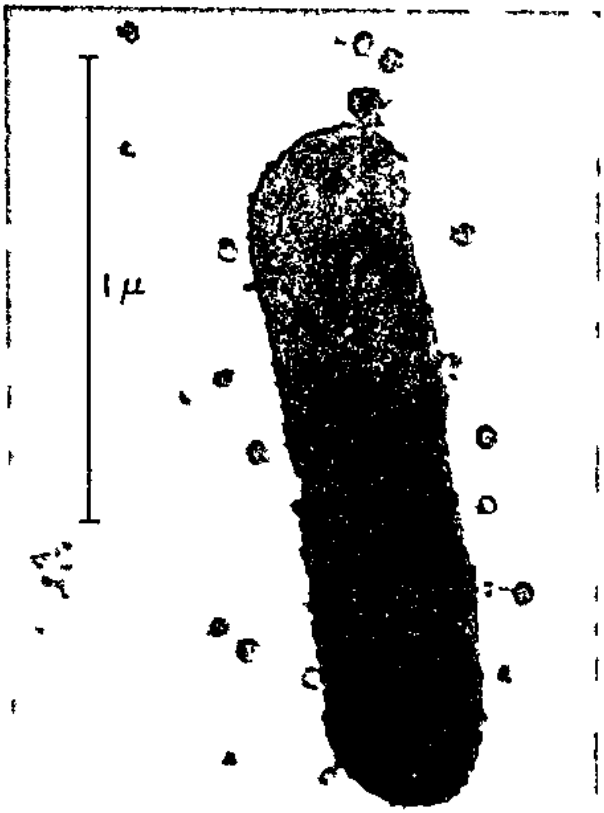


Fig 2 T5 coliphage adsorbed by the tail on *E coli* strain B (*From T F Anderson Morphology and osmotic properties of bacteriophage systems Symposia Quant Biol Cold Spring Harbor 18 199 1953*)

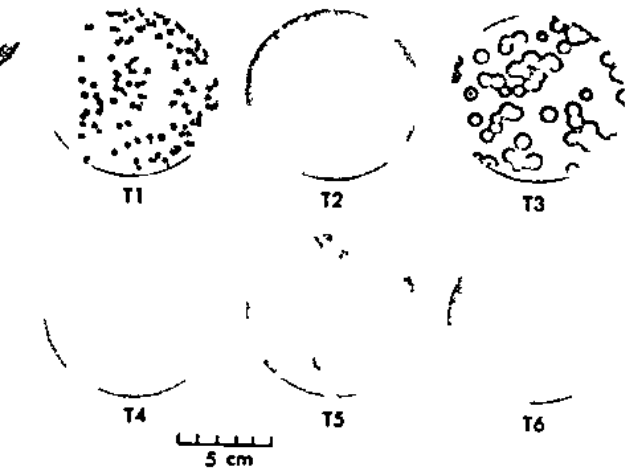


Fig 3 Plaques of T1 T6 coliphage on *E coli* strain B (*From M Demerec Department of Genetics Carnegie Institution of Washington*)

of lysis or cell dissolution Plaques are essentially virus colonies growing in a medium of bacteria They are clear areas produced wherever a phage particle is present on an agar plate seeded heavily enough with susceptible bacteria to result in confluent growth The particle infects a cell and is reproduced Subsequently the bacterium bursts and releases many new phage particles These infect the neighboring cells and the process continues as long as the bacterial culture grows The result is a circular area on the agar plate where nothing can be seen

A broth culture which has lysed may contain 10^9 or even more phage particles per milliliter The clear fluid may still contain bacteria for some cells may escape contact with the particles Also often a few cells mutate to forms resistant to phage and subsequently multiply The fluid may be made bacteria free by passing it through any one of a number of types of filters The phage may be concentrated by ultracentrifugation

The number of phage particles per milliliter is commonly determined by making serial tenfold dilutions mixing measured amounts of each dilution with a large number of susceptible bacteria and spreading this mixture over the surface of an appropriate culture medium After some hours cultures containing large amounts of phage will appear perfectly clear since all the cells will have been lysed The cultures of the higher dilutions where sufficiently few phage particles were initially present will be spotted with plaques The phage content of the original material is easily determined by counting these plaques and applying the proper dilution factor *See* ACTINOPHAGE BACTERIA LYSOGENIC BACTERIAL GENETICS INFECTION LYTIC RECOMBINATION GENETIC VIRUS

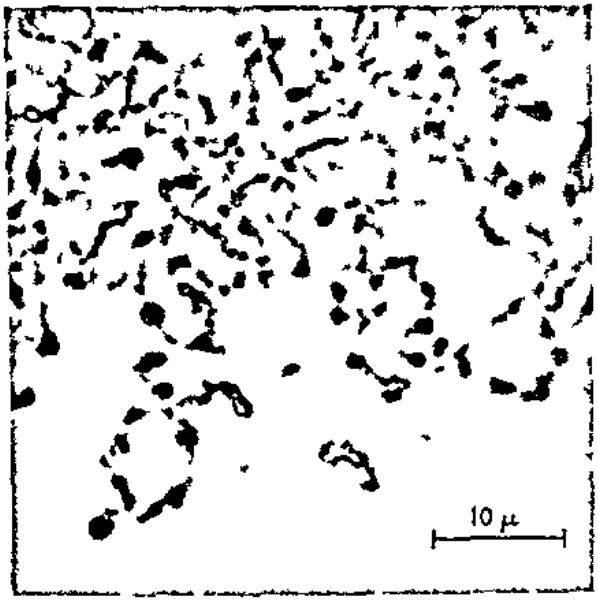
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Bacteroidaceae

A family of bacteria belonging to the order Eubacteriales They are obligate parasites normally occurring in the intestinal tracts and mucous membranes of animals and man They are sometimes pathogenic causing calf diphtheria contagious polyarthritis in mice ratbite fever (man) and Haverhill fever (man) The microorganisms are gram negative rod shaped obligatorily anaerobic (can grow only in complete absence of oxygen) or microaerophilic (need oxygen but grow best at or may even require a reduced oxygen tension of less than 10%) nonsporing and usually nonmotile

Morphology and growth The cells vary widely in size and shape They may be coccobacillary rod shaped or filamentous with rounded or pointed ends The cells may occur singly or be arranged in pairs or in chains Some species characteristically develop irregular swellings along the filaments particularly under less favorable artificial growth conditions The cytoplasm often contains granules or alternate dark and light areas True branching does not occur Creeping motility or motility by means of flagella has been described in a few species Colonies on solid media are small and discrete The organisms are sometimes fastidious requiring serum or ascitic fluid for growth which is often stimulated by the presence of 2 10% of carbon dioxide The viability of some species



Streptobac llus mon l formis Marg nal zone of a colony on sol d nutr ent med um

may be rapidly impaired on exposure to atmospheric oxygen

Biochemical Carbohydrates may or may not be attacked with the formation of acid gas is sometimes produced *See* BACTERIAL METABOLISM

Pathogenicity Bacteroidaceal strains are frequently isolated from a variety of inflammatory conditions in animals and man characterized by extensive destruction and putrefaction (necrosis and gangrene) of the tissues Examples are contaminated wounds peritonsillar abscesses appendicitis abscesses and gangrenous processes of the lungs liver and urogenital tract It is by no means clear whether the *Bacteroides* types play a role as primary pathogens because they are usually found in disease tissues in company with other microorganisms Certain species however have rather frequently been isolated in pure cultures from focal lesions and from the blood Some species are pathogenic to mice and other laboratory animals causing necrotic suppurations and possibly even a fatal generalized infection Exocellular and endocellular toxins have been demonstrated in one species (*Sphaerophorus necrophorus*)

Classification The family is divided into five genera each of which includes one or more species The genera are as follows

Bacteroides The best known species is *B fragilis* It is found with particular frequency in acute appendicitis and pulmonary gangrene and occasionally it invades the blood stream *B melaninogenicus* is distinguished by the production of a black pigment on prolonged incubation on blood agar

Fusobacterium The type species is *F fusiforme* which is found together with spirillar rods in ulcerative lesions of the throat (Vincent s angina) and mouth as well as in the normal buccal mucosa

Dialister Two species are included *D pneumosintes* and *D granuloformans* Both of these are commonly found in the upper respiratory tract of man

Sphaerophorus The most important species is *S necrophorus* (synonyms *Bacteroides funduliformis S funduliformis Necrobacterium necrophorum*) The evidence for independent pathogenicity of this species is stronger than with most of the other species of the family It is usually regarded as the causative organism of calf diphtheria a disease characterized by the formation of thick firmly adherent membranes in the respiratory passages Foot rot in cattle has been reproduced experimentally by the injection of pure cultures of the organism although other gram negative anaerobes have likewise been incriminated in that disease *S necrophorus* is frequently found in pure culture in multiple abscesses of the liver and kidneys in cattle and is probably carried to these organs via the blood stream Septicemia and inflammatory lesions caused by *S necrophorus* are not uncommon in man

Streptobacillus Only one species *S moniliformis* is known This differs from all other species of the group by being facultatively aerobic although anaerobic conditions are sometimes said to favor growth on primary isolation The spontaneous development of the so called L phase colonies on solid media colonies that are abnormal in morphology and growth characters is a distinguishing property of *S moniliformis* It is a normal saprophyte of the nasopharynx of laboratory and wild rats whereas in mice it causes a contagious polyarthritis (inflammation of many joints) sometimes occurring as widespread epizootics with a high attack rate and mortality In man it also causes septicemia and purulent polyarthritis which may be contracted either by rat bite (ratbite fever) or by ingestion of contaminated milk (Haverhill fever named from the Haverhill epidemic in the United States in 1926) *See* BACTERIA TAXONOMY OF BACTERIOLOGY MEDICAL EUBACTERIALES [E A F]

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Baddeleyite

A mineral having composition ZrO_2 and crystallizing in the monoclinic system Baddeleyite crystals flattened on the front pinacoid are common but the mineral may occur in botryoidal masses with concentric banding There is perfect basal cleav

tals and rolled pebbles in gem gravels of Ceylon and in gravels in the province of Minas Geraes Brazil It and zircon $ZrSiO_4$ are the two minerals serving as sources of zirconium *See* ZIRCONIUM [C S HU]

Badger

A large, powerful short legged, short tailed fosso rial carnivore of the family Mustelidae Its body is long The badger is found from northern Mexico into the Central Plains of Canada mainly in tree less areas and eastward to the eastern forests

The badger digs long, deep burrows for its nest For its principal food it digs ground squirrels and mice out of their homes It is primarily nocturnal



The badger *Taxidea taxus*, length 30 in (*From E L Palmer Fieldbook of Natural History, McGraw Hill, 1949*)

The badger is beautifully marked with a median white stripe over the head against a background color of yellowish gray There is a black spot in front of each ear the cheeks are white and the feet black *See* CARNIVORA [J D B]

Baking powder

A yeast substitute made of baking soda (sodium bicarbonate) plus cream of tartar (potassium acid tartrate) tartaric acid an alum (in modern bak ing powders usually anhydrous sodium aluminum sulfate) or monocalcium phosphate, or any com bination of these acids so formulated as to release carbon dioxide from the baking soda when mois tened Baking powder causes breadstuffs to rise without the fermentation effects of yeast Commer cial baking powders contain some inert materials, such as starch or flour to slow down the chemical reactions between the active ingredients *See* FOOD MANUFACTURING [C CO]

Balance (analytical)

A balance designed for use in exacting laboratory work The loads that can be weighed routinely with reasonable accuracy range from a few milli grams on the microbalance to about 200 g on the ordinary analytical balance or macrobalance Spe cial balances have been designed for microgram samples

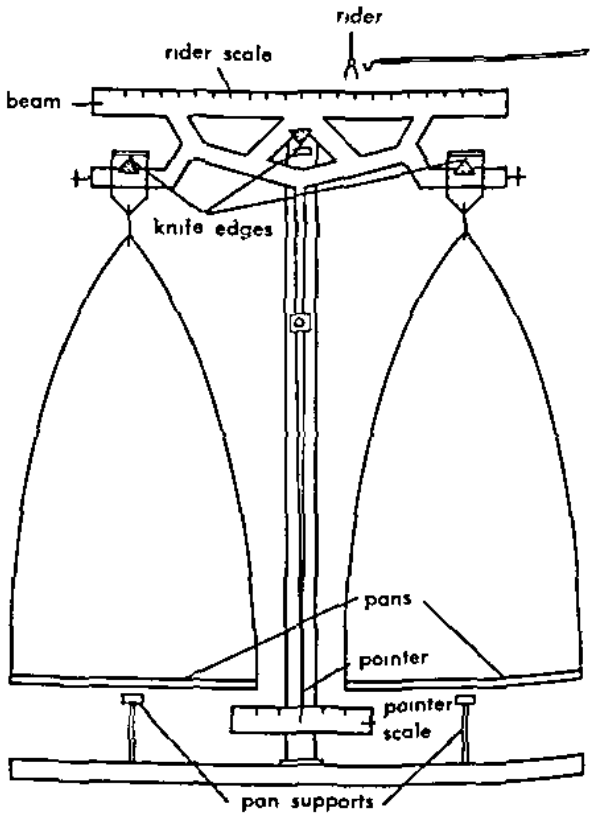
Construction. An analytical balance consists of a light but rigid beam mounted at its center point on a knife edge resting on an agate plate Two knife edges one at each end of the beam support stirrups from which pans are hung, one for the weights and the other for the object weighed A pointer attached to the center of the beam moves over a scale at the bottom of the assembly A care fully adjusted macrobalance is capable of weigh ing to the nearest 0 1 mg under a load of up to 200 g

The sensitivity (also called sensitiveness or sen sibility) of a balance is the tangent of the angle α through which the equilibrium position, or posi tion of rest, of the beam (or pointer) is displaced by a small excess load w on one of the pans *sensitivity* $= (\tan \alpha)/w$ With a small excess load, the angle is so small that, for practical purposes, sensitivity can de defined as the number of scale divisions through which the position of rest of the pointer is displaced by an excess load of 1 mg

Sensitivity varies directly with the length l of the beam, inversely with the weight W of the beam, and inversely with the distance d between the cen ter of gravity of the swinging portion and the point of support $(\tan \alpha)/w = l/Wd$. The sensitiv ity of a balance decreases slightly with increasing load

A rider balance is the simplest type of analytical balance and uses pan weights of denominations down to 5 or 10 mg Its beam is graduated into milligram divisions and subdivided to read to the nearest 0 1 mg The latter readings are obtained from the position on the beam of an aluminum rider which is released from a hook on the end of a rod projecting through the side of the balance case

A keyboard balance has a mechanical arrange ment of levers by means of which special weights



Rider type analytical balance (simplified diagram)

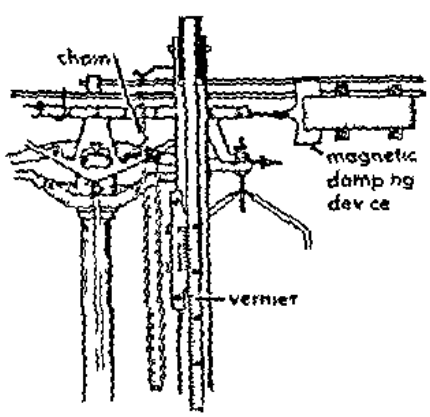
can be placed on an attachment of the beam by de pressing keys from outside the balance

A chain balance has a fine gold chain suspended from one side of the beam The other end of the chain is fastened either to a device which moves over a graduated vertical scale or to a graduated drum which serves as a scale Weight readings be low 100 mg are taken from the scale and vernier Most chain balances have beams with 10 equally spaced notches into which a dumbbell shaped rider can be placed to give weight readings to tenths of a gram Pan weights less than 1 g are thereby eliminated

A damped balance has a device attached to the end of the beam for setting up a resistance to the oscillation of the beam causing it to come quickly to rest The damper may be a plunger moving in a cylinder containing air or a liquid but more often it is an aluminum plate hanging between the poles of a powerful magnet Eddy currents generated as the plate moves in the magnetic field act to retard the movement of the plate and hence of the beam The sensitivity of the balance is not affected

A constant load balance consists of a single pan together with a set of weights that are suspended from a concealed counterpoised beam The object to be weighed is placed on the pan and by means of control knobs the weights are removed from the beam until equilibrium is reached Since the bal ance is under a constant load (of 200 g for the macrobalance) the sensitivity is constant and the angle of deflection of the beam from the horizontal position (which is registered under magnification on an illuminated scale) gives the final weight reading to the nearest 0 1 mg

Weighing Balance weights are used to deter mine the masses of objects Weights down to 1 g are usually made of lacquered or gold plated brass or of stainless steel Smaller weights are usually made of gold platinum or aluminum Analytical weights are usually rated according to the deviation in mass of each weight from that of a standard weight of the same denomination For very precise work it is de sirable to have the correction value of each weight determined at the National Bureau of Standards



Cha n weight balance with notched beam and mag netic damper

The fundamental standard of mass is the standard kilogram made of a platinum iridium alloy and kept on deposit at the Bureau of Standards

Direct weighing on an analytical balance is car ried out with the object on the left hand pan the appropriate weights on the right hand pan and the rider or chain in such a position as to cause the pointer on a damped balance to come to the cen ter of the scale or on an undamped balance to oscillate properly with respect to the center point of the scale

Weighing by substitution eliminates errors caused by balance arms of unequal lengths The ob ject is balanced against a tare (usually from a sec ond set of weights) The object is then removed and calibrated weights are placed on the same pan until the same state of balance is obtained

Double weighing likewise eliminates errors caused by unequal lengths of balance arms The object and weights are brought to a state of balance in the regular way then they are transposed from one pan to the other and again brought to a state of balance The mean of the two weight values is taken as the true weight *See* ANALYTICAL CHEMIS TRY BALANCE (WEIGHING INSTRUMENT)

[S G S]

Balance (weighing instrument)

An instrument for measuring weight or mass An unknown weight is measured directly by measuring an elastic deformation produced by it In the spring balance the deformation is an extension or compression of a spring in the torsion balance it is a twisting of a wire or band The mass of a body is commonly measured by comparing the weight of the body with the weight of a body of known mass This is done by letting the weights of the two bodies act vertically at two points of a horizontal beam itself supported at a fulcrum and using the principle of the lever to calculate the ratio of the weights This ratio is equal to the ratio of the masses *See* MASS WEIGHT

Equal arm balance The most commonly used balance is the equal arm balance in which the horizontal beam is supported at its center and the weights of the unknown mass and of the stand ard mass are applied at equal distances from the central support For more precise work as in the analytical balance agate knife edges are used as the fulcrum and to support the pans on which the unknown mass and the weights are placed A pointer rigidly attached to the center of the beam normally points downward a scale near the free end of the pointer indicates the equilibrium point If this point coincides with the equilibrium point for empty pans the masses in the two pans are equal, if it does not the difference in the masses can be calculated from the known sensitivity of the balance which is equal to the number of scale divi sions that corresponds to a unit (usually 0 001 g) excess of mass in either pan Sensitivity depends not only on the construction of the balance but also on the load *See* BALANCE (ANALYTICAL)

To ensure accuracy several precautions must be taken in using the equal arm balance Because of friction the pointer may come to rest off its equilibrium point To eliminate this error the equilibrium position of the pointer is not observed directly but is calculated from the extremes of its swings This is done by taking the average of an even number of pointer readings say to the left and of an odd number to the right and taking the mean of the two averages To minimize horizontal swinging of the pans due to air currents pointer

sities of the unknown mass and the weights increases Inequality in the lengths of the arms of the equal arm balance is corrected for by double weighing that is by weighing the unknown first in the left pan and then in the right pan If the two masses thus obtained are M_1 and M_2 the mass of the unknown is taken as $\sqrt{M_1 M_2}$ An alternative method is to weigh the unknown and then in the same pan to weigh a body whose mass is known and is nearly equal to that of the unknown If the substitute mass is known more accurately than the mass of the weights used errors in the latter as well as the error due to an inequality in the arms lengths may be compensated for by this method which is called substitute weighing

The precision of measurement attainable with the equal arm balance is limited by the unequal expansion of the balance arms because of changes of temperature that are too rapid to be eliminated by double weighing A partial solution of this difficulty is achieved by making the balance beam of quartz, a mineral whose temperature coefficient of expansion is low Metal beam balances can be used to measure masses of a few hundred grams with a precision of 1 part in 100 000 000 Quartz beam balances achieve the same precision for masses of about 0 1 g

Other types Beam balances with arms of unequal lengths have either a movable fulcrum as in certain types of the steelyard balance or a fixed fulcrum and riders that is weights that can be placed at different distances from the fulcrum as in the triple beam balance The common type of platform balance is an equal arm balance that has flat platforms above the beam instead of suspended pans It often has a sliding rider to eliminate the use of the smaller weights Density balances are used to measure densities of solids or liquids (*see* DENSITY MEASUREMENT) They may be of the spring type with a vertical spring at whose lower (free) end a pointer is fixed as in the Jolly balance or of the beam type as in the Westphal balance Microbalances used to weigh masses of a fraction of a gram may be of the beam or the torsion type Gravity balances are spring balances used to measure differences in the weight of a standard mass at different localities to indicate differences in the densities of underlying rocks

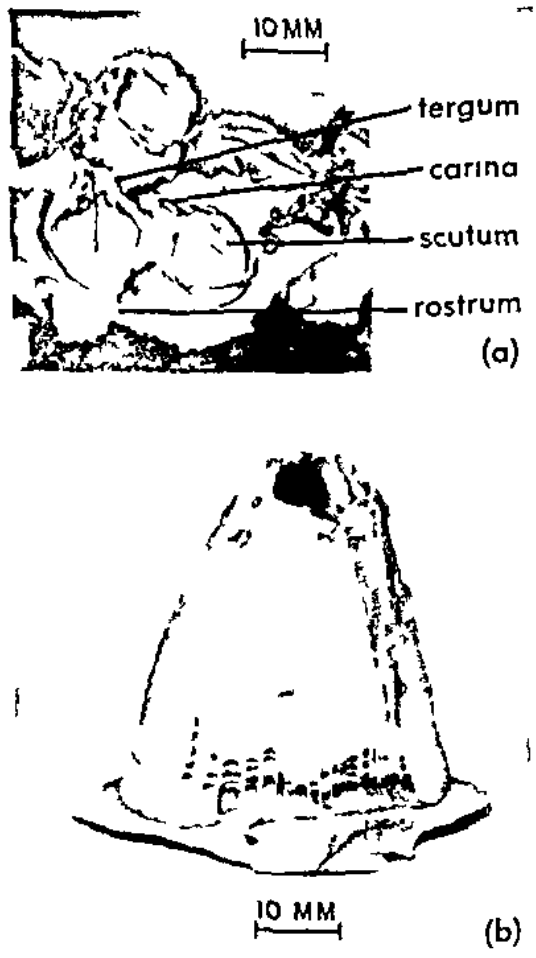
See TERRESTRIAL GRAVITATION WEIGHT MEASUREMENT [L.N.]

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Balanomorpha

A suborder of the Thoracica This group of crustaceans are symmetrical barnacles The plates of the wall (rostrum carina and 1 3 pairs of laterals) are immovably locked together occasionally all are fused Paired scuta and terga form a movable operculum with adductor and depressor muscles present The basis is calcareous or membranous and caudal furca are rarely present Branchiae are well developed and filamentary appendages are lacking These animals are hermaphroditic

Two families are differentiated the Balanidae and Chthamalidae The Balanidae include the most



(a) *Balanus balanoides* (L.) oper cal view (D. P. Henry *Studies on the sessile Cirripedia of the Pacific Coast of North America Univ. Wash. Publs. Oceanog.* 4(3) 99–131 1942) (b) *Balanus rostratus* Hoek rostrum filed at base to show complex wall consisting of longitudinal tubes with calcareous cross septa between an inner and outer layer (D. P. Henry *The Cirripedia of Puget Sound with a key to the species Univ. Wash. Publs. Oceanog.* 4(1) 1–48 1940)

highly evolved sessile forms indicated partly by reduction in number and increase in complexity of the plates The Balanidae are widely distributed and are most plentiful in littoral waters where the vertical distribution is often striking Several species are prominent fouling organisms others are associated with various other animal such as sponges corals turtles and whales Only one genus of the Chthamalidae is widely distributed and it usually occurs in the high intertidal zone above the level of the Balanidae [D P H]

Balanopsidales

An order of the plant subclass Dicotyledoneae with a single small family (Balanopsidaceae) and one genus (*Balanops*) containing seven species of trees growing in New Caledonia *See* DICOTYLEDONEAE EMBRYOPHYTA PLANT KINGDOM [P D S]

Balantidiasis

A disease of man caused by a ciliated protozoan *Balantidium coli* The ciliated parasite is one man shares with and probably contracts from swine *B coli* is an inhabitant of the large intestine where it may be well tolerated or provoke diarrhea or when the colonic epithelium is eroded dysentery At times such erosions progress to ulceration and finally to perforation of the intestine This is followed by hemorrhage and infection within the abdomen and may end fatally Prompt response to therapy has been reported for a great variety of compounds Infection takes place following ingestion of cysts Adequate precautions to protect food and drink from contamination will eliminate new infections Persons in contact with swine or pig excreta risk getting the infection *See* HETEROTRICHIDA [D W]

Ballast resistor

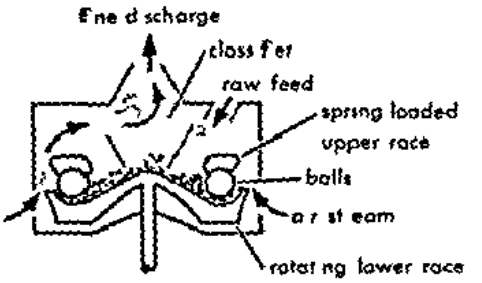
A resistor that has the property of increasing in resistance as current through it increases and decreasing in resistance as current decreases Thus it tends to maintain a constant current through it despite variations in applied voltage or changes in the rest of the circuit It acts as a variable load on the system and is therefore different from load resistors which have a constant resistance *See* RESISTOR

The ballast action is obtained by using resistive material that increases in resistance as temperature increases Any increase in current then causes an increase in temperature which results in an increase in resistance and reduces the current Ballast resistors are usually mounted in an evacuated envelope to reduce heat radiation they are therefore also called ballast tubes

Ballast resistors have been used to compensate for variations in line voltage or to compensate for negative volt ampere characteristics of other devices such as fluorescent lamps and other vapor lamps *See* VAPOR LAMP *see also* VOLTAGE REGULATOR

Ball bearing pulverizer

A grinding machine in which revolving balls under heavy pressure crush and rub material such as coal to reduce it to small size Feed enters through a chute to the inside of a ring of closely spaced balls The upper spring loaded ball race applies pressure to the balls, the lower race rotates causing the coarse material to be ground between it and the balls The fine material discharges along the outside of the race In pulverizing bituminous coal hot air enters along the outer race and carries the fines to a cyclone classifier at the center of the mill The action withdraws the finest particles and returns the others to the inside of the ring for further reduction Several rings of balls can be cascaded in one machine for higher capacity Such a mill is compact and consumes relatively little power *See* CRUSHING AND PULVERIZING [R M H]



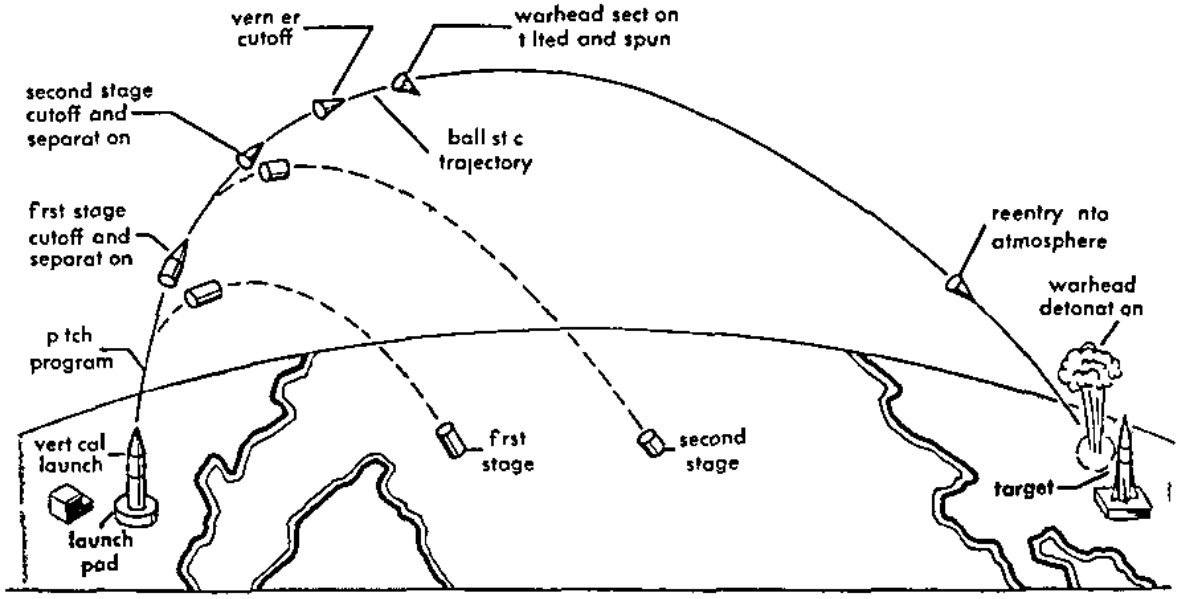
Coarse raw material is ground by crushing and attrition between balls and rotating race and withdrawn from mill by an air stream

Ballistic missile

A vehicle that follows a flight path partially consisting of a ballistic trajectory during a nonpowered phase This trajectory is the nearly elliptic curve determined by the momentum that the vehicle gains during a powered stage the pull of gravity and resistance of the air The total path is analogous to that of a gun fired projectile The missile s powered stage is equivalent to the travel of the projectile within the gun barrel As the gun may be aimed to establish the ultimate projectile path so may the missile s direction of momentum be controlled during its powered phase The missile has a significant advantage over the gun projectile combination in that its velocity at the start of the ballistic trajectory may be accurately established by controlled cut off of its thrust motor as illustrated

Although primarily intended for use as military weapons the most newsworthy ballistic missiles are those whose final stages attain a terminal trajectory that is an orbit of the earth or the sun

Most ballistic missiles are for surface-to surface military missions (*see* GUIDED MISSILE) Other types are launched from underwater submarines or from aircraft (*see* MISSILE)



Typ cal fl ght pattern for two stage intercont nental ball stic m ss le

After a missile is launched vertically its inertial guidance system works in cooperation with an automatically introduced pitch (or forward tilt) program Depletion of fuel for the first stage triggers the separation of that stage and ignition of a second stage Cut off and separation of the second stage is controlled by the missile s guidance system as is the cut off of the vernier motor when the velocity vector is correct for impact in the target area The warhead section is then tilted into correct reentry attitude relative to the spatially referenced stable platform by means of gas reaction jets Tangential jets then spin the warhead or other payload to maintain approximately the reentry angle by virtue of angular momentum or it can be stabilized by other methods After reentry into the atmosphere a fuze detonates the warhead immediately above the target Terminal guidance after reentry using aerodynamic vanes or reaction devices is possible in certain cases

ward its target at relentless hypersonic speed Early warning of its approach is problematical and successful defensive interception is difficult

[L S B]

Bibliography J Humphries *Rockets and Guided Missiles* 1956 W Ley *Rockets Missiles and Space Travel* rev ed 1957

Ballistic range

A long instrumented enclosure wherein tests of gun launched projectiles are conducted Ballistic ranges were originally used for study of projectile flight characteristics such as the rate of velocity loss and the dispersion of trajectories that is the imperfect following of the bore sight line of the gun Ballistic ranges are now used for the measurement of aerodynamic characteristics of projectiles and of scale models of vehicles intended for flight through the atmosphere including missiles aircraft and space flight capsules

Types of measurement Ballistic ranges may vary in length from less than 10 ft for limited investigations of small arms projectiles to greater than 1000 ft for detailed studies of projectiles from large bore guns Instrumentation may be as simple as a series of sheets of paper hung normal to the flight path (yaw cards) in which the projectile by punching its outline gives evidence of its vertical and lateral position and its angular orientation at the instant of penetration The more refined instruments required in modern practice are usually photographic A spark of extremely short duration (from 1 to 0 1 μsec) is discharged when the projectile reaches a position between the spark and a piece of film (Fig 1) The resulting shadow photograph (shadowgraph) records in projection two components of the linear position of the projectile and one component of angular orientation Two orthogonal pictures as in the simple system shown completely define the position in space of the model A number of shadowgraph stations placed in sequence along the flight path will define as a function of distance flown the history of position and attitude of the projectile in flight Corollary timing apparatus is used to measure the precise times frequently accurate within microseconds at which the pictures are recorded

The shadowgraph pictures further aid aerodynamic studies by making visible certain details of the air flow about the projectile (Fig 2) Refraction or bending of light rays by the variable air density field about the model makes visible the shock waves turbulence boundary layers and boundaries of expansion fans The flow visualization is most valuable for the study of aerodynamics

Principles of use Use of ballistic ranges for aerodynamic investigation derives from the fact

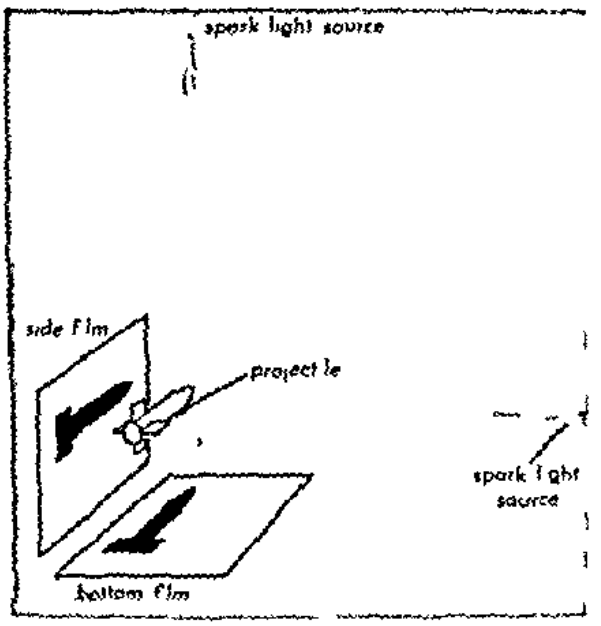


Fig 1 Simple shadowgraph system

that aerodynamic forces and moments due to the *relative motion of the projectile* through the air result in accelerations of the projectile which alter its motion From measurements of the altered motion *the forces and moments may be deduced*

Of the aerodynamic forces one which is always present is the drag or air resistance to forward motion Drag may be determined from a *careful* measurement of the rate of loss of forward velocity as a function of distance flown For a nonspinning axially symmetric projectile in perfect alignment with *the direction of flight (zero angle of attack)* drag is the only aerodynamic force encountered Because however the projectile is invariably disturbed *from perfect alignment on launching from* the gun several additional aerodynamic effects arise When disturbed an aerodynamically stable *projectile will oscillate* in angle of attack *continually* seeking alignment with the wind The oscillatory motion is similar to the oscillation of a mass suspended *from* a spring Linear displacement of the oscillating mass corresponds to angular displacement of the projectile the restoring force of the spring corresponds to the aerodynamic restoring moment termed the pitching moment of the projectile (both are proportional to the displacement to a first order of approximation) The mass corresponds to the moment of inertia of the projectile about a transverse axis through its center of gravity For a simple planar oscillation (oscillation *about one axis only*) *with the pitching moment* linearly dependent on the angle of attack the oscillation is sinusoidal and the pitching moment M is related to the wavelength λ of the oscillation through the equation

$$(2\pi V/\lambda)^2 = -M/(I\alpha) \qquad (1)$$

where V *is the velocity of flight* I *is the moment of* inertia about the axis of oscillation and M/α is a constant (for the given flight conditions) a measure of the *aerodynamic* stability

If a nonspinning axially symmetric projectile with constant M/α receives disturbances in two *planes, its nose will trace an elliptical oscillatory pattern relative* to the center of gravity This motion can be analyzed by resolving it into components along the major and minor axes of the el

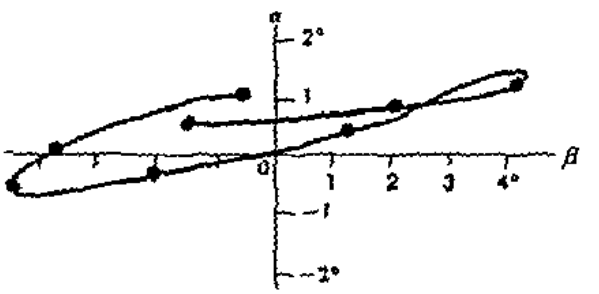


Fig 3 Complex pitching and yawing motion of a spinning unsymmetrical projectile (*Data from NASA Pressurized Ballistic Range Ames Research Center*)

lipse and applying Eq (1) to each Pitching motions progressively more complicated than the above will be observed if the projectile is spinning nonaxially symmetric (*such as a model with a wing* in one plane) or has nonlinear aerodynamic stability (M/α dependent on α) Then there will be gyroscopic effects differences in wavelength for different planes of oscillation and the oscillations will no longer be sinusoidal (Fig 3) Theories of oscillatory motion are available for many of these cases and by matching the equation of motion to the observations the aerodynamic moments can be deduced

Oscillatory motions may damp in amplitude as the oscillation proceeds (dynamically stable) or grow and diverge (dynamically unstable) The degree *of dynamic* stability *may be determined* directly from observation of the decay or growth of the oscillation and the definition of this dynamic *behavior is a principal objective of some ballistic* range tests

When the projectile departs from zero angle of attack *the aerodynamic force of lift is added Lift* the force which sustains airplanes in flight may be

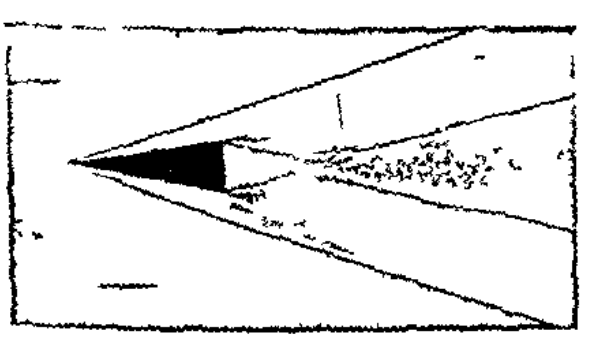


Fig 2 Shadowgraph of a cone in supersonic flight (*Courtesy of National Aeronautics and Space Administration Ames Research Center*)

defined more generally as the force component perpendicular to the flight path Because it is not in general balanced by the projectile weight it causes the flight path to become curved The lift oscillates in direction when the angle of attack oscillates from positive to negative and there results an oscillatory movement of the projectile center of gravity about a straight path referred to as a swerving motion The lift is to a first approximation proportional to angle of attack and for the linear case (both M_α and L/α constant) the swerving motion of the center of gravity will be sinusoidal The magnitude of the lift curve slope l/α can be deduced from simultaneous measurements of the amplitude of pitching oscillation and the amplitude of swerving oscillation

Although the aerodynamic properties discussed above (drag pitching moment damping in pitch and lift force) are usually the most important ones other properties may be of interest or importance These include rolling moments (moments tending to spin or retard the spin of the model about a longitudinal axis) pitching and yawing moments induced by deflected control surfaces and Magnus forces and Magnus moments (moments about the pitch and yaw axes due to rotation about the roll axis) All of these properties have been studied from trajectory analysis in ballistic ranges

Measurement of trajectory coordinates It is evident that the above uses of ballistic ranges require accurate records of the six trajectory variables three linear components of position x y and z as functions of time and three angular coordinates θ ψ and ϕ as functions of time The degree of accuracy needed in these coordinates depends on the extent of deviation of the trajectory from straight line flight at uniform velocity because the differences from such unaccelerated motion contain the information on the aerodynamic forces For successful measurement of the aerodynamic properties experiments should be designed to make appreciable the deviations from unaccelerated motion by selection of the model scale and materials of construction the air density and the range length Instruments to give trajectory coordinates with necessary accuracy must be based upon a set of measurement references and the measurement system must be carefully surveyed or calibrated The measurement references usually include a taut wire which runs the length of the range just above the surface of the bottom photographic film In plan view the wire constitutes by definition a vertical projection of the range x axis From its image and the model image the y coordinate and angle of yaw may be measured In side pictures sag in the taut wire lessens its value as an absolute reference for measurement of the z coordinate [illegible] and

nate can be measured by standards of length which project into the field of view of the shadowgraph stations Errors of measurement associated with projection of the model image from the plane of flight onto the film must be avoided by careful alignment of the light source and associated mirrors or lenses relative to the measurement references For the greatest precision errors in alignment due to both thermal expansion and lack of rigidity or dimensional stability of the system must be prevented Systems have been reported in which linear coordinates of models in flight are measured accurate to 0 003 in attitude angles accurate to 0 1° or better and times of transit between photographic stations recorded accurate to 0 025 μsec These extremes of precision are required in short ranges in the order of 25 ft long In longer ranges accuracy requirements on time and linear positions have sometimes been relaxed by about one order of magnitude from the above values

Comparison with wind tunnels The advantages of ballistic range aerodynamic tests as compared to wind tunnel tests are (1) absence of model support interference (2) great flexibility with respect to test velocity (3) lack of friction or restraint in dynamic tests (4) greater accuracy of measurement in such special cases as drag and (5) possibility of reaching test conditions notably speed stagnation temperature and Reynolds number that cannot be reached conveniently in wind tunnels This last point is particularly significant and accounts for much recent emphasis on ballistic ranges which have given test data at speeds to 20 000 ft/sec and at Reynolds numbers which sometimes match those of full scale aircraft and missiles depending on the level of pressure maintained in the range

There are also appreciable advantages of wind tunnels as compared to ballistic ranges such as (1) possibility of measuring aerodynamic characteristics not easily accessible in ballistic ranges including pressure distributions boundary layer velocity profiles and downwash distributions (2) directness of measurement as opposed to indirect character of ballistic range measurements and (3) controllability of test factors such as angle of attack which are somewhat less controllable in range tests The two methods of testing are complementary each supplying in some measure the things which the other does not provide *See* ROCKET SLED TESTING WIND TUNNEL [A SE]

Ballistics, exterior

The science dealing with the motions of projectiles not under propulsive power as of a shell after it has left the cannon or of a rocket after burning has ceased If the earth stood still and had no atmosphere such trajectories would be simple to describe mathematically The motion of a body projected at an angle to the earth s surface is perturbed by several forces so that the trajectory differs from the parabolic hyperbolic or elliptical form it would otherwise have The perturbing forces are drag cross wind forces and the Coriolis effect Their magnitude depends upon the shape and mass of the body the density of the air the wind currents and

the length of the path along the trajectory These effects seriously complicate the calculation of the trajectory

The trajectory of a projectile under the influence of the earth s gravitational field and in vacuum would be an arc of an ellipse with the center of the earth as one of the foci This arc can be closely approximated by a parabola if the motion does not carry the projectile so high that the gravitational force differs significantly from the force at the earth s surface The gravitational force varies with height in this fashion

$$g = g_0 \left(\frac{R}{R+y}\right)^2$$

where g is the acceleration of gravity at height y g_0 is its value at the surface ($y = 0$) and R is the earth s radius In order that g fall to $0.99 g_0$ y must be 20 miles

Motion of a body projected horizontally This is illustrated in Fig 1 After the projectile of mass m leaves the muzzle at $x = 0$ the only force acting upon it will be gravity this force will have a magnitude mg and will be directed downward It is assumed here that the range is so short that the earth may be considered flat that the height is so low

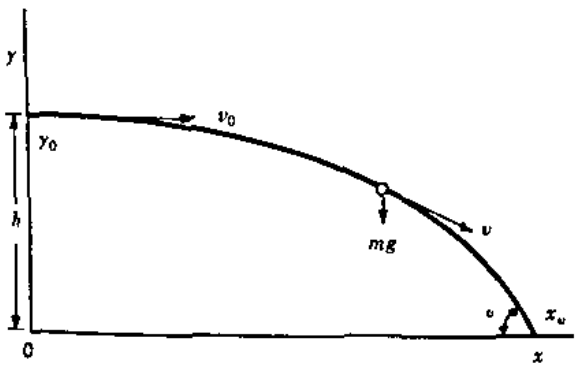


Fig 1 Parabolic trajectory of a body projected horizontally without resistance

that g is the same as at the earth s surface and that the projectile is in vacuo the complications introduced by the presence of the atmosphere will be dealt with later

The equations of motion are

$$m\frac{d^2x}{dt^2} = 0$$

$$m\frac{d^2y}{dt^2} = -mg$$

The initial conditions (subscript 0) are

$$x_0 = 0 \qquad y_0 = h$$

$$v_{x_0} = \left(\frac{dx}{dt}\right)_0 = v_0 \qquad v_{y_0} = \left(\frac{dy}{dt}\right)_0 = 0$$

$$\left(\frac{d^2x}{dt^2}\right)_0 = 0 \qquad \left(\frac{d^2y}{dt^2}\right)_0 = -g$$

The solutions to these equations are

$$x = v_0 t$$

$$y = h - g\frac{t^2}{2}$$

The curve of the trajectory obtained by eliminating t is the parabola

$$y = h - \frac{g}{2v_0^2}x^2$$

The range of the point of fall x_ω (the value of x when $y = 0$) is

$$x_\omega = v_0\sqrt{\frac{2h}{g}}$$

The time of flight t_ω (the value of t when $y = 0$) is independent of v_0 and is

$$t_\omega = \sqrt{\frac{2h}{g}}$$

The angle of fall ω is given by

$$\tan\omega = -\left(\frac{dy}{dx}\right)_{y=0} = \frac{\sqrt{2gh}}{v_0}$$

Motion of a body projected at an angle This trajectory is illustrated in Fig 2 Let a body with mass m be projected in vacuo with an initial velocity v_0 at an angle θ_0 to the horizontal and assume a flat earth with g constant The origin of coordinates is chosen at the point of projection the y axis is vertical and the x direction is so chosen that the trajectory lies in the xy plane

The equations of motion are

$$m\frac{d^2x}{dt^2} = 0$$

$$m\frac{d^2y}{dt^2} = -mg$$

The initial conditions are

$$\left(\frac{dx}{dt}\right)_0 = v_0\cos\theta_0 \qquad x_0 = 0$$

$$\left(\frac{dy}{dt}\right)_0 = v_0\sin\theta_0 \qquad y_0 = 0$$

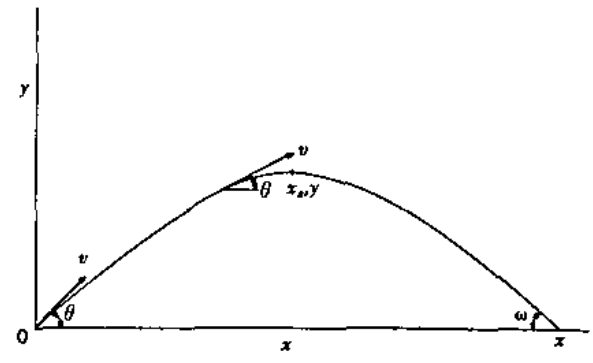


Fig 2 Parabolic trajectory of a body projected at an angle without resistance

Integrating the equations of motion and inserting the initial conditions one obtains

$$x = v_0 t \cos \theta_0$$
$$y = v_0 t \sin \theta_0 - \tfrac{1}{2} g t^2$$

To obtain the shape of the trajectory eliminate t

$$y = x \tan \theta_0 - \frac{g x^2}{2 v_0^2 \cos^2 \theta_0}$$

This is the equation of a parabola whose vertex the summit (x_s, y_s) of the trajectory can be found by equating dy/dx to zero

$$x_s = \frac{v_0^2}{g} \sin \theta_0 \cos \theta_0$$
$$y_s = \frac{v_0^2}{2g} \sin^2 \theta_0$$

The time of flight to the summit is then

$$t_s = \frac{v_0}{g} \sin \theta_0$$

The range of fall x_ω can be determined by setting $y = 0$

$$x_\omega = \frac{2 v_0^2}{g} \sin \theta_0 \cos \theta_0$$

The time of flight t is found by substituting $y = 0$ or $x = x_\omega$ in the equations involving t,

$$t_\omega = \frac{2 v_0}{g} \sin \theta_0$$

Both the range and the time of fall are just twice the values at the summit as would be expected from symmetry To obtain the condition for maximum range for a given v_0 let $dx_\omega/d\theta_0 = 0$ Then

$$\cos \theta_0 = \sin \theta_0$$

whence

$$\theta_0 = \frac{\pi}{4} = 45°$$

With a fixed initial velocity and for a less than maximum range two trajectories are obviously possible (Fig 3) one with $\theta_0 > \pi/4$ and one with $\theta_0 < -/4$

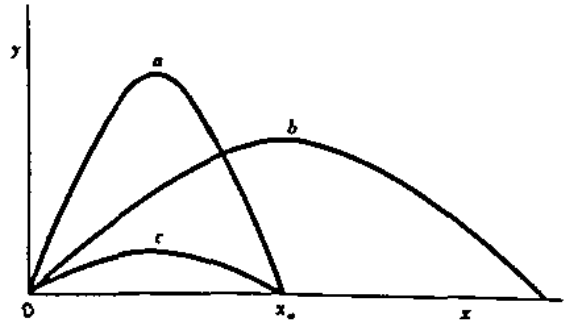


Fig 3 Possible trajectories of a body projected at the same initial velocity but at a different angle θ_0 (a) $\theta_0 > 45°$ (b) $\theta_0 = 45°$ (c) $\theta_0 < 45°$

Motions of bodies with resistance Resistance to the motion of a body through a fluid such as air derives from the fact that the body must move the fluid out of its way The fluid particles are accelerated as the forward moving body collides with them and this results in a force, called drag opposing the motion of the body and robbing it of some of its energy The drag is a function of the density of the fluid ρ of the area of the body, and of its velocity The expression for the drag is

$$D = \rho d v K_D$$

where d is the diameter of the body (assuming a circular cross section) v the velocity and K_D the drag coefficient The drag coefficient itself is a function of velocity and undergoes a rapid change as the velocity approaches that of sound Both D and K_D are functions of height since both the density and temperature of air vary markedly with height The velocity of sound varies with temperature according to the formula

$$a = a_s \sqrt{\frac{T}{T_s}}$$

where a is the velocity at absolute temperature T and a_s is the velocity at standard temperature T_s (15°C) The temperature in the atmosphere normally decreases with height for the first several miles

The effect of the drag is to modify the theoretical vacuum trajectory so that the projectile falls short of the impact point it would have reached in a vacuum and impacts with a larger value of ω Extensive tables have been determined empirically for the drag coefficient under wide variations of temperature and density The equations of motion in the presence of drag are

$$m \frac{d^2x}{dt^2} = -D \cos \theta$$
$$m \frac{d^2y}{dt^2} = -D \sin \theta - mg$$

The initial conditions are

$$\left(\frac{dx}{dt}\right)_0 = v_0 \cos \theta_0$$
$$\left(\frac{dy}{dt}\right)_0 = v_0 \sin \theta_0$$

In the equations of motion the drag force D is a function of the velocity along the trajectory and is thus a complex function of x y, and t For this reason these equations cannot be integrated by normal means and approximate numerical methods have been developed

The form of the drag coefficient when plotted against the projectile velocity expressed in terms of the velocity of sound is given in Fig 4

Prior to World War I when shells were fired at low angles of departure (less than 15 or 20 degrees) the Siacci method of calculating trajectories was commonly used During that war, the use

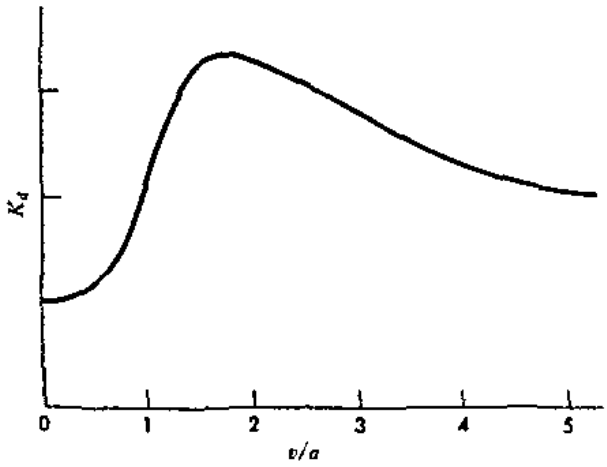


Fig 4 Plot of the drag coefficient K_d The quantity v in the abscissa is the velocity of the projectile and a is the velocity of sound

of trajectories with large angles of departure (quadrant angles) became common and new methods based on numerical integration were introduced in the United States by F Moulton These methods were adapted to ballistics from earlier uses in astronomy

The adequacy of the various approximations which can be used for the calculation of missile trajectories is determined in the main by the velocity of the missile and the elevation of the trajectory In order of complexity the methods are as follows

Vacuum approximation When the velocity is low the quadrant angle small and the projectile rather heavy (so that the range is short and atmospheric effects are small) the equations developed earlier for the vacuum trajectory may be used with good accuracy

Didion Bernoulli method This method may be used when the quadrant angle is low (less than about 20°) and the velocity is less than about 800 ft/sec so that the drag may be considered proportional to the square of the velocity The variables in the equations of motion are separated by employing in certain critical places in the solution the approximation that sec θ = constant Once this assumption is admitted the solution is exact and is found in formulas written around four functions These functions and the appropriate values of the constant representing sec θ are tabulated and in conjunction with the formulas representing the solution of the equations of motion make possible the nearly exact calculation of low velocity low angle trajectories

Siacci method This method is accurate and useful for trajectories of high velocity missiles with low quadrant angles of departure The basic assumptions are that the atmospheric density anywhere on the trajectory is approximately constant and that the angle of departure is less than about 15° The equations of motion can then be put in a form permitting a solution in terms of formulas for t x y and tan θ These formulas used in conjunction with the tables of four functions involved in the solution yield the trajectories of projectiles fired at low angles

Otto Lardillon method For trajectories of missiles with low velocities (so that the drag is proportional to the velocity squared) and quadrant angles of departure that may be high exact solutions of the equations of motion are arrived at by numerical integration and are then tabulated

Numerical integration When projectiles with high velocities and high quadrant angles of departure were introduced all earlier methods used in ballistics failed to give sufficiently accurate solutions The introduction of high velocities and high angles meant increased complexity both in the variation of the drag coefficient so that drag was no longer simply a function of the velocity squared and in the variations of atmospheric density along the trajectory Moulton and his associates introduced the method of approximate numerical integration long used in astronomy to obtain solutions for these trajectories Computing machines have been developed and used extensively to perform the necessary calculations *See* NUMERICAL ANALYSIS

Since the advent of rockets which travel high in the atmosphere the method of numerical integration has been very widely used The complexity of the problem is such that the newer large computers with large data handling capability and large capacity for storage or memory are necessary for rapid solutions

The basic approach in solving the rocket trajectory problem *is to determine the conditions* x y dx/dt dy/dt and θ at the end of burning and to go back along a hypothetical trajectory to determine the coordinates velocity and quadrant angle of departure of an equivalent cannon shell which will pass through the same point with the same velocity vector as the spent rocket Any of the five methods outlined in the preceding discussion may then be used to calculate the resulting trajectory An indication of the best method for use with various combinations of the initial conditions of velocity and quadrant angle is given in the table

Methods of trajectory computation

Velocity	Maximum range	Quadrant angle	Method
Low	Short	Low	Vacuum approximation
Low	Medium	Low	Didion Bernoulli
High	Medium long	Low	Siacci
Low	Medium	Any	Otto-Lardillon
High	Long	Any	Numerical integration

Effect of the earth's curvature The foregoing discussion of trajectories has been based on the assumption that the earth may be considered flat over

missile or projectile becomes great this assumption can lead to serious error thus the analysis must be modified to accommodate the fact that the force of

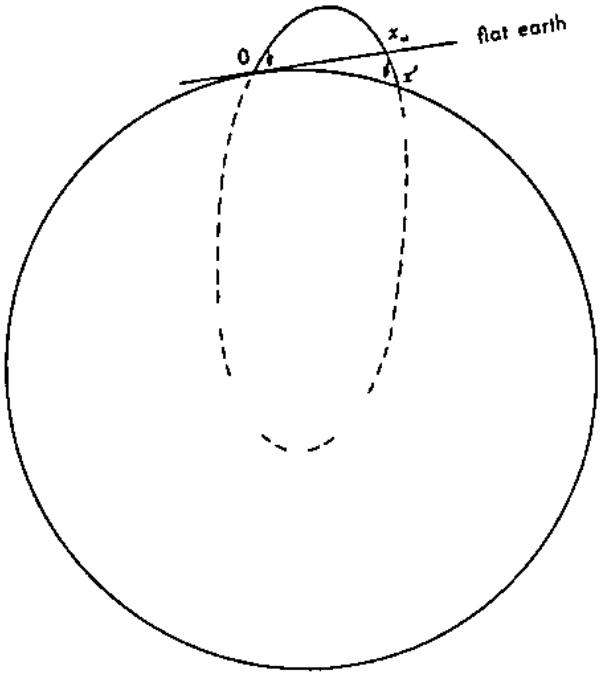


Fig 5 Elliptical trajectory of a long range missile The range of fall is x rather than x_0

gravity varies with height is directed toward the center of the earth and therefore changes direction as the projectile moves forward Also the impact point is depressed because of the earth s curvature and the range therefore is extended

These effects are customarily taken care of by the method of differential corrections but will be discussed here in a somewhat different fashion to clarify the point Assume a nonrotating earth for the time being A projectile hurled along a trajectory away from the surface of the earth is while in motion a satellite of the earth and moves in its trajectory which is really a section of an elliptical orbit about the center of the earth This is shown diagrammatically in Fig 5 All trajectories or orbits with velocities less than about 25 000 ft/sec intersect the surface of the earth The equations of motion for this two body problem have been solved in celestial mechanics except for the complications of drag and varying air density *See* CELESTIAL MECHANICS

The ballistic problem could be solved by treating it as one in celestial mechanics and determining the intersection of the earth s surface with the orbit to give the impact point For projectiles of intermediate range this is not done but rather the technique of differential corrections on existing methods is used However for extremely long range missiles the approach of celestial mechanics employing numerical integration to take account of changing air densities and drag coefficients is used

Effect of the earth's rotation Once the projectile is clear of the muzzle of the gun or the rocket is clear of the launching stand it is a separate entity free of the earth s rotation One component of its initial velocity is the velocity of the surface of the earth at the point of firing For this reason when the projectile arrives at the impact point it will miss by an amount dependent on the azimuth of the trajectory the range and the height of the trajectory This is called the Coriolis effect (*see* CORIOLIS ACCELERATION AND FORCE) For intermediate trajectories such as those with pronounced earth curvature the Coriolis effect is handled by means of differential corrections For very long proper vector velocity for the latitude of launch and by taking account of the rotation of the earth during the time of flight

Stabilization by spinning In order to stabilize a projectile in flight the projectile is frequently spun about its longitudinal axis The resulting gyroscopic stabilization keeps the projectile from tumbling and hence maintains the proper orientation in flight to keep drag at a minimum The spin of a shell is imparted by rifling the gun barrel that of a rocket by canting the exhaust nozzles or the fins While spin does tend to stabilize the orientation in practice the spin axis will precess so that the nose of the projectile follows a spiral path This causes troublesome complexities in the trajectory calculations in that oscillating lift and yaw terms must be introduced The equation of motion of a spinning projectile can be integrated by high speed computing machines

A further difficulty in spinning projectiles fired with large quadrant angles of departure is that the spin in stabilizing the orientation along the original direction causes the projectile to arrive at the point of impact at an undesirable inclination *See* BALLISTICS INTERIOR [J P H]

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Ballistics, interior

Ballistics is that branch of applied physics which deals with the motion of projectiles and the conditions governing that motion Commonly called the science of shooting it is for practical purposes subdivided into exterior and interior ballistics

Exterior ballistics begins at the instant the projectile leaves the muzzle of the gun barrel interior ballistics logically deals with the events preceding this instant that is the events inside the gun barrel The term is also used to refer to the similar events inside the casing of a solid fuel rocket in which case the exhaust blast is regarded as equivalent to the projectile *See* BALLISTICS EXTERIOR

Gas pressure changes If the propelling charge of the cartridge is changed into gas instantaneously the gas pressure curve from the instant of ignition to the instant the projectile leaves the

muzzle would be very nearly an adiabatic curve, quite similar to the curve showing the diminishing potential of a gravitational field In reality, it takes some time for the powder charge to burn, furthermore, various resistance factors must be overcome Therefore, the gas pressure in the gun barrel behind the projectile does not reach its maximum value until after the projectile has started moving inside the barrel The pressure should reach a minimum value at the instant the projectile leaves the gun barrel as shown in Fig 1 hence there is a definite relationship between powder charge gas pressure and barrel length If the pressure is still rather high even when the projectile "unseals" the gun barrel a portion of the propelling charge has been wasted If the pressure drops too low before the projectile reaches the muzzle, the projectile is slowed down inside the barrel, in this case shortening the barrel would actually improve the performance

Minimizing of recoil Even when the pressure drop has been properly calculated (and achieved) the exit velocity of the powder gases is still 2 2½

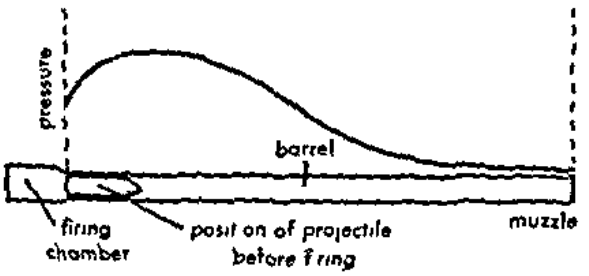


Fig 1 Gas pressure in gun barrel

times the muzzle velocity of the projectile This fact can be utilized to prevent or to minimize the recoil of the weapon by means of the muzzle brake first developed by Schneider Creusot in France The muzzle brake deflects the direction of motion of the gases by 120–180° thereby creating what might be called a gas recoil opposite in direction to the projectile recoil Recoilless guns eliminate recoil by discharging a quantity of the propelling gases through the rear

Resistance factors The expanding gases in the gun barrel have to overcome the following main resistance factors (in addition to their own inertia) (1) the inertia of the projectile (2) the friction in the barrel caused by the copper driving bands against the lands and grooves of the rifling and (3) the inertia of the air inside the barrel between the nose of the projectile and the muzzle of the gun This last factor is rather unimportant for small guns or for short barreled pieces of any caliber and is often overlooked However it does influence performance in large and long barreled pieces especially when the muzzle velocity of the projectile is much larger than Mach 1 since in that case the air is not only accelerated but also compressed The existence of this "plug" of compressed air often makes the experimental determination of the muzzle velocity difficult

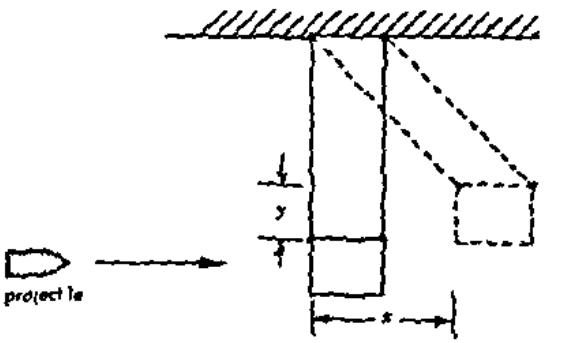


Fig 2 Ballistic pendulum before projectile impact (solid lines) and after projectile impact (dotted lines) Measurement of the distances x and y and knowledge of the mass and initial velocity of the projectile give the projectile's momentum

Further energy losses are caused by gas leakage by the recoil motion of the gun barrel and by the heating of the barrel This last phenomenon not only absorbs energy but may increase the leakage It can easily be seen that there are many mutually interdependent factors present which make an exact calculation impossible Empirical values must often be used

Measuring devices At first the only tool of the ballistician was the ballistic pendulum (Fig 2) which caught the projectile and indicated its momentum by the magnitude of its swing This method was first suggested by J D Cassini in 1707 and was brilliantly utilized by Benjamin Robins some 30 years later However it permitted only indirect conclusions as to gas pressure inside the barrel The first useful device for measuring gas pressure was A Noble's copper pressure gage in which a copper plug was deformed by the gas pressure (Fig 3) The copper pellet (a lead pellet is used for weapons where the gas pressure is expected to be low) has remained the most useful tool since its introduction in 1860 Not until about 1910 was

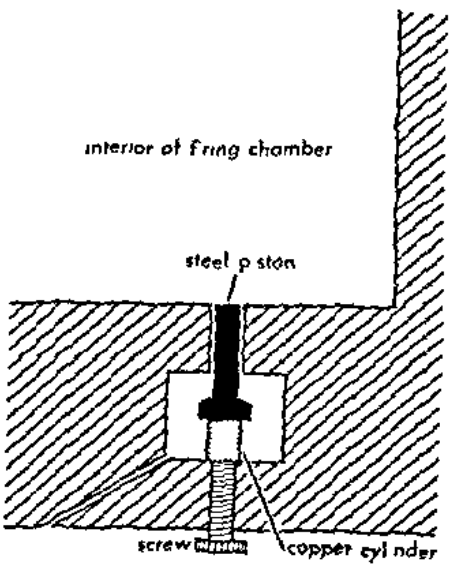


Fig 3 Diagram of Noble's copper

it supplemented by the piezoelectric gage (suggested originally by Sir J J Thomson) which consists of a tourmaline disk that generates electric currents proportional to the pressure to which it is subjected

In addition to these devices strain gages are used which have shown among other things that a gun barrel momentarily expands slightly as the projectile moves toward the muzzle

Basic equations The main problem of interior ballistics has been defined by H Athen as follows

For a gun of which caliber barrel length firing chamber volume weight of projectile and type and weight of the propelling charge are known the following factors must be determined duration of burning of the powder charge duration of travel of the projectile inside the barrel gas pressure inside the barrel and projectile velocity Of these factors the peak gas pressure and the muzzle velocity are especially important since they can most easily be checked experimentally and are also of most practical value to the designer

Investigations of this problem led to three equations which are known as the energy equation the combustion equation and the equation of motion

Energy equation The derivation of the energy equation is based on the well known van der Waals equation

$$\left(p + \frac{\beta}{s_v^2}\right) \quad (s_v - \alpha) = RT$$

where p is the pressure T the absolute temperature R the gas constant s the specific volume of the gas α the volume of the gas for $T = 0$ and β a constant It is empirically known that β/s^2 is nearly zero it is further known that for each type of powder RT (T is the combustion temperature) is a constant value which is designated f and is called the specific pressure If the volume of the closed space in which the powder is burned is designated as S and the weight of the powder as W W/S might be called D (density of the charge) and one obtains the much simplified Abel equation

$$p = f\frac{D}{1 - \alpha D}$$

It has been shown that this equation holds true for pressures from 1200 to 4500 kg/cm By introducing a few additional factors Resal's equation (the energy equation) is obtained

Equations of combustion and motion The combustion equation is

$$y = A(y)p^k$$

where $y = dy/dt$, (y) is a function determined by the grain shape of the charge and A is a constant characteristic for the propellant under investigation The factor k is generally taken to be equal to unity

The equation of motion, finally, is derived from Newton's second law It is

$$v = t\frac{dt}{dx} = \frac{qp}{\mu}$$

See EXPLOSION AND EXPLOSIVE, GAS [WLY]

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Balloon

A vehicle for traveling through the atmosphere A balloon consists essentially of a container for a gas which is lighter than air resulting in a combination which displaces a volume of air of greater weight To this gas bag is often attached a payload consisting of instruments a basket or car to carry passengers or any other heavier than air object that the balloon is to carry A balloon may float freely in the air with the wind or it may be driven and steered in a preferred direction by a suitable propulsion and control system The powered vehicles are known as dirigibles or airships A captive balloon is attached by cable to an anchorage on the ground Early balloons were fabricated from a variety of materials such as oiled silk paper goldbeater's skin and rubber with or without a base cloth The lifting gas often was heated air coal

struments aloft is made of a synthetic rubber (neoprene) Its average daytime performance can be summarized as follows

Weight of balloon	1000–1400 g
Payload	1700 g
Free lift	1000–1500 g
Amount of hydrogen used	120 ft³
Approximate initial diameter	6½ ft
Approximate diameter at 90 000 ft	25 ft
Unstrained thickness	0 004 in
Thickness at burst	0 0002 in
Ascensional rate	1000 (+100 ft/min) (−50 ft/min)
Altitude attained	90 000 ft (80% of time) 100 000 ft (37% of time)

Large plastic balloons have reached approximately 140 000 ft during the daytime and have ranged in size up to 6 000 000 ft³ Attempts have been made to improve the ascensional rate and specially shaped balloons have attained stable rates of climb in excess of 2000 ft/min up to an *altitude of 45 000 ft*

Manned free balloons Basically the man carrying free balloon is made up of the following parts

gas bag net basket load ring gas valve appendix rip cord gland rip panel and drag rope (Fig 1)

The gas bag is usually spherical in shape and is made up of any substance which has good gas retaining qualities is light in weight and is of sufficient strength to withstand the loads imposed upon it These requirements permit the use of anything from paper to high grade balloon cloth The spherical shape is most often used because it permits the storage of the greatest volume of gas with the least amount of material and is the natural shape the body would approach under pressure when fabric strains became practically equalized throughout the surface (This of course is a basic idealized assumption and varies with application of load) The gas bag is made up of a large number

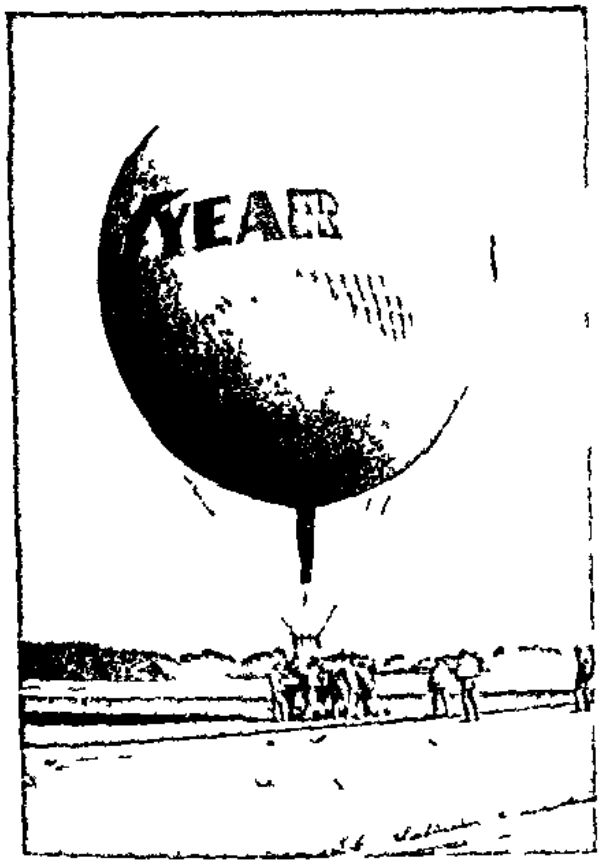


Fig 1 Training balloon being prepared for take-off

of flat surfaces cut as gores or sections of a cone cemented and sometimes sewed together to make a generally spherical shape When inflated the elasticity of the material permits it to take on a double curvature thus resulting in an almost perfect surface of revolution

If the balloon is to support a load the gas bag is sometimes covered with a net made of a network of cords which distributes the load over the entire bag Thus the fabric itself receives little local strain and can be made extremely light in weight Cotton is the most common net material although Italian hemp silk and linen cords have been used The net is made of diamond shaped meshes which are attached to a crow's foot and finally to a foot rope

The container which carries the load and passengers is called the basket and as the name implies it is usually made of reed or willow It is extremely light weighing only about 60 lb and is usually about 3½ ft high by 3 ft wide by 3½ ft long The floor and rim are reinforced to take the strain of the passengers and suspension ropes This basket can carry three persons with some crowding Some of the larger manned balloons use a pressurized sealed compartment A convenient method of attaching the basket to the foot ropes of the net is accomplished by means of the load ring This is usually made of wood and is about 2 3 ft in diameter its thickness depending upon the size of the balloon

The gas valve is used to discharge gas from the balloon and is located at the extreme top where the head of gas is the greatest A rope to operate this valve passes *down through the balloon through the* appendix and into the basket The valve is held shut by rubber springs which prevent it from leaking when not in use

Located directly opposite the valve is the appendix which is at the lowest point of the bag and is in the form of a vertical sleeve affording an opening serving three purposes an inlet for gas during inflation an opening for the valve cord and a safety valve It is left open during almost the entire flight and permits expanding gas to escape without bursting the balloon It is made large enough to permit the expansion of gas equivalent to a vertical velocity of 1000 ft min

The rip cord gland is similar to but smaller than the appendix and serves as an opening in the balloon for the rip cord which passes through it to the top of the balloon The rip cord is kept separate from the appendix so that it will not tangle with the valve cord because the rip cord is used only when it is desired to remove all of the gas from the balloon

The panel to which the rip cord is attached is called the rip panel it extends about one-fourth or one-fifth of the circumference of the balloon along one of its meridians When the rip cord is pulled this panel is torn open and all the gas in the balloon escapes rapidly This action is necessary in landing to prevent the dragging of the basket and passengers over the ground

The drag rope is a long heavy rope carried in the basket and permitted to hang over the side and drag on the ground in order to lighten the basket It is often used when traveling under a cloud in order to save ballast or at night when it is desired to ride low and also when landing from a high altitude Its length and weight are functions of the size of the balloon and can be determined from empirical formulas The length of the drag rope which will keep the balloon above tall trees is $5D$ plus 60 ft where D is the diameter of the balloon in feet The proper weight of the drag rope is

equal to $0.02V\psi\ (5D + 60)/3.5D$ where V is the volume of the balloon and ψ is the lift of 1 ft³ of the lifting gas This equation is based on a weight of drag rope which will stop a descent with a force equivalent to a contraction of 2% of the volume of the balloon

Early manned free balloons which used heated air as the lifting medium made primarily experimental and demonstrative flights The cotton rubber bags and wicker baskets of the later version could be reused many times and became standard for training lighter than air crews in the use of aerostatic principles Large sized balloons made of cotton rubber fabric and later of polyethylene or Mylar film with a pressurized gondola as payload provided the means for men to reach altitudes of approximately 100,000 ft for periods of many hours These men remained aloft long enough to carry on scientific investigations of upper atmospheric phenomena These balloons ranged in size up to 3 000 000 ft³ and carried payloads of approximately 1700 lb Development of stronger lighter materials and improved fabrication and handling techniques will permit increases in altitude and payload

For the flight of manned plastic balloons into the stratosphere light gage material such as polyethylene about 1 5 mils thick is used In these flights the launching (Fig 2) is the most critical period because the majority of the balloon is loose material with a gas bubble of about 1–1½% of the expanded volume at the apex (Fig 2) At this time slight winds can readily damage the balloon and therefore highly experienced crews use a special technique of releasing the balloon and payload in a programmed manner to minimize punishment to the system

These balloons distribute the weight of the manned capsule into the seams of the balloon itself and do not use a separate net as in the training balloon described above These systems also usually contain a large parachute built into the rigging to permit a safe descent in the event of balloon failure (Fig 3) If balloons of this type are to be used for extended service consideration should be given to coated lightweight synthetic fabrics *See* AEROSTAT [KAR, RSR]

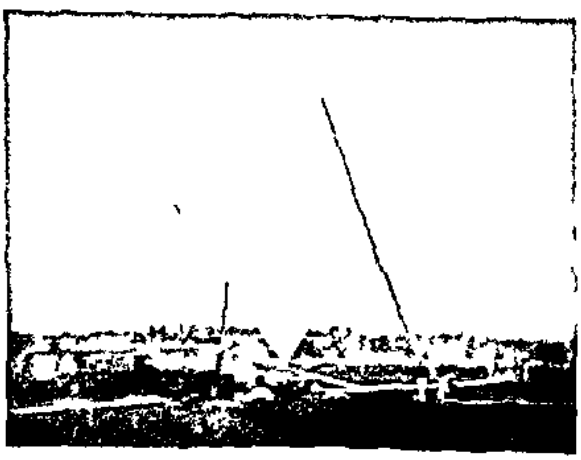


Fig 2 Inflation of polyethylene stratosphere balloon



Fig 3 Polyethylene balloon and capsule soon after launching

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Balsa

A fast growing tree, *Ochroma lagopus*, widely distributed in tropical America, especially in Ecuador The leaves are simple, angled or lobed and the flowers are large yellowish white or brownish and terminal on the branches

With plenty of room for growth in a rich well drained soil at low elevations trees may attain a height of 50–60 ft and a diameter of 24–30 in in 5–6 years Under such conditions the wood is very light and soft weighing about 6 8 lb/ft³ when dry However under adverse conditions the wood is heavier and may weigh 25 lb/ft³ Culture is important for if the trees are injured only slightly the wood develops a hard and fibrous texture thereby losing its commercial value To secure a uniform product the trees must be grown in plantations

The wood decays easily in contact with the soil and is subject to sapstain if not promptly dried Seasoned lumber absorbs water quickly but this can be largely overcome by waterproofing Balsa became popular during World War I and large quantities were used for life preservers and mine buoys It owes most of its present commercial applications to its insulating properties Containers made of balsa are used successfully for the shipment of precooled perishable commodities such as yeast dairy products fresh fruits meat and fish These are more economical than ordinary wooden boxes being much lighter and usable for from 50 to 100 round trips Balsa has sound deadening qualities and is also used under heavy machinery to prevent transmission of vibrations Certain other woods are lighter but they lack the strength of balsa and are not available in sufficient size or quantity to be commercially important The heartwood of balsa is pale brown or reddish whereas the sapwood is nearly white often with a yellowish or pinkish hue Luster is usually rather high and the wood is odorless and tasteless *See* FOREST AND FORESTRY TREE [A H C]

Baltic Sea

An intracontinental mediterranean type sea connected with the North Sea by Skagerrak Kattegat and the Danish Sounds which include Little Belt

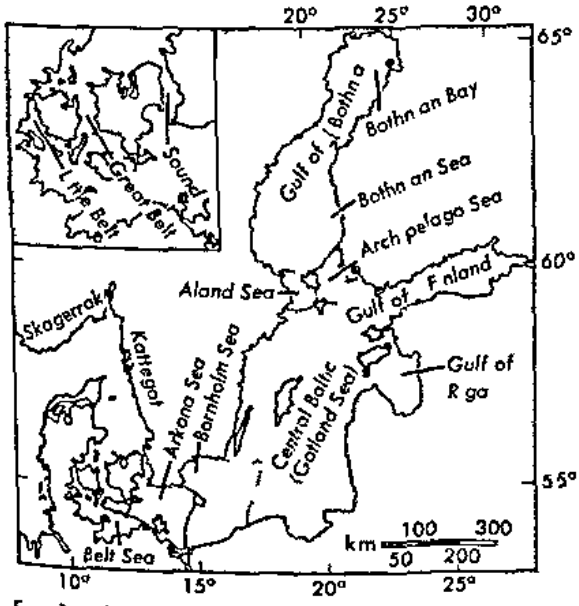


Fig 1 Areas of the Baltic Sea

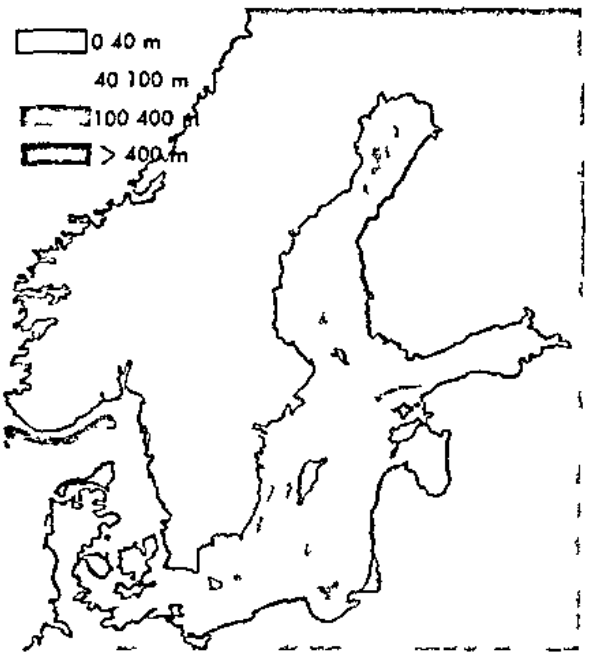


Fig 2 Depth chart of the Baltic Sea (*Adapted from Geographical Society of Finland A General Handbook on the Geography of Finland Fennia 72 1952*)

(Lillebaelt) Great Belt (Storebaelt) and the Sound (Öresund) The total area including the Gulf of Bothnia and the Gulf of Finland is 154 000 mi² (400 000 km²) The mean depth is only 55 m and the greatest depth off Landsort is 459 m (Figs 1 and 2)

Geologic history The Baltic Basin is an old depression in Fennoscandian primary rocks Its waters were part of the ocean several times before the last glacial age Among the postglacial stages are the Baltic Ice Lake Yoldia Sea Ancylus Lake and Littorina Sea (Fig 3) The Baltic Ice Lake was a meltwater lake dammed up by the edge of the retreating ice sheet and by the Belt and Sound region which was higher then than at present Yoldia Sea was formed when the ice sheet retreated north of central Sweden Lake water drained across the present great lake region after which salt water entered the basin from the ocean Later this sea was connected with the White Sea Ancylus Lake came into existence when the basin waters were again separated from the ocean by land upheaval and basin tilting but with an outlet westward across the lake region of Sweden Littorina Sea the early stage of the present Baltic was initiated about 6000 or 5000 B C as crustal sinking produced the Danish Sounds The waters of this sea were much more saline than those of the present Baltic *See* WARPING EARTH CRUST

Circulation and salinity The area drained by rivers emptying into the Baltic is about four times the size of the sea area Annual runoff and precipitation at sea less evaporation loss is equal to 1/40 of the Baltic Sea s volume This fresh water outflow in the upper layers leaves the Baltic through the Sounds Beneath it the more saline and

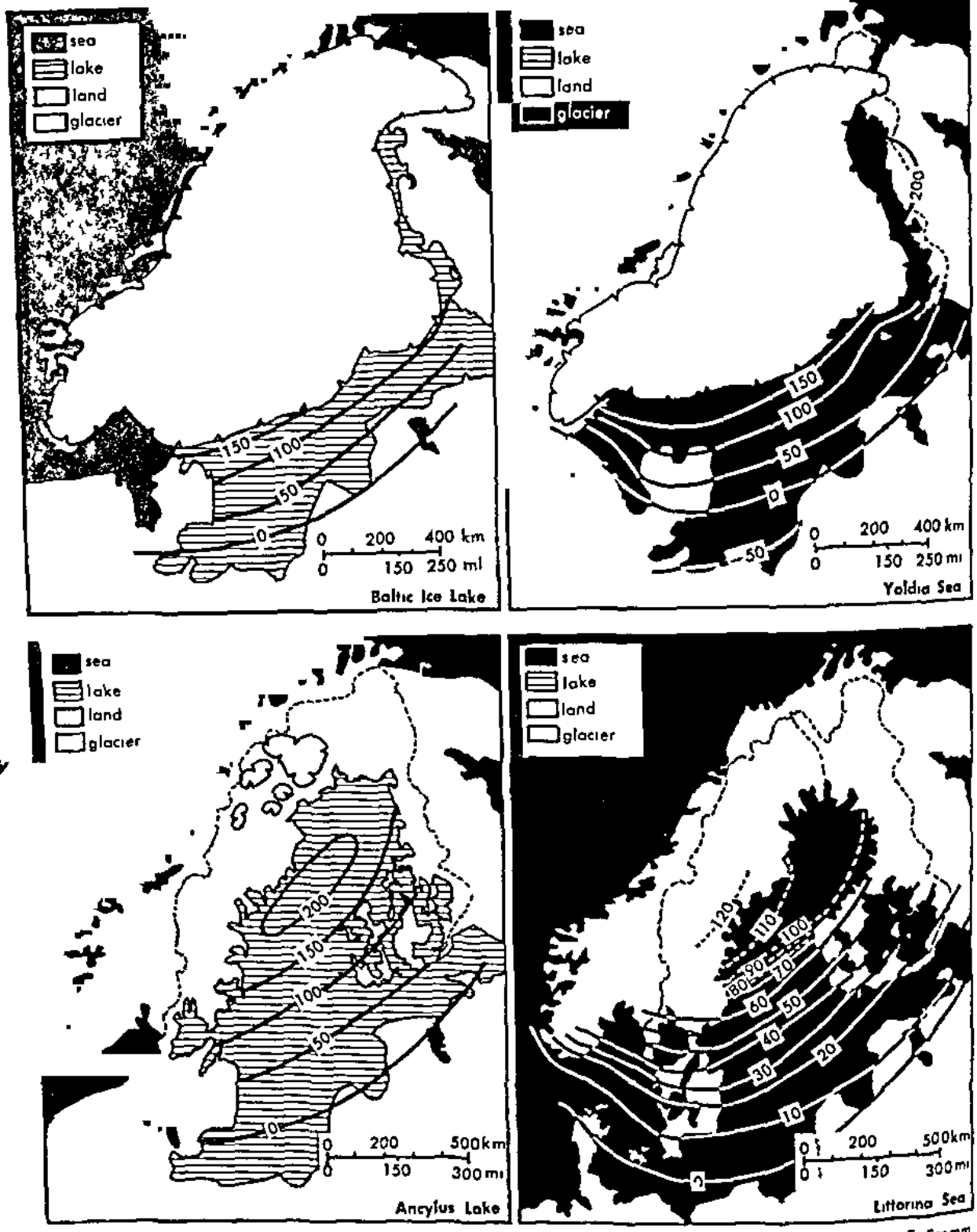


Fig 3 Successive water bodies in the Baltic Sea basin during the last deglaciation Isobases (contour interval in meters) show present positions of the related strand lines with respect to existing sea level (*After E Fromm Atlas over Sverige 1953, in R F Flint Glacial and Pleistocene Geology, Wiley, 1957*)

denser water from Kattegat penetrates the basin along the deeper parts Difference in surface and bottom salinity is thus very marked

convectional processes reach a depth of about 60 m

Salinity ranges, parts per thousand, in Baltic Sea

Area	Surface	Bottom
Kattegat	15–20	30–36
Inside Danish Sounds	8–10	15–20
Middle Baltic	6–7	9–12
Innermost gulfs	0–1	1–4

The annual range in temperature in surface waters is 0–18°C and in deeper waters 2 5°C *See* OCEAN CURRENTS THERMOCLINE

Water level Tidal ranges are small in the Baltic off Copenhagen about 6 in off Stockholm less than 1 in and off Leningrad 6 in Drift currents are generally about 0 2 knot but speeds of 1 5 knots may occur Storms cause abrupt changes in water level as much as 10 ft in the northern part of the Gulf of Bothnia and even more at Leningrad

Ice In winter severe storms make navigation hazardous among the numerous shallows and rocks Navigation also is impeded by sea ice from early December to early May Ice disappears in the northern Baltic in early June In very severe winters the whole Baltic is covered with ice On the average the area of maximum coverage is about 83,000 mi (214 000 km) In the northern Baltic fast ice may be 2½ ft thick

Ecology The Baltic Sea is the largest brackish water area of the world Its low productivity may be attributed in part to the narrowness of the Danish Sounds and to the low nutrient content of northern rivers Commercial catches in the Baltic consist of herring salmon sprat and freshwater fish (whitefish pike perch and trout) in the northern gulfs herring cod salmon and flounder in the middle Baltic and herring cod eel salmon flounder and plaice in the southwest Baltic [F H]

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Bamboo

The common name of various perennial ornamental grasses There are 5 genera with approximately 280 species They have a wide distribution but occur mainly in tropical and subtropical parts of Asia Africa and America extending from sea level to an elevation of 15 000 ft Their greatest development occurs in the monsoon regions of Asia The plants grow very rapidly From the jointed rhizome numerous usually erect straight stems arise which at their full height produce dense masses of horizontal branches The giant bamboo *Dendrocalamus giganteus* the largest known grass attains a height of 120 ft and a diameter of 8–12 in Most are woody a few are herbaceous or climbing The economic uses of bamboo are numerous and varied The seeds and young shoots are used as food The leaves make excellent fodder for cattle In varying sizes the stems are used for pipes timber masts bows furniture bridges cooking vessels buckets wickerwork paper pulp cordage and weaving Entire houses are made of bamboo stems Certain bamboos have been naturalized in California Louisiana and Florida *See* GRAMINALES [P D S]

Banana

A large tropical plant also its edible fruit which occurs in hanging clusters is usually yellow when ripe and is about 6–8 in long The banana belongs to the family Musaceae The banana of commerce *Musa sapientum* believed to have originated in the tropics was one of the earliest fruits cultivated by man For commercial production the plant requires a tropical climate within the temperature range 50–105°F and a constant supply of soil moisture provided by rainfall or irrigation (*see* IRRIGATION OF CROPS) Bananas must be protected from mechanical injury because strong winds tear the leaves or blow down the plants

The plant portion above the ground is a false stem (pseudostem) consisting of several concentrically formed leaves from the center of which develops the inflorescence stalk *See* FLOWER (BOTANY) INFLORESCENCE The rhizome or true stem is underground *See* STEM (BOTANY) Near the tip of the flower stalk are several groups of sterile male flowers subtended by brilliant purple bracts The lower female flower clusters on the same stalk give rise to the fruit and contain aborted stamens (male organs) The single fruits are called fingers a single group of 8–12 fingers is termed a hand and the several (6–18) hands of the whole inflorescence comprise the stem

After the single fruiting stalk has produced the fruit bunch the whole pseudostem is cut off at the ground allowing one of several new buds or suckers at the base of the underground stem to develop into a new plant The fruit bunch requires 75–150 days to mature and must be removed from the plant to ripen properly Chilled banana fruits do not soften normally hence for best edibility the fruit is kept well ventilated at room temperature

Kinds and distribution Banana fruits of commerce set without pollination by parthenocarpy and hence are seedless (*see* REPRODUCTION

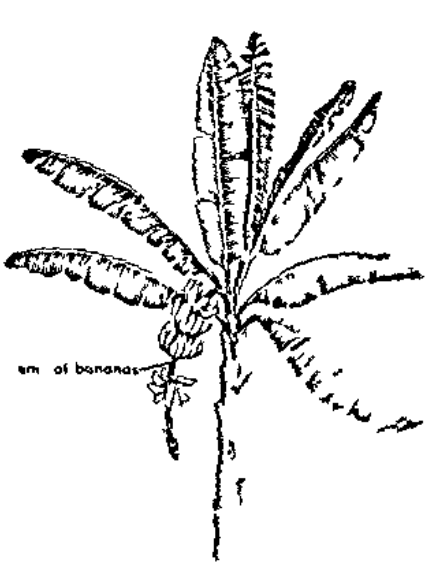


Fig 1 Pseudostem and fruits of the (plant height 1
Fieldbook of



Fig 2 Banana plants 20–30 ft tall are sprayed with Bordeaux mixture for the control of *Cercospora musae* the fungus causing Sigatoka disease Spray is directed up over the plants and pumped through permanent pipelines installed throughout the farms (*United Fruit Company*)

PLANT) When mature most varieties are yellow, although fine red skinned types are well known The most important commercial variety, Gros Michel, is one of several h ndred

lized locally The more starchy bananas, known as plantains *M paradisiaca*, must be cooked before they can be eaten

Yearly world production averages nearly 100 000 000 bunches over 60% of which are consumed in the United States Three fourths of the world's bananas are grown in the Western Hemisphere The greatest production occurs in Mexico, Guatemala Nicaragua, and other tropical Central and

nomical cultivation of the fruit *See* FRUIT (BOTANY), FRUIT (TREE) [C A S]

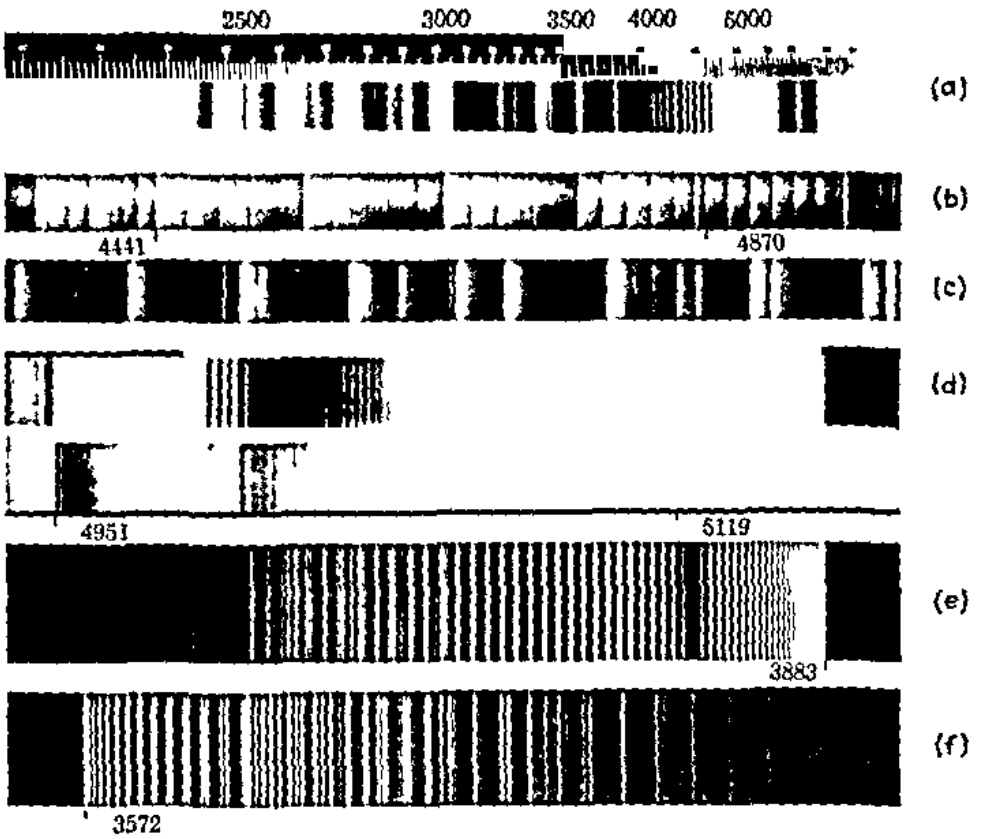
Banana diseases Among the principal diseases of the commercial banana is Sigatoka *a wide* spread disease caused by the fungus *Cercospora musae* It must be controlled for successful commercial production Copper fungicides are quite effective, especially when applied by means of permanently installed pipes and a central pumping station, oil mist sprays applied by helicopter, offer possibilities for more efficient control (*see* FUNGISTAT AND FUNGICIDE) Panama wilt, caused by the fungus *Fusarium oxysporum* f *cubense*, is widespread and damaging and results in the abandonment of extensive acreages of land once profitably planted to bananas Control is difficult, methods include prolonged flooding of plantations following an outbreak of wilt, development of commercially acceptable resistant varieties, and use of systemic fungicides Moko, a bacterial wilt which occasionally becomes damaging, can be controlled readily by appropriate sanitary practices, including destruction of diseased banana plants Bunchy top, a virus disease, occurs only in Oceania Elimination of diseased plants and the control of insect vectors are recommended control measures (*see* PLANT VIRUS) Fruit rots, fungus diseases, occur in the field, in packing houses, in transit, or in storage Careful handling, use of fungicides, and control of temperature and humidity in cold storage minimize losses from fruit rots *See* FRUIT (TREE) DISEASES, PLANT DISEASE CONTROL.

[J C H]

Band spectrum

A spectrum consisting of groups or bands of closely spaced lines Band spectra are characteristic of molecular gases or chemical compounds When the light emitted or absorbed by molecules is viewed through a spectroscope with small dispersion, the spectrum appears to consist of very wide asymmetrical lines called bands These bands usually have a maximum intensity near one edge, called a band head and gradually decreasing intensity on the other side In some band systems, the intensity shading is toward shorter waves, in others toward longer waves Each band system consists of series of nearly equally spaced bands called progres-

Shown on the opposite page are photographs of band spectra The wavelengths of the spectra are in angstroms (*a*) Spectrum of a discharge tube containing air at low pressure Four band systems are present the γ-bands of NO (2300–2700 A), negative nitrogen bands (N_2^+, 2900–3500 A), second positive nitrogen bands (N_2, 2900–5000 A), and first positive nitrogen bands (N_2, 5500–7000 A) (*b*) Spectrum of high frequency discharge in lead fluoride vapor Bands fall in prominent sequences (*c*) Spectrum showing part of one band system of SbF, obtained by vaporizing SbF into active nitrogen Spectra in (*b*) and (*c*) taken with large quartz spectrograph (*after Rochester*) (*d*) Emission and absorption band spectra of BaF Emission from a carbon arc cored with BaF_2 absorption of BaF vapor in an evacuated steel furnace Bands are closely grouped in sequences Spectra were obtained in the second order of a diffraction grating as were spectra in (*e*) and (*f*) (*e*) CN band at 3883 A from argon discharge tube containing carbon and nitrogen impurities (*f*) Band in ultraviolet spectrum of NO, obtained from glowing active nitrogen containing small amount of oxygen (*From F A Jenkins and H E White Fundamentals of Optics, 3d ed., McGraw-Hill, 1957*)



sions corresponding bands of different progressions form groups called sequences When spectroscopes with adequate dispersion and resolving power are used it is seen that most of the bands obtained from gaseous molecules actually consist of a very large number of lines whose spacing and relative intensities if unresolved explain the appearance of bands of continua (parts *e* and *f* of the figure) *See* MOLECULAR STRUCTURE AND SPECTRA [W F M]

Band theory of solids

A quantum mechanical theory of the motion of electrons in solids Its name comes from the fact that it predicts certain restricted ranges or bands for the energies of electrons in solids

Suppose that the atoms of a solid were separated from each other to such a distance that they did not interact The energy levels of the electrons of this system would then be those characteristic of the individual free atoms and thus many electrons would have the same energy Now imagine the atoms being slowly brought closer together As the distance between atoms is decreased the electrons in the outer shells begin to interact with each other This interaction alters their energy and in fact broadens the sharp energy level out into a range of possible energy levels called a band One would expect the process of band formation to be well advanced for the outer or valence electrons at the observed interatomic distances in solids Once the atomic levels have spread into bands the valence electrons are not confined to individual atoms but may jump from atom to atom with an ease that increases with the increasing width of the band

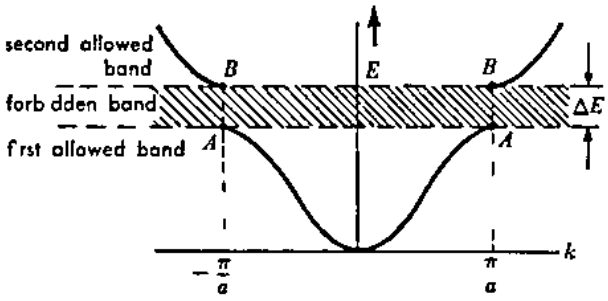
Although energy bands exist in all solids so little is known of the electronic structures of disordered materials such as glass that the term energy band is usually used in reference only to ordered substances that is those having well defined crystal lattices In such a case an electron energy state can be classified according to its crystal momentum $\mathbf{p}$ or its electron wave vector $\mathbf{k} = \mathbf{p}/\hbar$ (where $\hbar$ is Planck s constant h divided by 2π) If the electrons were free the energy of an electron whose wave vector is k would be

$$E(\mathbf{k}) = E_0 + \hbar^2\mathbf{k}^2/2m_0 \qquad (1)$$

where E_0 is the energy of the lowest state of a valence electron and m_0 is the electron mass In a crystal however the electrons are not free because of the effect of the crystal binding and the forces exerted on them by the atoms consequently the relation $E(\mathbf{k})$ between energy and wave vector is more complicated The statement of this relationship constitutes the description of an energy band

A knowledge of the energy levels of electrons is of fundamental importance in any attempt to compute the electrical magnetic optical or thermal properties of solids

Allowed and forbidden bands The bands of possible electron energy levels in a solid are called allowed energy bands It often happens that there are also bands of energy levels which it is impossible for an electron to have in a given crystal Such bands are called forbidden bands or gaps. The allowed energy bands sometimes overlap and sometimes are separated by forbidden bands The pres



Plot of electron energy E vs wave vector k for a monatomic linear lattice of lattice constant a (*After* C Kittel *Introduction to Solid State Physics* 2d ed Wiley 1956)

ence of a forbidden band or energy gap immediately above the occupied allowed states (such as the region A to B in the illustration) is the principal difference in the electronic structures of a semiconductor or insulator and a metal In the first two substances there is a gap between the valence band of normally occupied states and the conduction band which is normally unoccupied In a metal there is no gap between occupied and unoccupied states

The presence of a gap means that the electrons cannot easily be accelerated into higher energy states by an applied electric field Thus the substance cannot carry a current unless electrons are excited across the gap by thermal or optical means

Effective mass When an external electromagnetic field acts upon the electrons in a solid the resultant motion is not what one would expect if the electrons were free In fact the electrons behave as though they were free but with a different mass which is called the effective mass This effective mass can be obtained from the dependence of electron energy on the wave vector $E(\mathbf{k})$ in the following way

Suppose there is a maximum or minimum of the function $E(\mathbf{k})$ at the point $\mathbf{k} = \mathbf{k}_0$ The function $E(\mathbf{k})$ can be expanded in a Taylor series about this point For simplicity assume that $E(\mathbf{k})$ is a function of the magnitude of k only that is is independent of the direction of k Then

$$E(\mathbf{k}) = E(\mathbf{k}_0) + \tfrac{1}{2}(\mathbf{k} - \mathbf{k}_0)^2 \left(\frac{d^2E}{dk^2}\right)_{\mathbf{k}_0} \qquad (2)$$

approximately By analogy with Eq (1) a quantity m^* with the dimensions of a mass can be defined by the relation

$$\hbar^2/m^* = \left(\frac{d^2E}{dk^2}\right)_{\mathbf{k}_0} \qquad (3)$$

The quantity m^* is called the effective mass of electrons at $\mathbf{k}_0$ For many simple metals the average effective mass is close to m_0 but smaller effective masses are not uncommon In indium antimonide a semiconductor the effective mass of electrons in the conduction band is 0 013 m_0 In a semiclassical approximation an electron in the solid responds to an external, applied electric or magnetic field as though it were a particle of mass m^* The equation of motion of an electron is then

$$m^* \frac{d\mathbf{v}}{dt} = e(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \qquad (4)$$

where v is the electron velocity, E the electric field B the magnetic induction, and e the charge of the electron

It may happen that the energy $E(\mathbf{k})$ does depend upon the direction of k In such a case the effective mass is a tensor whose components are defined by

$$\hbar^2/m_{ij}^* = \left(\frac{\partial^2 E}{\partial \mathrm{k}_i\, \partial \mathrm{k}_j}\right)_{\mathbf{k}_0} \qquad (5)$$

Equation (4) remains valid with a tensor m^*

Transitions between states Under external influences such as irradiation electrons can make transitions between states in the same band or in different bands The interaction between the electrons and the vibrations of the crystal lattice can scatter the electrons in a given band with a substantial change in the electron momentum but only a slight change in energy This scattering is one of the principal causes of the electrical resistivity of metals *See* Resistivity

An external electromagnetic field (for example visible light) can cause transitions between different bands In such a process momentum must be conserved Because the momentum of a photon h/c (where ν is the frequency of the light and c its velocity) is quite small the momentum of the electron before and after collision is nearly the same Such a transition is called vertical in reference to an energy band diagram Conservation of energy must also hold in the transition so absorption of light is possible only if there is an unoccupied state of energy $h\nu$ available at the same k as the initial state These transitions are responsible for much of the absorption of light by semiconductors in the visible and near infrared region of the spectrum

Energy band calculation As is the case for any quantum mechanical system the energy levels of electrons in solids are determined in principle by solution of the Schrodinger wave equation for the system however the enormous number of particles involved makes solution of this equation completely impossible so that approximate methods are required The basic approximation is that of the Hartree-Fock equation The wave function of the many electron system is written as a determinant of one electron functions in order to satisfy the Pauli exclusion principle The one electron functions themselves satisfy a Schrodinger like equation in which each electron moves in the field of the nuclei of the system and the average field of all other electrons There is an additional exchange term which takes account of the reduction of the average electronic repulsion because the probability of close encounters of electrons of parallel spin is reduced by the Pauli exclusion principle The Hartree Fock equations are quite compli

tated In practice solution of the actual equations is seldom attempted, further approximations are made so that the one-electron function $u(r)$ which describes the behavior of an electron in state i, satisfies the equation,

$$\frac{-\hbar^2}{2m_0}\nabla^2 u_i(r) + V_i(r)u_i(r) = E_i u_i(r) \qquad (6)$$

in which V_i represents the potential energy of an electron in state i because of the nuclei and other electrons and E_i is the energy eigenvalue The energy V_i is *periodic in space with the periodicity of the crystal* The *one electron* Schrodinger equation is only approximate The principal defect is the neglect of the details of the interaction or correlation between the electrons particularly those of antiparallel spin Determination of an adequate crystal potential *is the principal physical problem in the calculation of energy levels in solids* Several techniques exist for solving the wave equation at least for certain states notably the Wigner Seitz method and the orthogonalized plane wave method

Experimental determination Experimental information concerning the energy levels of electrons *in solids is not so easy to obtain as in the case of* free atoms The semiconductors silicon and germanium are the most thoroughly investigated systems Much less detailed information is available for any of the metals

The *smallest width of the characteristic energy* gap between the valence and conduction bands can often be determined by measuring the wavelength at which the fundamental optical absorption begins The effective masses of electrons in the conduction band and holes (unoccupied energy states) *in the valence band* are most accurately determined by cyclotron resonance For a discussion of this *see* CYCLOTRON RESONANCE EXPERIMENTS *See also* BRILLOUIN ZONE CRYSTAL STRUCTURE, EXCITON FREE ELECTRON THEORY OF METALS HOLES IN SOLIDS KRONIG PENNEY MODEL QUANTUM THEORY NONRELATIVISTIC SEMICONDUCTOR WIGNER SEITZ METHOD [J C]

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Bandwidth requirements (communications)

The difference between the limiting frequencies of a frequency band containing the useful components of a signal is called the bandwidth expressed in cycles per second (cps) Each communication system requires some optimum bandwidth for the satisfactory transmission of intelligence

Electrical communications involve the variation of *some electrical quantity as a representation* of the signal to be transmitted In the case of simple wire telephony where the speech sound waves cause variation of current in the line the bandwidth required is the same as the desired bandwidth of the signal to be reproduced or about 3000 cps In wire telegraphy the bandwidth required depends on the signaling speed used

When the signal to be transmitted causes the variation of the amplitude, phase frequency or pulsing of a carrier wave the process is known as modulation (*see* MODULATION) Bandwidth requirements then depend on the frequency stability of the carrier wave the character of the modulation process and the bandwidth of the modulating signal The minimum bandwidth possible is equal to the bandwidth of the modulating signal The bandwidth of the modulating signal for a given message may however be altered by encoding the message so as to require either greater or less signal bandwidth than that of the information in its original form *See* INFORMATION THEORY

Over all bandwidth requirements for the transmission and reception circuits of a simple amplitude-modulation system may be determined from the frequency response specifications for the system For example if transmission of voice frequencies up to 3000 cps is required the radio-frequency bandwidth when *both* upper and lower *sidebands* are included must be at least 6000 cps A single sideband system transmitting the upper or lower sideband only occupies a bandwidth of about 3000 cps

In frequency modulation systems when the input signal to noise ratio exceeds a certain threshold value the signal-to-noise power ratio is improved at the expense of increased bandwidth relative to that of a simple amplitude modulation system in accordance with the following relation

$$\frac{\text{FM signal/noise ratio}}{\text{AM signal/noise ratio}} = 3\frac{F^2}{B^2}$$

where F is the greatest frequency deviation of the carrier from the quiet or unmodulated condition and B is the highest modulation frequency *Other* kinds of modulation systems such as pulse modulation also provide improved signal to noise ratio in exchange for greater required bandwidth and have an improvement threshold

Bandwidth requirements determine the amount of radio spectrum needed by communications systems In allocating the spectrum to the many radio services and stations their bandwidth requirements are taken into account For discussion of factors affecting such allocations *see* RADIO SPECTRUM ALLOCATIONS

Transmitted signal spectra can be computed when the waveform of the modulating signal and modulation parameters are known by use of Fourier analysis for amplitude and pulse-modulation systems and of Bessel functions for frequency modulation systems

Radio communications bandwidth requirements are characterized by reference (1) to the bandwidth of the transmitted signal (emission bandwidth) or (2) to the frequency response of the electrical circuits through which the signal passes including transmitter and receiver Emission bandwidth is usually stated in terms of the frequency

band which contains a specified portion of the total signal power or beyond which components on any discrete frequency are less than a specified power For example the International Radio Regulations 1947 contain the following definition Bandwidth Occupied by an Emission The band of frequencies comprising 99 per cent of the total radiated power extended to include any discrete frequency on which the power is at least 0 25% of the total radiated power

Bandwidths necessary for various kinds of communications systems have been designated in Appendix 5 of the International Radio Regulations The following list shows the approximate bandwidth necessary for several kinds of communications systems

System	Bandwidth cps
Telegraphy	
100 words/min	100
Telephony	3 000
High speed data transmission	
1 000 bits/sec	2 000–3 000
AM radiotelephony	
Commercial	6,000
Broadcasting	15 000
FM radiotelephony	
Commercial	16,000
Broadcasting	180 000
Radiotelegraphy	
Frequency shift	1 700
AM facsimile	5 000
FM facsimile	25 000
Television U S	
Broadcasting	6×10^6

For further information on specific systems *see* DATA TRANSMISSION FACSIMILE RADIO TELEGRAPHY TELEPHONY TELEVISION [E W A]

Bibliography H S Black *Modulation Theory* 1953 S Goldman *Information Theory* 1953 International Telecommunication Union *Final Acts of the International Telecommunication and Radio Conferences* Atlantic City 1947

Barbiturates

An important group of central nervous system depressants The original compound barbituric acid is a combination of urea and malonic acid and was first used in 1903 Since then numerous ureides have been developed for various uses and in attempts to reduce unwanted side effects In many of the barbiturates increasing doses will successively induce sedation (quieting) hypnosis (sleep) anticonvulsant activity (as in the treatment of epilepsy) and anesthesia In other compounds these effects have been separated to a large extent thus creating a wide array of possible combinations

The barbiturates have little analgesic or pain killing ability but mild discomfort anxiety sleeplessness and similar symptoms can be allayed by their proper use Clinically these drugs are grouped into four categories based on the length of their hypnotic effect Phenobarbital represents the long acting preparations, Amytal the intermediate and Seconal the short acting Pentothal is an example of the useful ultrashort compounds that are often employed as general anesthetics

Habituation is a problem especially in certain personality types and barbiturate poisoning is not infrequently seen as the result of either accidental or intentional overdosage Death may result from depression of the respiratory centers of the brain

Each barbiturate has its own characteristics and not all are broken down and excreted in the same manner Professional selection of such compounds for each patient especially those with heart liver or kidney disease is of great importance *See* CENTRAL NERVOUS SYSTEM, UREID [E G ST]

Barite

A mineral with the chemical composition $BaSO_4$ Barite occurs mainly in white and yellowish orthorhombic tabular crystals or masses Fracture is uneven and luster is vitreous to pearly Hardness is 3–3 5 on Mohs scale and specific gravity is 4 5 It decrepitates and fuses with difficulty It is insoluble in acids The barium present in barite imparts a characteristic yellowish green color to the flame *See* BARIUM

Because of the high specific gravity of barite nearly three quarters of the domestic output of the mineral is used as a weighing agent in rotary well drilling fluids Barite has numerous other uses for example in the manufacture of glass white pigment and as a filler or extender in paint inks oil cloth linoleum and rubber and in the manufacture of barium compounds for various industrial applications

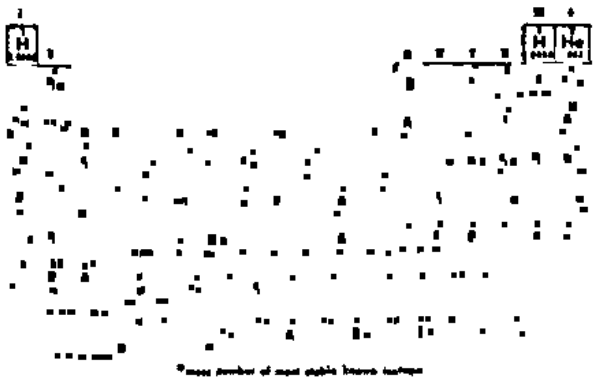
Barite will continue to be in great demand as well drilling mud It has recently been used to weight concrete around pipelines in river crossings and swampy areas or in the manufacture of barium titanate for use in ultrasonics Large tonnages of barite might also be used as an aggregate in concrete shield for atomic power plants constructed in the future

Barite is commonly found in ore veins frequently associated with fluorite calcite dolomite and quartz It is also widely distributed in limestone as veins lenses or cavity fillings The principal domestic barite producing areas are in Washington County Mo and the Ouachita Mountains of Arkansas Although known reserves of commercial grade material in excess of 40 million tons are adequate for the near future new deposits are being sought to meet the expanding demand of barite in drilling as well as in the metallurgical chemical and electronic fields [F C T C]

Barium

Chemical element number 56 barium Ba is eighteenth in abundance in the earth s crust It is found to the extent of 0 04% which makes it intermediate in amount between calcium and strontium the other alkaline earth metals

Natural occurrence Barium compounds are ob tained from the mining and conversion of two bar ium minerals Barite barium sulfate is the princi pal ore and contains 65 79% barium oxide Other names for this mineral include baryta barytes and heavy spar Ordinarily the naturally occurring substance is a heavy whitish translucent mineral but may be any color and transparent to opaque



The crystallinity is not always evident and granu lar and fibrous ore bodies are common Earthy de posits have been described but are uncommon Im purities are common and include calcium sulfate calcium carbonate calcium fluoride silica alu mina and strontium sulfate The largest deposits in the United States are in Colorado California and Nevada

Witherite sometimes called heavy spar is bar ium carbonate and is 72% barium oxide It crys tallizes in the orthorhombic system and because the crystals are nearly all twinned they resemble hexagonal pyramids The mineral may be color less white yellowish or grayish Witherite is much less common than barite and in its usual mode of occurrence it is associated in veins with galena It is found in northeastern England Germany and El Portal California

The first reference to barite in the literature was in the seventeenth century Heavy spar was found near Bologna Italy and was experimented with by a shoemaker and alchemist named Casciarola who noticed that when mixed with combustibles and heated to redness it emitted a phosphorescent glow Barite thus received the name Bologna stone In 1750 A S Marggraf produced sulfuric acid from barite but believed the base to be lime K W Scheele discovered baryta and found that a white material was obtained with sulfuric acid Scheele in 1779 first distinguished the oxide which he ob tained from barite from lime Barite mining began in the United States about 1845

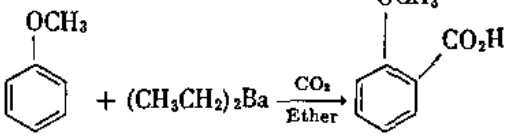
Extraction of the metal The metal was first iso lated by Sir Humphry Davy in 1808 by electrolysis The great affinity of this element for halogens oxy gen nitrogen hydrogen and sulfur has made the metal expensive and difficult to produce Indus trially only small amounts are prepared these are used in barium nickel alloys for spark plug wire (the barium increases the emissivity of the alloy) and in Frary metal which is an allo ium and calcium used in place of Babbitt metal be cause it can be cast The fused salt electrolysis to yield the metal has not been satisfactory on an in dustrial scale so aluminum reduction of barium ox ide in large retorts is used

The metal reacts with water more readily than do strontium and calcium but less readily than so dium it oxidizes quickly in air to form a surface film that inhibits further reaction but in moist air it may inflame Freshly cut pieces have a lustrous gray white appearance and the metal is both duc tile and malleable The physical properties of the elementary form are given in the table

Properties of barium

Atomic number	56
Atomic weight	137 36
Isotopes (stable)	130 132 134 135 136 137 138
Atom c volume cm^3/g atom	36 2
Crystal structure	Face-centered cubic
Electron configuration	2 8 18 18 8 2
Valence	2+
Ionic radius (A)	1 35
Bo ling point °C	1140 (?)
Melting point °C	850 (?)
Density g/cm^3	3 75
Latent heat of vaporization at boiling point kilojoules/g atom	374

The metal is sufficiently active chemically to re act with most nonmetals It burns in oxygen at elevated temperatures to form the peroxide BaO_2 (erroneously called the dioxide) forms a carbide (acetylide) BaC_2 and a boride BaB_6 which shows metallic conductivity The absorption of hy drogen by barium metal becomes noticeable at 120°C At 180°C the absorption is vigorous and the reaction goes rapidly to completion to form the hydride BaH which is a more powerful reduc ing agent than the corresponding compounds of calcium and strontium but otherwise similar to calcium hydride The organometallic compounds $(C_6H_5)_2Ba$ and $BaZn(CH_2CH_3)_4$ are isolable as white reactive solids $(CH_3CH_2)_2Ba$ prepared in solution behaves as a Grignard reagent



Barite Commercial barite is marketed in several forms as crude barite washed free of clay and picked to remove adhering impurities as ground barite obtained by grinding and purifying crude ore and as a barium compound The crude barite of commerce must be over 95% barium sulfate with a ferric oxide content of less than 1% For the glass trade however the amounts are 96 and 0 1% respectively Flotation with soap or cationic rea gents can be applied satisfactorily to barite ores Most barite is leached before being finely ground this is accomplished by sulfuric acid in lead lined tanks with the occasional addition of sodium

ground to a fine powder to be used as a filler for rubber oilcloth linoleum plastics and resins Bleached barite prime white is used as a pigment or extender in white paint but is less satisfactory than blanc fixe (precipitated barium sulfate) or lithopone for this application Granular barite is applied in glass manufacture to improve the properties of molded materials and as a scavenging flux in brass manufacture Finely ground barite is used as a thixotropic mud in oil well drilling

Principal compounds For the manufacture of barium compounds soft (easily crushable) barite is preferred but crystalline varieties may be used Crude barite is crushed to pea size and then mixed with pulverized coal in the proportion 1 part coal to 4 parts barite by weight The mixture is roasted 4 hours in a rotary reduction furnace and the barium sulfate is thus reduced to barium sulfide or black ash Black ash is roughly 70% barium sulfide and is treated with hot water to make a solution used as the starting material for the manufacture of many compounds When in compound manufacture a sodium salt is added to the barium sulfide solution sodium sulfide is produced as a valuable by product

Lithopone a white powder consisting of 20% barium sulfate 30% zinc sulfide and less than 3% zinc oxide is produced when zinc sulfate is added to hot barium sulfide solution The precipitate is dried calcined at 500°C in a muffle furnace and quenched in water The product is then ground to a pulp washed and filtered dried and passed through a disintegrator Lithopone is widely used as a pigment in white paints

Blanc fixe is chemically precipitated barium sulfate obtained by adding sodium sulfate to the barium sulfide solution It is a white insoluble amorphous powder having chemical properties identical with but physical properties different from those of barite It is used in the manufacture of brilliant coloring compounds It is the best grade of barium sulfate for paint pigments excelling the best ground barite in whiteness fineness and oil adsorption Because of the large absorption of x rays by barium the sulfate is used to coat the alimentary tract for x ray photographs in order to increase the contrast Although barium salts are highly poisonous the insolubility of barium sulfate makes its use acceptable The commercial product is marketed as a powder or as a pulp with 30% water

Barium carbonate is obtained as a white precip

wares such as brick or tile It is used also as a pottery glaze in optical glass and in rat poisons

Barium chloride is obtained by roasting barite

salt

softener in boiler compounds and in medicinal preparations

Barium nitrate or the so called baryta saltpeter is obtained commercially by adding sodium nitrate to a solution of barium chloride or barium sulfide It is also obtained by dissolving witherite barium oxide or barium hydroxide in nitric acid It finds use in pyrotechnics and signal flares (to produce a green color) and to a small extent in medicinal preparations

Barium oxide known as baryta or calcined baryta is available as a white or yellowish white powder or as grayish white amorphous lumps It reacts at elevated temperatures with oxygen to form the peroxide and it absorbs carbon dioxide and water strongly even at room temperature It is formed from either barium nitrate or barium carbonate by calcination It finds use both as an industrial drying agent and in the case hardening of steels

Barium peroxide BaO_2 is made as described above and is sometimes used as a bleaching agent because it releases hydrogen peroxide when treated with cold water

Barium chromate lemon chrome or chrome yellow is sold as a yellow insoluble powder and is made by addition of potassium chromate to various soluble barium compounds It is used in yellow pigments and safety matches

Barium chlorate $Ba(ClO_3)_2$ is produced by the electrolysis of barium chloride and is sold as a white soluble monohydrate in the form of monoclinic plates or prisms It finds use in the manufacture of pyrotechnics

Barium acetate and cyanide are used industrially as a chemical reagent and in metallurgy respectively

Analytical methods Qualitatively barium minerals moistened with hydrochloric acid give a green flame test but boron and phosphorus will interfere if not previously separated Barium may be determined *quantitatively by precipitating* and weighing as the sulfate *See* ALKALINE EARTH METALS RADIUM [R F B]

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Barium titanate

A ferroelectric solid which exhibits a number of anomalous dielectric properties Barium titanate $BaTiO_3$ is the most important and most thoroughly studied representative of the compounds which have the perovskite crystal structure Below a critical temperature (Curie point) of 120°C $BaTiO_3$ is spontaneously electrically polarized that is it has a permanent electric dipole moment A $BaTiO_3$ crystal consists in general of regions which differ in the direction of spontaneous polarization (ferroelectric domains) The spontaneous polarization can be aligned in the whole crystal and reversed by an electric field Single crystals of $BaTiO_3$ as well as $BaTiO_3$ ceramics exhibit a large piez elec

tric effect when the spontaneous polarization has been aligned A number of compounds with the perovskite crystal structure have similar properties *See* FERROELECTRICS PIEZOELECTRICITY POLARIZATION (DIELECTRICS)

Compared with other piezoelectric materials such as Rochelle salt barium titanate has numerous advantages Its Curie point is substantially higher it is much less temperature sensitive it is mechanically more rugged and it is practically unaffected by humidity Because of these properties the material is widely used in devices such as microphones phonograph pickups underwater sound transducers and the like

Because of its very high dielectric constant (approximately 2000 at 25°C and 10^3 cps when the electric field is perpendicular to the principal crystal axis) its high volume resistivity and low dielectric loss over a wide frequency range barium titanate is also much used as the dielectric material in capacitors It has the further advantage that its temperature coefficient of capacitance can be readily varied over a range of positive and negative values by admixtures of other materials notably strontium and calcium titanates *See* DIELECTRIC CONSTANT [W A]

Bark

A word generally referring to the surface region of a stem or a root The term has a somewhat variable meaning and sometimes part or all of the bark is called rind Occasionally the word is used as a substitute for periderm or even for cork only Most commonly however bark refers to all tissues external to the cambium (Fig 1) If this definition is applied to stems having only primary tissues it includes phloem cortex and epidermis the bark of roots of corresponding age would contain cortex and epidermis In the more general usage the term bark is restricted to woody plants with secondary growth

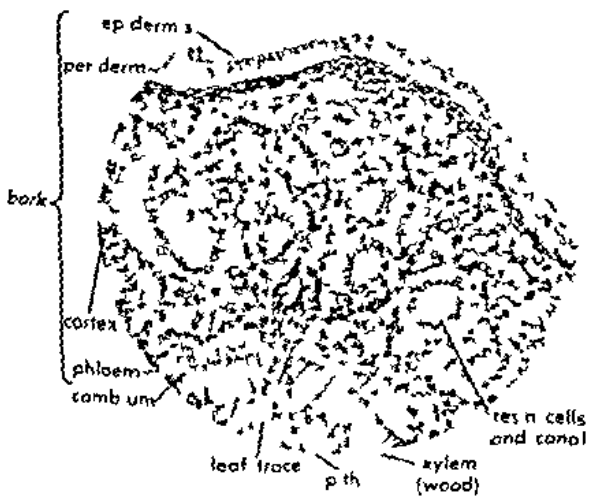


Fig 1 Bark Transverse section of a young twig of balsam fir (Abies balsamea L) showing tissues frequently included in the term bark (*Forest Products Laboratory USDA*)

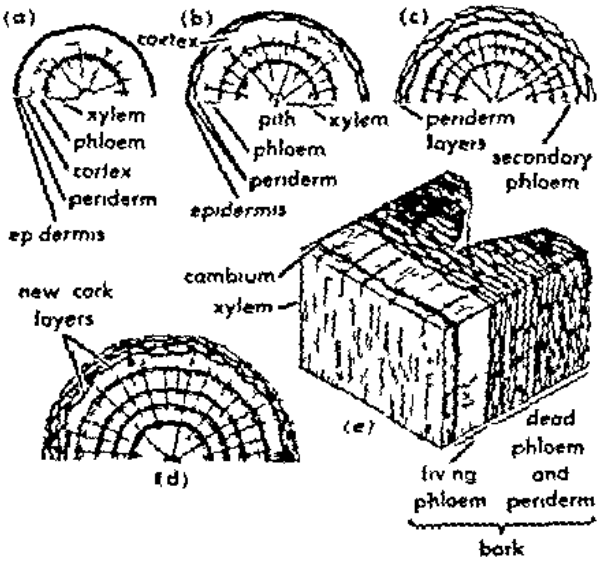


Fig 2 Diagrams showing the position and extent of successively formed periderm layers in a typical woody stem (a) A 1 year-old twig with a complete cylinder of periderm formed beneath the epidermis (b) A 2 year-old twig with the epidermis and first periderm ruptured and new shell shaped layers of periderm formed deeper in the cortex (c) A 3 year-old stem with the outer tissues weathered away and further periderm layers formed still more deeply in the stem invading the secondary phloem (d) A 4 year-old stem the cortex and outer secondary phloem with their periderm layers are largely weathered away and the new cork layers are invading the younger phloem (e) The outer tissues of an old tree trunk showing the narrow band of living secondary phloem and the thick deeply fissured rhytidome consisting of dead phloem and many shell-shaped periderm layers a considerable amount of similar tissue has weathered away (*From A J Eames and L H MacDaniels An Introduction to Plant Anatomy 2d ed McGraw-Hill 1947*)

In most roots with secondary growth the bark consists of phloem and periderm since the cortex and epidermis are sloughed off with the first cork formation in the pericycle that is, beneath the cortex In stems the first cork cambium may be formed in any living tissue outside the vascular cambium and the young bark may include any or all of the cortex in addition to the phloem and periderm The first cork cambium may persist throughout the life of the plant The resulting periderm has a relatively smooth surface In most plants however new periderms are formed in successively deeper tissues The new layers of cork are often shell like in form and enclose islands of dead phloem (Fig 2) In some plants the successive cork layers occur in wide bands or even in whole cylinders The region composed of the successive layers of periderm and the enclosed dead tissues is called outer bark The outer bark gradually splits wears and weathers and acquires a characteristic surface pattern in relation to the form of origin of the cork cambium and the composition of the dead tissues The surf

be fairly smooth or broken into strips conforming to the fibrous layers of the phloem or into plates or strips conforming to the size and shape of the alternating zones of cork and phloem

The outer bark composed of dead phloem alternating with bands of cork is called technically rhytidome Both stems and roots may have rhytidome The inner bark is living and consists of phloem only In this phloem only a narrow band next to the vascular cambium contains functioning sieve elements but ray cells and parenchyma are alive throughout the inner bark From these living cells new cork cambia may develop *See* CORTEX PLANT EPIDERMIS PLANT PARENCHYMA PERICYCLE PERIDERM PHLOEM ROOT (BOTANY) STEM (BOTANY) [H W BL]

Barkhausen effect

An effect due to discontinuities in size or orientation of magnetic domains as a body of ferromagnetic material is magnetized whereby the magnetization proceeds in a series of minute jumps *See* FERROMAGNETISM MAGNETIZATION

Ferromagnetic materials are characterized by the presence of microscopic domains of some 10^{12} to 10^{15} atoms within which the magnetic moments of the spinning electrons are all parallel In an unmagnetized specimen there is random orientation of the various domains When a magnetic field is applied to the specimen the domains turn into an orientation parallel to the field or if parallel to the field the domains increase in size During the steep part of the magnetization curve whole domains suddenly change in size or orientation giving a discontinuous increase in magnetization If the specimen being magnetized is within a coil connected to an amplifier and loudspeaker the sudden changes give rise to a series of clicks or when there is a rapid change a hissing sound This is called the Barkhausen effect it is an important piece of evidence in support of a domain theory of magnetism [K V M]

Barley

The plant *Hordeum* sp is widely grown in nearly every country in the world Perhaps no cereal grain has as wide a range of adaptation to length of growing season rainfall and temperature In the United States the major acreage is now centered in the Red River Valley between North Dakota and Minnesota and in the Sacramento Valley in California Important but less concentrated areas of production include most of the states in the northern and central Great Plains Barley is used primarily as a feed grain for livestock in the malting industry and for human consumption as pearled barley Its average annual farm value for the 10 year period 1945 1954 was $337 607 500

Origin and description Barley is believed to be one of the ancient cereal grains Charred remains of barley kernels over 5000 years old have been found in Mesopotamia From this area barley culture extended into Abyssinia the Near East China and Europe Throughout the world many kinds of barley are grown Plant height and spike density vary greatly and included are types with naked and hulled grains spring and winter growth types awned hooded and awnless lemmas black and white kernel color and spikes with two and six rows of kernels (Fig 1) Barley is naturally self pollinated spikelets have a single floret with from one to three spikelets at each node alternately arranged on a zigzag rachis

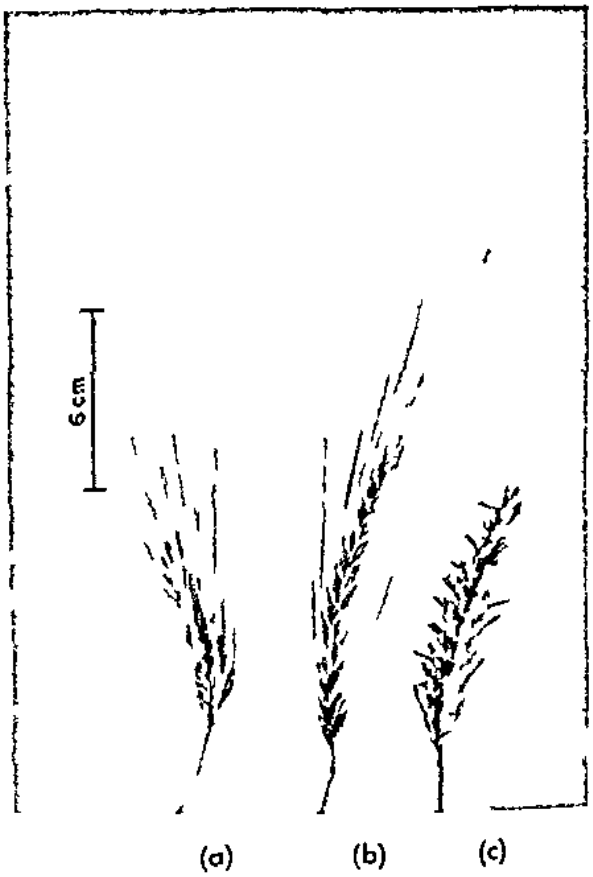


Fig 1 Spikes of three distinctive barleys (a) Six row awned (b) Two row awned (c) Six row hooded

All cultivated species of barley have seven pairs of chromosomes Three species of cultivated barley include *Hordeum vulgare* the true six row type *H distichon* a true two row type in which the two lateral spikelets have reduced lemmas and paleas and *H deficiens* a true two row type in which the palea and sexual parts of lateral spikelets are absent These three species can be freely intercrossed and differ genetically by only one or two genetic factor pairs controlling the expression of fertility and development of lateral spikelets (*see* CHROMOSOME GENETICS REPRODUCTION PLANT) In addition to the above three species eight other seven chromosome noncultivated species have been recognized Four species have 14 pairs of chromosomes including *H bulbosum H jubatum H secalinum* and *H murinum* One species *H nodosum* has 21 pairs of chromosomes Although many attempts have been made to hybridize species differing in chromosome number results to date have shown that crosses do not produce seeds capable of

germination Limited success has been obtained by dissecting young hybrid endosperms from the caryopsis (fruit) and rearing them in nutrient media *See* FRUIT (BOTANY), SEED (BOTANY) Failure to obtain viable hybrid seeds in crosses between *Hordeum* species which vary in chromosome number differs from successful results in the genera *Avena* (oats) and *Triticum* (wheat)

Varieties Over 4000 varieties of barley are recognized including kinds grown in other countries and those resulting from improvement programs in the United States In the southern states the winter annuals predominate The degree of winter hardiness in barley is considerably less than in winter wheat, hence the northern limit of winter barley adaptation does not extend beyond the latitude of central Missouri In the northern states spring sown varieties are grown Barley varieties used for malting must possess special characteristics to meet the exacting requirements of maltsters and brewers such as uniformity of germination diastatic power and absence of those chemical compounds that adversely affect flavor color and other characteristics of the brew

Cultural practices The methods used in barley production are similar to those of wheat and oats Spring varieties in the northern states are planted as early as a good seedbed can be prepared usually in mid April in the Red River Valley In California spring varieties are planted in November and December Winter barley varieties are planted in late September in the northern area of its adaptation and in October further south The most common rate of planting is 1½–2 bushels per acre

Barley generally is harvested with a combine from the standing grain in the low rainfall areas or it is first windrowed to dry and then combined in the more humid areas Special care must be taken in combining barley to be used for malting purposes to avoid breaking or skinning the hull on the kernels Skinned kernels do not germinate uniformly hence they produce a poor grade of malt *See* GRAIN CROPS [1 1 1]

Barley diseases Of the cereals barley is the one most subject to diseases Many diseases affect barley particularly in the humid areas For this reason the varieties currently available in these areas have been less consistent in yield than varieties of other cereal grains Diseases have resulted in a gradual reduction of barley acreage in corn belt states that at one time led in barley production

The annual loss from diseases in the United States is 5% or about 16 000 000 bushels Destructive epidemics are not uncommon In 1945 barley production in Minnesota decreased from about 50 000 000 bushels to less than 13 000 000 and yield per acre dropped more than 30% because of two successive epidemics of root rot and foliage blight

Kinds of diseases Twenty five years ago seed borne diseases like covered smut *Ustilago hordei* loose smut *U nuda* and barley stripe *Helminthosporium gramineum* were of great economic importance Today these diseases are to a large extent controlled by treating the seed with chemical fungicides and by growing resistant or semiresist

Spot blotch, and scald, *Rhynchosporium secalis* have become very prevalent and are often destructive over wide areas

Root rots including basal stem rot are among the most destructive diseases of barley particularly in the United States Their importance varies tremendously with the season locality and the variety The plants are subject to attack from the time the seeds are sown until the barley matures The pathogens are of many types and attack all underground parts of the plant inducing seedling blight root decay stem rot and premature death of adult plants

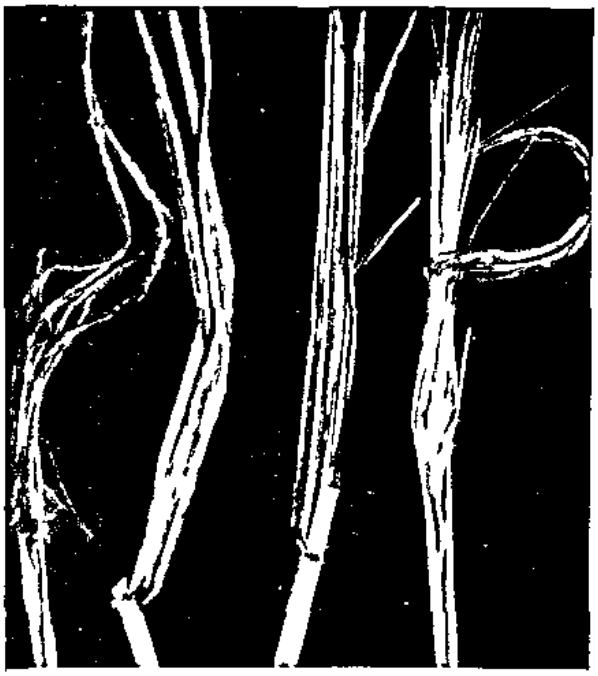


Fig 2 Barley stripe caused by *Helminthosporium gramineum* (*Minnesota Agr Exp Sta*)

In most years kernel blight caused chiefly by *Gibberella zeae H sativum* and *Alternaria* sp is common and shrivels or discolors the grain thus reducing quality and market value Storage molds caused by many saprophytic organisms often cause rapid deterioration of barley in storage *See* FUNGI

Although both stem rust *Puccinia graminis* and leaf rust *P hordei* of barley are common diseases they seldom cause severe losses Powdery mildew *Erysiphe graminis* is widespread and sometimes causes heavy losses in certain regions In recent years viruses especially false stripe and yellow dwarf have become prevalent and destructive on certain varieties Nematodes also are widely distributed but their economic importance has not yet been ascertained *See* NEMATODA PLANT VIRUS



Fig 3 Spot blotch of barley caused by *Helm ntho spor um sat vum* (*M nnesota Agr Exp Sta*)

Disease problems in barley are continually changing primarily because new disease prod ic ing organisms are introduced or new virulent strains or races of established pathogens are devel oped or introduced from other regions Sometimes disease problems change because minor diseases become major under certain conditions The introduction of new varieties often shifts disease prob lems Changes in cropping systems and cultural practices may also change disease problems

Disease control Although losses from many of tl ese barley diseases can l e reduced by planting sound and disease free seed by treating the seed and by using appropriate crop sequences and cul t iral practices including proper fertilizing the most feasible and practical method of control of d sease consists in the growing of d sease resistant varieties As no variety is resistant to all *of the* major diseases a control program involves tl e de velopment of varieties resistant to the major dis eases in each region *See* PLANT DISEASE PLANT DISEASE CONTROL [J J C]

Pot and pearl barley The term pot barley is ap plied to the food product which res ults after the husk has l een removed l y coarse grinding Pearled l arley is ol tained l y a more involved dry milling process

Barley is pearled in a machine consisting of a perforated cylinder with indentations smaller than the kernels and a cylindrical revolving *millstone* rotat ng in the opposite d rection at faster speed The perforations cause the grain to turn rapidly while the revolving millstone grinds off the hull From the pearler the barley passes through reels which separate the hulls Dust and fine particles are removed by aspiration and the pearled barley is then transferred to cooling bins Pearled barley is small round and white It is classified according to size by passage through a grading reel Nor mally 100 lb of barley will yield al out 65 lb of l ot l arley or 35 lb of pearled barley In the manu facture of pearled barley some flour is produced as a by product

Malting For malting purposes the brewing in dustries in the United States use different types of barley from those desired throughout the re mainder of the world Outside the United States the demand is for large kerneled barley of the two-



Fig 4 Infected barley seed plated out on nutr ent agar (a) *G bberella zeae* (b) *Helm nthospor um spp* and *Alternar a spp* (*M nnesota Agr Exp Sta*)

and enzyme content

There are two systems of malting flour malting and pneumatic or drum malting The malting process involves the germination of the barley in a controlled state followed by drying under proper conditions that retain enzymatic activity These basic steps are taken during malting The barley is cleaned graded for uniformity of size and steeped in cold water until the moisture content reaches about 45% The steeped grain is germinated in compartments or drums under suitable moisture temperature and aeration conditions to modify the kernels Germination usually is stopped when the acrospire has grown to the length of the kernel which requires several days During this period enzyme development takes place

The next step is drying the germinated grain under conditions which will stop germination and any further chemical change Drying temperatures vary from 120 to 180°F with the final moisture content reduced to about 6% The rootlets are then removed by cleaning and the malt is ready for industrial use

During malting there are certain losses of dry substances from barley Steep loss is usually 1 5 2 0% respiration loss equals 3–5% and removing the rootlets contributes another 3–5% loss At the start of the malting process barley moisture is likely to be from 10–18% whereas the moisture of the finished malt is low

Industrial value of malt depends on its starch splitting and protein degrading enzymes Brewers malts are used to produce beer and ale and to a lesser extent for malt syrups and evaporated malt extracts Distillers' malts are employed for starch conversion in the production of distilled beverages and industrial alcohol and for converting starch for the sizing of paper and textiles [J A SH]

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Barn (unit)

A unit of nuclear cross section equal to 10^{-24} cm^2 Typical nuclear reactions have cross sections measuring their probability of occurrence that range from millibarns to several thousand barns A related quantity which is connected with the probability that a reaction will emit radiations in a particular direction is the differential cross section which has the dimensions of barns per steradian *See* NUCLEAR REACTION [W W BU]

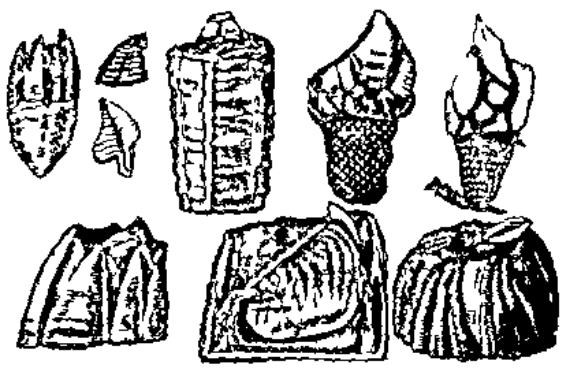
Barnacle

Any member of the class Cirripedia phylum Crustacea There are five orders As adults all are sessile and attached or parasitic and are very highly modified from the typical crustacean structure They are marine and world wide in distribution

Barnacles are perhaps best known for their habit of growing on ship bottoms in great numbers When growing in such a manner they are said to foul a ship and can reduce its speed materially The removal of barnacles from ships or in more recent years the prevention of their attachment by the use of antifouling paints is an item of great expense

Some species are used by man for food and are also utilized in the food cycle of certain marine animals Still others are parasitic within other animals

Typically the carapace of a barnacle usually limy in nature is modified into a mantle surrounding the body thus forming a shell from which six or fewer pairs of slender biramous appendages protrude Some forms lack a shell Barnacles attach to their substrate by cement produced from glands in the base of the anterior pair of antennae The abdomen is vestigial



Barnacles (From P M Duncan ed Cassell's Natural History Cassell)

Barnacles are almost all hermaphroditic The larvae are free swimming resembling certain young crabs in their early stages The crablike nauplius state is followed by a two shelled or cypris stage which swims with a butterflylike movement This stage ultimately settles down on a support sheds its swimming legs and develops into the adult form

The goose barnacles of the genus *Lepas* are represented by five species on the coasts of the United States The common name of these long narrow stalked barnacles is derived from the fact that medieval zoologists thought them to be the young of the bernacle goose which sometimes appears in great flocks on the European coasts Later zoologists considered barnacles to be molluskes because their shelled bodies could easily lead to that conclusion The rock or ship barnacles lack a peduncle and are covered by a series of six heavy limy plates arranged to form a cylinder from which the animal extends its legs to grasp food There are several species which are quite common and widely distributed

Most highly modified are the parasitic barnacles of the order Rhizocephala They have a mantle but no shell, the appendages and gut are greatly altered for their parasitic existence A typical form is *Sacculina*, parasitic on certain species of crabs After attaching to the host it discards its mantle and burrows into the host It lives attached to the host's intestine as a mass of cells until the host molts Then a part of the barnacle protrudes as a sac on the ventral side of the crab, between the abdomen and carapace, while the remainder of the parasite branches out, like roots of a plant, into all parts of the crab's body from which they absorb nourishment at the crab's expense The sac is ultimately filled with eggs *See* CIRRIPEDIA, RHIZOCEPHALA [J D B]

Baroclinic field

A distribution of atmospheric pressure and mass such that the specific volume or density, of air is a function not solely of pressure When the field is baroclinic solenoids are present there is a gradient of air temperature on a surface of constant pressure and there is a vertical shear of the geostrophic wind Significant development of cyclonic and anticyclonic wind circulations typically occurs only in strongly baroclinic fields Fronts represent baroclinic fields which are locally very intense *See* FRONT, GEOSTROPHIC WIND, SOLENOID (METEOROLOGY), STORM, WIND [F S]

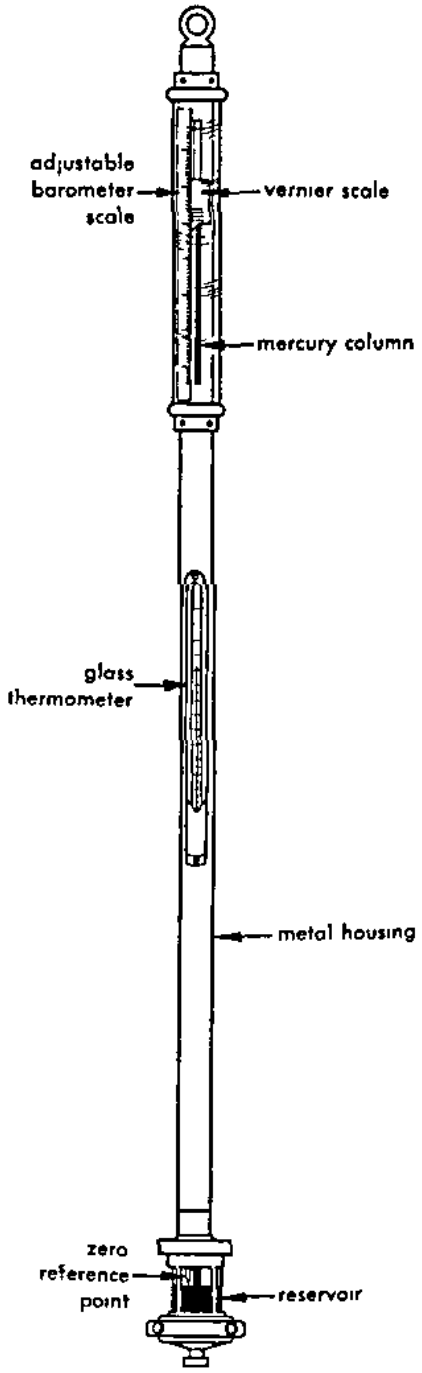
Barometer

An absolute pressure gage specifically designed to measure atmospheric pressure *See* PRESSURE MEASUREMENT

The basic meteorological barometer is a well type liquid column gage (*see* MANOMETER) which has been filled with mercury and the vertical leg sealed As atmospheric pressure acting on the open surface of mercury in the well allows the mercury level to drop in the vertical leg a vacuum is created above the mercury The mercury height is a direct measure of the pressure difference between the full vacuum and the atmosphere hence of the absolute pressure of the atmosphere

Apparent mercury column height must be corrected for temperature deviation from standard conditions (0°C or 32°F) for which purpose a mercury in glass thermometer is mounted on the barometer For consistent comparison of atmospheric pressure readings over the earth's surface barometer readings must be corrected for elevation of the barometer site above mean sea level where standard atmospheric pressure is taken to be 760 mm, or 29 92 in , of mercury

The scale is calibrated in millimeters or inches of mercury and is equipped with a vernier scale for precise reading A micrometer adjusts the scale to compensate for changes in height of mercury in the reservoir Mercury barometers with a vernier scale may be accurate to within 0 005 in



Mercury barometer

Aneroid indicating and recording barometers using metallic diaphragm elements are usually less accurate though often more sensitive, devices [B D H , H G P]

Barotropic field

A distribution of atmospheric pressure and mass such that the specific volume or density of air is a function solely of pressure When the field is barotropic there are no solenoids air temperature is constant on a surface of constant pressure and there is no vertical shear of the geostrophic wind Significant cyclonic and anticyclonic circulations

typically do not develop in barotropic fields Considerable success has been achieved paradoxically in prediction of the flow pattern at middle tropospheric elevations by methods which are strictly applicable only to barotropic fields despite the fact that the field in this region is definitely not barotropic *See* WEATHER (FORECASTING AND PREDICTION) *see also* BAROCLINIC FIELD GEOSTROPHIC WIND, SOLENOID (METEOROLOGY) WIND

[F S]

Barracuda

Any of about 20 species of marine fishes of the family Sphyraenidae found in tropical and temperate waters About seven species occur off North America They are elongate and cylindrical with a large forked tail the other fins are relatively



The barracuda Sphyraena barracuda length to 10 ft (From E L Palmer Fieldbook of Natural History McGraw-Hill 1949)

small The two dorsal fins are set well apart Barracudas are ferocious predators equipped with large sharp teeth Best known is the great barracuda *Sphyraena barracuda* which has been reported up to 10 ft long, but is usually less than 5 ft in length This savage fish once thought poisonous is now considered a good food fish as are the others of the family The great barracuda is a favorite fish of deep-sea anglers It ranges from Brazil northward to Charleston S C and is a typical member of the West Indies fauna It is considered dangerous to bathers on some beaches *See* PERCIFORMES

[J D B]

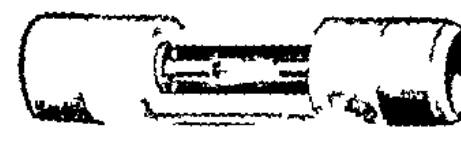
Barretter

A fine wire having a high temperature coefficient of resistance which is used as a power absorbing device in bolometric methods Its change of resistance is a measure of the power dissipated within it and it is used either to measure the power directly or to indicate when a comparison dc power is equal to an unknown radio frequency (rf) power A barretter is shown in the illustration The over all length of typical units is about 1 in

A barretter is frequently used as an arm of a Wheatstone bridge to which is applied a known dc voltage The bridge is first balanced with the barretter dissipating the rf power to be measured The rf power is then cut off and the bridge is rebalanced by increasing the applied dc voltage The *increase in the dc power dissipated in the barretter* in the two cases is then to a first approximation equal to the applied rf power Errors may arise from the assumption that the effects of dc and rf powers are completely equivalent when parasitic high frequency losses occur in parts of the barretter other than the fine wire itself This occurs when the wire length becomes comparable with the wavelength and when the cooling mechanism leads to different current distributions at radio frequencies and at dc

Careful studies of these errors have led to a thorough understanding of them and to the design of accurate barretters such as Wollaston wires operated in vacuum and lamp filaments operated in a hydrogen atmosphere When used with sufficiently sensitive bridges barretters can measure powers as small as 10^{-5} watt The need to maintain small physical dimensions at microwaves imposes a restriction on maximum power that may typically be of the order of 100 watts

Barretters must be so operated that they readily absorb the rf power to be dissipated without permitting rf leakage to the auxiliary dc circuits used for resistance measurement and power comparison They must therefore have a resistance approximating the characteristic impedance of the transmission line with which they are used they must be so mounted that a smooth transition to the line minimizes reflections and they must be provided with bypassed terminals to which dc connections



Cutaway view of commercial barretter element (Sperry Gyroscope Co)

can be made without disturbing the rf characteristics *See* ELECTRIC POWER MEASUREMENT WAVELENGTH MEASUREMENT

[D B S]

Barrier reef

A reef ordinarily of corals or other organisms that parallels the shore at the seaward side of a natural lagoon The surface may be regularly awash at low tide or may break water only at times of strongest swell Ordinarily the lagoonward slope is gentle the seaward slope abrupt Subsidiary reef patches are common in barrier reef lagoons and locally beyond the ends or front of the continuous reef Barrier reefs may develop by continuous upward growth or veneer ridges at the seaward edges of submerged erosional benches but sinking bottom or rising water is probably essential at some stage of their development *See* CORAL REEF ORGANIC REEF REEF

[F E C]

Barycentric calculus

The application of the properties of the centroid of a set of weighted points to geometry For certain new operations such as the addition of point and point, or of point and vector, it is possible to give their vector equivalents and work within the framework of vector algebra

Theorems. A point P associated with a real number λ (for example, its mass or electric charge) is called a weighted point and is denoted by λP With a given origin O, the point λP has the companion vector $\lambda\overrightarrow{OP}$

The sum $\mathbf{S} = \Sigma_i\overrightarrow{OP_i}$ of the companion vectors of n given points will be independent of the origin when, and only when, their total weight $\Sigma\lambda_i = 0$

If $\mathbf{S}' = \Sigma\lambda_i\overrightarrow{O'P_i}$

$$\mathbf{S} - \mathbf{S}' = \Sigma\lambda_i(\overrightarrow{OP_i} - \overrightarrow{O'P_i}) = (\Sigma\lambda_i)\overrightarrow{OO'}$$

hence $\mathbf{S} = \mathbf{S}'$ implies $\Sigma\lambda_i = 0$ and conversely

The properties of $\Sigma\lambda_i\overrightarrow{OP_i}$ thus depend on whether $\Sigma\lambda_i = 0$ (case 1) or $\Sigma\lambda_i \neq 0$ (case 2)

Case 1 $\Sigma\lambda_i = 0$ $\mathbf{S}$ may be computed by taking O successively at $P_1, P_2, \ldots, P_n$, then all n vectors $\Sigma_{i\neq j}\lambda_i\overrightarrow{P_jP_i}$ $(j = 1, 2, \ldots n)$ are equal to $\mathbf{S}$ This is one source of geometric theorems

In particular, the vector $\mathbf{S}$ may be zero When $n = 2$ 3, 4, the points are coincident, collinear or coplanar, respectively Writing $\overrightarrow{OA} = \mathbf{a}$ $\overrightarrow{OB} = \mathbf{b}$, gives the important theorems I and II

Theorem I Three distinct points A, B, C are collinear when and only when, there are three nonzero constants α β, γ such that

$$\alpha\mathbf{a} + \beta\mathbf{b} + \gamma\mathbf{c} = 0 \qquad \alpha + \beta + \gamma = 0 \qquad (1)$$

Theorem II Four distinct points A, B C, D, no three collinear are coplanar when, and only when, there are four nonzero constants α β, γ, δ such that

$$\alpha\mathbf{a} + \beta\mathbf{b} + \gamma\mathbf{c} + \delta\mathbf{d} = 0 \qquad \alpha + \beta + \gamma + \delta = 0 \qquad (2)$$

The point C is said to divide the segment AB of a straight line in the ratio β/α if $\alpha\overrightarrow{AC} = \beta\overrightarrow{CB}$ or $\alpha(\mathbf{c} - \mathbf{a}) = \beta(\mathbf{b} - \mathbf{c})$, then

$$\mathbf{c} = \frac{\alpha\mathbf{a} + \beta\mathbf{b}}{\alpha + \beta} \qquad (3)$$

Thus Eqs (1) imply that A, B, C divide BC, CA, AB in the ratios γ/β, α/γ, β/α

Equations (2) imply that $ABCD$ is a plane quadrilateral whose diagonal points P, Q, R are given by

$$\mathbf{p} = \frac{\alpha\mathbf{a} + \beta\mathbf{b}}{\alpha + \beta} \qquad \mathbf{q} = \frac{\beta\mathbf{b} + \gamma\mathbf{c}}{\beta + \gamma} \qquad \mathbf{r} = \frac{\gamma\mathbf{c} + \alpha\mathbf{a}}{\gamma + \alpha}$$

Metric and projective properties of the complete quadrilateral readily follow

Case 2 $\Sigma\lambda_i = \lambda \neq 0$ The sum $\mathbf{S}_0 = \Sigma\lambda_i\overrightarrow{OP_i}$ now depends on O But the equation

$$\Sigma\lambda_i\overrightarrow{OP_i} - \lambda\overrightarrow{OP^*} = 0$$

defines the same point λP^* for any choice of O, for the total weight of the points λ_iP_i and λP^* is zero If O is taken at P^*, this gives the basic relation defining P^*

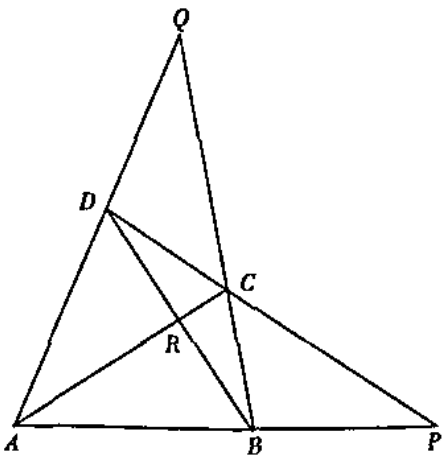
$$\Sigma\lambda_i\overrightarrow{P^*P_i} = 0$$

The point λP^*, is called the centroid of the points λ_iP_i For an arbitrary origin the centroid is given by

$$\lambda\mathbf{p}^* = \Sigma\lambda_i\mathbf{p}_i$$

On the right the sum extended over any subset of nonzero weight may be replaced by their centroid This replacement principle is a second source of geometric theorems It also reduces the problem of centroid location to that of two points

If $\alpha + \beta \neq 0$ the centroid of αA and βB is the point $(\alpha + \beta)C$ given by $(\alpha + \beta)\mathbf{c} = \alpha\mathbf{a} + \beta\mathbf{b}$, and Eq (3) shows that C divides AB in the ratio β/α The centroid of A and B is $2\mathbf{c} = \mathbf{a} + \mathbf{b}$, and C is the midpoint of AB



Complete quadrilateral

The centroid $3D$ of A, B, C is $3\mathbf{d} = \mathbf{a} + \mathbf{b} + \mathbf{c}$ Since

$$3\mathbf{d} = \mathbf{a} + 2\frac{\mathbf{b} + \mathbf{c}}{2} = \mathbf{b} + \frac{\mathbf{c} + \mathbf{a}}{2} = \mathbf{c} + \frac{\mathbf{a} + \mathbf{b}}{2}$$

the medians of a triangle meet in a point which divides each in the ratio 2 1

The meaning of $\Sigma\lambda_i\mathbf{p} = 0$ when $\Sigma\lambda_i = 0$ is now apparent If such a set is divided into two groups of nonzero weight, the subsets have centroids at the same point, whose weights differ only in sign

Barycentric coordinates. If ABC is a triangle of reference, weights α, β, γ can be applied to A, B, C so that the centroid of αA, βB, γC is at any given point P in the plane of ABC, and

$$(\alpha + \beta + \gamma)\mathbf{p} = \alpha\mathbf{a} + \beta\mathbf{b} + \gamma\mathbf{c}$$

only the ratios of the barycentric coordinates α β γ

are determined and

$$\frac{\alpha}{PBC} = \frac{\beta}{PCA} = \frac{\gamma}{PAB} = \frac{\alpha+\beta+\gamma}{ABC}$$

where PBC is the area of the triangle PBC taken + or − depending on whether the circuit PBC is taken in the same sense as ABC or the opposite

The equation $l\alpha + m\beta + n\gamma = 0$ represents a straight line and $\alpha + \beta + \gamma = 0$ is the line at infinity

In 3-space the weights α β γ δ given to the vertices of a reference tetrahedron $ABCD$ are the barycentric coordinates of the centroid of αA βB γC δD The equation $l\alpha + m\beta + n\gamma + k\delta = 0$ represents a plane and $\alpha + \beta + \gamma + \delta = 0$ is the plane at infinity The ratios of α β γ δ may now be given in terms of oriented tetrahedra *See* CENTROIDS OF AREAS AND LINES [L BR]

Bibliography L Brand *Vector and Tensor Analysis* 1947

Baryon

A collective name for a nucleon or any particle which can be transformed into one nucleon and some number of mesons and lighter particles The known baryons are the nucleons (protons and neutrons) and the Λ Σ and Ξ hyperons (*see* HYPERON) For each baryon there is expected to exist a corresponding antibaryon the existence of the antinucleons (*see* ANTINEUTRON ANTIPROTON) and the Λ antihyperon has already been established

A principle of fundamental importance is that of the conservation of baryons which requires that the total number of baryons less the total number of antibaryons remain constant through all physical processes The formation of a baryon therefore involves the simultaneous disappearance of some other baryon or the simultaneous production of some antibaryon *See* ELEMENTARY PARTICLE SYMMETRY LAWS (PHYSICS) [R H D]

Basalt

An aphanitic (not visibly crystalline) rock of volcanic origin composed largely of plagioclase feldspar (labradorite or bytownite) with smaller amounts of dark colored (mafic) minerals (pyroxene and olivine) Basalt is dark gray to black relatively heavy and chemically equivalent to gabbro For a general discussion of textural structural and compositional characteristics *see* IGNEOUS ROCKS

Formation Through rapid cooling basaltic lava solidifies with a fine grained texture In many cases crystals developed before eruption and were later frozen into a very fine grained matrix to develop porphyritic texture The large crystals (phenocrysts) may be white plagioclase dark pyroxene or green glassy olivine As phenocrysts become more abundant porphyritic basalt passes into basalt porphyry The highly fluid nature of basaltic lava permits solidification without the formation of much glass Hence extremely glassy types occur only where chilling has been severe as at the surface of flows or the margins of small dikes Basaltic glass (tachylite) with abundant crystals or phenocrysts is called basaltic vitrophyre *See* PHENOCRYST PORPHYRY

Composition Most detailed features of basalt must be observed microscopically Plagioclase phenocrysts are well formed (euhedral) and commonly zoned with highly calcic interiors grading out to more sodic margins Zones may be vague or sharply defined Occasionally reversed or repeated zoning is present Large phenocrysts have an average composition more calcic than smaller ones in the same rock and these in turn are more calcic than plagioclase of the matrix The average composition of the total plagioclase however cannot be less calcic than labradorite otherwise the rock is classed as andesite

Two types of clinopyroxene may be present Diopsidic augite tends to be in the larger (early formed) grains and pigeonite (later formed) is more or less confined to the groundmass Within either type of pyroxene earlier formed crystals are relatively richer in magnesium than later ones Augite phenocrysts may be brownish or purplish (titanium rich) and show strong zoning or hour

nodular aggregates with pyroxene and other minerals If olivine is abundant and plagioclase subordinate the rock is a picrite basalt Where olivine is still more abundant the rock is called oceanite

Dark brown hornblende as corroded phenocrysts is not common and biotite is uncommon Small amounts of quartz tridymite cristobalite orthoclase or feldspathoid occur in some basalts Quartz in excess of 5% makes the rock a quartz basalt Feldspathoids in excess of 5% make the rock a tephrite Accessories include magnetite ilmenite and apatite

Spilite may be considered a variety of basalt which is more or less altered and rich in soda *See* SPILITE

Texture A common texture is pilotaxitic in which tiny crystals or microlites of plagioclase form a tightly felted mass without interstitial glass As the amount of plagioclase gradually decreases and glass fills interstices the texture first becomes intersertal then hyaloophitic and finally hyalopilitic Granules of augite magnetite and olivine may fill interspaces of the feldspar crystals to give an intergranular texture If interstitial pyroxene (generally augite) is in crystallographic continuity over small areas so that it actually forms large irregular grains the texture is subophitic As the size of the feldspar crystals decreases and the pyroxene becomes more abundant so that it encloses or largely wraps around the smaller feldspars the texture becomes ophitic

Structure In some basalts there is a distinct alignment of elongate phenocrysts or feldspar microlites Such fluidal structures are formed by flow



Textures of basalt (a) Pilotaxitic texture with feldspar microlites and interstitial, microcrystalline material, (b) Intersertal texture with feldspar microlites and some granular pyroxene and much interstitial glass (c) Hyalopilitic texture with feldspar microlites in glass (d) Intergranular texture with feldspar laths and interstitial granular pyroxene

age of the crystallizing lava Variolitic structures, in which plagioclase microlites are radially arranged in a very fine grained or glassy matrix are characteristic of basalt Interesting vesicular structures are found in basalt Abundant gas cavities which give the rock a coarse spongy appearance are found in the variety of basalt called scoria The more ellipsoidal gas cavities, usually less than 1 in long and commonly filled with quartz, calcite, epidote, and zeolites, are called amygdules Where these are abundant the rock is called amygdaloid In some flows the amygdules are pipelike They rise from the base of the lava flow and are 1 ft long and ½ in across They probably form by upward streaming water vapor formed at the moist surface over which the lava flows Some basalts carry scattered crystals of quartz commonly up to several millimeters across These do not appear to have been in equilibrium with the basaltic lava and are probably not indigenous but are xenocrysts, derived from some external source They show strong corrosion embayment and rounding and may have developed reaction rims of pyroxene or other minerals

Occurrence. Basalt is the most widespread and abundant volcanic rock It occurs predominantly as flows and less commonly as tuffs and small intrusions (such as dikes and sills) It may erupt as

Snake and Columbia River area in northwestern United States the Deccan of western India, and the Parana Basin of South America Rocks of the oceanic island volcanoes are known as oceanic or olivine basalts Those of great areal eruption are called flood, plateau, or tholeiitic basalts Tholeiitic basalts may be more or less distinguished from oceanic basalts by the small quantity or absence of olivine, by abundant pigeonite, and by the presence of minor quartz and alkali feldspar or acid glass in the matrix Oceanic or olivine types are usually associated with trachybasalt and minor amounts of latite, trachyte, and phonolite In addition to forming great lava floods, tholeiitic basalt is associated with andesite and rhyolite in orogenic (fold mountain) belts *See* MAGMA, PETROGRAPHIC PROVINCE [C A CA]

Base, chemical

Any chemical species, ionic or molecular, capable of accepting or receiving a proton (hydrogen ion) from another substance The other substance acts as an acid in giving up the proton A substance may act as a base, then, only in the presence of an acid The greater the tendency to accept a proton the stronger the base The hydroxide ion (OH^-), therefore, acts as a strong base in the reaction

$$H^+ + OH^- \rightarrow H_2O$$

Water, in undergoing the reaction

$$H^+ + H_2O \rightarrow H_3O^+$$

acts as a weaker base

This broad definition has replaced the older, more familiar concept of a base as any substance yielding hydroxyl ions in solution *See* ACID AND BASE [F J J]

Basement rock

The rocks of the Precambrian, Archean, Primitive, or Basement complex consisting mainly of lavas poorly sorted mud rocks, called greywacke, or consolidated gravel, known as conglomerate In places however, they consist of recrystallized limestone quartzite, slate, or other sediments of the well sorted class All of these rocks have been folded and intruded by granitic igneous rocks The intru



Poorly sorted conglomerate of the Archean, Timiskaming Series Rouyn Township, Western Quebec, Canada Hammer is 18 in long (*Geological Survey of Canada*)

sions accompanied the mountain building of which the folding is an evidence *See* PRECAMBRIAN

[M E W]

Bibliography R T Prider The Precambrian succession in western Australia *Pan Indian Ocean Sci Cong (Perth) Proc sec C* 1954 M E Wilson Early Precambrian Rocks of the Timiskaming Region Quebec and Ontario Canada *Bull Geol Soc Am* 67 1956

Basidiomycetes

A class of fungi of the subdivision Eumycetes The Basidiomycetes are important as food (mushrooms) as causal agents of plant diseases (rusts smuts heart rots of trees) and as causes of dry rots of timbers The characteristic structure of the Basidiomycetes is the basidium a specialized sporangium which is the site of nuclear fusion and reduction division After this division usually four basidiospores are formed in outpocketings in such a way that they appear to be borne on the basidium

The vegetative stage (mycelium) of Basidiomycetes is composed of filaments (hyphae) with cross walls Some species reproduce nonsexually by non motile spores (conidia) Specialized sexual structures are lacking except in rusts Some Basidiomycetes are self compatible but in most sexual reproduction requires the fusion of two compatible mycel a or of a conidium with a mycelium In some species of the latter type compatibility is determined by one pair of allelic genes in others it is determined by two series of alleles located on different chromosomes After fusion the nuclei pair and a free living secondary mycelium each cell of which is binucleate develop Sooner or later the secondary mycelium produces basidia All species of the subclass Homobasidiomycetidae and some Heterobasidiomycetidae produce basidia in or on a fruiting body (basidiocarp) of macroscopic size *See* EUMYCETES HETEROBASIDIOMYCETIDAE HOMOBASIDIOMYCETIDAE MUSHROOM UREDINALES USTILAGINALES

[R M P]

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Basin

A low lying area wholly or largely surrounded by higher land Basins vary from small nearly enclosed valleys to extensive mountain rimmed depressions such as the Bighorn Basin of north central Wyoming and the larger Tarim and Dzungarian Basins of central Asia or to equally broad but shallower features such as the Congo Basin of central Africa A basin is shown in the illustration at the bottom of the page

Mississippi Basin occupying most of the United States between the Rocky Mountains and the Appalachians or of the Amazon Basin an area of similar size in northern South America Depressions that drain entirely inward without outlet to the sea are basins of interior drainage Examples are the Aral and Caspian depressions (the Volga River drains into the latter) in Russian Turkestan and the Great Basin of the United States actually an area of many smaller mountain ringed basins of interior drainage occupying most of Nevada and parts of the adjacent states

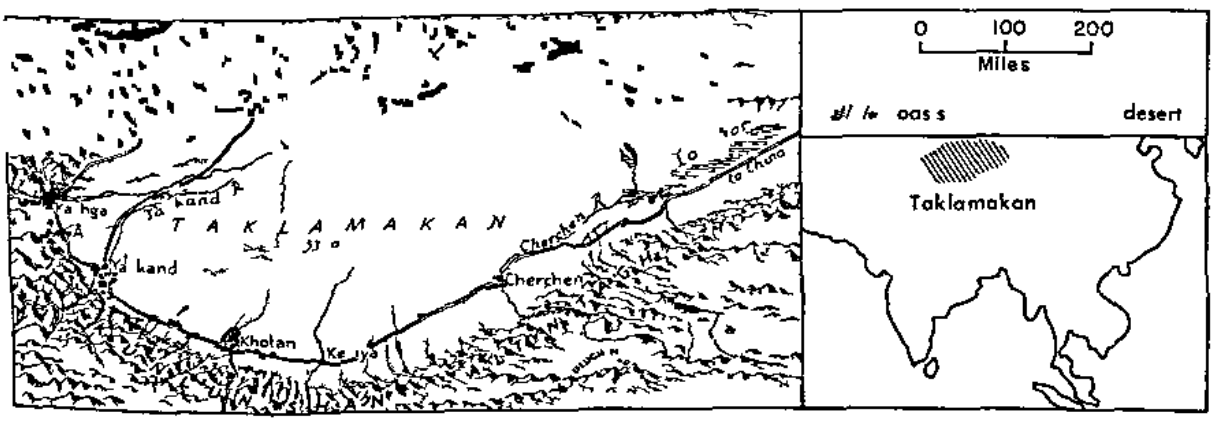
A geologic basin is an area in which the rock strata are inclined downward from all sides toward the center Because of erosion and deposition the surface may not show the form of a depression The Paris Basin the London Basin and the Illinois Western Kentucky Coal Basin are examples of this type

[F H HA]

Bass

A general term applied to a variety of fishes in both salt and fresh water The fishes most commonly called basses are the true basses of the family Serranidae and the so called black basses of the family Centrarchidae

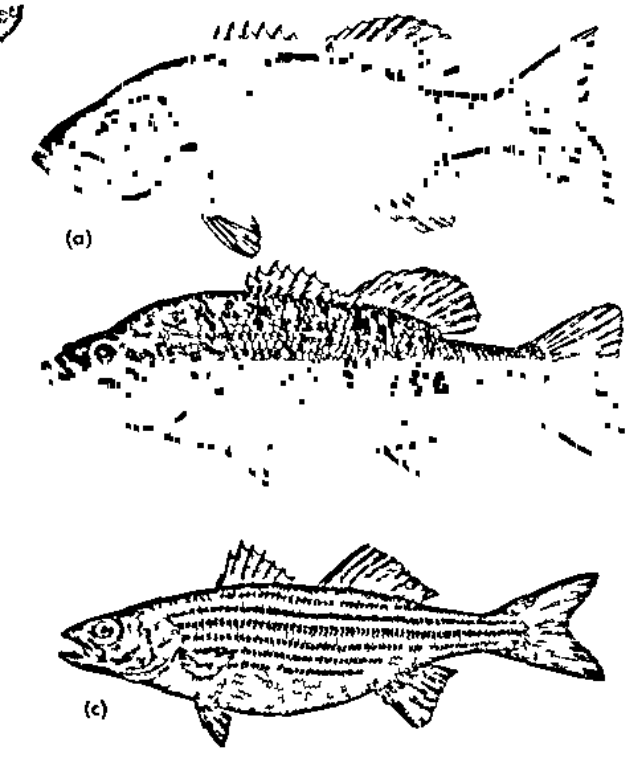
The fishes in the genus *Micropterus* of the sunfish family Centrarchidae are usually called bass or black bass Included here is the common large mouthed black bass *Micropterus salmoides* originally native to eastern North America but now



Tarim Basin in central Asia a mountain rimmed desert basin of interior drainage (*After E Raisz in P E James An Outline of Geography Ginn 1935*)

found throughout the world The large mouth tol erates a wide variety of water conditions and is a famous sport fish readily taking natural and artifi cial baits, and fighting fiercely when hooked The small mouth black bass *M dolomieui*, prefers colder water and occurs over most of eastern North America, it has been introduced elsewhere, but not to the extent of the large mouthed species In the northern part of the United States the small mouth is a lake fish, in its southern range it is found in streams The Kentucky bass, *M punctulatus*, oc cupies a somewhat intermediate habitat in moder ately large streams in an east west belt across the central portion of the United States east of the Great Plains There are a few less important spe cies in the group

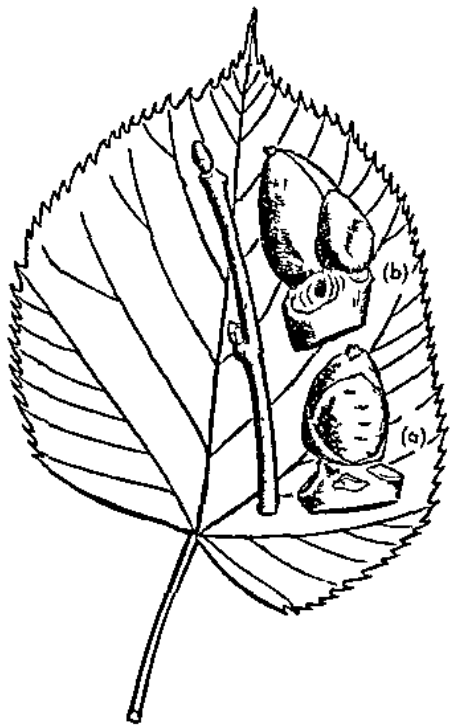
The family Serranidae includes both fresh water and marine species Best known of the fresh water forms is the white bass *Morone chrysops* which has become unusually plentiful in many artificial lakes in the United States since about 1930 Among the marine species the striped bass *Roccus saxa tilis*, is perhaps the best known It weighs up to 125 lb and specimens over 50 lb are rather fre quently captured It is a native of the Atlantic Coast of the United States, but has been success fully introduced on the Pacific Coast There are over 400 species in the family Serranidae, any of which may be called bass *Morone americana*, in correctly called white perch is common along the Atlantic Coast, thriving in fresh, brackish, or salt water, and being somewhat anadromous in its hab its *See* PERCIFORMES [J D B]



Bass (a) Small mouthed, *Micropterus dolomieui* length to 2 ft (b) Large mouthed *Micropterus salmoides*, length to 3 ft (c) Striped, *Roccus saxatilis* length to 5½ ft (*From E L Palmer, Fieldbook of Natural His tory, McGraw Hill, 1949*)

Basswood

A tree *Tilia americana*, also called American lin den belonging to the linden family, Tiliaceae or der Malvales (*see* MALVALES) It is a timber tree of the northeastern quarter of the United State and adjacent Canada and grows to a height of 12(ft The leaves are heart shaped coarsely toothed long pointed and alternate



American basswood, *Tilia americana* (a) End of seo son s growth (profile view) showing stipule scar and leaf scar (b) End of season s growth (surface view) showing leaf scar and smaller accessory bud (*From A H Graves, Illustrated Guide to Trees and Shrubs rev ed , Harper, 1956*)

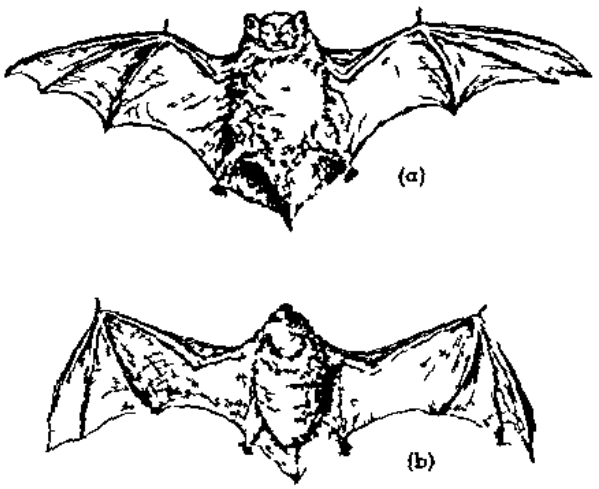
All species of *Tilia* can be recognized by the peculiar winter buds which have a large outer scale that gives the bud a humped asymmetrical appear ance, and by the small spherical, nutlike fruits borne in clusters *Tilia* is also an ornamental tree *T europea*, or lime tree of Europe, is often culti vated along the streets A species of the southern United States *T heterophylla*, the bee tree linden has leaves that are white beneath or brownish with a dense hairy coat

The wood of basswood also known as whitewood is white and soft and is used for boxes, venetian blinds millwork, furniture and woodenware In re cent years the cut of basswood timber has been greatly reduced from a former 400 000 000 board ft to about 100 000 000 The Lake states furnish about one-half of the supply The lindens are also important as bee trees There are about 30 species

in the temperate regions of the Northern Hemisphere in North America south to Mexico but none in the western part In Asia lindens grow south to central China and south Japan *See* Forest and forestry, Tree [A H G]

Bat

Any member of the successful cosmopolitan mammal order Chiroptera Bats are essentially similar to the insectivores but differ in having the forelimbs modified as wings with membranes connecting the wings to the hind legs and the latter to the tail Most bats are small insect eating animals but a few have other diets These include the blood sucking vampires small American bats in the genus *Desmodus*, the fish-catching *Pizonyx* and the large fruit bats of the genus *Pteropus* from the Australian Oriental area



Bat (a) Hoary *Lasiurus cinereus* length 5¼ in (b) Little brown *Myotis lucifugus* length 3¾ in (From E L Palmer *Fieldbook of Natural History* McGraw-Hill 1949)

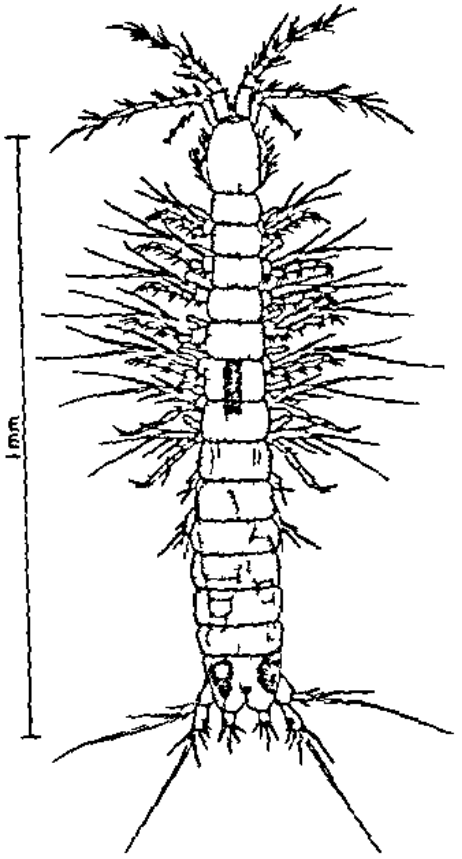
Almost all bats are beneficial or neutral in their effects on man Fruit bats or "flying foxes may at times damage fruits used by man The vampires and more rarely other species sometimes carry rabies *See* Chiroptera [J D B]

Batholith

A geologic name for a body of igneous rock of moderate or large size (40 mi² or more in cross sectional diameter) emplaced at great or intermediate depth in the earth's crust Batholiths are commonly discordant with (cut across) the enclosing rocks but on a grand scale most of the large batholiths are elongated parallel to the dominant structure of the enclosing crustal rocks The shape of batholiths in depth is a point of debate One school argues that batholiths continue downward with increasing size or at least with no reduction in size The other school argues that large batholiths are composites of many smaller units, each of which maintains a nearly constant cross section thus suggesting variation in shape with downward development *See* Pluton [J A N]

Bathynellacea

An order of syncarid crustaceans found in subterranean waters in Central Europe and England The body is elongate and segmented Organs and limbs

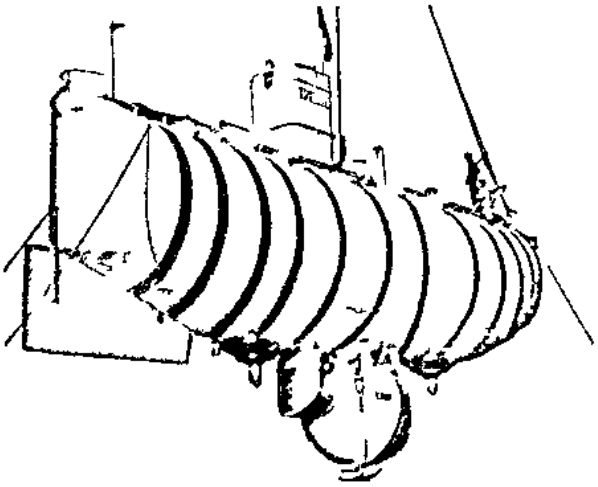


Bathynella natans female

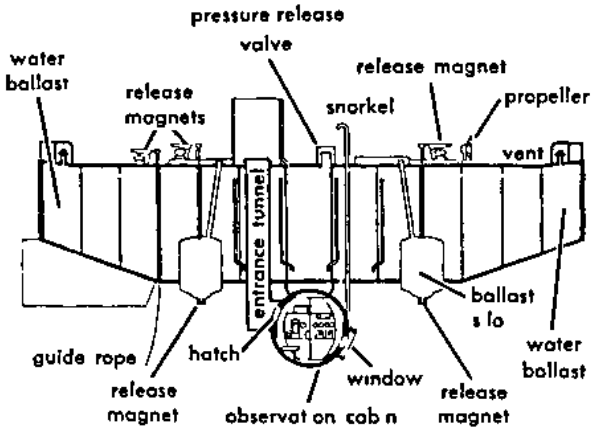
are primitive Each of the thoracic limbs has two epipodites which function as gills The thorax and abdomen have a similar form These animals have no metamorphosis *See* Syncarida [H J]

Bathyscaph

The bathyscaph is a free and self contained submersible craft which has dived over 6 miles to the greatest known ocean depths Simple in basic concept the bathyscaph may be thought of as the underwater equivalent of a blimp consisting as it does of a gasoline filled flotation hull (bag) and a manned spherical pressure resistant cabin (gondola) The hull is not designed to withstand the enormous hydrostatic pressure of the deep sea instead sea water is freely admitted to the bottom of the hull where the gasoline being lighter than and immiscible with water floats on top The gasoline having a density of about 0 70 provides the necessary buoyancy and ballasting is accomplished by iron pellets which can be jettisoned at will Since this ballast is held by magnetic valves it is automatically jettisoned in event of electrical failure so that the craft returns to the surface This is termed the bathyscaph's fail safe p Electrically driven propellers provide



Fg 1 Bathyscaph *Tr este*



Fg 2 Schemat c cross sect on of the *Trieste*

scaph with sluggish horizontal maneuverability for short distances The cabin is provided with plastic portholes for viewing the ocean the bottom and any marine life Accessory apparatus includes floodlights navigational instruments and other scientific devices *See* OCEANOGRAPHY

The bathyscaph was invented by the Swiss professor Auguste Piccard The first successful (although unmanned) dive was made to 1500 meters (m) off Cape Verde in 1948 with bathyscaph FNRS-2 This craft was subsequently rebuilt by the French Navy and under Commandant G Houot about 60 descents were made as of 1958 without serious mishap attaining a maximum depth of 4100 m off Dakar A second bathyscaph *Trieste* was built in 1953 by A Piccard and has made about 50 plunges in the Mediterranean Sea under the pilotage of J Piccard It reached a maximum depth of 3700 m (12 400 ft) in the Tyrrhenian Sea In 1958 the *Trieste* was transferred to the U S Navy in San Diego California

In January 1960 the *Trieste* with Jacques Piccard and Lt Don Walsh (U S Navy) aboard reached a depth of 10 906 m (35 800 ft) in the Marianas Trench off Guam The descent took 4 hours 48 min and the ascent 3 hours 17 min A half hour was spent at the bottom During that time the hull of the bathyscaph was subjected to a pressure of 16 883 psi

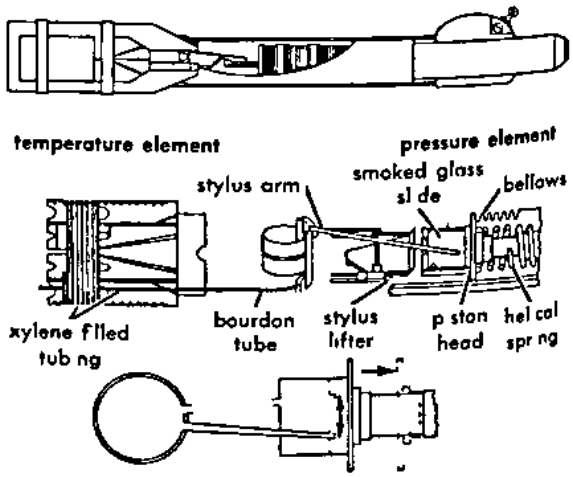
A schematic cross section of the *Trieste* is shown in Fig 2 The 11 center compartments of the hull are filled with 28 000 gallons of gasoline providing a buoyancy of 32 tons The forged steel cabin is 2 m in diameter 9 cm thick, and weighs 10 tons in air The entrance air lock is flooded during descent and blown out with compressed air upon surfacing The cabin contains 12 lead throughs for the multiconductor electric cables which are necessary to operate the craft Submergence is initially effected by taking on water ballast into the air tanks at the two ends of the hull additional negative buoyancy can be attained if needed by valving off some gasoline [R S D]

Bibliography R S Dietz et al The bathyscaph *Sci American* 198(4) 27–33 1958, A Piccard *In Balloon and Bathyscaphe* 1956

Bathythermograph

A self contained nonelectronic instrument for obtaining a permanent graphical record of water temperature (°F) against depth (ft) as it is lowered and raised in the ocean The bathythermograph or BT can be used while the ship is underway and therefore provides a rapid means of obtaining temperature data in the upper 250 to 900 ft The depth or pressure element is a spring and bellows which moves a smoked glass slide A stylus attached to a temperature element scratches the record on the slide This unit consists of liquid filled tubing wound around the tailfin and is in direct contact with the sea water As the liquid (xylene) expands or contracts with changing water temperature the pressure change inside the tubing is transmitted to a Bourdon tube which in turn guides the stylus at its free end (Fig 1)

The speed of thermal response is 0 8 sec for a 90% response and the accuracy obtained is about 2% for depth and 0 2°F for temperature depend



Fg 1 View of bathythermograph thermal and depth elements (*From U S Navy Hydrograph c Office Publ 607 2d ed , 1955*)

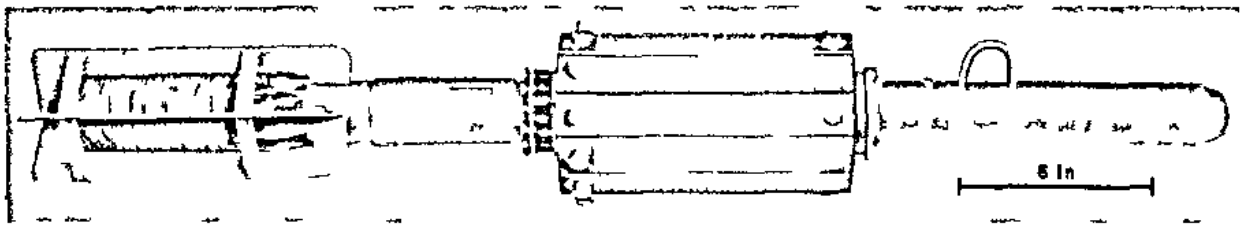


Fig 2 Spilhaus-Miller bathythermograph and water sampler (*U S Navy Hydrographic Office*)

ing somewhat on the instrument and manner in which it is used The temperature of the surface water (to the nearest 0 1°F) is obtained by means of bucket sample and standard thermometer while the BT is being towed This reading establishes the surface reading of the BT The BT trace is read by comparing it with a grid calibrated for the particular instrument The slides are sent to data processing centers for photocopying and tabulation of the data There are now several hundred thousand temperature depth traces for the top 50 to 250 m over much of the ocean The data obtained are pertinent to the study of mixing within the upper layer of the ocean and the depth of the thermocline *See* THERMOCLINE

The Spilhaus Miller sea sampler (Fig 2) is basically a BT with 12 water sampling bottles attached Valves at each end of the bottles close at predetermined depths The sampler performs the same function as the reversing water bottles and thermometers do on deep casts but to limited depths and with less accuracy For further treatment of temperature-measuring devices and water samplers *see* SEA WATER [A C V]

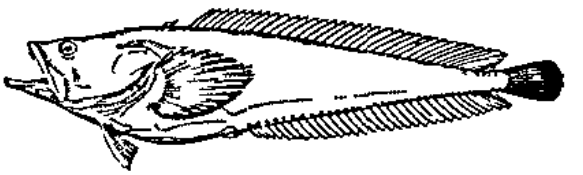
Batoidea fossils

Where known the body of extinct skates and rays (order Batoidea) appears to have resembled that of modern types in its depressed shape expanded pectoral fins and slender tail In general however remains consist of teeth only Many Paleozoic sharks appear to have been bottom dwelling feeding on shelled invertebrates these sharks became extinct however and the first relatively rare batoids are found in the Late Jurassic By the Upper Cretaceous the group had assumed as prominent a position as it has today and with the exception of the eagle rays and torpedoes all major living groups as well as a number of then existing genera were present *See* ELASMOBRANCHII RAJIFORMES [A S R]

Batrachoidiformes

The toadfishes which make up an order (or suborder) of actinopterygian fishes This group also known as the Haplodoci is derived from the Perciformes and is most closely related to the Lophiiformes The first vertebra of Batrachoidiformes is rigidly fused with the broad flattened cranium the short posttemporal is not forked and is suturally attached to the skull There are no epiotics opisthotics or ribs and the 4–5 pectoral radials are elongate There are only 3 gill arches and the gill openings are reduced in size The pelvic fins are on the throat

The single family Batrachoididae known from Pliocene to Recent time includes 10 genera and about 30 species Most live in tropical and temperate oceanic shore waters or in moderate depths but a few ascend tropical rivers Some species are luminescent Others have hollow opercular and dorsal spines associated with venom glands *See* ACTINOPTERYGII BIOLUMINESCENCE [R M B]



Atlantic midshipman Porichthys porosissimus length to 8 in (After D S Jordan and B W Evermann The Fishes of North and Middle America U S Natl Museum Bull 47 1900)

Battery (electric)

A device which transforms chemical energy into electric energy The term is usually applied to a group of two or more electric cells connected together electrically In common usage the term battery is also applied to a single cell such as a flashlight battery

Types There are in general two types of batteries primary batteries and secondary storage or accumulator batteries Primary types although sometimes consisting of the same plate-active materials as secondary types are constructed so that only one continuous or intermittent discharge can be obtained Secondary types are constructed so that they may be recharged following a partial or complete discharge by the flow of direct current through them in a direction opposite to the current flow on discharge By recharging after discharge a higher state of oxidation is created at the positive plate or electrode and a lower state at the negative plate returning the plates to approximately their original charged condition

Primary and secondary cells may be constructed from several materials For the more important of these types *see* PRIMARY BATTERY STORAGE BATTERY

Applications Primary cells or batteries are used as a source of dc power where the following requirements are important

1 Electrical charging equipment or power is not readily available

2 Convenience is of major importance as in the case of the hand or pocket flashlight

3 Stand by power is desirable without cell deterioration during periods of nonuse for days or years Reserve electrolyte designs may be necessary as in torpedo guided missile and some emergency light and power batteries (*see* RESERVE BATTERY)

4 The cost of a discharge is not of primary importance

Secondary cells or batteries are used as a source of dc power where the following requirements are important

1 The battery is the primary source of power and numerous discharge recharge cycles are required as in industrial hand or rider trucks electric street trucks mine or switching locomotives and submarines

2 The battery is used to supply large short time (or relatively small longer time) repetitive power requirements as in automotive and airplane batteries

3 Stand by power is required and the battery is continuously connected to a voltage controlled dc circuit With proper voltage the battery is said to float (drawing from the dc circuit only sufficient current to compensate automatically for the battery s own internal self discharge) Telephone exchange central station circuit breaker and emergency light and power batteries are in this category

4 Long periods of low current rate discharge followed subsequently by recharge are required as in buoy service

5 The very large capacitance is beneficial to the circuit as in telephone exchanges

Size Both primary and secondary cells are manufactured in many sizes and designs from the small electric wristwatch battery and the small penlight battery to the large submarine battery where a single cell has weighed one ton In all applications the cell must be constructed for its particular service so that the best performance may be obtained consistent with cost weight space and operational requirements Automotive and aircraft batteries generally use thin positive and negative plates with thin separation to conserve space and weight and to provide high rates of current discharge at low temperatures Stand by batteries use thick plates and thick separators to provide long life Notable improvements have been made in reducing size and weight through the use of new plastic materials active materials and methods of construction

Ratings Since the power that can be obtained from a cell varies with its temperature and the rate of current discharge the power output rating is very important Common secondary battery practice is to rate cells in terms of ampere hours (discharge rate in amperes times hours of discharge) and to specify the hourly rate of discharge A popular automotive battery capable of giving 5 amp for 20 hours is rated at 100 amp-hr at the 20-hour rate This same battery may provide an engine cranking current of 300 amp for only 8 min at 80°F or for 4 min at 0°F giving a service of only 40 and 20 amp hr respectively By multiplying ampere hours by average voltage during discharge watt hour rating is obtained Ratings must be made to a specified final voltage which is either at the point of rapid voltage drop or at minimum usable voltage The rating of primary batteries is generally stated as the number of hours of discharge which can be obtained when discharging through a specified fixed resistance to a specified final voltage

Life Life of cells varies from the single discharge obtainable from primary types to 1 000 000 or more discharge-charge cycles obtainable from some secondary cells operating at very high rates for very short times Automotive batteries may generally be expected to give approximately 300 cycles or to last 2 years Industrial truck sizes may be expected to give 1500 to 3000 cycles in 5–10 years Stand by sizes may be expected to float across the dc bus 8–30 years Generally the most costly largest heaviest cells are the longest lived

To obtain life from batteries certain precautions are necessary The stated shelf life and temperature of wet primary cells must not be exceeded For dry reserve electrolyte primary cells and secondary cells of the dry construction with charged plates the cell or battery container must be sealed against moisture and storage must be within prescribed temperature limits Wet charged secondary batteries require periodic charging and water addition depending upon the kind of construction

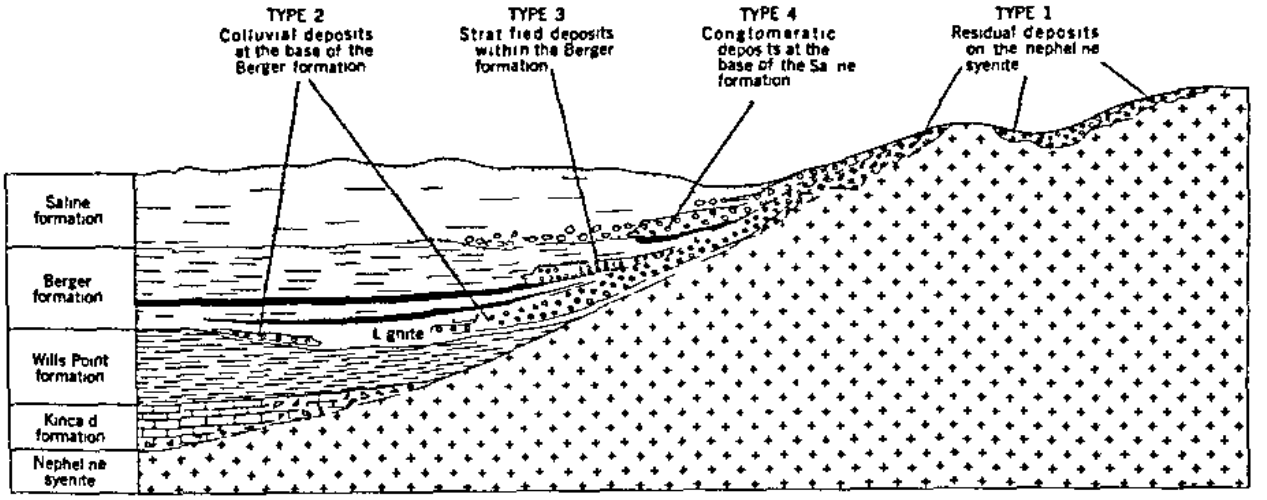
Reliability Batteries are probably the most reliable source of power known In fact most critical electric circuits are protected in some manner by battery power There are no moving parts and with good quality control in component materials and construction one can be assured of power particularly since adequate checks to indicate the condition of the cells usually exist To ensure reliability manufacturer s stipulations on storage and maintenance must be followed

For other sources of electric energy known as batteries or cells *see* FUEL CELL NUCLEAR BATTERY SOLAR BATTERY [H C R]

Bauxite

A rock name for weathering products composed largely of hydrous aluminum oxides aluminous laterite also ore of aluminum Red nonplastic claylike material from Les Baux in southeastern France was first analyzed by P Berthier in 1821 named beauxite by A Dufrenoy in 1845–1847 and corrected to bauxite by H Sainte Claire Deville in 1861 The type material is a mixture and not a mineral species

Bauxite occurs in a variety of structures textures and colors The color depends on the content of iron oxides and ranges from white to dark red or brown Commonly bauxite is pisolitic and concretionary but it may be fine grained dense or ver



Diagrammatic section of the principal types of deposits in the Arkansas bauxite region (M Gordon J I Tracey Jr, and M W Ellis, Geology of the Arkansas Bauxite Region USGS Prof Paper 299, 1958)

micular Earthy bauxite is difficult to identify in the field and may require chemical x ray petrographic, or differential thermal analysis Portable differential thermal analysis units and quick chemical methods commonly are used in exploration

Commercial bauxite These deposits consist largely of gibbsite $Al(OH)_3$ or boehmite AlO(OH), or mixtures of these minerals The chief impurities are clay minerals and iron oxides and bauxite may grade into clay or into ferruginous laterite (*see* LATERITE) Some bauxite derived from basaltic rocks in India and Hawaii contains large amounts of titania Clayey bauxite is beneficiated by washing to remove the finer grained clay minerals (Binton Island Palau Islands Brazil)

C S Fox in 1927 suggested two main groups of bauxite deposits laterite type and terra rossa type All deposits are not easily placed in this classification but bauxite formed more or less in situ from crystalline rocks is of the first type whereas the deposits that overlie limestone or dolomite commonly are referred to as the terra rossa type

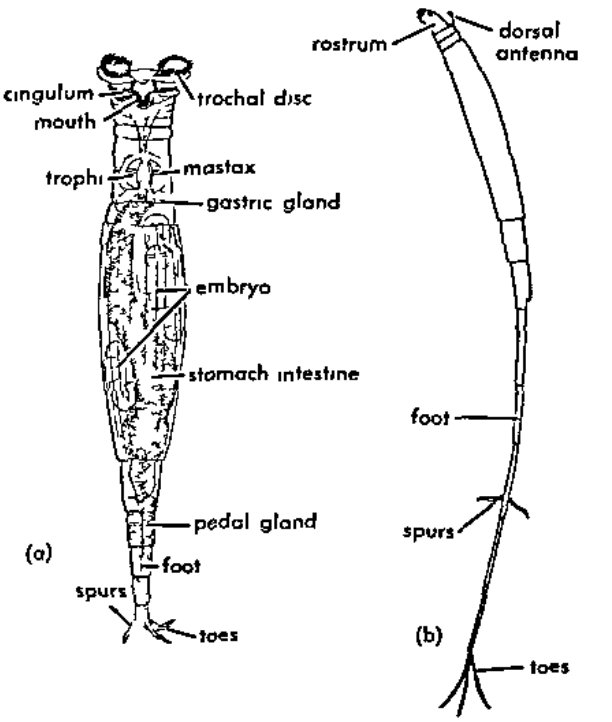
Bauxite from crystalline rocks generally is gibbsitic (Arkansas Surinam British Guiana Brazil French West Africa Gold Coast India Australia) The terra rossa bauxite usually contains appreciable amounts of boehmite (France Italy Yugoslavia Greece Hungary Jamaica Haiti Dominican Republic) Diaspore HAlO in some Mediterranean deposits is attributed to metamorphism and is not a product of weathering

Production The world production of bauxite has steadily increased and in 1957 was more than 18 000 000 tons (Mineral Industry Surveys) Production in the United States in 1957 was approximately 1 400 000 long tons (dried equivalent) with 96% coming from Arkansas and 4% from Alabama and Georgia The domestic production amounts to about one-fourth of the total bauxite used Imports are mainly from Jamaica and Surinam Ferruginous bauxite has been explored in Oregon and in the Hawaiian Islands [s s c]

Bibliography E C Fischer *Annotated Bibliography of the Bauxite Deposits of the World*, USGS Bull 999 1955, C S Fox *Bauxite and Aluminous Laterite* 2d ed 1932, S S Goldich and H R Bergquist *Aluminous Lateritic Soil of the Republic of Haiti, W I*, USGS Bull 954-C 1948

Bdelloidea

An order of the class Rotifera comprising animals which resemble leeches both in body shape and manner of locomotion The elongated body is composed of from 15 to 18 false segments, or annuli, which do not follow the inner segmentation of the body, those of the head, neck, and foot can be re-



Bdelloid rotifers (a) Rotaria (b) R neptunia (After Weber, 1898 from L Hyman, The Invertebrates, vol McGraw Hill 1951)

tracted telescopically into the wider central body The corona is typically developed in many bdelloids and consists of a cingulum and two trochal disks raised on pedicels The corona however is quite reduced in *Philodinavus Adineta* and related genera The corona is utilized for swimming by some species The mastax is of the ramate type in which the plate-shaped unci are the most developed parts

Males are unknown among bdelloids and all reproduction is assumed to be parthenogenetic A few genera such as *Rotaria* and *Dissotrocha* are viviparous but most are oviparous germovitellaria are paired

The majority of bdelloids living in the littoral zone of ponds and lakes have colorless transparent bodies while the majority of species living in dry mosses have colored bodies Curiously enough the water dwelling species of high mountain regions and Arctic countries are vividly colored Some bdelloid rotifers secrete shells which may become covered with debris, a few species live in the discarded shells of rhizopod protozoans much as hermit crabs live in discarded snail shells The shortest known bdelloid *Habrotrocha minuta* is less than 0 08 mm while the largest *Rotaria elongata*, attains a length of 1 50 mm *See* ROTIFERA [E H A]

Bdellomorpha

An order of the class Enopla of the phylum Rhynchocoela containing the single genus *Malacobdella* The three species of *Malacobdella* are ectocommensals on mollusks and feed on plankton in the mantle chamber of the host The proboscis is unarmed special sense organs such as eyes are lacking in the adult and a posterior adhesive disk is present Both the middorsal and lateral vessels are branched *See* ENOPLA, HOPLONEMERTINI [C B C]

Beam

A structural member horizontal or nearly so which extends between supports and on which a building floor a bridge roadway or other surfacing may rest The load carried by the beams acts transversely to the principal axis of the beams *See* LOADING TRANSVERSE [W J KR]

Beam column

A structural member subjected simultaneously to axial load and bending moments produced by lateral forces or eccentricity of the longitudinal load These conditions are frequently found in frame structures

Secant formula The maximum load that produces collapse with or without twisting occurs after yielding due to the combined bending and axial loads Failure is thus a phenomena of inelastic instability If yielding of the material is assumed to be the critical condition for the approach of failure the load that produces yield stress represents a minimum estimate of the collapse load For the case of an eccentrically loaded column with equal end eccentricities the limiting average stress for design is given by the secant formula

$$\frac{P}{A} \leq \frac{S_y/n}{\left[1+\left(\frac{ec}{r^2}+\frac{e_o c}{r^2}\right)\right]\sec\frac{L}{2r}\sqrt{\frac{nP}{AE}}}$$

where S_y is yield point stress n is the safety factor e is applied eccentricity between line of action of the load and the axis of the column e_o is an additional empirically determined eccentricity equivalent to the effects of crookedness defects and residual stress This formula is derived for steel with a distinct yield point free ends and bending in the plane of the moments Modifications in bridge specifications provide for end conditions and eccentricity about both axes of the section

Interaction formula Strength of members subjected to combined bending and axial load can be expressed in terms of ratios of actual maximum thrust and bending moment at failure to the corresponding ultimate resistance to compression as a column and bending moment when acting alone In its simplest form the expression is

$$\frac{P}{P_u}+\frac{M}{M_u}=1$$

where P and M are actual longitudinal load and bending moment at failure P_u is axially applied load at collapse when no external bending moment exists and M_u is the ultimate resisting moment when no end load is applied For allowable stress design the formula is expressed in terms of stresses and when corrected to account for the secondary moment produced by the load and lateral deflection it is modified to the form

$$\frac{f_a}{F_a}+\frac{f_b}{F_b(1-nf_a/f_e)}\leq 1$$

where f_a is maximum average compressive stress f_b is maximum bending stress neglecting deflection F_a is allowable stress according to a column formula for axial load F_b is allowable bending stress as a beam n is the safety factor and f is Euler s critical buckling stress

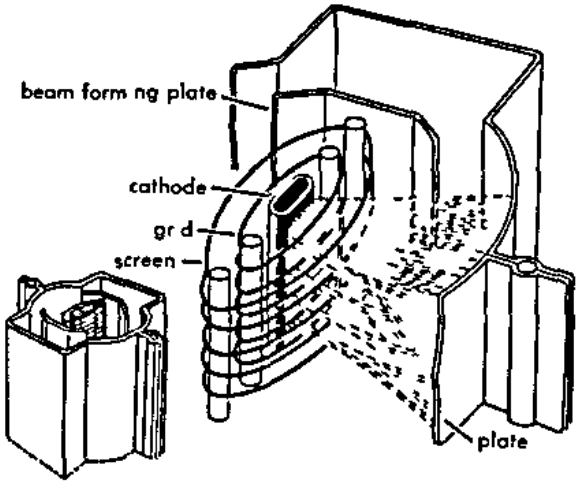
Application of the interaction formula presupposes a column formula for axial loads applicable to the conditions and prescribed limitations on the allowable bending stress where lateral buckling is involved

The interaction formula is convenient in application to a wide variety of practical loading conditions *See* COLUMN [W J KR]

Bibliography Column Research Council *Guide to Design Criteria for Metal Compression Members* 1960

Beam power tube

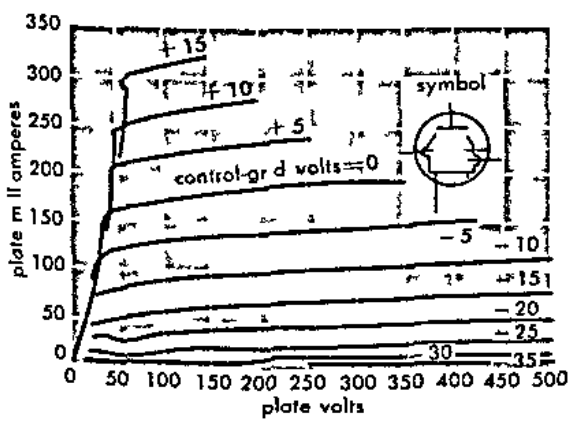
A special form of tetrode used as a power amplifier The beam power tube was developed to overcome some of the limitations of the early pentode power amplifier



Fg 1 Cutaway v ew of the electrode arrangement n a beam power tube (*Rad o Corporat on of Amer ica*)

A cut away view of a beam power tube is shown in Fig 1 It differs from the ordinary screen grid tube in several respects The distance between the screen grid and the plate is comparatively large the control grid and the screen grid are aligned so that the electrons move in sheetlike beams and beam forming plates at the sides serve to keep the elec tron stream from spreading These construction features serve to increase the space charge density of the electron beam between the screen and the plate and this in turn depresses the potential in this region and serves to inhibit the exchange of secondary electrons between the screen and the plate

The resultant current voltage characteristics of a beam power tube have the form shown in Fig 2 These are free of distortions due to secondary emis sions except for some minor effects at very nega tive control grid voltages Typical plate current plate voltage characteristics show a steep initial rise followed by a region of low uniform slope The characteristics are in addition fairly parallel and uniformly spaced There is a peculiar hump on the shoulder of the characteristics for large p s itive control grid voltage which requires further discussion



Fg 2 Plate current versus plate voltage character st cs of a beam power tube (*From K R Spangenberg Vacuum Tubes McGraw H ll 1948*)

The steep initial rise in the plate-current–plate voltage characteristic is caused by the formation of a virtual cathode between the screen grid and the plate because of the large space charge density at low plate potential When this occurs only a frac tion of the current injected into the screen plate region is transmitted to the plate As the plate voltage is increased this fraction increases while at the same time the distance between the virtual cathode and the plate decreases Both of these fac tors act together to give a more rapid increase in plate current than the usual $\frac{3}{2}$ power of voltage The virtual cathode can exist only up to a point where a certain large fraction of the current is be- ing transmitted to the plate This occurs at some moderate plate voltage At this point the virtual cathode disappears and the potential distribution suddenly rises to a smooth curve joining the screen and plate This curve is concave upward and may have a potential minimum slightly less than the plate voltage but will not have a zero potential As plate voltage is increased still further the potential minimum persists but now all of the screen cur rent is transmitted to the plate The potential mini mum which is usually 20 volts or more below either the plate or screen voltage serves to suppress the exchange of secondary electrons between the screen and the plate

This cycle of action does not reverse itself per fectly upon reversal of plate voltage As the plate voltage is reduced the potential minimum drops to quite a low point before it suddenly saturates and jumps to a condition of a virtual cathode As a re sult the condition of complete transmission of cur rent tends to persist to a lower voltage upon re d ction of plate voltage than that at which it comes into being as the plate voltage is increased The result is that ideally there should be a little hys teresis loop in the shoulder of the characteristic Actually this degenerates into an S shaped curve because of the external resistance of the power supplies with which the characteristics are meas ured

driving power They cannot however be used in pulse applications because there is a maximum cur rent which can be transmitted through the space charge region between screen and plate *See* ELEC TRON TUBE VACUUM TUBE [K R S]

Bean

A common name loosely used to designate several leguminous plants which have long been used as food by man and his livestock Seventeen species in six genera produce beans of commercial impor tance in the world In the United States three gen era are recognized in the commercial bean classes These are *Phaseolus* the so-called true beans *Vigna sinensis* or California blackeye a culinary

cowpea and *Cicer arietinum* commonly called garbanzo or chickpea

Four species of the genus *Phaseolus* all of which originated in America produce the beans of greatest economic importance in the United States They are *P vulgaris* the common bean *P multiflorus* the runner bean, *P lunatus* the lima bean, and *P acutifolius* var *latifolius* the tepary bean

Plants of *Phaseolus vulgaris* the most important of the four American species may be either bush or vine type Kidney beans are of the bush type whereas the pea bean Michelite and Robust varieties is of the vine type Flowers may be white yellow or lilac The seed coat color may be white red brown black or speckled for example in pinto and cranberry beans Seeds are borne in a straight or curved pod (fruit) Pods of the dry bean type may be high in fiber those of the snap bean varieties are low in fiber Beans are normally self pollinated although a small amount of natural crossing may occur in the field as a result of insect activity All *Phaseolus* species have 11 pairs of chromosomes

Production statistics The bean crop in the United States in 1955 was produced on 1 814 400 acres with a farm value of $209 225 000 Production was divided into the commercial crop of green lima and snap beans produced on 312 400 acres with a farm value of $92 484 000 and the dry edible bean crop produced on 1 502 000 acres with a farm value of $116 741 000 Soybeans and mung beans are not included in these figures

The annual average dry edible bean production in the United States during 1946–1955 was 16 573 000 bags of 100 lb each These were harvested from 1 580 000 acres which yielded an average of 1058 lb/acre The farm value averaged $137 265 000 In 1956 Michigan was the leading state in acreage and in total production of dry edible beans The 1955 production in the United States of the various commercial classes of dry edible beans is shown in the table

Production of commercial classes of dry edible beans in the United States in 1955

Class	Production 100 lb bags cleaned
Pea (navy)	4 627 000
Great Northern	2 029 000
Small white	836 000
White marrow	36 000
White kidney	8 000
Pinto	3 853 000
Red kidney	1 121 000
Pink	414 000
Small red	1 038 000
Cranberry	61 000
Yelloweye	78 000
Black turtle soup	39 000
Large lima	1 077 000
Baby lima	318 000
Blackeye California	967 000
Garbanzo	28 000
Other	767 000
Total	17 287 000

Most of the white pea (navy) beans are produced in Michigan and New York, Great Northern beans in Nebraska Wyoming and Idaho, pinto beans in Colorado and Idaho, red kidney beans in New York California and Michigan, and large and small lima beans in California The regional distribution of classes is the result of climatic influences

Culture Beans are a warm season crop although most of the extensive producing areas have a mean August temperature of 70°F or less Except for lima beans which require the highest temperature there is little difference between classes in their mean temperature requirements However, there are important differences in their tolerance of high temperature in drought resistance and in water requirements Lima beans are day neutral in flowering habit (not affected by length of day or photoperiod) whereas *P vulgaris* the common field beans are short day in behavior except some such as Boston yelloweye and red kidney which are day neutral

Beans are grown on a wide variety of soil types In Michigan the most productive bean soils are the well drained dark colored heavy loams silt loams and clay loams abundantly supplied with organic matter Sandy soils are less satisfactory because of the possibility of drought Unlike many legumes the bean is a soil depleting crop under most production systems

The bean crop is normally planted after the danger of frost has passed and when the soil temperature reaches 65°F Inoculation with nodule-producing bacteria is not usually necessary The seeding rate varies according to the seed size and the area The recommended seeding rates in Michigan are pea beans 40 lb/acre, kidney beans 80 lb/acre and cranberry and yelloweye beans 60 lb/acre In the western dry farming areas the planting rate is designed to space the plants 18–24 in apart in 42 in rows as contrasted to spacing 4 in apart in 28 in rows in the humid regions

For maturity beans require a growing season of 90–120 days Bean seeds are very susceptible to damage from commercial fertilizer applied in direct contact with the seed Application of fertilizer 1 in to the side and 2 in below the level of the seed at rates up to 300 lb/acre is recommended The fertilizer analysis depends upon the soil type and the soil test

Weeds are controlled principally by cultivation but several herbicides such as isopropyl *N* (3-chlorophenyl) carbamate (CIPC) and the enthanolamine salt of dinitro-*sec* butyl phenol (DNBP) have been used safely when applied as preemergence sprays Cultivation is avoided when the bean plants are wet because disease organisms are easily spread under these conditions

Field beans are usually harvested when most of the pods have matured and the seeds have hardened but before the seeds fall from the plant The plants are pulled or harvested by a machine which

has two blades arranged to cut the roots about 2 in below the soil surface The pulled plants are placed in windrows and when harvest conditions are good they are threshed from the windrow with a combine or special bean harvester In wet seasons it is sometimes necessary to stack the pulled plants to protect the seed from staining sprouting and decay while drying

Utilization The bean crop is utilized as food in several forms Lima beans are used as a fresh vegetable or as dry beans and are processed by canning or freezing Snap beans are processed by canning and freezing and are also consumed as a fresh vegetable In 1955 4 lb of snap beans per capita was processed in the United States

The 1955 per capita consumption in the United States of dry edible beans was 7 8 lb Dry beans of the different classes have different markets Dry beans are high in protein calcium phosphorus and vitamin B_1 Navy bean proteins are chiefly of the globulin types The proteins of all the beans of the various species of *Phaseolus* are similar in their physical and chemical properties

Although dry edible beans are used principally for food industrial utilization of them is being investigated Dry beans which are aged or otherwise of low quality may be used for livestock feed The common bean contains about two-thirds as much protein (23%) as the soybean (38%) Navy beans contain about 2 5% oil of which 5 0–6 0% is unsaponifiable The unsaponifiable component consists of 55–60% crude sterols of which 23–25% is stigmasterol The protein of navy beans is also adaptable to plastic formation

Recent developments The Sanilac variety of pea beans a bush type developed by the Michigan Agricultural Experiment Station and the U S Department of Agriculture was introduced for commercial production in 1958 An x ray produced mutant bush type was in the parentage It is the first commercial variety developed in the United States by this technique although three are reported in Europe *See* AGRICULTURAL SOIL AND CROP PRACTICES BREEDING (PLANT) FOOD ENGINEERING HERBICIDE LEGUME VEGETABLE GROWING [L V N]

Bean diseases There are two types of bean diseases the parasitic and nonparasitic Parasitic diseases are caused by fungi bacteria and viruses and nonparasitic by unfavorable environment mineral deficiencies and related conditions Of some 40 parasitic field diseases of beans only 18 are of major importance About 20 nonparasitic diseases are recognized few of which regularly cause serious losses These diseases cost the American farmer an estimated $35 000 000 annually Some common diseases kill young seedlings others cause injury or death of older plants and some produce spots on pods and seeds that make the product unsalable

Fungus diseases The most important world wide fungus diseases of beans are anthracnose root rots and rust Anthracnose causes dark sunken cankers

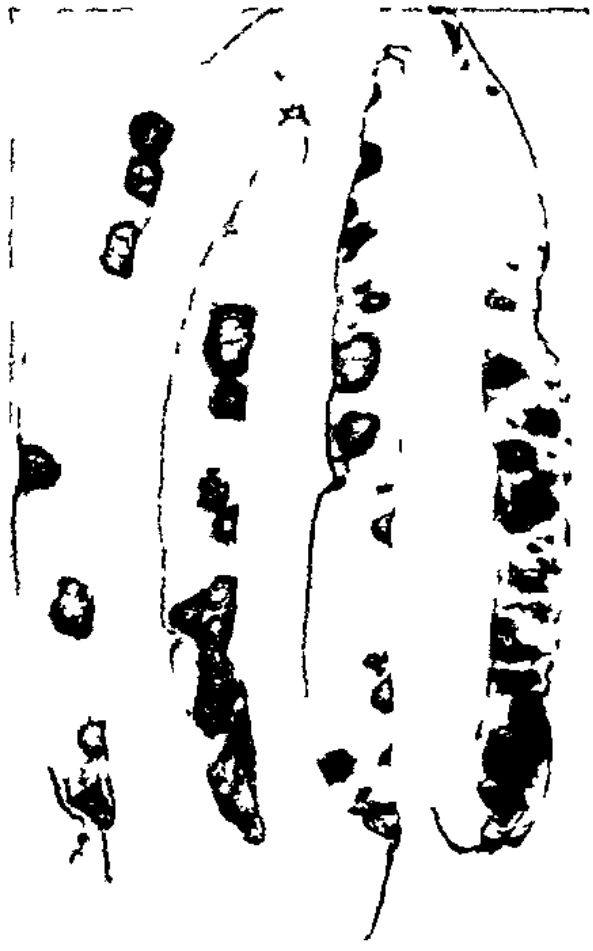


Fig 1 Anthracnose on bean pods (fruits)

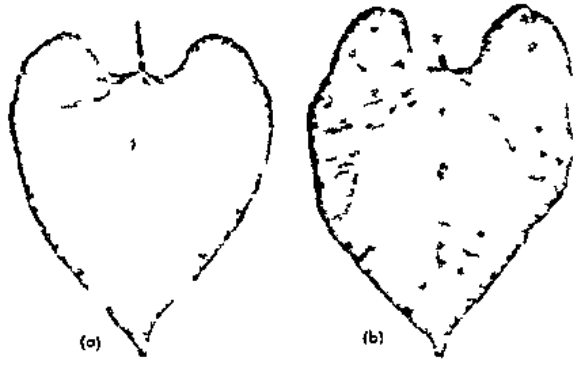


Fig 2 Rust on bean leaves (a) Healthy (b) Infected

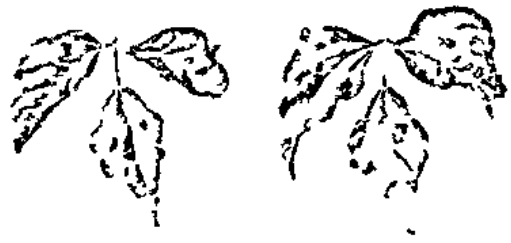


Fig 3 Virus infection of bean leaves

on pods and angular dead spots on leaves (Fig 1) The causal fungus is spread by such means as infected seed, wind, rain, and insects Root rots are caused by several organisms which produce black or reddish brown lesions on the roots and some root decay Infected plants are often stunted and their leaves turn yellow, or they may suddenly wilt and die Rust is chiefly a disease of leaves (Fig 2) It appears as small rust colored lesions that may be so numerous that they cause the leaves to shrivel and drop Each lesion contains thousands of reddish brown spores which are carried by the wind and spread the disease

Bacterial diseases Blights and wilts, caused by bacteria, are important wherever rain falls frequently during the growing season The blights show up most strikingly on leaves as small water soaked spots which later merge and form extensive brown, dead areas The pods also show very small water soaked spots that later form dry and sunken lesions with reddish brown or brick red margins The bacteria may infect the hinge or upper suture, of the pod and cause discoloration and water soaking of tissue Through the hinge they may attack the seed Bacterial wilt causes shriveling of plants Seedlings produced by infected seeds may be stunted or may not emerge from the soil

Virus diseases These diseases including the important common bean mosaic and curly top, are characterized by leaf mottling and malformation stunting of the plants, and sometimes death (Fig 3) Viruses are spread from plant to plant chiefly by aphids and other insects Some are carried in seeds

Disease control. Use of disease free seed is one important method of control Some seed borne diseases such as anthracnose, and bacterial blights and wilt do not develop where rainfall is low and temperatures are high during the growing season, therefore, seeds produced in the mountain and Pacific states are freer of these diseases than seeds grown east of the Rocky Mountains Other control measures include use of resistant varieties, crop rotation, field sanitation, spraying plants, or treating seeds with chemicals *See* PLANT DISEASE, PLANT VIRUS [W J Z]

Bear

Any of several large carnivores of the family Ursidae, found in Eurasia and in North and South America Bears are stout bodied short tailed plantigrade animals with five toes on each foot They have broad heads, the eyes and ears are small Some bears hibernate, but others are active the year around As a group they are omnivorous, eating whatever food is most readily available

In North America the many recognized species may be divided into four distinct groups The black bear, *Ursus americanus*, occurs in varying shades of brown as well as black (Fig 1) It formerly ranged over most of North America but is now usually found only in scattered woodland areas This is the smallest of the North American bears,



Fig 1 Common brown bear, *Ursus americanus* length to 4½ ft (*From P M Duncan, ed, Cassell's Natural History, Cassell*)



Fig 2 Polar bear, *Thalarctos maritimus*, length to 11 ft (*From P M Duncan, ed, Cassell's Natural History, Cassell*)

the adults weigh 200–400 lb The polar bear, *Thalarctos maritimus*, the familiar white bear of the zoo, is native to the Arctic ice pack (Fig 2) The grizzly bear, *U horribilis*, now occurs sparsely in the western mountains of the United States as far south as New Mexico, and more commonly in Alask Alaskan brow carni

CARNIVORA [J D B]

Bearing, antifriction

A machine element that permits free motion between moving and fixed parts Antifrictional bearings are essential to mechanized equipment, they hold or guide moving machine parts and minimize friction and wear Friction wastefully consumes energy, and wear changes dimensions until a machine becomes useless

Simple bearings. In its simplest form a bearing consists of a cylindrical shaft, called a journal, and a mating hole, serving as the bearing proper Ancient bearings were made of such materials as wood, stone, leather, or bone, and later of metal It soon became apparent for this type of bearing that a lubricant would reduce both friction and

wear and prolong the useful life of the bearing Convenient lubricants were those of animal, vege table, or marine origin such as mutton tallow, lard goose grease fish oils castor oils and cottonseed oil Egyptian chariot wheels show evidence of the use of mutton tallow for bearing lubrication

The use of mineral oils dates back principally to the discovery of Drake's well at Titusville Pennsyl vania in 1859 Petroleum oils and greases are now generally used for lubricants, sometimes containing soap and solid lubricants such as graphite or molyb denum disulfide, talc, and similar substances

Bearing materials. The greatest single advance in the development of improved bearing materials took place in 1839 when I Babbitt obtained a United States patent for a bearing metal with a spe cial alloy This alloy, largely tin contained small amounts of antimony, copper, and lead This and similar materials have made excellent bearings They have a silvery appearance and are generally described as white metals or as Babbitt metals For many decades they have served as the measure of excellence against which other bearing materials have been compared

Wooden bearings are still used however for lim ited applications in light duty machinery and are now frequently made of hard maple which has been impregnated with a neutral oil Wooden bearings made of lignum vitae the hardest and densest of all woods are still used Lignum vitae is native only to the Caribbean area This wood weighs approxi mately 80 lb/ft³ and has a resin content of some 30% by volume, thus it is remarkably self lubricat ing The grain is closely interwoven, giving the ma terial high resistance to wear and compression and making it difficult to split Applications are cur rently found in chemical processing and food in dustries where lignum vitae wood can successfully resist the destructive action of mild acids alkalies oils, bleaching compounds liquid phosphorus and many food drug and cosmetic compounds

About 1930 a number of significant developments began to occur in the field of bearing metals Some of the most successful heavy duty bearing metals are now made of several distinct compositions com bined in one bearing This approach is based on the widely accepted theory of friction which is that the best possible bearing material would be one which is fairly hard and resistant but which has an over lay of a soft metal that is easily deformed Figure 1 shows a number of combinations of bearing mate rials made up as indicated of combinations of hard and soft materials Figure 2 shows actual bearings in which graphite carbon plastic, and rubber have been incorporated into a number of designs illus trating some of the material combinations that are presently available

Rubber has proved to be a surprisingly good bearing material especially under circumstances in which abrasives may be present in the lubricant Rubber bearings have found wide application in the stern tube bearings of ships on dredge cutter heads on a number of centrifugal pumps and for shafting bearings on deep well pumps The rubber used is a tough resilient compound similar in tex ture to that in an automobile tire These bearings are especially effective with water lubrication which serves as both coolant and lubricant

Cast iron is one of the oldest bearing materials Iron bearings were used in ancient India and China With the advent of more complicated machinery during the industrial revolution cast iron became a popular bearing material It is still used where the duty is relatively light

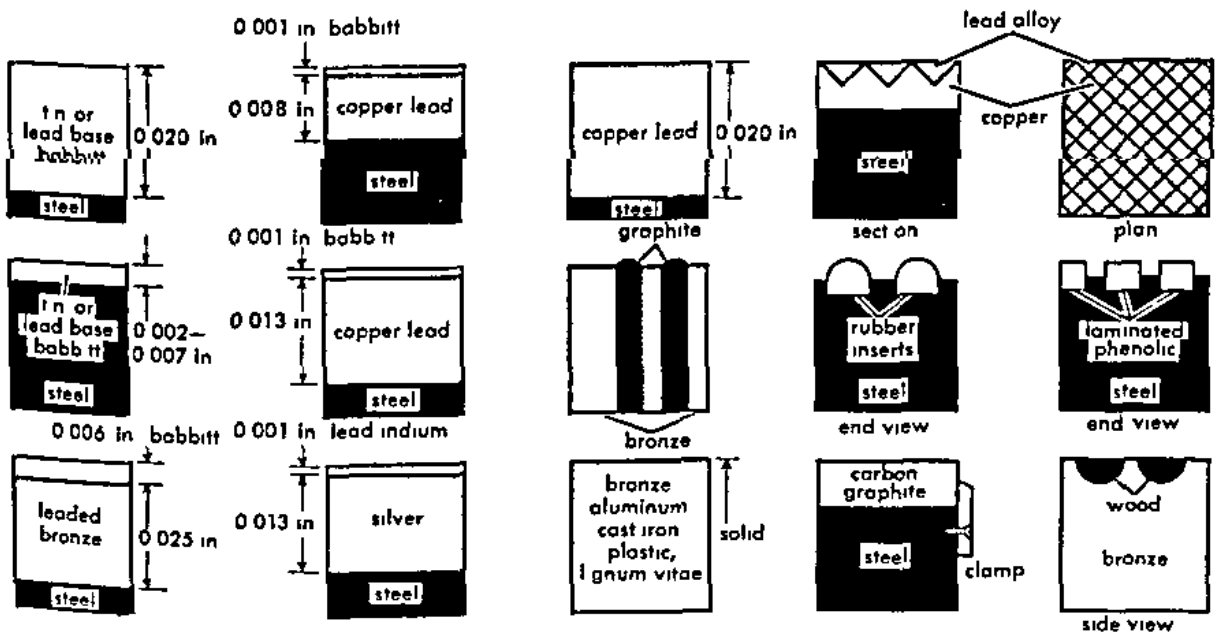


Fig 1 Bearing material combinations (*From J J O'Connor, ed, Power's Handbook on Bearings and Lubrication McGraw Hill, 1951*)

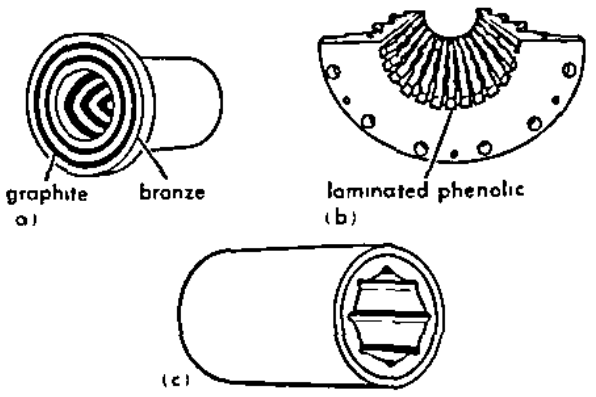


Fig 2 (a) Graphited bearings (b) Wood plastic and nylon bearings (*from J J O Connor, ed Power s Handbook on Bearings and Lubrication McGraw Hill 1951*) (c) Rubber bearings (*Lucian Q Moffit, Inc*)

Porous metal bearings are frequently used when plain metal bearings are impractical because of lack of space or inaccessibility for lubrication These bearings have voids of 16–36% of the volume of the bearing These voids are filled with a lubricant by a vacuum technique During operation they supply a limited amount of lubricant to the sliding surface between the journal and the bearing *In general these bearings are satisfactory for* light loads and moderate speeds

In some areas recent research has shown that surprisingly enough, very hard materials when rubbed together provide satisfactory bearing characteristics for unusual applications Materials such as Stellite Carboloy Colmonoy Hastelloy and Alundum are used Because of their hardness these bearings must be extremely smooth and the geometry must be precise for there is little possibility that these materials will conform to misalignment through wear

Bearing lubricants Petroleum oils and greases have been fortified by chemical additives so that they are effective in reducing wear of highly stressed machine elements such as gears and cams The additives include lead naphthenate, chlorine, sulfur, phosphorous or similar materials In general compounds containing these elements are used as additives to form through reaction with the *metal surfaces, chlorides, sulfides, and phosphides* which have relatively low shear strength and protect the surface from wear and abrasion

The method of supplying the lubricant and the quantity of lubricant which is fed to the bearing by the supplying device will often be the greatest factor in establishing performance characteristics of the bearing For example if no lubricant is present the journal and bearing will rub against each other in the dry state Both friction and wear will be relatively high The coefficient of friction of a steel shaft rubbing in a bronze bearing *for example,* may be about 0 3 for the dry state If lubricant is

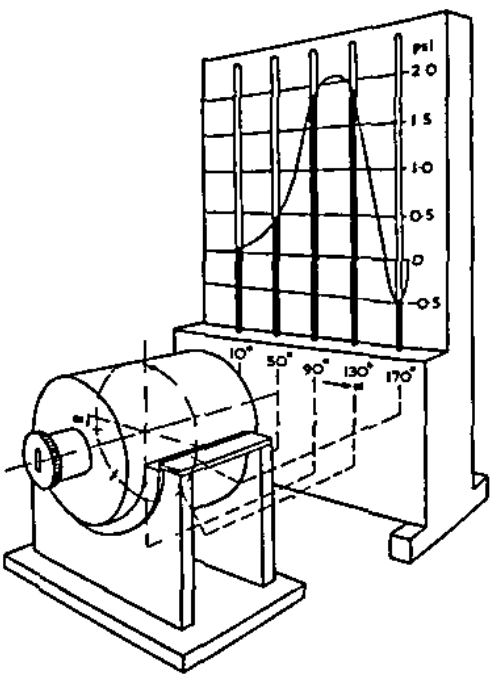


Fig 4 Test device for determining pressure in a journal bearing (*From H Drescher, Air lubrication bearings The Engineers Digest 15 103–107, 1954*)

present even in small quantities the surfaces become contaminated by this material whether it be an oil or a fat, and depending upon its chemical composition the coefficient of friction may be reduced to about 0 1 Now if an abundance of lubricant is fed to the bearing so that there is an excess flowing out of the bearing it is possible to develop a self generating pressure film in the clearance space as indicated in Fig 3 These pressures can be *sufficient to sustain a considerable load and* to keep the rubbing surfaces of the bearing separated This is the type of bearing that is found on the crank shaft of a typical automobile engine Unit pressures on these bearings reach and exceed 2500 psi and with little attention will last almost indefinitely, provided that the oil is kept clean and free

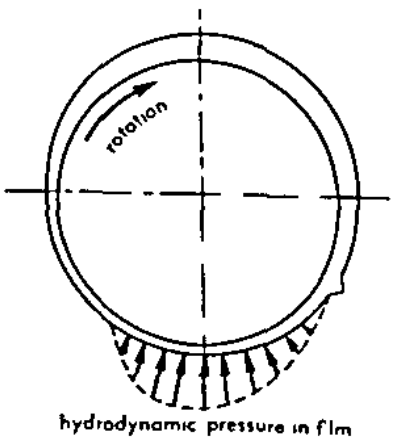


Fig 3 Hydrodynamic fluid film pressures in a journal bearing (*From W Stanaar, ed, Plant Engineering Handbook, 2d ed, McGraw Hill, 1959*)

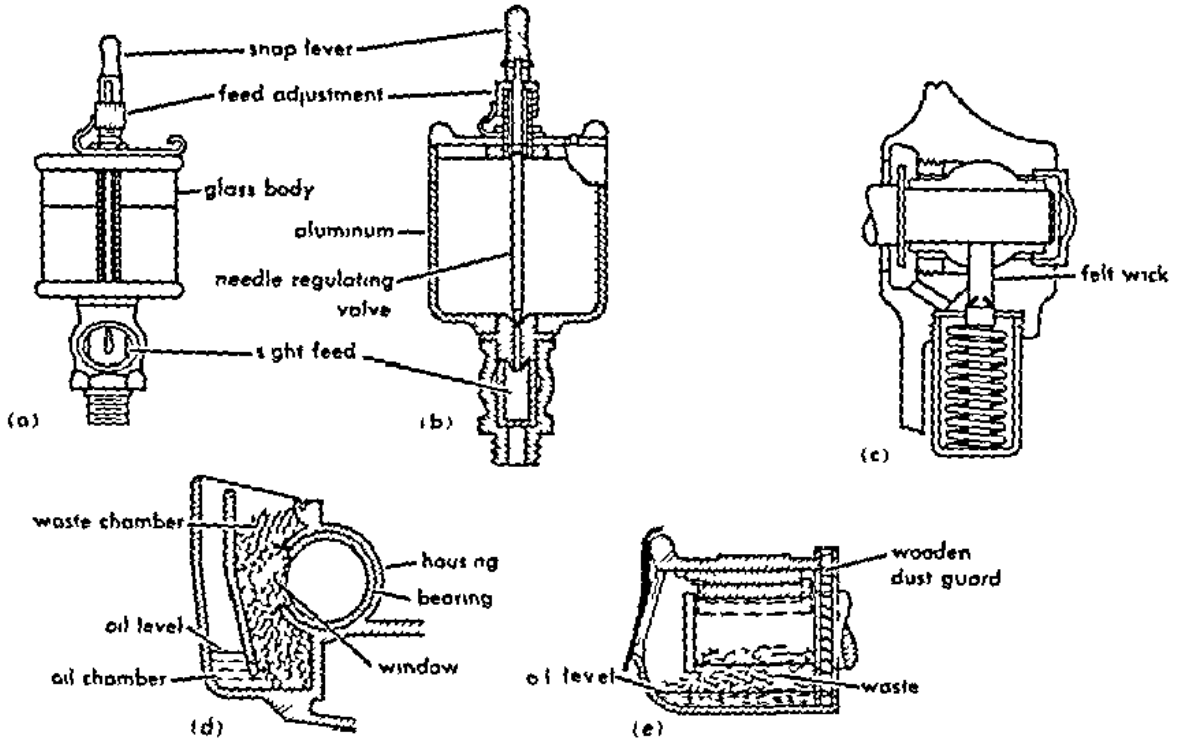


Fig 5 Lubrication devices (a b) Drop-feed oilers (c) Felt wick oiler for small electric motors (d) Waste packed armature bearing (e) Waste packed railroad bearing (*From W Staniar ed Plant Engineering Handbook 2d ed McGraw Hill 1959*)

from abrasive particles and that the bearing materials themselves do not deteriorate from fatigue erosion or corrosion Figure 4 shows a schematic diagram of a simple test device which indicates the pressure developed in the converging clearance space of the journal bearing The position shown where the center of the journal is eccentric to the center of the bearing is that which the journal naturally assumes when loaded If the supply of lubricant is insufficient to fill the clearance space completely or if the load and speed of operation are not favorable to the generation of a complete fluid film the film will be incomplete and there will be areas within the bearing which do not have the benefit of a fluid film to keep the rubbing surfaces apart These areas will be only lightly contaminated by lubricant

The types of oiling devices that usually result in insufficient feed to generate a complete fluid film are for example oil cans drop feed oilers waste-packed bearings, and wick and felt feeders

Oiling schemes that provide an abundance of lubrication are oil rings bath lubrication and forced feed circulating supply systems The coefficient of friction for a bearing with a complete fluid film may be as low as 0 001 Figure 5 shows typical devices which do not usually supply a lubricant in sufficient quantity to permit the generation of a complete fluid film Figure 6 shows devices in which the flow rate is generally sufficient to permit a fluid film to form Figure 6*a*, *b* and *d* show some typical forms of fluid film journal bearings The table shows current design practice for a number of bearings in terms of mean bearing pressure This is the pressure applied to the bearing by the external load and is based on the projected area of the bearing *See* LUBRICANT LUBRICATION ENGINE

Current practice in mean bearing pressures

Type of bearing	Permissible pressure psi of projected area
Diesel engines, main bearings	800–1500
Crankpin	1000–2000
Wrist pin	1800–2000
Electric motor bearings	100–200
Marine diesel engines, main bearings	400–600
Crankpin	1000–1400
Marine line-shaft bearings	25 35
Steam engines main bearings	150–500
Crankpin	800–1500
Crosshead pin	1000–1800
Flywheel bearings	200–250
Marine steam engine main bearings	275 500
Crankpin	400–600
Steam turbines and reduction gears	100–220
Automotive gasoline engines main bearings	500–1000
Crankpin	1500–2500
Air compressors, main bearings	120–240
Crankpin	240–400
Crosshead pin	400–800
Aircraft engine crankpin	700–2000
Centrifugal pumps	80–100
Generators low or medium speed	90–140
Roll neck bearings	1500–2500
Locomotive crankpins	1500–1900
Railway car axle bearings	300–350
Miscellaneous ordinary bearings	80–150
Light line shaft	15–25
Heavy line shaft	100–150

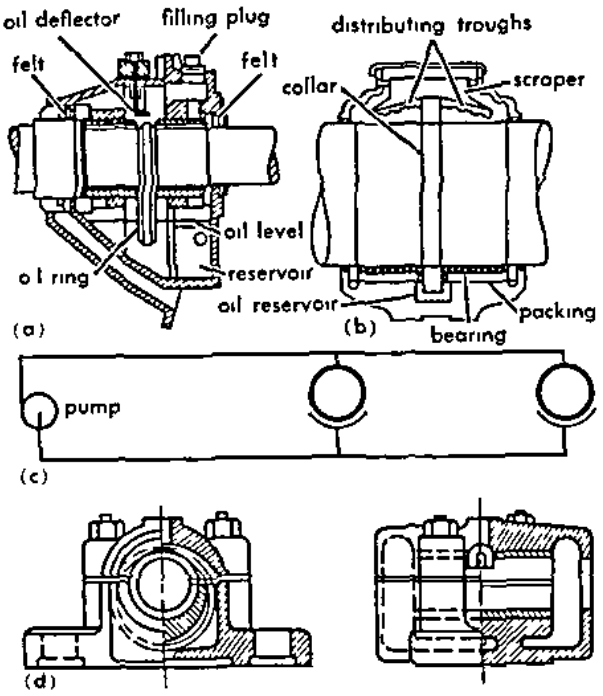


Fig 6 (a) Ring oiled motor bearing (b) Collar-oiled bearing (from W Staniar ed , Plant Engineering Hand book 2d ed McGraw Hill 1959) (c) Circulating system for oiling bearings (from J J O Connor ed Power s Handbook on Bearings and Lubrication McGraw H ll 1951) (d) Rigid ring-oiling pillow block (from T Bau meister ed , Marks Mechanical Engineers Handbook 6th ed McGraw Hill 1958)

Fluid film hydrodynamic bearings. If the bear ing surfaces can be kept separated, the lubricant

which fluid film bearings operate with lubricants consisting of water highly corrosive acids, molten metals gasoline steam liquid refrigerants mer cury gases and so on The self generation of pres sure in such a bearing takes place no matter what lubricant is used but the maximum pressure that is generated depends upon the viscosity of the lu bricant Thus for example the maximum load carrying capacity of a gas lubricated bearing is much lower than that of a liquid lubricated bear ing The ratio of capacities is in direct proportion to the viscosity

Considerable research is currently directed to ward the operation of machinery at extremes of temperature On the low end of the scale this may mean −400°F On the upper end of the scale ex pectation is that some devices may be called upon to function at 2000–3000°F Gas is the only pres ently known lubricant that could possibly be used for such extremes of temperature Because the vis cosity of gas is so low, the friction generated in the bearing is correspondingly of a very low order Thus gas lubricated machines can be operated at extremely high speeds because there is no serious problem in keeping the bearings cool A rotor sys tem has been operated on gas lubricated bearings up to 433,000 rpm

The self generating pressure principle is applied equally as well to thrust bearings as it is to jour nal bearings One of the first commercial applica tions of the self generating type of bearing was in the *tilting pad type of thrust bearing* One tilting pad is shown schematically in Fig 7*a* There is cer tainly no question regarding the great value of the tilting pad thrust bearing It excels in low friction and in reliability A model of a typical commercial thrust bearing is shown in Fig 7*b* This thrust bearing is made up of many tilting pads located in a circular position One of the largest is on a hy draulic turbine at the Grand Coulee Dam There a bearing 96 in in diameter carries a load of 2 150 000 lb with a coefficient of friction of about 0 0009 Large marine thrust bearings are of this type and transfer the entire thrust of the propeller to the hull of the ship

Fluid film hydrostatic bearings. Sleeve bearings of the self generating pressure type, after being brought up to speed, operate with a high degree of efficiency and reliability However, when the rota tional speed of the journal is too low to maintain a complete fluid film or when at starting stopping or reversing, the oil film is ruptured friction in creases and wear of the bearing accelerates This condition can be eliminated by introducing high pressure oil to the area between the bottom of the journal and the bearing itself, as shown schemati cally in Fig 8 If the pressure and quantity of flow are in the correct proportions, the shaft will be raised and supported by an oil film whether it is rotating or not Friction drag may drop to one tenth of its original value or even less and in certain

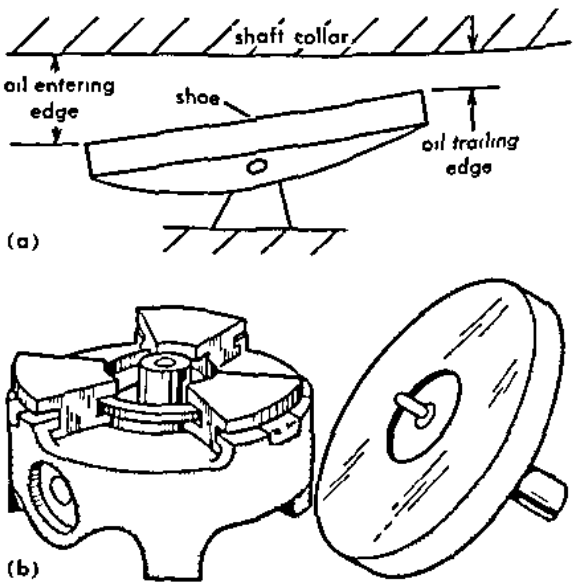


Fig 7 Tilting shoe type bearing (a) Schematic (from W Staniar, ed , Plant Engineering Handbook 2d ed McGraw Hill 1959) (b) Commercial thrust bearing (from D D Fuller, Theory and Practice of Lubricat on for Engineers Wiley, 1959)

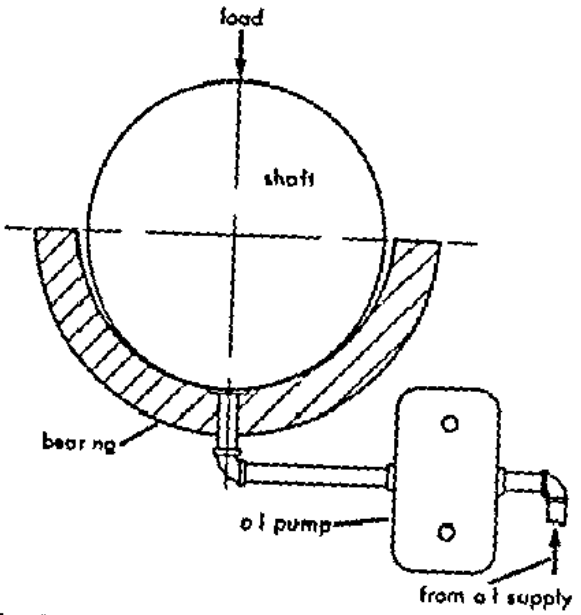


Fig 8 *Hydrostat c o l l ft can reduce start ng fr ct on drag to less than one-tenth of usuol start ng drag (From W Stan or ed Plant Engineer ng Handbook 2d ed McGraw Hill 1959)*

kinds of heavy rotational equipment in which available torque is low this may mean the difference between starting and not starting This type of lubrication is called hydrostatic lubrication and as applied to a journal bearing in the manner indicated it is called an oil lift Synchronous condensers need the oil lift when the unit is of large size Rolling mill and foil mill bearings may be equipped with an oil lift to reduce starting friction when the mills are under load Occasionally hydrostatic lifts are used continuously on bearings that are too severely overloaded to maintain a normal hydrodynamic or self pressurizing oil film

Hydrostatic lubrication in the form of a step bearing has been used on various machines to carry thrust Such lubrication can carry thrust whether the shaft is rotating or not and can maintain complete separation of the bearing surfaces Figure 9 shows a schematic representation of such a step thrust bearing High speed machines such as ultra centrifuges have used this principle by employing air as the lubricant at speeds upwards of 100 000 rpm.

Large structures have been floated successfully on hydrostatic type bearings For example the Hale 200-in telescope on Mt Palomar weighs about 1 000 000 lb yet the coefficient of friction for the entire supporting system because of the hydrostatic type bearing is less than 0 000004 The power required is extremely small and a ½-hp clock motor rotates the telescope while observations are being made Hydrostatic bearings are currently being applied to large radio telescopes and radar antennas, some of which must sustain forces of 5 000 000 lb or more considering wind loads as well as dead weight One such unit now being constructed at Green Bank West Virginia by the Associated Universities has a parabolic disk or antenna 140 ft in diameter

Rolling element bearings Everyday experiences demonstrate that rolling resistance is much less than sliding resistance The wheelbarrow the two-wheeled baggage truck and similar devices are striking examples of the reduction in friction by the use of the wheel Heavy crates and similar objects are easily moved by introducing rollers under the leading edge of the load while the crate or object is pushed along Egyptian engineers building the pyramids transported huge blocks of stone from the quarry to the building site by means of rollers This principle is used in the rolling element bearing which has found wide use

The first major application of these bearings was to the bicycle the use of which reached its peak just before the year 1900 In the development of the automobile ball and roller bearings were found to be ideal for many applications, and today they are widely used in almost every kind of machinery

Structure These bearings are characterized by balls or cylinders confined between outer and inner rings The balls or rollers are usually spaced uniformly by a cage or separator The rolling elements [illegible] because they transmit the [illegible] to the stationary [illegible] spherical but the rollers may be [illegible] or they may be barrel or cone shaped or of other forms depending upon the purpose of the design The rings called the races supply smooth hard accurate surfaces for the balls or rollers to roll on Some types of ball and roller bearings are made without separators In other types there is only the inner or the outer ring and the rollers operate directly upon a suitably hardened and ground shaft or housing Figure 10 shows a typical deep grooved ball bearing with the parts that are generally used and their nomenclature indicated

These bearings may be classified by function into three groups namely radial thrust and angular contact bearings Radial bearings are designed principally to carry a load in a direction perpendicular to the axis of rotation However

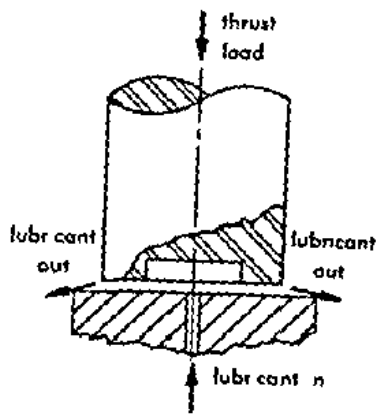


Fig 9 *Step bear ng (From W Stan or ed Plant En g neer ng Handbook 2d ed McGraw-H ll 1959)*

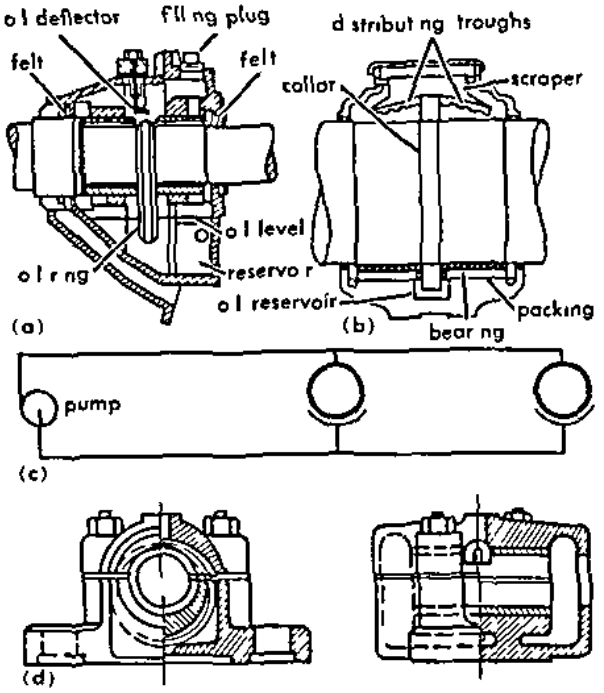


Fig 6 (a) Ring-oiled motor bearing (b) Collar oiled bearing (*from W Standard Plant Engineering Handbook* 2d ed McGraw Hill 1959) (c) Circulating system for oiling bearings (*from J J O Connor ed Power's Handbook on Bearings and Lubrication* McGraw Hill 1951) (d) Rigid ring-oiling pillow block (*from T Baumeister ed Marks Mechanical Engineers Handbook* 6th ed McGraw Hill 1958)

Fluid film hydrodynamic bearings If the bearing surfaces can be kept separated the lubricant no longer needs an oiliness agent such as the fats oils and greases described above As a consequence many extreme applications are presently found in which fluid film bearings operate with lubricants consisting of water highly corrosive acids molten metals gasoline steam liquid refrigerants mercury gases and so on The self generation of pressure in such a bearing takes place no matter what lubricant is used but the maximum pressure that is generated depends upon the viscosity of the lubricant Thus for example the maximum load carrying capacity of a gas-lubricated bearing is much lower than that of a liquid lubricated bearing The ratio of capacities is in direct proportion to the viscosity

Considerable research is currently directed toward the operation of machinery at extremes of temperature On the low end of the scale this may mean −400°F On the upper end of the scale expectation is that some devices may be called upon to function at 2000–3000°F Gas is the only presently known lubricant that could possibly be used for such extremes of temperature Because the viscosity of gas is so low the friction generated in the bearing is correspondingly of a very low order Thus gas lubricated machines can be operated at extremely high speeds because there is no serious problem in keeping the bearings cool A rotor system has been operated on gas lubricated bearings up to 433 000 rpm

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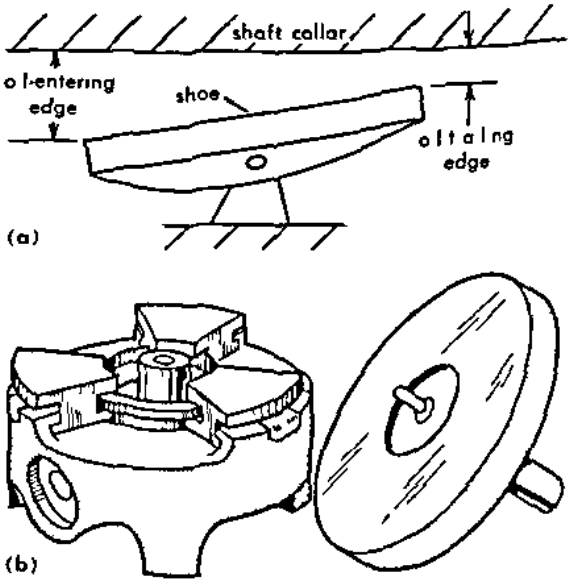
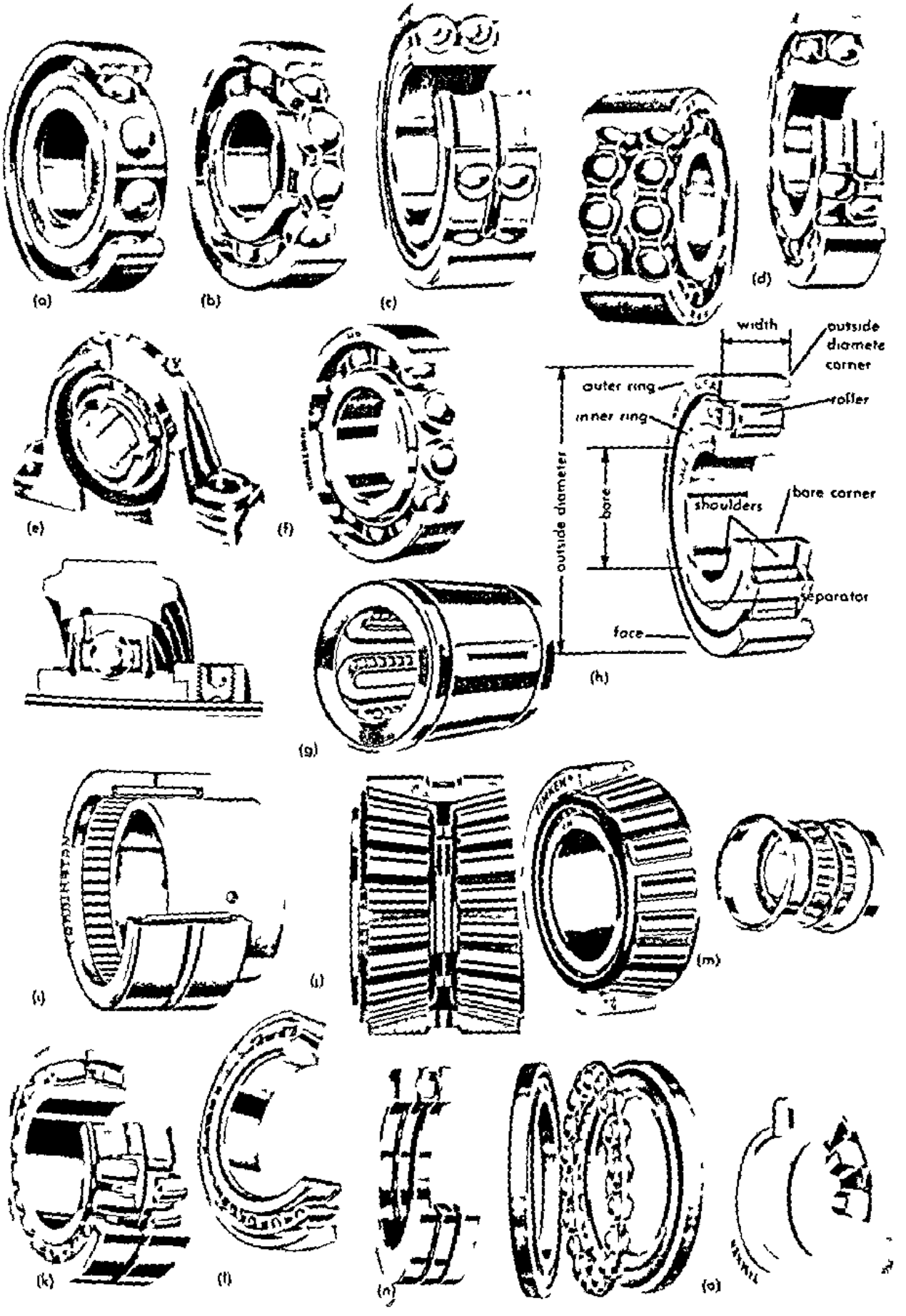


Fig 7 Tilting shoe type bearing (a) Schematic (from *W Standard Plant Engineering Handbook* 2d ed McGraw Hill 1959) (b) Commercial thrust bearing (*from D D Fuller Theory and Practice of Lubrication for Engineers* Wiley 1959)


(a)
(b)
(c)
(d)
(e)
(f)
(g)
width
outside diameter corner
outer ring
roller
inner ring
outside diameter
bore
shoulders
bore corner
separator
face
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)

loaded to take up any possible slack or clearance An interesting development a ball bushing is shown in Fig 11*g* This is used for translational motion or motion of a shaft in its axial direction Any such motion should be at a very low speed and with light radial loads Roller bearings with short straight rollers are shown in Fig 11*h* They permit free movement in the axial direction when the guide lips are on either the outer or inner race Needle bearings (Fig 11*i*) have rollers whose length is at least four times the diameter They may be furnished with a retainer but have their maximum load capacity when there is no retainer and the clearance space is completely filled with rollers They are available with or without an inner race and are most useful where space must be saved If the shaft is used as an inner race it should be hardened

The tapered roller bearings shown in Fig 11*j* permit heavy radial and thrust loads These may be procured as double tapered rollers with two inner races and one outer or two outer races and one inner The race cones intersect at the axis of the bearing Figure 11*k* shows a self aligning bearing with two rows of short barrel rollers The spherical outer race is one piece or it may be in two parts for preloading The thrust is taken on the spherical surfaces of the center flange of an inner race Figure 11*l* shows a barrel roller with spherical outer race Figure 11*m* is a self aligning bearing with hourglass rollers This bearing is also built as a two row bearing with a one piece inner race

The ball thrust bearing shown in Fig 11*n* is used only for carrying thrust loads acting in the direction of the axis of the shaft It is used for low speed applications while other bearings must support the radial load Straight roller thrust bearings are made of a series of short rollers to minimize twisting or skewing The tapered roller thrust bearing shown in Fig 11*o* eliminates the twisting that may take place with the straight rollers but causes a thrust load between the ends of the rollers and the shoulder on the race

Mountings Many types of mountings are available for rolling element bearings and their selection will depend upon the variety of service conditions encountered In the preferred method of mounting the inner and outer races are held securely in place to prevent creeping or spinning of the races in the housing or on the shaft In rigid mountings provision must be made for expansion either by building slip clearances into one mount or by using a straight roller bearing on the free end of the shaft A bearing can be mounted on a shaft with a snap ring on the outer race which locates the bearing against a shoulder Bearings may

[DDF]

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Beat

A variation in the intensity of vibration perceived from two sources having very nearly the same frequency Qualitatively, the source of higher frequency changes phase more rapidly than the source of lower frequency, the two sources becoming alternately in the same phase and in the opposite phase The amplitude of the combined sources becomes alternately the sum and the difference of the amplitudes of the individual sources

The entire phenomenon is completed every time the higher frequency source gains a change in phase of one whole cycle as compared to the phase of the lower frequency source Therefore the number of beats per second is the difference in frequency of the two sources This difference is known as the beat frequency

If the two sources are represented as sine waves having frequencies f and $f + \epsilon$ and amplitudes A_1 and A_2 respectively, the apparent frequency of the observed vibration will depend upon the relative amplitudes of the two sine waves If A_2 is much greater than A_1 the resultant will appear to be a vibration of frequency f whose amplitude varies at the rate of ϵ If A_1 is equal to A_2 the resultant will appear to be a vibration only at frequency ϵ If A_1 is almost but not quite equal to A_2 the resultant will appear to consist of two signals having varying amplitudes and frequencies of $f + \epsilon$ and $f + (\epsilon/2)$ except at the instant of minimum amplitude when the frequency f will exist In general if ϵ is small these separate frequencies normally cannot be distinguished

The most important practical use of beat phenomena is in determining the frequency of one source by comparing it with the frequency of a second source of known frequency and counting the number of beats to determine the beat frequency between them Such procedure is used in the heterodyne or beat frequency oscillator [WJC]

Beattie-Bridgeman equation

A modified virial equation of state for real gases The Beattie-Bridgeman equation is useful in studying properties of vapor close to the liquid phase at pressures less than critical and for volumes greater than twice critical The equation is

$$p = \frac{R_u T(1-\epsilon)}{v^2}(v + B) - \frac{A}{v^2}$$

$$A = A_0\left(1 - \frac{a}{v}\right) \qquad B = B_0\left(1 - \frac{b}{v}\right) \qquad \epsilon = \frac{c}{vT^3}$$

Beattie-Bridgman constants

Gas	A_0, $\frac{\text{atm ft}^6}{\text{mole}^2}$	a, $\frac{\text{ft}^3}{\text{mole}}$	B_0, $\frac{\text{ft}^3}{\text{mole}}$	b, $\frac{\text{ft}^3}{\text{mole}}$	$c(10^{-?})$, $\frac{\text{ft}^3(°\text{R})^3}{\text{mole}}$
Air	331	0 309	0 738	−0 01⁻6	406
CO	34>	0 419	0 808	−0 111	393
CO_2	1283	1 14	1 69	1 16	61 0 4⁻
H_2	50 7	−0 081	0 336	−0 698	
N_2	34>	0 419	0 808	−0 111	393
O_2	383	0 411	0 ⁻41	0 06⁻1	419

where p is pressure in atmospheres v is molar volume in ft³/lb-mole T is temperature in degrees Rankine and R_u is the universal gas constant 0.729 atm ft³/(mole)(°R) The other constants are listed for some common gases in the table *See* THERMODYNAMIC PRINCIPLES VIRIAL EQUATION

[G A H]

Beaver

The only living species *Castor canadensis* of the rodent family Castoridae widely distributed over Eurasia and virtually all of North America The beaver is the largest North American rodent attaining a length of 43 in and a weight of 60 lb It is readily recognized by its large size rich brown



The beaver *Castor canadensis* length 43 in (*From* P M Duncan ed *Cassell's Natural History* Cassell)

color and large flattened paddlelike tail This valuable fur animal was greatly reduced during the past century by trappers but under legal protection it has regained its numbers rapidly It is now found in many areas especially in the South where it did not originally occur

In addition to its value as a fur bearer the beaver is beneficial in water conservation because of its habit of erecting dams behind which it builds houses and stores pieces of trees for food Beavers sometimes damage agricultural crops and cut valuable trees but their value far outweighs these losses *See* RODENTIA

[J D B]

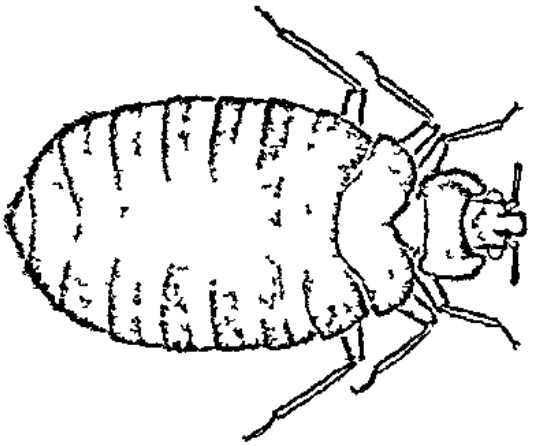
Bedbug

The common bedbug *Cimex lectularius* is a member of the family Cimicidae order Hemiptera It is one of the best known parasites of man and is found throughout the world

The bedbug is a flattened ovate wingless insect about ¼ in long when adult It is reddish brown and possesses a distinctive odor It sucks the blood of its host in nocturnal raids spending the day in hiding on or near the bed Its bites leave characteristic red spots The female lays up to 500 eggs a life cycle runs 6 or 8 weeks Bedbugs have been known to survive without food for a year

Prior to the development of DDT control was difficult but oil sprays of DDT are highly effective against this parasite

Bedbugs are sometimes called red coats or flats They are not known to be a vector for any human



The bedbug *Cimex lectularius* length about ¼ in (*From* E L Palmer *Fieldbook of Natural History* McGraw-Hill 1949)

disease The common bedbug also lives on rats mice and poultry A related form *Cimex hemipterous* is a human parasite in the tropics other forms occur on bats and birds Those found on bats usually do not bite man *See* HEMIPTERA

[J D B]

Bee and beekeeping

Bee is a name given to a number of insects of which about 2500 species exist in North America Bees differ from others of the order Hymenoptera primarily in that they feed their young honey and pollen The structural modifications that distinguish bees are usually those related to pollen and nectar gathering Branched and plumose hairs on the body and pollen baskets on the hind legs are two important modifications

Although honeybees and bumblebees are best known there are many other kinds of bees some of them occur in large numbers Carpenter bees resemble bumblebees in appearance but excavate tunnels for their nests in solid wood Andrenids solitary bees nest in the ground except for a few species which are parasitic Leaf cutting bees line the cells of their nests with neat circular bits of leaves The honeybee is discussed later under beekeeping

In North America there are about 50 species of bumblebees of the family Bombidae Nests are made in cavities or in piles of grass where the overwintering and already fertilized queen carefully prepares a soft bed for the food material upon which the first eggs are laid These eggs develop into workers who assume the duties of the nest as the queen lays more eggs Males and queens are produced only in the last few generations They mate and then all males and workers die during the winter Bumblebees are valuable as pollinators especially of red clover *See* HYMENOPTERA

[J D B]

BEEKEEPING

This branch of agriculture concerned with management and maintenance of colonies honeybees *Apis mellifera* is practiced t

the world except in the polar regions The honey bee originated in the Mediterranean area of Europe and has been transported by man throughout the world Commercial beekeeping is based on the production of the natural products of the honeybee such as honey beeswax royal jelly queen bees and package bees or on the renting of colonies of bees to farmers to aid in the pollination of agricultural crops

The value of honeybees to agriculture for its services in the cross pollination of fruits vegetables legumes and other crops is estimated at many times the value of the honey the bees produce *See* FRUIT (TREE) FRUIT GROWING (SMALL) LEGUME FORAGES VEGETABLE GROWING

Federal statistics for 1956 show that in the United States 5 332 000 colonies of bees produced 214 524 000 lb of honey having a value of $40 728 000

Honeybee colony The honeybee a social insect can exist only in colonies made up of several thousand individuals Honeybees one of the few insects that feed and care for their young store food for future needs and remain active throughout the winter period The three castes of bees that make up the colony have become so specialized in structure and habits that no one of them can maintain itself alone for any extended period or perpetuate the species The normal colony is made up of a single queen bee (female) thousands of worker bees (females) and a few hundred drones (males) The worker bees of each colony build a series of beeswax combs in which they rear the young and store their food

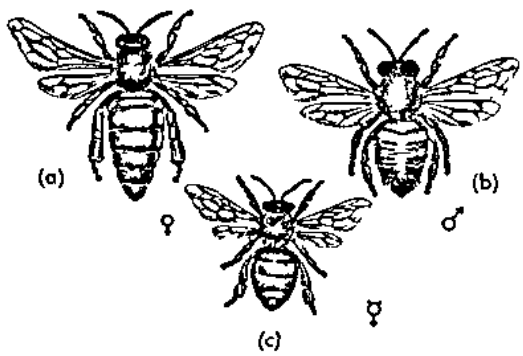


Fig 1 Honeybees *Apis mellifera* (a) Queen length ¾–1 in (b) Drone ¾–1 in (c) Worker ½ in (From E L *Palmer Fieldbook of Natural History* McGraw Hill 1949)

Queen bee The queen is the only sexually developed female in the colony and after heading the colony for a few weeks is the mother of all the individuals in the colony During the summer period the queen may produce 1500–1800 eggs per day The queen produces fertilized eggs that yield female bees workers or queens and unfertilized eggs that yield the drone or male bees The queen mates in flight when a few days old and the supply of male sperm that is to last throughout her life is stored in her spermatheca The queen may live several years but her useful period as the head of a thriving colony is approximately 2 years

Worker bees Female worker bees produced from fertilized eggs are not developed sexually but are so modified structurally that they are able to perform the many duties required in the colony The worker bee has well developed food and wax glands and pollen collecting structures that are not developed in queen bees Worker bees perform nearly all the useful duties in the hive such as comb building gathering food supplies feeding the queen and the developing brood maintaining proper temperatures and sanitation and guarding the hive The life span of the worker bee depends on the amount of work it is required to perform and varies from 6 weeks for the spring and summer period when gathering food supplies in the field to several months during the winter period when activities are restricted to the winter cluster The age of the worker bee usually determines the type of duties it will undertake The first 3 weeks of its life are spent on duties within the hive such as comb building feeding the brood ripening honey and house cleaning whereas the remainder of its life is spent as a field bee gathering the pollen and nectar food supplies

Drones These are the males of the colony produced from unfertilized eggs They perform no useful activities other than mating with the queens The normal colony will tolerate a few hundred drones during the summer period but forces them from the hive when nectar supplies fail or when cold weather approaches

Female caste determination The differentiation of queens and worker bees both produced from fertilized eggs is determined by the amount and type of food provided during the 6 day larval feeding period The queens reared in a special peanut shaped cell receive only an abundant supply of royal jelly a secretion of the food glands of the young worker bees A queen emerges as an adult 16 days after the egg is deposited The worker bees are reared in worker cells of the comb The larvae receive royal jelly only during the first 3 days of the feeding period but during the last 3 days their food is a combination of pollen and nectar The worker bee emerges as an adult 21 days after the egg is deposited

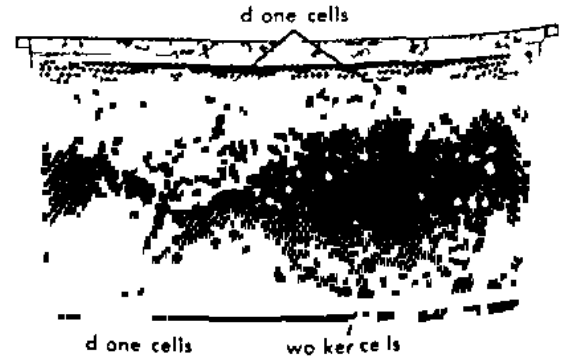


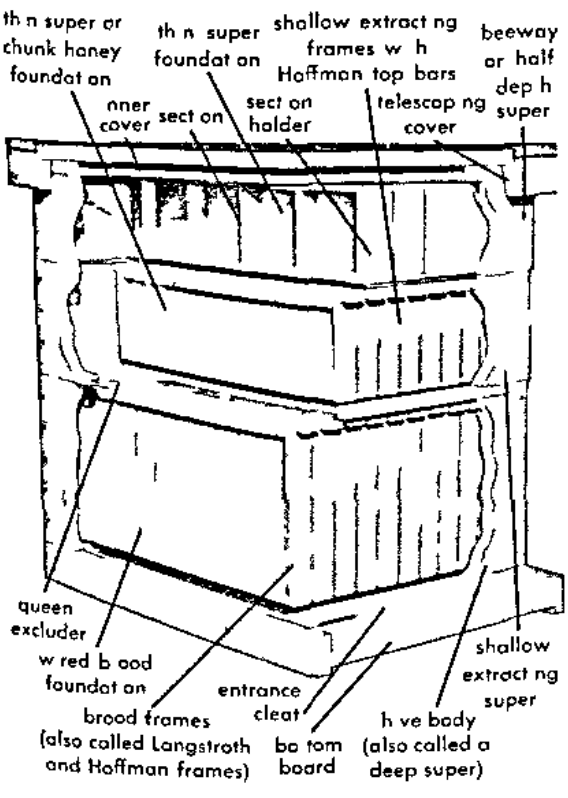
Fig 2 Drone and worker bee cells in comb (Photograph by Walter T Kelley Co Clarkson Kentucky)

Honeybee comb The natural comb is built of beeswax secreted by the worker bees The comb is attached to the top of the nest and built downward It has a midrib with hexagonal cells on both sides Cells of two sizes are constructed The smaller cells about five to the linear inch are called worker cells because worker bees are reared in them The larger cells about four to the linear inch are the drone cells The bees use both worker and drone-sized cells for the storage of food

Food of honeybees The food of the honeybee is pollen and nectar Both these materials produced by flowers are gathered in the field by the worker bees

Pollen produced by the male portion (stamen) of flowers constitutes the protein in the diet of bees *See* FLOWER (BOTANY) Pollen is collected on the branched body hairs of the bees as they visit the flowers It is removed from the body hairs by combs located on the hind legs and collected in masses *on the pollen baskets of the hind legs for transportation* back to the hive Pollen is stored in the cells of the honeycomb until needed for feeding the developing larvae or adults The amount of pollen gathered by a colony of bees during the year has been reported to range from 60 to 125 lb

Nectar is a liquid secreted by the floral nectaries of plants and contains 8 55% sugar as well as minerals and organic materials that are responsible for the aroma and flavor of nectar (*see* SECRETORY STRUCTURES PLANT) Nectar is sucked up by the mouthparts of the worker bee and stored in a honey sac for transportation to the hive Within the hive nectar is placed in the cells of the comb and ripened into honey Various authorities have estimated that 150–300 lb of honey are required to maintain a colony throughout the year



Fg 3 A movable frame beehive (*Photograph by Walter T Kelley Co Clarkson Kentucky*)

Colony reproduction, swarming In nature the home of the honeybee colony is usually a hollow tree or a similar location where space is limited The colony builds combs and stores sufficient honey to last through the winter However during the spring and summer period there is not sufficient space to provide additional combs for the brood rearing and honey storage needs of the colony Because of the crowded conditions the colony prepares to swarm Before swarming the bees start queen cells to ensure a future queen for the old colony and then the old queen and a majority of the worker bees leave and establish a new home elsewhere

Modern beekeeping Adoption of the movable frame hive after 1851 allowed beekeepers to *remove frames of honey from the hive without* destroying the colony (Fig 3) The modern bee hive has been standardized in size so that several hives or units can be stacked on top of each other to provide increased comb space to meet the needs of colonies Under this system of management swarming can be largely controlled and honey yields can be increased

Honey Honey is stored in the combs by bees to ensure food for future needs When bees store more honey than they require for colony maintenance the beekeeper removes the surplus and markets it as comb or liquid honey

According to the Food and Drug Administration of the U S Department of Agriculture honey is the nectar and saccharin exudations of plants gathered modified and stored in the comb by honey bees *Apis mellifera* and *A adorsata* it is levorotatory (*see* OPTICAL ACTIVITY) and it contains not more than 25% water 0 25% ash or 8% sucrose Honey may have various colors aromas and flavors because bees gather nectar from many kinds of flowering plants Many of these plants bloom at the same time so that honey may be a blend of several nectars Variations in plants in different geographical locations are responsible for the several types of honey found in the markets of the world *See* AGRICULTURAL SCIENCE (ANIMAL)

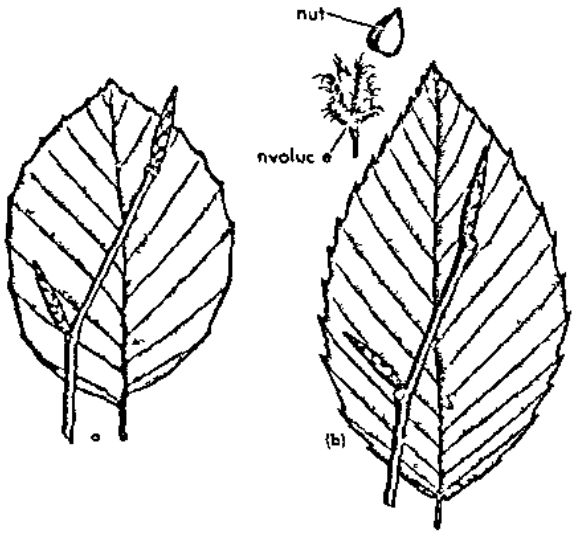
[R S F]

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Beech

A genus *Fagus* of deciduous trees of the beech family Fagaceae order Fagales (*see* FAGALES) They can best be distinguished by their long (often more than 1 in) slender scaly winter buds their thin gray bark smooth even in old trees and their simple toothed ovate or ovate oblong deciduous leaves *F grandifolia* the American beech grows to a height of 120 ft and is native in

lower Missi sippi Valley The hard strong wood is u ed for furniture handles woodenware cooper age and veneer The small edible three sided nuts called beechnuts are valuable food for wildlife They are borne in pairs surrounded by a spiny involucre the homolog of the spiny covering in the chestnut bur and the cup of the acorn which al o belong to the beech family *See* FRUIT (BOTANY) The European beech *F sylvatica* is more



(a) European beech *Fagus sylvatica* (b) American beech *Fagus grandifolia* (*From A H Graves Illustrated Guide to Trees and Shrubs* rev ed Harper 1956)

popular as an ornamental tree than the American species Its leaves are smaller with 5–9 pairs of primary veins compared with 9–14 pairs in the American beech The leaf teeth are also shorter Important ornamental varieties are *F sylvatica*

[illegible]

[illegible] TREE [A H G]

Beet

The red or garden beet (*Beta vulgaris*) a cool season biennial of Mediterranean origin belonging to the plant order Centrospermales This beet is grown primarily for its fleshy root but also for its leaves The so-called seed is a fruit containing 2 6 true seeds Detroit Dark Red strains predominate Beets are only slightly tolerant of acid soils and have a high boron requirement Cool weather favors high yields of dark red roots Exposure to temperatures of 40–50°F for 2 weeks or more encourages undesirable seed stalk development Roots are harvested when they are 1 3 in in diameter generally 60–80 days after planting Wisconsin New York and Texas are important beet producing states The total annual farm value in the United States is approximately $4 600 000 *See* CENTROSPERMALES VEGETABLE GROWING *see also* SUGAR BEET [H J C]

Beetle

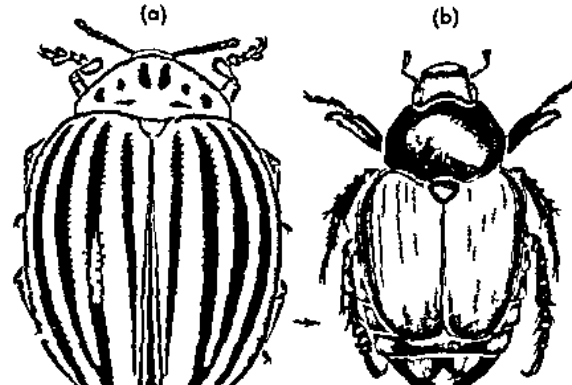
Any member of the insect order Coleoptera This is the largest order of insects and by far the largest order of animals known There have been more than 250 000 species described or about 40% of all known insects the total will probably be twice this number as many new forms are discovered every year About one tenth of the known species of beetles are found in North America

This order includes many of man s most serious enemies they attack his food clothing and housing at practically every stage of their development Most beetles are plant feeders but there are many exceptions Many have underground larvae and destroy plant roots others eat leaves flowers fruits and stems of important plants still others ravage stored food supplies especially grains and also fruits meats and cheese Several attack clothing and other fabrics and some even destroy dry tobacco Several species damage both living and dead wood the damage done to forests by beetles exceeds that done annually by forest fires

A few beetles are predaceous and useful notably the ladybird beetles frequently called ladybugs which prey upon aphids The larvae of the blister beetles feed upon grasshopper eggs although the adults are garden pests Many other predaceous forms are of little economic importance Several like the rove beetles and carrion beetles are scavengers A few are endoparasitic on other insects

Along with this remarkable diversity of feeding habits the beetles occupy a wide range of habitats Many are aquatic or semiaquatic numerous species spend much of their life in wood some live only on fungi the vast majority are terrestrial

Morphology Beetles range in size from minute animals scarcely 1 millimeter long to the ponderous 5 in rhinoceros beetles of the tropics there are many longer insects but probably none as heavy as these A related form the unicorn beetle *Dynastes tityrus* 2¼ in long is the heaviest North American insect



Beetle (a) Colorado potato *Leptinotarsa decemlineata*; length under ½ in (b) Japanese *Popillia japonica* length about ½ in (*From E L Palmer Fieldbook of Natural History* McGraw-Hill 1949)

Beetles have chewing mouthparts a heavy cuti cle and two pairs of wings the outer pair of which are thick veinless and leathery These outer wings are called elytra They serve as shields which pro tect the frail membranous inner wings and the ab domen in most species Some like the rove beetles have shortened or rudimentary elytra

Metamorphosis is complete with egg larva pupa and adult stages The pupa is of the exarate type that is the legs are free The larvae vary widely in form Several are active running insects similar to the adult of the silverfish these are called campodeiform larvae Others called elateri form are slender hard and glossy wireworms the majority are scarabeiform or grubs All beetle larvae have six legs except the grubs of the snout beetles which are legless and the larvae of some parasitic species which have maggotlike larvae

Life cycle The length of the life cycles of various beetles varies as much as their other characteris tics In most species there is one generation a year and they may overwinter as adults pupa larvae or a few as eggs In a few species there may be as many as four generations a year in still others 3 or 4 years are required for the development of each *generation*

Important beetles Among the better known and important beetles are the cotton boll weevil stored grain weevils ladybird beetles mahogany beetles frequently called June bugs Mexican bean beetle click beetles often called snapping bugs the lar vae of which are the highly destructive wireworms the Japanese beetle lightning bugs and glow worms blister beetles flea beetles the long and short horned wood borers bark beetles the tum blebug or dung beetle the larder beetle powder post beetles destructive to lumber and furniture and the sacred scarab of Egypt *See* COLEOPTERA

[J D B]

Beggiatoales

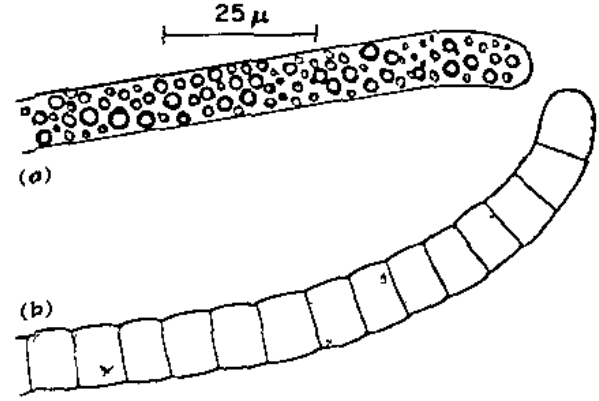
An order of filamentous or unicellular bacteria of the class Schizomycetes The sulfur bacteria in this order are widely distributed being found wherever sulfur and hydrogen sulfide are present for exam ple in swamps sewage and sulfur mines The mi croorganisms move by gliding on a substrate a method of locomotion also found in many Cyano phyceae (blue green algae) from which the Beg giatoales differ in their lack of photosynthetic pig ments The close relationship of these colorless gliding organisms to Cyanophyceae is shown by the existence of forms clearly belonging to genera of the Cyanophyceae but devoid of photosynthetic pigments found in some species of the genera *Chamaesiphon Oscillatoria* and *Spirulina*

In *Bergey s Manual of Determinative Bacteriol ogy* (1957) the Beggiatoales are divided into the Beggiatoaceae Vitreoscillaceae Leucotrichaceae and Achromatiaceae The genus *Thiothrix* is in cluded in the Beggiatoaceae but that genus is closely related to *Leucothrix* and these two genera should therefore be grouped among Thi

Although many members of the Beggiatoales are able to oxidize hydrogen sulfide and deposit drop lets of amorphous sulfur in their cells the Vitreo scillaceae are not able to do this There is a certain similarity morphologically and in the type of loco motion between members of the Vitreoscillaceae and filamentous Myxobacteria (*see* MYXOBACTERA LES) Further investigations for example in cy tology might determine whether or not there is a true relationship

Beggiatoaceae The Beggiatoaceae belong to the physiological group known as the sulfur bacteria whose members include other organisms like the purple sulfur bacteria and some colorless genera which do not belong to the Beggiatoaceae The iron bacteria is another physiological group which com prises a variety of taxonomic entities that can be distinguished on a morphological basis

The genus *Beggiatoa* is characterized by its fila ments or trichomes which are composed of cy lindrical cells The organisms move by gliding often while rotating along solid surfaces covered with water The end cell may be hemispherical



Beggiatoa alba (a) End of trichome filled with sulfur droplets drawn from life (b) The same free of sulfur as in culture without hydrogen sulfide

cap or knob shaped *Beggiatoa* has all these fea tures in common with the genus *Oscillatoria* of the Cyanophyceae from which it differs in being devoid of chlorophyll and associated pigments and in depositing sulfur However such droplets have been seen occasionally in pigmented members of *Oscillatoria* of which pale or colorless species are also known

For these reasons the grouping of *Beggiatoa* as a colorless member of the Cyanophyceae has been advocated Another reason is that *Beggiatoa* like trichomes have been found in bundles within a common sheath in the genus *Thioploca,* which is a counterpart of the pigmented sulfur free genus *Microcoleus among the Cyanophyceae*

The trichomes of *Beggiatoa* range in diameter from less than 1 micron (μ) to more than 40 μ The narrower trichomes are found both in fresh water and under marine conditions those tri chomes wider than 15 μ have been recorde

Beggiatoa has been shown by S Winogradsky to deposit sulfur in its cells only when provided with hydrogen sulfide (H_2S) and to oxidize this further to sulfuric acid when the supply of H_2S ceases Winogradsky derived his famous theory of chemo-autotrophism from his culture experiments (*see* BACTERIAL METABOLISM) He observed that multiplication took place only when chemical energy was provided by such oxidations and that organic nutrients were not necessary

F Keil demonstrated that (1) no carbon source other than carbon dioxide (CO_2) is necessary (2) the indispensable gases oxygen (O_2) H_2S and CO_2 must be present in certain proportionate volumes and (3) *Beggiatoa* can be grown in the absence of bacteria which might furnish growth factors

M S Cataldi has shown that *Beggiatoa* is also able to utilize organic substances and can be grown on agar with dilute solutions of substances like beef extract In this way pure cultures of the narrower types can be grown the filaments of which contain no sulfur

Vitreoscillacea The filaments of the Vitreoscillaceae are similar to the filaments of the *Beggiatoa* They have the same filamentous habit and the same kind of locomotion but they never store sulfur and they rely in their metabolism on organic nutrients



Photomicrograph of *Vitreoscilla filiform* creeping on surface of agar

Leucotrichaceae The genus *Thiothrix* is similar in appearance and metabolism to the *Beggiatoa* But *Thiothrix* lives attached to solid bodies and only the tip produces gliding reproductive stages by breaking up into short lengths The width of the filaments in *Thiothrix* varies from 1 to 30 μ with the largest forms being restricted to salt water

The marine genus *Leucothrix* has the same morphological structure as *Thiothrix* but does not deposit sulfur in its cells It can readily be grown in pure culture on mineral agar supplemented with small amounts of organic matter such as peptone or yeast extract.

Achromatiaceae The Achromatiaceae are unicellular, spherical to egg shaped and exhibit a very slow creeping movement They hold sulfur and calcium carbonate in cells that vary from 7 to 100 μ in length Some occur in fresh some in salt water but only where the water is rich in H_2S and calcium carbonate *Thiovulum* and *Thiospirillum* genera of the Pseudomonadales also contain sulfur The species of *Thiovulum* resemble *Achromatium* in shape However, *Thiovulum* and *Thiospirillum* differ from *Achromatium* in having another type of motility and cannot therefore be included in the Beggiatoales Thiospirillum is motile by means of polar flagella and while *Thiovulum*'s motility suggests that it moves by the means of polar flagella this has not been substantiated *See* BACTERIA TAXONOMY OF, BACTERIAL MOTILITY SCHIZOMYCETES [E C P]

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Behavior, ontogeny of

Behavior is the observable response of an organism to stimuli in the environment A study of behavior considers the interaction of constitutional and environmental factors the developing responses in the embryo the effects of experience on the young of the species and the genetic or hereditary factors This article discusses the concept of the interaction of constitutional and environmental factors the developing response in the embryo and the effects of experience on the young For a discussion of the genetic factors in behavior *see* BEHAVIOR AND HEREDITY

Constitutional and environmental interaction The behavior of an organism refers to all its response potentialities Behavior therefore includes innate reflexes (pupil dilation in dim light) complex motor acts (walking) ability to perform perceptual discriminations physiological responsivity and the variety of skills social response patterns and motives acquired through interaction with the environment

The development and maintenance of any segment of behavior results from the interaction of two major classes of variables constitutional and environmental Constitutional factors refer to the physiological and biochemical characteristics of the organism both genetic and nongenetic in origin Environmental variables include those events in the external environment of the organism that exert an influence on the characteristics of the developing behavior To illustrate phenylpyruvic oligophrenia which is an inherited form of mental deficiency is primarily due to a serious metabolic defect that is a constitutional variable The alteration of the naturally occurring song of the chaffinch as a result of special rearing with certain birds is the product of an environmental influence In most cases a given behavior reflects the interaction of these two classes of variables Sensory and perceptual functioning motor acts and mental develop

ment result from the action of the environment on a specific constitution *See* PHENYLPYRUVIC OLIGOPHRENIA

Behavioral parameters The range of behaviors occurring in the animal world is so varied and the interphyletic and even interspecific differences are so dramatic that it is impossible to discuss behavioral development in any general way It is useful therefore to specify at least three basic parameters before describing or explaining a class of behavior These three parameters are (1) the behavioral system (sensory motor perceptual social emotional) (2) the species and (3) the critical period the age at which the behavior or underlying process is developing

Critical period This last parameter stage of development introduces the concept of the critical period This concept states that in each stage of development certain processes may be proceeding at a more rapid rate than they are at other periods and that a specific response predisposition is highly vulnerable to alteration during certain developmental periods To illustrate if a monkey is deprived of patterned light during the first 18 months of postnatal life his vision will be seriously and permanently impaired Deprivation of patterned light

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tioning A critical period has meaning only with reference to a specific behavior for a given species An exhaustive description of the development of behavior would include an almost infinite number of combinations of critical periods behaviors and species Some representative examples are discussed in the following paragraphs

Critical period I prenatal growth During the first phase of prenatal growth in vertebrates the central nervous system is developing most rapidly Chemical or mechanical interference with the developing organism at this time is more likely to have a deleterious effect on subsequent behavior than comparable injury during later prenatal periods

Critical period II infancy The period of infancy varies widely in the animal world and there is no one time period that is equally meaningful for all species The period of infancy is often a period of vulnerability to strong conditioning to external stimuli Infancy is a time when important responses may be learned quickly and to such a high level of strength that their subsequent elimination or alteration is either impossible or very difficult For example the first 16 hours after hatching are a critical period for the imprinting response shown by certain species of birds During this critical time the first object to elicit a social response from the infant animal will become the preferred social and sexual object during the later life of the animal The animal becomes most strongly conditioned to this object if the conditioning occurs between 13 and 16 hours after hatching In puppies the period between 3 and 7 weeks of age after the eyes and ears open is a critical one for the development of social responses in later life The data on human infants are less reliable than the information on animals However it appears that lack of consistent nurture by a mother or mother substitute during the first 2 years of life can lead to permanent and irreparable insult to the mental and emotional life of the child

Other critical periods The juvenile period and period of adolescence are associated with the acquisition of complex skills and especially in primates symbolic behavior At adolescence important endocrine changes facilitate the emergence of mature sexual behavior

The detailed mapping of critical developmental periods and associated behaviors has just begun It is emphasized however that the analysis of behavior and its development requires specification of the behavior species and age period under investigation [J KG]

PHYSIOLOGICAL DEVELOPMENT

Behavior is the result of a complicated interaction of all parts of a living organism which keep a central nervous system in communication with the internal and external environments The components upon which these complex behavior patterns are built can be examined and followed to some extent as they appear in early development

Because a functional capacity requires a certain level of structural differentiation a functional manifestation of developing behavior should be correlated as far as possible with an appropriate structural mechanism In an effort to discover some of the fundamental principles upon which behavior develops numerous investigators have followed progressive stages of body movement in embryos of various vertebrates in response to tactile and other stimuli Although such investigation tests only part of the activities of an organism it

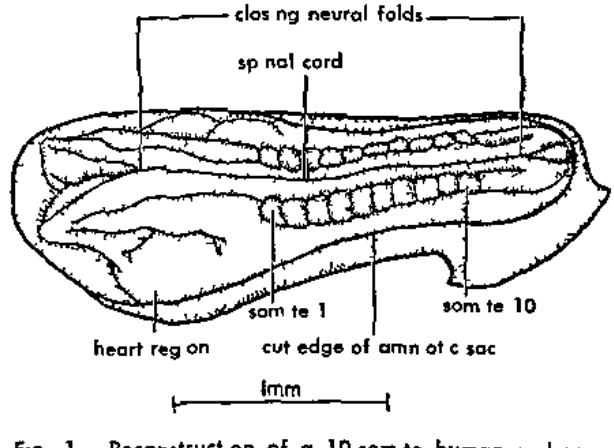


Fig 1 Reconstruction of a 10 somite human embryo about 23 days old lying on exposed floor of amniotic sac Except at the brain and tail ends the neural folds have closed to form the primitive tube of the central nervous system Ten somites future muscle segments and the prominent early heart have appeared X40 (Modified from G C Corner 1929)

serves to give a satisfactory picture of the early organization of behavior

The first organ system to develop in the vertebrate embryo is the central nervous system comprised of the brain and spinal cord It first appears as a neural plate a shield shaped thickening in the surface (ectodermal) cells Then the plate elongates and its lateral edges rise as folds approach each other in the midline fuse (Fig 1) and form a primitive tubular brain and spinal cord The underlying layer of cells (the mesoderm) on either side of the primitive spinal cord rapidly segments into blocklike masses called somites which vary in number in different vertebrates Some of the trunk musculature develops from the somites They are conspicuous superficial markings in young embryos and are known to influence the number of nerve trunks which are later related to the spinal cord In human embryos the first pair of somites appears at about the eighteenth day and the last of a possible maximum of 42 to 44 at about the ninth week A rough estimate of the age of early human embryos has been based upon the number of somites present

To form a clear picture of the early vertebrate embryo it must be kept in mind that the heart along with a few vessels leading to it, begins developing from mesoderm almost at the same time as the neural tube Because of the inherent property of cardiac muscle fibers to contract, the heart begins a functional pulsation state without aid of nervous connections This is termed a myogenic property with regard to a muscle contraction and is distinct from the neurogenic activity of body muscle when the latter responds to a stimulus brought to it by fibers of motor nerve cells It will be shown later that, after the effector or motor neuron fibers have established connection with muscle tissue the fibers of an intermediate receptor or sensory neuron are inserted into the picture to complete what is known as a reflex arc This brings about a third type, reflexogenic activity, very important in the visualization of behavior

Very early in their development, the heart is disproportionately large in birds and mammals Its continuous pulsations may move the entire embryo, as in the case of the developing bird Movements which result from a displacement of the embryo by the pulsations of a large heart soon become imposed upon movements emanating from progressive embryonic reflex activities within the embryo The reflex mechanism may then be receiving continuous

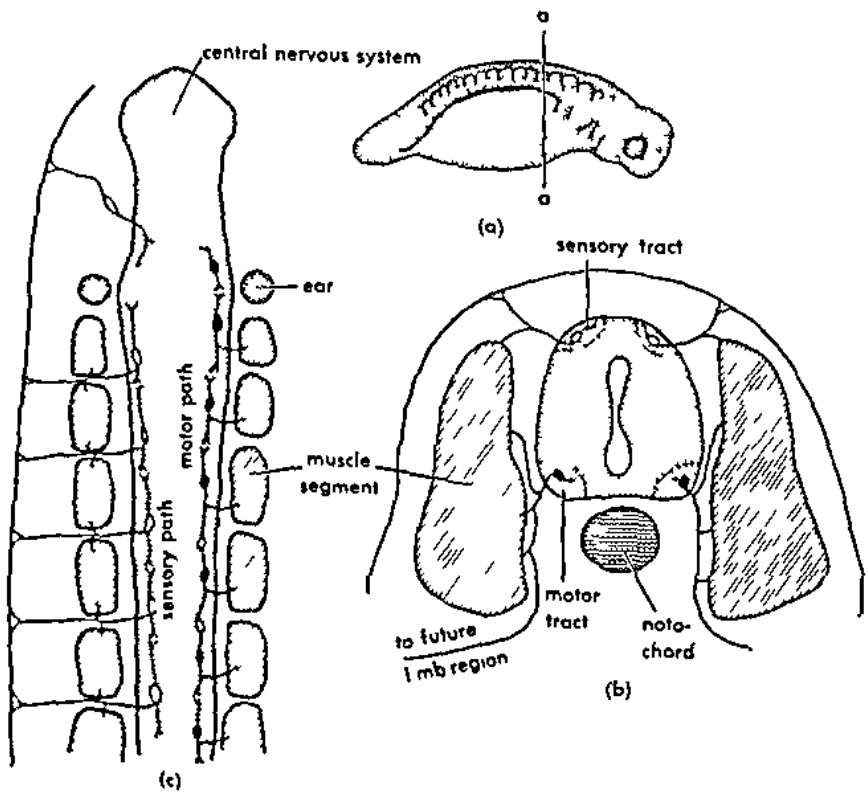


Fig 2 (a) Side view sketch of *gross features* of a salamander embryo Ambystoma at a *nonmotile stage* just before the first reflex activity appears (b) Diagram showing relations of nervous system to muscle and skin in a transverse plane (a-a) through embryo (a) (c) Diagram showing in a frontal plane through the long axis of embryo (a), upper sensory tract (left) and lower motor tract (right) with same muscle and skin relations to nerve fibers as in (b) and absence of communication between motor and sensory tracts (*Modified from Coghill*, 1929)

stimuli which make it difficult to analyze the development of behavior

At this stage the continuous stream of incoming stimuli may evoke reflexive movements but it is not necessary that these simple responses occur before more complex activities can appear Many experiments have shown that amphibian embryos kept anesthetized in chloretone for several days continue normal development but do not move Within a few minutes after they are placed in clear tap water they are capable of producing complex activities normal for their age

Development in salamanders Observations of the activities of embryos have been recorded for all classes of vertebrates from fishes to man but many of these investigations have given only fragments of a whole picture The most extensive studies of the development of behavior have taken place since 1930 largely as a result of the stimulus of one investigator G E Coghill whose fundamental findings centered around the activities of the embryos of a salamander the *Ambystoma* He presented a clear picture correlating behavior with associated structural changes in the nervous system and put forth a total pattern idea of the development of behavior which is accepted by most workers in this field

Coghill s selection of an experimental animal was ideal because upon morphological grounds the salamander is relatively primitive but typical among the vertebrates The embryos develop from clusters of fertilized eggs laid in water like frog eggs They can be removed from their gelatinous capsule and observed while they continue to grow for a long period from the time the first muscular contraction appears to the stage when a pattern of behavior is perfected Coghill analyzed six progressive stages in the development of behavior of the salamander embryo chiefly in response to tactile stimulation by human hair Electrical and direct mechanical stimulations were sometimes used Each physiological stage was correlated with the underlying structural basis in the nervous system The developmental stages are discussed in the following sections

Premotile stage This includes all early stages in which movement of the head or body can not be elicited by any method of stimulation Histological examination reveals that no muscle tissue has dif

Immotile stage Embryos at this stage (Fig 2a) show no response to tactile stimulation in any region on the surface of the body Histological examination shows that some muscle fibers in the neck region are differentiated sufficiently to respond to electrical or direct mechanical stimulation Such a muscle activity is considered to be myogenic because it arises within the muscle and not in the nervous tissue

Histological analysis of the central nervous system shows a chain of neurons that is nerve cells on either side in the upper (dorsal) wall of the spinal cord (Fig 2*b* and *c*) which with their fibers form the future sensory pathway (Fig 2*c*) Also in the floor of the spinal cord on either side a similar arrangement of cells and fibers (Fig 2*b* and *c*) forms the future motor pathway (Fig 2*c*) The fibers of the sensory cells are in communication with the skin and muscle while the motor cells are beginning contact with the muscle segments and starting to send some fibers to the future limb region But since no intermediate neurons have yet differentiated in the spinal cord to bring the sensory and motor pathways into communication with each other and complete a reflex arc as in the stage shown in Fig 3 no stimulus in the skin through the sensory path can reach the motor cells to set off a contraction wave in the muscle fibers

Early flexure stage A gentle touch of a hair on the surface of the neck region (Fig 3*a* indicated by arrow) causes a typical sharp bending of the head towards the contralateral side that is away from the side stimulated This is a stereotyped reaction and is the first neuromuscular response to tactile stimulation Nerve impulses initiated by a stimulus in the skin (Fig 3*b*) travel along the sensory nerve fibers into the central nervous system and pass downward first through one newly differentiated neuron on the side of the spinal cord and then into another median floor plate cell (Fig 3*b* and *c* cell marked X) This cell communicates with the neurons in the motor path on the side opposite the source of stimulus so that the contracting muscle segments (Fig 3*b* and *c* cross hatched segments) pull the head to the contralateral side In Figs 2*b* and 2*c* only the upper sensory pathway on one side and the motor path in the floor of the opposite side are reconstructed to present a simplified picture of the structural arrangements by which the receptor (sensory) and effector (motor) mechanisms come into communication through the differentiation of the new intermediate or commissural cells A similar system of cells and their fibers not reconstructed in the diagrams exist for carrying stimuli in the reverse direction A beginning of simple neuromuscular activity and establishment of reflex arcs are found in the developing embryos of all vertebrates but the differentiate and new reflex arcs are completed by additional intersegmental commissural cells shown in Fig 3*b* and *c* On stimulation with a stroke of a hair the entire trunk bends to the contralateral side so that the tail eventually overlaps the head (Fig 3*d*) In general there is a gradual spread of reflex units *from head to tail in all developing* vertebrate embryos

S reaction stage Very soon a new total response to a stimulus in the head region takes place (Fig 4*a*) For example in the neck region collateral

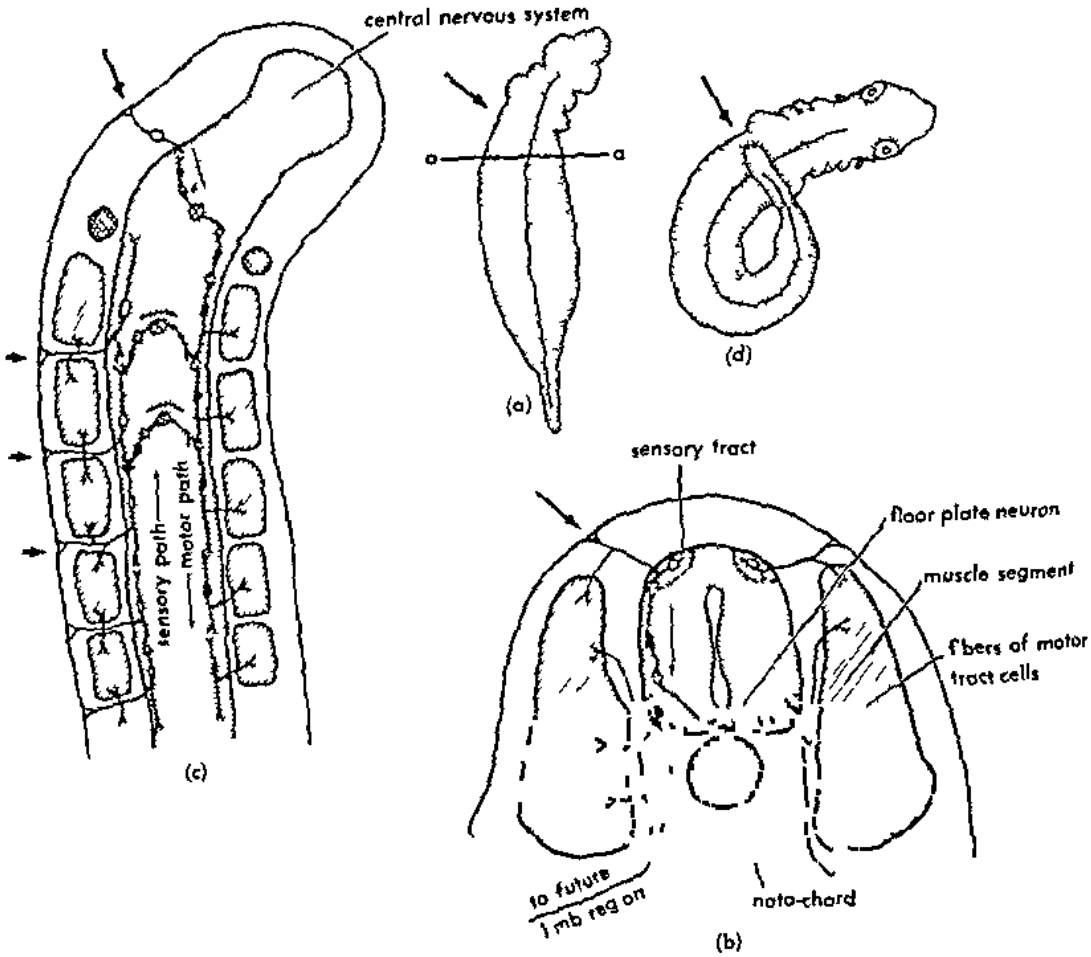


Fig 3 (a) Diagram of dorsal (top) view of a salamander embryo *responding* to a stimulus (arrow) in the *neck region on the left side* (b) Diagram showing relations of nervous system to muscle *and skin in a transverse plane* (a-a) through embryo (a) Path of stimulus in skin shown by arrows (c) Diagram showing in a frontal plane through long axis of embryo in (a) pathway (arrows) of stimulation on the left side to contracting muscle segment (d) Diagrammatic sketch of a salamander embryo responding to a stimulus (arrow) in the neck region on the left side (*Modified from* Coghill 1929)

fibers from neurons in a motor pathway now grow towards *the midline to communicate* (synapse) with the commissural floor plate cells which are already in contact with the motor path on the opposite side The mechanism is illustrated *in Fig 4b* where only the two motor pathways and *not the sensory* ones are indicated

A stroke of a hair on the left *side of the head* produces a wave of muscular contractions *down the* rapidly down the right motor *pathway toward* the tail contracting the muscle segments on that side (Fig 4b) As the contraction *spreads tailward* on the right side some of the initial *impulse spills* over to the left motor pathway through the collateral motor neuron fibers and *floor plate cells* (Fig 4b and c) thus starting a *contraction of the* neck muscles which pull the head to the left (Fig 4a and b) just as the contraction wave is *passing* towards the tail on the right side This second impulse follows the first and excites a third on the *other side* and so on

Swimming stage As these alternate flexions increase in tempo and are continued longer the young larva can now swim in the sinuous fashion thus passing from the S reaction stage to the swimming stage

The neural mechanisms which have made these reactions possible have been built up in an orderly sequence within the spinal cord to produce what Coghill called a total pattern response The earlier reflex responses were localized in the neck region where the muscles and motor nerve connections were first developed This type of development spread caudally In these reaction patterns commissural neurons developed to carry nervous impulses from the sensory cells on one side to the motor cells on the opposite side Added to this new collateral fibers from the motor neurons (Fig 4c) came along to carry part of a stimulus going down the motor pathway on one side over to the

motor pathway on the opposite side This provided a method for continuing alternating waves of con traction to l ring about the complicated swimming response

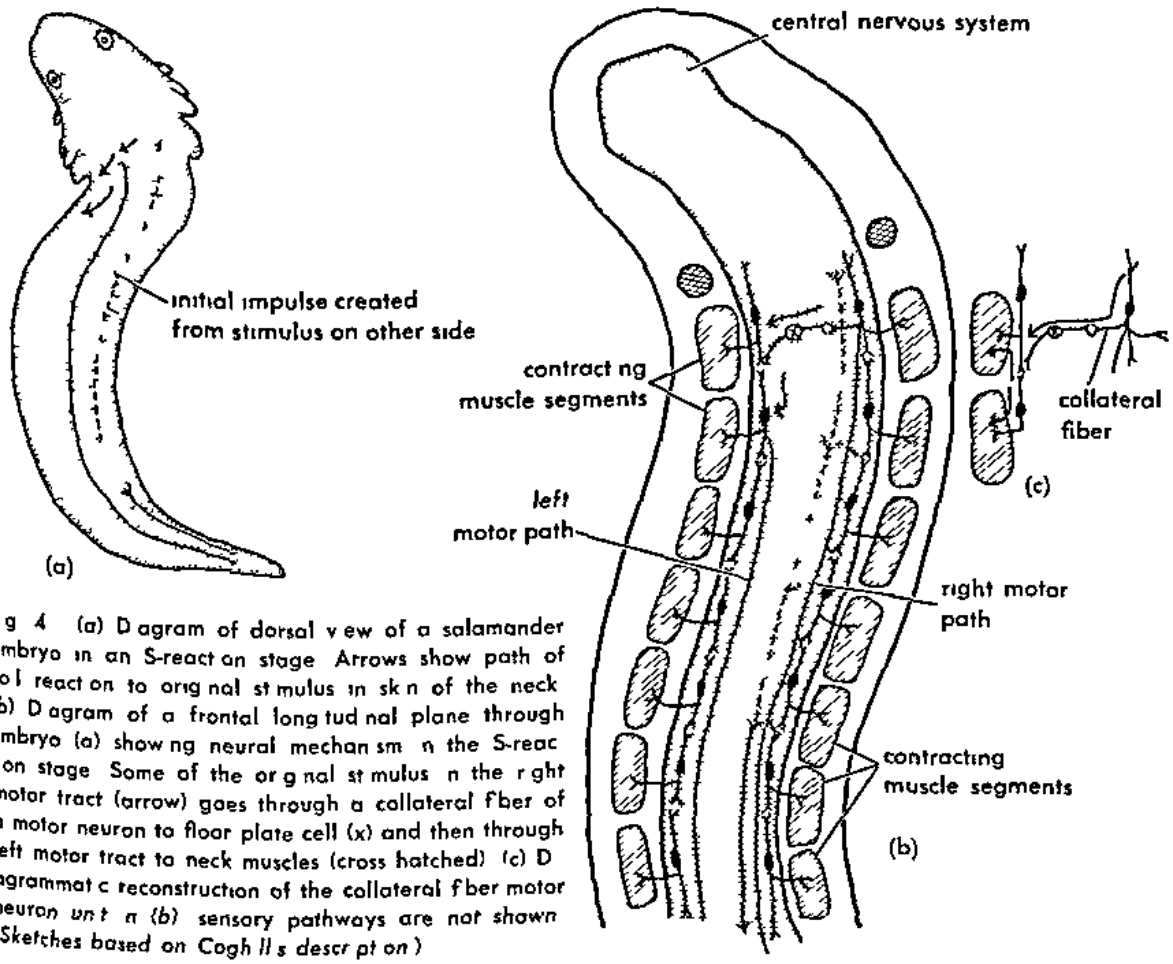
Chemodifferentiation During this same time chemodifferentiation has been taking place in nu merous regions in the embryo especially in the neuromuscular systems which have l een discussed Enzymes have been working as a series of ma chines each performing a single operation on the products which are passed along from one to the other

For example cholinesterase increases in muscle tissue as it becomes functionally differentiated This enzyme appears early in amphibian embryos before movements occur and increases in amount as nerve cells differentiate The enzyme is synthesized in chick embryos as the nerve endings and synapses appear This is important because it is known that cholinesterase depolarizes a nerve fiber after a nerv ous impulse has passed over it and readies the fiber for transmission of the next impulse

The amount of phosphagen increases sharply in the muscles of the embryo chick when movements appear in the head and trunk There is also an in crease of this substance in the musculature of the limb and tail as contraction begins Ribonucleic acid increases in somites when muscle is forming but decreases after full differentiation is completed In fact ribonucleoprotein synthesis slows down when the characteristic proteins for each organ have been formed As the whole field of chemical embryology advances much information will be acquired which will have a bearing on early genesis of behavior

Partial pattern concept Following the early de velopment of the swimming stage in the *Ambys toma* larva Coghill observed the reflex mechanisms developing in such structures as the gills limbs and apparatus associated with feeding He noticed that each new structural complex as it began to function is at first coordinated with the trunk movements as part of the total pattern As addi tional nervous elements develop localized move ments or partial patterns split off from the total pattern

Development of movements in the forelimb illus trates this idea very well First the whole limb moves with the body Elbow flexion then occurs first with the arm as a whole and only later as an independent local reflex The same sequence fol lows in the movements of the hand and digits All of these individual reflexes arise in sequence out of the total pattern This is not difficult to under stand because the motor nerve fibers first to reach the limb region are branches of those already inte



Fg 4 (a) D agram of dorsal v ew of a salamander embryo in an S-react on stage Arrows show path of co l react on to orig nal st mulus in sk n of the neck (b) D agram of a frontal long tud nal plane through embryo (a) show ng neural mechan sm n the S-reac t on stage Some of the or g nal st mulus n the r ght motor tract (arrow) goes through a collateral fber of a motor neuron to floor plate cell (x) and then through left motor tract to neck muscles (cross hatched) (c) D agrammat c reconstruction of the collateral f ber motor neuron *unt n (b)* sensory pathways are not shown (Sketches based on Cogh ll s descr pt on)

grating the trunk movements They arrive there before the limb muscles are formed Therefore the early limb movements become integrated with the trunk movements Hindlimb movements also de velop in the same sequence

The development of the forelimbs is much in ad vance of the hindlimbs both morphologically and functionally In fact the forelimbs acquire all their reflex activities before the hindlimbs begin to move The locomotor activity of the forelimb is brought about simultaneously in both limbs Both limbs flex forward then both extend backward The animal moves by falling forward The first alternate move ments of the forelimbs in walking are a part of the trunk movements swinging the head end from side to side one limb forward the oth er backward like a slow swimming movement At first both hind limbs are drawn forward while the fore limbs are walk ing Finally coordination of all limbs in walking takes place through essential independent reflex mechanisms within the nervous system

Development of movements in other areas follows a similar pattern Movements of the gills at first oc cur only with movements of the head and trunk They are depressed when the trunk muscles con tract Later as local reflex patterns develop their m vement becomes independent

An analysis was made of the complicated per form [illegible] of th hair forward without eliciting jaw movements Later this performance involves snapping at the hair It is believed that an early development of a fiber tract from the midbrain picks up incoming visual impulses on their way to the motor centers in the trunk This excites the short trunk movements in the feeding reaction The jaws and gill arches be come allied early with the trunk movements of feed ng because fibers of the motor neurons con trolling the jaws and arches communicate with motor neurons exciting action of the trunk These c nnections provide simultaneous action of jaws arches and trunk when an excitation passes tail ward through the long motor tract in the spinal cord Swallowing then enters into the picture as motor neurons controlling the gullet (esophagus) commun cate with the spinal cord motor tract The development of the various components has there fore been in the order of trunk jaws branchial arches and esophagus and this has also been the c rder of the behavioral actions

Behavior development in birds Many investi gators who have studied development of behavior in other vertebrates interpret their results in favor of the concept of development of the total and par tial patterns outlined by Coghill There are others however who agree that the concept can be ap pl ed to amphibians but believe that it does not apply to all forms They cite examples of total pat terns of behavior which they believe are built up gradually by a union of partial patterns Some investigators have even concluded that neither idea applies to the form upon which they work especially in birds

Bird embryos have been a favorite subject for observations They are fairly large and easily ac cessible the shell can be opened at various inter vals during incubation and the contents observed Long term observations have been made of the movement of the developing chick embryo using transparent windows sealed to an opening in the shell of an egg However the interpretation of the movements of the embryos is extremely difficult The heart starts pulsations at 36 hours of incuba tion and as it grows rapidly in size its pulsations lift and turn the head and vibrate the body of the embryo In addition from the fourth to the four teenth day spontaneous contractions of the wall of the amniotic sac agitate the movements of the head heavy embryo floating within the sac D ring this period of about 9 days the embryo is kept in a continuous swinging and rocking motion

Chickens Z Y Kuo devised an ingenious tech nique for studying the developing chick embryo After carefully chipping away the shell from the large end of the egg where the air space is located he covered the white opaque membrane with warm vaseline to render it transparent With strong trans lumination of the shell he could observe the embryo at frequent intervals up to the time of hatching He studied several thousand eggs more than 200 of them from earliest movements to hatching and re corded a continuous picture of the development of behavior of the chick within the shell

He concl ded that the activities of the heart and amnion possibly excite spontaneous activities in the embryo which begin as reflex activities on the fourth day of incubation These reflexes steadily in crease in frequency in a head to tail direction They are listed in the table

Therefore before hatching the chick embryo has developed all the patterns of behavior essential for

Development of reflexes in chick embryos

Age of embryo	Reflex
70 hours	Head bend ng
84 hours	Trunk ben ling
90 hours	Hea l turning
90 hours	Forel mb movements
90 hours	Hindlimb movements
90 hours	Tail movements
5 days	Beak movements
5 days	Toe movements
6 days	Eyeli t movements
7 days	Eyeball movements
8 days	Swallowing
9 days	Bill clapping
11 days	Trunk w ggl ng
12 days	Trunk rotation
16 days	Respiratory movement
17 days	Tear ng shell membrane
17 days	Peep ng
17 days	Light response
18 days	Breaking of shell response to sound and vibration
19–21 days	Hatching

respiration locomotion and feeding Many of its reflex activities make it possible for the chick to release itself from the shell

Kuo came to the unique conclusion that the problem was purely physiological and that the assumption that the level of function was a sign of structural maturation must be abandoned He did not believe that his data supported the idea that individual patterns of behavior evolved from a total pattern or that a total pattern becomes built up from individual patterns

Pigeons However another investigator observed the development of behavior in several hundred pigeon eggs largely from embryos released from the egg and placed in warm saline solution At 3½ days of incubation the earliest spontaneous myogenic movement was observed Studying responses to skin stimulation with human hair the development of neurogenic reflexes was followed as they spread from the head to the tail region Gradually independent reflexes appeared progress-

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mbryos

on a less extensive scale using electrical and mechanical stimuli having different degrees of intensity Some of these workers have recorded various activities which occur later in time than those reported by others The observed sequence of the appearance of the activities led observers to conclude that local reflexes were being integrated into mass movement However as noted earlier though bird embryos are easy to observe they are not an ideal group for the study of development of behavior because pulsations of the large heart and contraction of the amnion during critical periods of growth impose conditions which often make interpretation difficult

Behavior development in mammals A study of the development of behavior in mammals has been made on the embryos and fetuses of rats guinea pigs opossums rabbits cats sheep and human beings by a number of investigators many of whom interpret their observations in support of the Coghillian views Some interpret them differently But all face the technical difficulties of not observing their subjects under normal physiological conditions because they must be removed from the maternal host for study The embryo or young fetus can be placed in warm fluid which is its normal environment but interference with blood supply and oxygen soon brings on shock and death Progressive anoxemia gradually blots out different local reflexes so that responses that appear only once during a few seconds can be missed if conditions are not right Great difficulty is encountered in creating the most favorable conditions for the experiment

Certain drug anesthetics affect the fetuses as well as the mother so in working with small mammals anesthesia is usually produced by ligating the blood vessels to the head of the maternal host Under these conditions many fetuses of rats have been studied in various saline solutions while still attached to the placenta The nonmotile myogenic neurogenic and reflex stages were found to appear in a pattern which was very similar to the sequence shown by Coghill

Also in a short study on rabbit fetuses six steps in development of behavior were reported which give in general a picture of an over all total pattern breaking up into local reflexes in the head and limb regions This also supports Coghill's ideas

Other investigators studying the behavior of cat fetuses paid considerable attention to the effects of anoxemia and concluded that all activities of early embryos examined more than 1 min after the opening of the uterus were abnormal as a result of hypoxic conditions which induced the contralateral total pattern responses (Coghillian type) in mammals They also concluded that with few exceptions behavior developed by secondary integrations of discrete reflexes rather than by primary integration from an initial total pattern

A sequence of events recorded for sheep embryos and fetuses associates the function responses with the nervous structures in the brain and spinal cord In these studies the pregnant ewe was usually given a spinal anesthetic and the hindquarters were submerged in warm saline Under this solution the uterus was exposed and the embryo or fetus was delivered in the intact amniotic sac through an opening made in the uterus More than 100 embryos and fetuses were observed between 22 and 143 days of gestation some within 4 days before birth

There is the usual definite inactive stage which ends in the sheep embryo at the thirty third day of gestation At this time some muscle tissue has differentiated in the head and neck regions which responds to electrical stimulation Up to this time nerve fibers of the motor tracts passing down the central nervous system have communicated with the spinal cord motor horn cells which have already sent their fibers to muscle segments

During the next few days local segmental neurons develop as the motor tracts descend from nerve cells in the brain Without communication with sensory neurons the muscle contraction is still elicited only by direct application of electric current

When the developing sensory elements become associated with the motor path the earliest movements may be induced by stimuli around the face These responses are a ventrolateral bending and rotation of the head and thoracic trunk is found in all young embryos at the beginning Early appearance of movements of the forelimb may also be associated with this A gradual spread of movements develops from head to trunk forelimb bending of elbow and wrist followed by trunk and hindlimb movements A spread of movements over the mouth face tongue eyes and the respiratory reactions reveals a gradual unfolding of restricted individual reactions building up more or less out of a total pattern in the Coghillian sense

Man. Few investigators have been able to observe human embryos and early fetuses which were still connected with the intact placenta. Separation from the placenta, as in the case of spontaneous premature deliveries, results in anoxemia which ultimately obliterates embryonic reflexes. Observations obtained at the time of an operation and within the 2 min from the time of placental separation reveal characteristic activity varying with the age of the fetus. Then there is a gradual slowing of responses and eventually obliteration of them. This may be extended to 7–20 min for the older fetuses. Sometimes respiration can be established on a temporary basis as early as the twenty-third week and then observations can be prolonged beyond 20 min.

Special arrangements have to be made for ideal studies. Many drugs used for maternal anesthesia completely anesthetize the fetus; therefore spinal anesthesia is often used since it has no effect upon the fetus. Release from uterine pressure itself seems not to influence responses. The usual procedure in making observations involves handling with great care and controlling the temperature in a warm isotonic solution for the younger stages and "premature beds" for those capable of respiration.

A few investigators have recorded the behavior of human embryos and fetuses observed under various conditions. However, one investigator (D. Hooker) has recorded the most recent and complete analysis of 151 cases, 4 of which were twins. His reports are based on 84 of those which were observed under the most ideal conditions. Because this is the most important and comprehensive study yet made on human material, Hook

40 weeks after the last menstrual period (menstrual age) *the actual day of full term delivery* cannot be determined because there are individual variations and other factors involved. Because of this it has always been difficult to *determine the age of a human* embryo or young fetus unless one knows at least the date of the last menstrual *period*. Often only a hazy idea of this can be obtained, so that in a study of *a large series of human* material one has to resort to a timetable based partly upon crown-rump length (CR) sitting *height and crown-heel* (CH) standing height measured in millimeters (Fig. 9*c*). For very early embryos length and somite counts are used for determining age (Fig. 5). These charts are constantly *being corrected* on the basis of data accumulating from unusually complete and accurate *clinical histories*. The age scale used for the Hooker *collection* was a menstrual age estimated from such a standardized table.

The stroking end of a mounted human hair tipped with a nonabrading bead of inert *cement was moved* over the skin as a source of stimulus. The pressure value of the hair was always *recorded*. *Electrical* stimuli were also used occasionally.

The development of behavior in the human material is discussed in the following sections.

6 weeks. The fetus has a 12 mm CR measurement. Muscle contraction is localized and produced only by electric stimulation.

7½–8 weeks. The fetus has a 23 mm CR measurement. Stroking the fetus around the mouth and nose produces the first reflex, chiefly a movement of the head and neck to the opposite side. The structural mechanism in the central nervous system which makes the first reflex possible has been demonstrated by T. Humphrey, who collaborated in these studies. From sensory fibers of the fifth cranial nerve (trigeminal) which are in contact with the facial skin area a stimulus descends by a tract into the cervical spinal cord where collateral nerve fibers connect with the ventral motor horn cells on the contralateral side. Fibers from these cells discharge the stimulus to the muscles which they innervate and thus produce the contraction which pulls the head and neck to that side.

8½ weeks. The fetus in this stage of development has a 26 mm CR measurement and is in an [illegible] g. 5*a*, *b*) pro- areas of the skin are sensitive to stimuli. Figure 5*a* shows the area of stimulation with a human hair around the mouth of a 26 mm (CR) human embryo with an estimated age of 8¼ weeks. The immediate reaction is a backward movement of the whole arm pivoting at the shoulder (Fig. 9*b*). This accompanies a body and head flexion, chiefly to the contralateral side along with a slight twist of the pelvic region, all of which are difficult to show in the drawing. The legs do not move. The embryo then quickly returns to its original posture.

9¼ weeks. The fetus at this stage has a 33 mm CR measurement. Trunk flexion is now more marked and becomes separated from contralateral *trunk and bilateral* arm extension. From the seventh to about the tenth week the only sensitive area is perioral (around the mouth). Movements gradually spread toward the rump beginning at first only as dominant contralateral head, neck and upper trunk movements. Then extension of the arms at the shoulder joint becomes associated with the trunk movements which, as rump rotation appears, may not always be a flexion to the contralateral *side*.

10¼ weeks. The 10¼-week old fetus has a 44-mm CR measurement. A new sensitive area now appears in the fetus, the palms of the hands respond to stimulation. Trunk extension begins to replace contralateral flexion of the trunk.

11 weeks. The 11 week old fetus has a 48.5 mm CR measurement. The palms of the hands face each other (Fig. 5*c*), rather than caudally as before (Fig. 5*a*). Stimulation with a hair shows that sensitive areas are spreading over the face and the hands. Eyelids contract and fingers flex. Even the toes show some flexion. There are still no sensitive areas on the trunk.

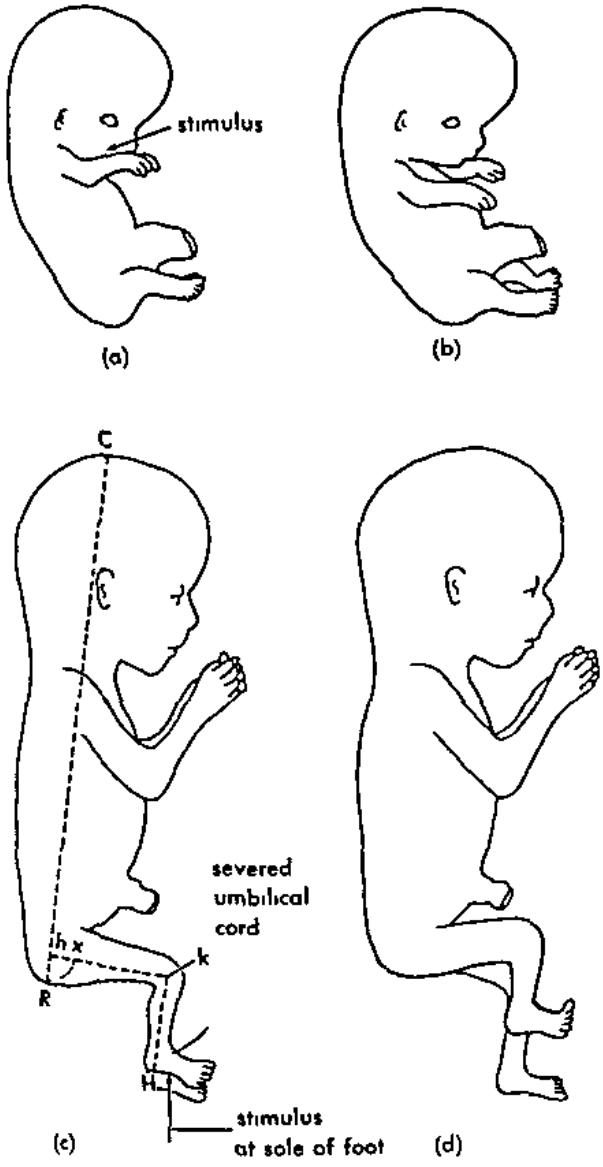


Fig 5 (a) Tracing of a photograph taken from a cinema film of a human embryo, 26 mm (CR) estimated age 8½ weeks showing perioral (around the mouth region) point of stimulus by a human hair touching side of the face (b) Immediate reaction of the same embryo to the stimulus, a quick backward movement of the whole arms pivoting only at the shoulders (c) Tracing of a photograph taken from a cinema film of a human embryo 88 5 mm (CR) estimated age 14 weeks Points for obtaining the crown rump (CR) and crown heel (CH) measurements indicated The arc of a circle described about the hip joint (h) as a center, with a radius equal to hR, cuts the hip knee (hk) axis at x indicating the leg length (xk kH) to be added to the sitting height (CR) in order to obtain the standing height (CH) Point of stimulus of a hair to sole of right foot is indicated (d) The immediate reaction of the fetus to the stimulus, a localized reflex with flexion of the right leg toward the body slight bending of the knee and flexion of the big toe upward and fanning of the other toes Normal size (*From cinema films of the Hooker collection of embryos and fetuses through the courtesy of Davenport Hooker*)

11½ weeks The fetus at this stage has a 56 mm CR measurement On stimulation of the face areas, reflexes now spread to the chest, trunk extension is strong and the arms rotate medially When the arm is stimulated, there is flexion of the wrist and forearm When the sole of the foot is stimulated there is a swift kicking motion

12½ weeks The 12½-week old fetus has a 67 mm CR measurement By the 12½-week stage the total pattern of activity is rapidly fading as many specific reflexes appear on local stimulation Lips close with some swallowing When eyelids are stimulated the eyeballs move Stimulation of palm of hand produces wrist flexure and finger closing and wide arm motion The big toe fans upward upon stimulation of sole of foot

14 weeks At this important stage in development of behavior the fetus has an 88 5 mm CR measurement This approaches the time (normally set at 20 weeks) when movements of the fetus can be felt by the mother because the fetus is very active All surfaces of the skin except the top and back of the head are sensitive to stimulation All reflexes are strong avoidance reactions The total pattern has given way to individual reflexes forming the framework for postnatal life Still to appear are grasping respiration phonation, sucking tendon reflexes additional neuromuscular mechanisms and sensitivity over the back and top of the head Figure 5*c* and *d* show the features of a human fetus at this age which already resembles those of a newborn infant By stimulating the sole of the foot (Fig 5*c*) with the stroke of a hair the individual reflex which has developed from a total pattern is the flexion of the leg toward the body (Fig 5*d*), slight bending of the knee flexion of the big toe upward and fanning of the other toes similar to the Babinski reflex

15–24 weeks The fetus at this stage of development has a 120–230 mm CR Reflexes become strong and spread rapidly Grasping of a glass rod, much movement of the extremities ankle and knee jerks protrusion of the lips and chest, and abdominal contractions leading to breathing indicate the complex behavior patterns which are maturing

25 weeks Eyelids are now open and the eyes move Respiration may last for 24 hours after the fetus is delivered The fetus at this stage has a 250 mm CR measurement

27 weeks Grasping with one hand is now sufficient to support the entire weight of the fetus for a short period For the first time the thumb now participates in grasping showing how individual reflexes gradually spread over a limited area These are the earliest prematures, they require the en

be held in the palm of the hand It measures 270 mm CR The fetus is shriveled and wrin because very little subcutaneous fat has yet

developed No doubt the environment produces some shock to the organism Movements are meager Breathing is shallow The head flops about and the limbs are flaccid The head will follow slowly if the trunk is rotated The lips are active and the tongue protrudes but sucking and swallowing are not prolonged The fetus gives occasional squeaks or cries It drowses and stirs but there is no definite wake sleep cycle There is usually a curved posture as if it were still floating in the amniotic sac There is a blinking and mild avoidance to bright light and a slight blinking or frown at the sound of a bell Grasping can be induced and when placed face down the head is turned to the side to free the nose

32–36 weeks The fetus now weighs 3½–4 lb and measures 310–346 mm CR The skin is smooth with fine hair on a slender body It is still weak drowsy, and indifferent most of the time although it is strongly active when handled The hands tend to close but can grasp a rod thrust into them It rolls its head and trunk and stretches its limbs The eyes often open and show primitive movements following a moving red ring It sneezes yawns cries and will suckle a bottle when fed every 2½–3 hours

36–40 weeks The fetus weighs 5¼–6 lb is chubby measures 360 mm CR and is close to full term The blood pressure breathing and temperature are better regulated States of sleep and waking are sharply defined While asleep it stirs about the mouth twitches the eyeballs roll and eyelids flutter When awake increased sensory capacity is evident At the sound of a bell the eyes open wide and the limbs move about The eyes are often in a fixed position but they blink at a flashing light and follow a moving object The hands are usually tightly fisted but grasp a rod inserted into the hand Signs of conditioning to its environment are evident When resting the head appears to rest on a preferred side It becomes quiet when picked up or fed

Full term newborn The fetus weighs approximately 7 lb and measures about 510 mm crown heel (CH) The body is plump red and at first in a cramped posture with limbs drawn toward the body but soon the legs often take on a crawling motion The muscles have a strong tonus although the head and neck muscles appear weak There are extremes of irritability and quiescence with disturbances such as irregular breathing crying hiccoughing choking head and trunk rolling and oscillation of body temperature and blood glucose levels At moments the eyes can follow moving objects The actions of a premature at this menstrual age are slightly more advanced than the full term newborn but this is only temporary while the newborn is also adjusting to its new environment

Further neuromuscular development, which makes it possible for a 14-month old infant to balance itself independently on its feet and to stand and walk at about 25 months follows an orderly sequence from the pattern already laid down before the fourth month of fetal life as shown by Hooker's observations

With regard to the movements of the upper extremities the visuomotor responses alone require gradual coordinating neuromuscular mechanisms developing to the point where the visual organ is very early prepared to become a part of the responses Early postnatal vision is rather rudimentary even though the head can turn with the eyes and briefly follow a moving object The eyes freely follow the movements of the hands passing from right to left across the field of vision by the tenth to twelfth weeks after birth The distinction between the hand and an object in it is clearly present by the twentieth week and by the twenty fourth week the infant readily reaches for and grabs the object on sight An account of the development of postnatal activity and the extensive analysis of learning and conditioning which become imposed upon a pattern of behavior is presented in the next section [L S ST]

EFFECTS OF EXPERIENCE IN MAMMALS

Approaches to a study of experience Experience as a factor in the development of action patterns has been studied both by experimental analysis and by means of systematic observations of animals in the course of adjusting to life situations These methods complement each other in different stages of research They have been applied to the study of the growth of many action patterns ranging from the simple responses appearing in newborn animals to the complex action patterns shown by adults As a result evidence has been gathered revealing the way in which experience influences the development of behavior

Two principal experimental methods have been employed to study the effects of experience The *first* involves a procedure of rearing animals in a restricted environment where they are deprived of certain types of experience believed to be important in their development The second method introduces special types of experience in order to test their effects on later development In evaluating the results of these two procedures the performance of experimental animals in special test situations is compared in the same test situations with that of normally reared animals or animals reared under contrasting experimental conditions Since the beginning of experimental psychology in the late nineteenth century and especially in the recent period from 1949 to 1959 results of studies using these methods have established that many adult behavior patterns are influenced by experience during the entire preceding period but of particular importance for later behavior are the early *periods of development*

Systematic observational studies conducted in the laboratory and in the field provide a background for the experimental methods described previously, first by indicating the types of behavior, the development of which is most likely to be influenced by experience and by suggesting the nature of the effective experience Second observational studies permit the investigator to see the behavior of an animal toward its species mates and in

relationship to different aspects of its environment Thus attention is focused on the function of different action patterns and on the relationships that exist among the many action patterns that an animal is able to perform In the course of observing the development of characteristic action patterns in newborn animals changes in specific action patterns can be seen as well as changes in the relationships among types of behavior Analysis shows that although they occur continuously these changes can be conveniently described with reference to series of developmental stages Much of the evidence concerning the influence of experience comes from the apparent relationships that have been noted between action patterns appearing in successive stages of ontogeny and in a few instances from experimental analyses of these relationships

A successful combination of both approaches to a study of the effects of experience will eventually enable the investigator to characterize developmental stages in ontogeny through a knowledge of processes underlying the organization action patterns For the present however, evidence that has been accumulated by use of each of these procedures is best presented in two separate actions In the first of these two sections studies of animals reared under restricted conditions will be presented to show the effects on the development of action patterns A generalized picture of mammalian development based on an analysis of successive stages will be outlined in the second section The characteristic mode of organizing behavior in each stage will be described and the relationships that exist between various stages in the development of a number of typical action patterns will be analyzed

Effect of restricting experience For the normal development of vision in the rat rabbit cat monkey and the chimpanzee a certain amount of early exposure to patterned light appears to be necessary This conclusion is based upon experiments in which the young of these species were reared in dark rooms starting soon after birth Later in life when such animals were placed in normally illuminated rooms they did not guide their movements by the use of visual cues Their ability to learn to discriminate between different visual forms such as circles and triangles and between different objects was far below that of normally reared animals The behavior of an experimental chimpanzee when first exposed to light showed the effects of its having been reared in the dark for the first 18 months of life Despite the fact that he had handled a milk bottle in the dark since birth this animal failed to recognize the bottle placed directly in front of his face *See* PERCEPTION, VISION

Once perception has begun to develop further development may be limited by reducing the variety of tactual and visual experience to which an animal is exposed or by restricting his movement In one experiment a kitten was removed from its mother and littermates after spending its first 25 days with them The animal was reared under solitary conditions for the remaining 20 days of the litter period and then returned to its mother and siblings Upon its return at 45 days this kitten showed broad differences in its perceptual adjustment to the mother and littermates as compared with mother reared kittens It was unfamiliar with the current behavior of the mother and kittens for this behavior had changed since the time of its removal and social isolation As a result the experimental kitten became frightened and withdrew from movements on the part of the mother and littermates These movements would otherwise elicit suckling approaches and playful forms of behavior

Young kittens that are allowed visual experience with patterned light but are prevented from moving by being held in a harness are no better in their perception of movement than kittens reared in the dark with only a minimum of visual experience with nonpatterned light

The opposite effect that of accelerating perceptual development may be produced by enriching the tactual and visual environment during early life In one experiment rats that had been reared in a visually homogeneous environment from an early age did not readily make use of visual cues to solve mazes in adulthood On the other hand individuals which had been reared in an enriched environment containing a wide variety of visual stimuli were easily able as adults to perform visual discriminations and they readily made use of visual cues to solve maze problems

Several studies have shown that the development of motor patterns may be interfered with by rearing animals under restrictive or otherwise unusual conditions An aberrant walking pattern developed in a kitten as a result of rearing the animal on a trough shaped floor surface that did not permit it to stand in a typical upright posture In tests conducted at 30 days of age this animal was able to raise itself from a horizontal surface but there was a marked lack of coordination between the movement of the forelegs and the hindlegs in fact the hindlegs frequently moved four times more rapidly than the forelegs While it managed to locomote this cat frequently extended its paws outward a pattern it had developed in adjusting to the sloping sides of its earlier environment This pattern resembles the walking pattern of a very young kitten that is just beginning to stand on all four feet and is unable to keep its legs under its body

A chimpanzee that was reared with its arms and legs enclosed within cylindrical tubes for two and a half years after birth was prevented from developing normal arm extension and grasping In the absence of reaching and hand grasping an infantile pattern of mouth grasping was retained for more than three years Other complex action patterns such as grooming climbing and clasping an attendant were also prevented from developing until the animal received special practice after release from the experimental restrictions

Retarded motor development has also been reported in two human infants reared [illegible] tions of limited physical and social adults during most of the first year

normal activities as rising to a sitting position sitting alone, standing while holding furniture, and stepping either sideways or forward were delayed in some instances for more than a month

Interference with tactual localization was also observed in the chimpanzee described previously When vision was temporarily excluded this animal attempted only occasionally to bring his fingers to a region of his chest arms or legs to which a tactile stimulus was applied Normally reared chimpanzees of a similar age are able to localize points of stimulation on their body almost immediately and with great accuracy In contrast the occasional finger placing movements of this experimental animal were very slow halting and grossly inaccurate In two human infants reared in a restricted environment the sensory motor integrations required to perform arm reaching movements accompanied by head turning and visual perception were significantly retarded although there was no evidence that either reaching alone or visual perception itself was disturbed

Developmental stages The four developmental stages in the growth of complex action patterns are discussed in the following sections

First stage In this early stage of a newborn's development its principal responses are determined in a more or less orderly manner by appropriate stimulation from the environment Initial behavior toward the mother occurs in response to the overall low intensity of stimulation that she presents A newborn kitten and an infant monkey react directly to the soft fur of the mother's body by approaching it just as the human infant cuddles against the soft warm skin of the mother Periodic arousal of the newborn by internal and external stimuli sets in action movements that are oriented first towards one then towards another specific region of the mother's body The varied movements of the young aided by the mother's actions as she licks or gently supports it eventually lead the infant to find and attach to a nipple [illegible]

ment continue to play a principal role in the integration of successive acts that form the pattern

Second stage Behavior of the newborn individual undergoes rapid changes shortly after birth Underlying these changes are shifts in responsiveness to more specific features of stimulation based not only on their low intensity but also on experience of the neonate during the first few days

In the first suckling soon after birth the newborn kitten shows repeated nuzzling movements with its nose buried in the fur of the female's ventral (belly) region Pushing over the surface of her body it progresses by following gradients of temperature surface texture and olfactory stimulation until contact with a protruding nipple elicits a slight head withdrawal and mouth-opening movement whereupon the kitten may grasp the nipple and suck By the second day, after repeated detachments and reattachments to nipples nuzzling is [illegible] and no the nipple

a brooder They were thus deprived of early suckling experience with the mother during this period of solitary rearing and they did not show the same behavior as their littermates Upon return to the mother at six days, or as late as twenty five days they showed a nonlocalized pattern of nuzzling re- [illegible]

male's legs as she stands or lies in a nursing position By remaining in contact with her body the kid eventually makes contact with her nipples and shortly afterward attaches to them Initial attempts at sucking by the infant chimpanzee while clinging to the female, minutes after birth consist of mouth grasping movements directed at protruding tufts of hair Only through the infant's continued efforts incidently aided by the mother as she provides body support is the infant finally successful in taking a nipple Within a short time however nipple attachments are rapidly performed as the infant climbs the mother's body and quickly localizes and grasps a nipple with its mouth

In the suckling behavior of newborn human infants changes resulting from earlier experience can be seen during the first two weeks after birth At the end of the first week the stimulus zone for nursing movements narrows to a region around the mouth and lips During the same period the reaction to stimulation of the cheek and mouth regions changes from a slow pendular movement of the head with periodic lip protrusion to one in which the head is rotated toward the source of stimulation Head turning is accompanied by extension of the lips and mouth opening thereby facilitating later nipple attachment and sucking Lying back while sucking and bringing its arms up to the bottle or breast while looking up at the mother gradually becomes a characteristic nursing position which the infant assumes on its own initiative when taken into the mother's arms and presented with the bottle or breast Within a short time the infant focuses its attention on the mother and responds to her preparations for feeding by becoming restive and by reaching toward her The appearance of these preparatory nursing movements by the infant indicates that it has developed a pattern of simple expectation Nursing actions that had previously been performed in a sequence accompanying the mother's actions in feeding the infant are now elicited merely by the introductory phases of her preparation

A basis for more specific types of expectations may have been established in the infant after birth as a result of the periodic nature of its feeding schedule A pattern of general activity timed to coincide with feeding was shown to have developed in infants during the first ten days after birth In two different groups of infants bottle feedings

were scheduled at either 3- or 4-hour intervals At the end of the 10-day period the two groups differed in the time at which they awoke from sleep and became active prior to being fed One group reached its peak of general activity 3 hours after its last feeding whereas in the second group this was not reached until the end of a 4-hour interval approached

Third stage In this stage the young mammal extends the range of its functioning in the environment It becomes increasingly more versatile in its capacity to organize movement patterns in accord with its advancing perceptual analysis of the environment

During this stage young kittens show the growing influence of visual function on their nursing behavior This is reflected in the change from nursings which are initiated by the female s approach to the young to nursings in which the young approach the female from a distance in order to initiate sucking

In its approach the kitten is able to maintain an orientation toward the mother for periods of several minutes during which it may be seen following her through a variety of wandering movements each time adjusting its nursing approach to a different posture of her body and at times being led to climb to a shelf in order to feed Solitary reared kittens that have been deprived of experience in making the initial simple adjustments to the mother are unable when returned to the mother during later stages of development to accomplish the *more advanced* types of *approaches to her from* a distance Simple approaches from nearby are controlled chiefly by proximal tactual thermal and olfactory stimuli from the mother whereas the more advanced types shown by mother reared kittens are based upon distant visual cues

The way in which a simple action pattern developed first in relation to contact stimulation is gradually extended by the introduction of vision is shown in a study which traced changes in a human infant s response to a very mild pinprick applied to its leg during its first 2 years After repeated tests in successive weeks the infant began to reach toward his leg and at the same time directed his eyes at the stimulated region An initial diffuse reaction was in large part inhibited by the development of a more patterned response aimed at relieving the local source of irritation The infant showed no reaction at this time to the visually perceived approach of the pin responding only when actual contact was made However the beginning of visual following of the experimenter s hand as it moved towards the infant s leg could be seen

The importance of visual following became apparent in later tests when anticipatory arm movements appeared as the pin approached the infant At first these were aimed at guarding the area of the leg customarily pricked by the experimenter but as the infant more readily detected movement of the experimenter s hand he reached for it directly and prevented its approach In subsequent weeks protective *arm movements* were supplemented by behavior in which the infant faced toward the experimenter and was able to halt the application of the irritating stimulus by means of facial expressions directed at the adult

What appears to be a simple action pattern in human infants reaching for and grasping objects has proved to be a highly complex one in which vision plays an important role in advancing the behavior from a simple to a complex action The first stage in its development consists of bilateral arm raising by an infant in response to gross visual or auditory stimulation By the seventh month this is modified into a pattern of unilateral reaching and a leading waiting relationship is established between the functioning of the two arms The waiting arm begins to receive objects brought in by the leading arm and the infant s earlier pattern of bringing objects directly to his mouth is gradually replaced by hand manipulation of objects accompanied by visual examination of them in detail

Use of the leading arm undergoes rapid development until finally the infant directs its reaching toward an object through a straight path without the intervening support provided by a table surface At this time its reaching is guided by orientation of the eyes in the direction of the object and by continuous perceptual focusing on the object The infant now reaches toward objects with an anticipatory grasping posture of its hands and with the fingers poised to handle the distant object Preparatory motions of the waiting hand anticipating the *approach of the object accompany reaching and* show how earlier experiences of the infant in handling and observing objects contribute in detail to the nature of this action pattern

Further advances in reaching behavior in infants have been studied by tracing the development of string pulling behavior over the first 2 years in a setting that at the same time permitted observation of the development of goal directed behavior of infants Infants were placed behind a grid barrier from which a string led to a toy which was out of reach but within easy sight of the child Children were required to modify an action of direct reaching toward a toy to one which involved pulling in a string String pulling thus became a mediating action which functioned to obtain the toy

At the age of 7 months infants centered their activity on the nearby string by mouthing it thereby accidentally bringing the toy within their reach By 8 months interest in the distant toy appeared and the infants reached directly toward it Upon encountering the grid barrier they shifted their attention to the string and began pulling it Meanwhile they watched the movement of the toy as it approached Gradually awareness of the functional connection between string and toy developed as the infants glanced from string to toy with each tug on the string The earlier accidental method of obtaining the toy was gradually modified into one in which the infants pulled on the string in to obtain the toy In the final stages of this de with the functional connection

string and toy firmly established all of the infants directed their attention to the toy at the beginning of the trial then immediately reached for the string and while still watching the movement of the toy pulled the string until the toy was within reach

Although this pattern appeared to be considerably advanced in development the infants still lacked versatility in using it This was revealed in a subsequent series of tests when multiple strings were presented to the infants each string leading in the direction of the toy Only one of the many strings was connected to the toy and it would bring the toy to the child if it was pulled The action fixed character of the infants behavior was shown dramatically when they consistently reached for that string which had been the correct one during their earlier training but which in the current series of tests was not attached to the toy at its far end Development of a more refined perceptual analysis of the string toy connection was necessary When this was accomplished the infants were able to distinguish between apparent perceptual connections and actual functional connections As a result a more versatile use of reaching replaced their earlier pattern in the novel situation

Similar processes requiring an increasingly specific visual orientation may be seen in the development of typical predatory reactions of lower mammals such as the cat and the skunk An initial reaction of leaping directly at a small moving object such as a fleeing rat or mouse is followed immediately by mouth grasping At first different parts of the prey s body may be grasped but grasping of certain parts still permits the prey to turn around and defend itself hence more specific orientation of the mouth grasp is developed Visual control and orientation of leaping and mouth grasping are gradually refined leading eventually to specific orientation of the killing bite to the neck of the prey Who h

animals Kittens reared with rats or mice from an early age develop an attachment to their cage mates and this frequently precludes predatory reactions towards them and towards similar animals In such cats the initial leap towards a small animal may develop into a pattern of playful behavior reminiscent of the play behavior shown toward its small cagemate

Fourth stage The action patterns which form the behavioral repertoire of an animal are brought together in this stage to form new patterns of behavior which serve the needs of an animal in many different areas of its functioning Complex action patterns are developed which function in mating behavior parental care and social behavior of various types (*see* REPRODUCTIVE BEHAVIOR) In addition a variety of action patterns developed during play the exploratory manipulation of objects and the process of solving problems are representative of the types of integrations appearing during this stage of development

The joining together of two sticks by a chimpanzee to form a single long pole may appear suddenly during problem solving behavior when the long pole can be used to rake in a reward such as a banana Often cited as an example of 'insight behavior this is in reality an action pattern that is formed from earlier behavior patterns that have been modified and combined in new ways The development of this pattern requires first that the animal modify an earlier pattern of direct reaching toward an object that is out of reach Mastery of use of a stick occurs in stages, it may be handled initially as an object in itself but set aside by a chimpanzee as an interference to its reaching and

reach Experience gained during this period has been proven essential for later use of a stick as an extension of the arm in reaching for distant objects It is characteristic of complex action patterns of this nature as well as action patterns involved in reproductive behavior that they are developed gradually although they may appear fully formed when favorable environmental conditions are established and when special internal states such as those produced by hormones or by the arousal of goal directed attitudes are present *See* HORMONE

The ontogeny of mating behavior in chimpanzees follows just such a gradual course of development Long before sexual maturity, parts of the pattern are seen in the approaches and attacks occurring among males and females during play and in the counter reactions that appear in patterns of retreat flight and what has been described as submissive posturing Central to sexual development are a number of action patterns involving body contact and mutual manipulation between individuals The origin of these patterns can be traced from the period of infantile nursing through the period of juvenile play Numerous actions involving genital contact occur among chimpanzees during embracing cuddling and manual oral exploration and these may lead to erection in the male and excitement in the female without the appearance as yet of the full mating pattern The final phases of integration of these part actions to make up the complete mating pattern depend upon the effects produced in the male and female by sex hormones as well as upon mutual guidance of each other during sex play It occurs more readily and more reliably if a sexually experienced animal can guide an inexperienced partner in the adjustments required to perform the mating act

Particularly complex situations may arise when animals are confronted with a problem that tends to arouse direct goal directed responses but actually demands the employment of mediating action patterns Chimpanzees confronted with the problem of obtaining a food lure which is out of reach or behind a barrier tend to react on the basis of their previous experience Initial reactions vary on the basis of such experience they vary from simple

direct attempts to evade the barrier and reach the bait to activities which indicate that the animal anticipates the blocking effects of the barrier or the impossibility of reaching directly for the food and is seeking some means of overcoming these difficulties Older, more experienced chimpanzees placed in a problem situation, readily adopt a prob lem solving attitude They are able to inhibit direct reaching toward a lure and can even reach with a single short stick in order to get a second stick that is out of reach so as to form a longer more effective pole They are also capable of inhibiting a direct reaching toward a lure suspended from a ceiling Instead they may stack two or more boxes under the lure before climbing to the highest point to start their reaching attempts In developing this pattern transporting a box under the lure must be mastered first Following this one box is pulled on top of another, while the chimpanzee stands on the lower box Finally, boxes are stacked while the chimpanzee is at ground level and only then does he climb them in order to reach the suspended lure

There is some evidence that chimpanzees make use of gestures to arouse in themselves the memory of parts of a situation that may be missing These gestures consist of an act such as reaching which because of its association with use of a stick in ear lier situations may recall a missing stick in the present circumstances The social use of gestures by one animal has been noted when two chimpan

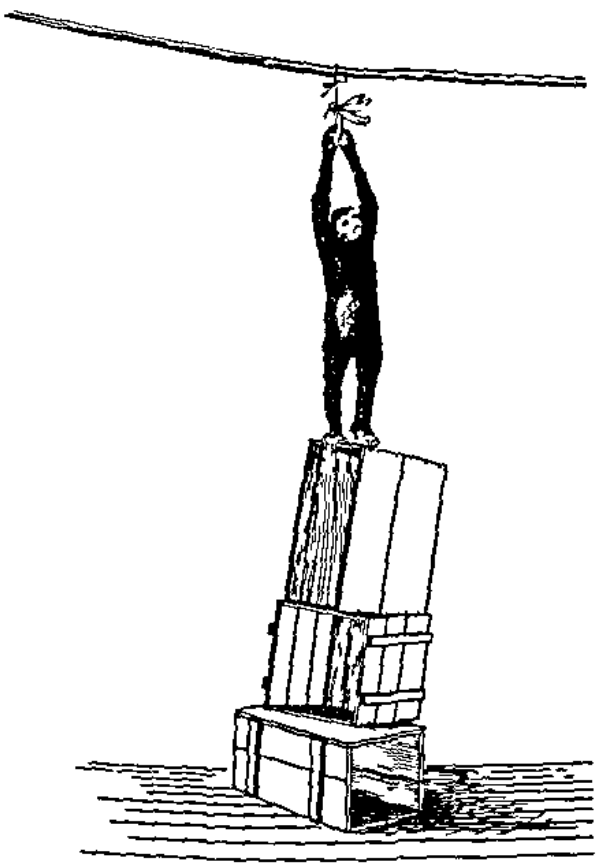


Fig 6 Chimpanzee reaching for lure after stacking boxes and climbing them (*Adapted from W Kohler, Mentality of Apes*)

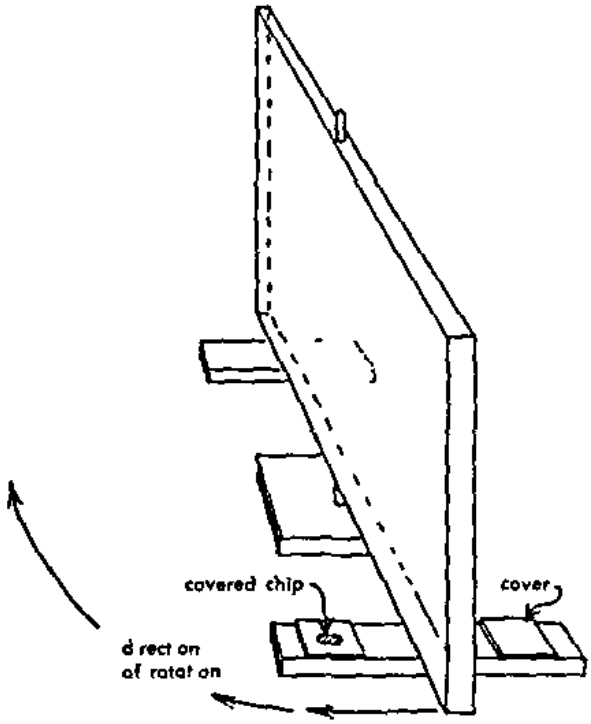


Fig 7 Rotating device used to test the ability of chil dren to replace gestures with words as development increases (*Adapted from E Meyer J Genetic Psychol 57 119–151 1940*)

zees are forced to work jointly in order to solve a problem For example two chimpanzees can be taught to pull on a pair of ropes to bring into reach a weighted box baited with food When a pair has learned to cooperate in this fashion one chimpanzee can be induced to pull with his part ner if the latter pulls gently at his arm The use of gestures both as individual symbols and as a means of interindividual communication, indicates the height to which development of action patterns has proceeded in chimpanzees Part actions made by the animal itself in response to inner urgings and to an outer situation arouse the animal to per form self directed action patterns consisting of a complex series of sensory motor integrations

Among young children a capacity to organize separate action patterns into new sequences and to coordinate them in varying relationships to form new patterns is closely related to the development and use of language At first the child may use ges tures to direct his own activity and to influence the activity of others around him In this way, for ex ample by standing under a cupboard and reaching upward the child may signal to both himself and his mother completion of the action pattern of get ting a cookie for eating Gestures and parts of ac tion patterns may also be used by a child to bring together two actions that had previously been per formed separately Adults sometimes orient their bodies in one direction, "facing north" in order to figure out a route to reach their destination and children make even greater use of body orientation and movements to direct their thinking In one experiment children learned to pull on one str

to procure a toy then separately learned to pull one of two strings in order to bring the original string into position In the test situation they made use of body orientation and tentative head and arm movements toward each of the two strings alternately in order to arouse their earlier experience with each as an aid in deciding which would procure the toy

In time words may replace gestures and contribute greater specificity and increased scope to action patterns One study was made of children's ability to obtain an object placed on a small platform at the front end of a board that could be rotated in a circular path away from the child After a 45 degree rotation the object a small button passed out of sight behind the rotating board

The results show how a word may be introduced to an already complex action pattern to advance its development Children 3½ years old were unable to follow or to complete the circular path of an object when it passed out of sight and they therefore did not know where to reach for it At four years children were able to follow the path of the object visually using a finger to trace its path They continued the circular movement of their finger through space even though the object had disappeared out of sight Having located it in this manner they could then reach for it directly behind the screen

At a later age eye movements and movement of the head replaced finger tracing of the path of the rotated object Finally at 4½ and 5 years the circular path as a whole was summarized by a word (for example circle round) At this stage the child had only to note the starting point of rotation he then turned away while the object was rotated yet he was able to reach for the object in the correct place immediately upon returning to the problem

In the solution of puzzle problems or mazes younger children make many movements and commit a large number of overt errors whereas older children hesitate before making active attempts to solve a puzzle or to follow a maze path During this preliminary period the older children substitute for the overt performance of action patterns the use of verbal directions which they form into a pattern for example turn left or turn right and so on By means of this symbolic process they are able to test the usefulness of performing overtly the entire action pattern and to rearrange parts of it as the problem requires

The further development of action patterns in humans depends upon the acquisition of broad conceptual systems (for example of numbers space and time) and the development of cognitive organizing processes Both of these extend the temporal and spatial references of behavior and the complexity of relationships that may be ordered in a single trend of thought or action With these advances action patterns reach their highest level of complexity yet even in this state there is a close reciprocal relationship between current ongoing processes of response to the environment and the accumulated effects of experience from early stages of ontogenetic development [JSR]

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Behavior and heredity

Different animal species behave differently Some of the behavioral differences are subtle shadings of common patterns and are the province of investigation of certain psychological and zoological specialities Others are so prominent as to be apparent to all dogs bark wag tails and bury bones cats climb trees purr and on occasion arch their backs and hiss It may be assumed from the principles of evolution that different species are different because of accumulated differences in their genetic composition It is therefore plausible to conclude that the genetic differences account in part for the behavioral differences It is necessary to include the qualifying phrase 'in part' because environmental and genetic differences are interwoven For example whale behavior is different from cow behavior not only because of hereditary dissimilarities but also because of the differences in the environments in which whales and cows develop and live

From this line of reasoning the evidence for the importance of heredity in behavior is therefore indirect and qualified and is likely to remain so since the crossbreeding of different species which would be necessary for experimental analysis is for the most part not possible

Accordingly the role of genetic differences in behavior is examined by studying the individual differences that exist among the animals within a species These differences are also apparent and man is particularly aware of their existence within his own species where diversity of personality and intelligence is a matter of everyday concern (see INTELLIGENCE) The notion that humans might differ in these characteristics because of hereditary influence has long been entertained and finds expression in phrases such as 'like father like son' Once again however effects of environmental factors are confounded with hereditary factors It is never clear whether the delinquent child of a thief or the studious child of a scholar is what he is be-

cause of the hereditary material contributed by his parents or because of the environment that is partially provided by, and also includes the parents

Since no animal can be reared without both a genetic constitution and an environment it is not possible to determine the effect of either environmental or of genetic variables in the complete absence of the other It is possible however to observe the effects of different environmental conditions on individuals of similar or identical genetic constitutions and also the expression of different genetic constitutions in similar environmental circumstances The meaningful way to phrase questions concerning heredity and environment therefore is to inquire as to the relative contributions of genetic and environmental differences to the variability exhibited among individuals

The research area of behavioral genetics is concerned with answering such questions with respect to characteristics of behavior Investigations have been made on a number of species ranging from fruit fly to man with a particularly strong emphasis on rats and mice, and the kinds of behavioral topics which have been examined span a range from the response of flies to light to human intelligence and personality This article discusses research performed with subhuman animals For information derived from research on humans *see* HUMAN GENETICS For information on development of behavior in the embryo and the effects of experience on the young of the species *see* BEHAVIOR ONTOGENY OF

LEARNING

Research on the inheritance of learning ability has been particularly persevering as might be expected in view of the prominent position of learning theory in psychology (*see* LEARNING THEORIES) The bulk of information available on this topic has grown out of selective breeding programs using rats as subjects The general procedure of these studies may be described as follows (1) the ability to learn a maze was measured in a genetically heterogeneous group of rats (a "foundation stock") (2) the quickest learning males were mated with the quickest learning females and the slowest learning males with the slowest learning females (3) the offspring of these matings were tested on the maze and the quick learners of this generation were again mated with quick learners and slow learners with slow learners This cycle of events was consistently repeated for each successive generation The first mating established two lines quick and slow and from that time on no breeding between the lines was permitted

If the differences in learning ability within the original foundation stock were completely due to environmental differences among the animals such a selection program would have no effect that is there would be no differences in the average performance of the two lines On the other hand insofar as the behavioral differences within the original group were determined by genetic differences selection would be expected to result in two strains which differed consistently in the trait for which they were selected

The selection study carried out by R C Tryon is first considered and then the investigations that developed from it

The Tryon study In Tryon's maze, a hungry rat ran for a distance down an alley until it reached a juncture At this "choice point" one alley led to the left and another led to the right One of these alleys terminated in a dead end from which the animal had to retreat before he could continue through the maze The other alley terminated in another choice point from which two more alternative alleys proceeded, one to the left and one to the right and so on After 17 choices the animal emerged into a chamber containing food The measure of an animal's performance was the total number of entrances into blind alleys

The effects of selective breeding on learning in this maze were sharply defined as shown in Fig 2 which presents the results through the seventh generation Two clearly distinct strains which may be called bright' and dull" had been established by this time and the differences persisted thereafter

With two such discrete strains available Tryon was able to deliberately alter genotype (the hereditary properties) and observe the effect of this manipulation on phenotype (the observable characteristic) This was accomplished by mating bright animals with dull animals and then testing the resultant offspring in the maze When this experiment was carried out it was found that the F_1 (the hybrid offspring) were on the average intermediate to their parents These two sources of information—the success of selective breeding and the alteration of behavior subsequent to alteration of the genetic constitution—provided unequivocal demonstrations of the importance of genetic determinants in the maze performance of rats

A number of subsequent studies sought to describe the nature of maze brightness and maze-dullness in more detail In one of these the rats were tested in a maze that offered visual, as well as positional cues At each choice point there was

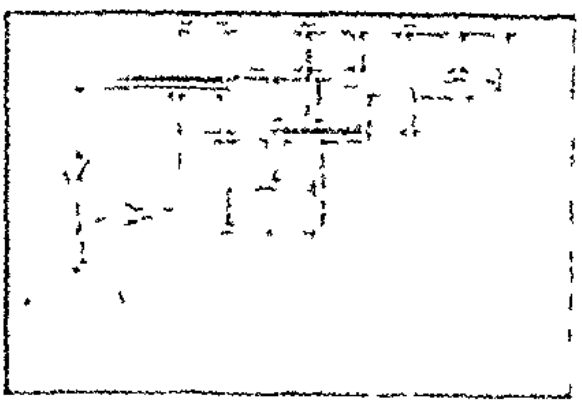


Fig 1 Floor plan of Tryon's 17 unit T maze (From R C Tryon *Studies in individual differences in learning* J Comp Psychol 29 241 [illegible])

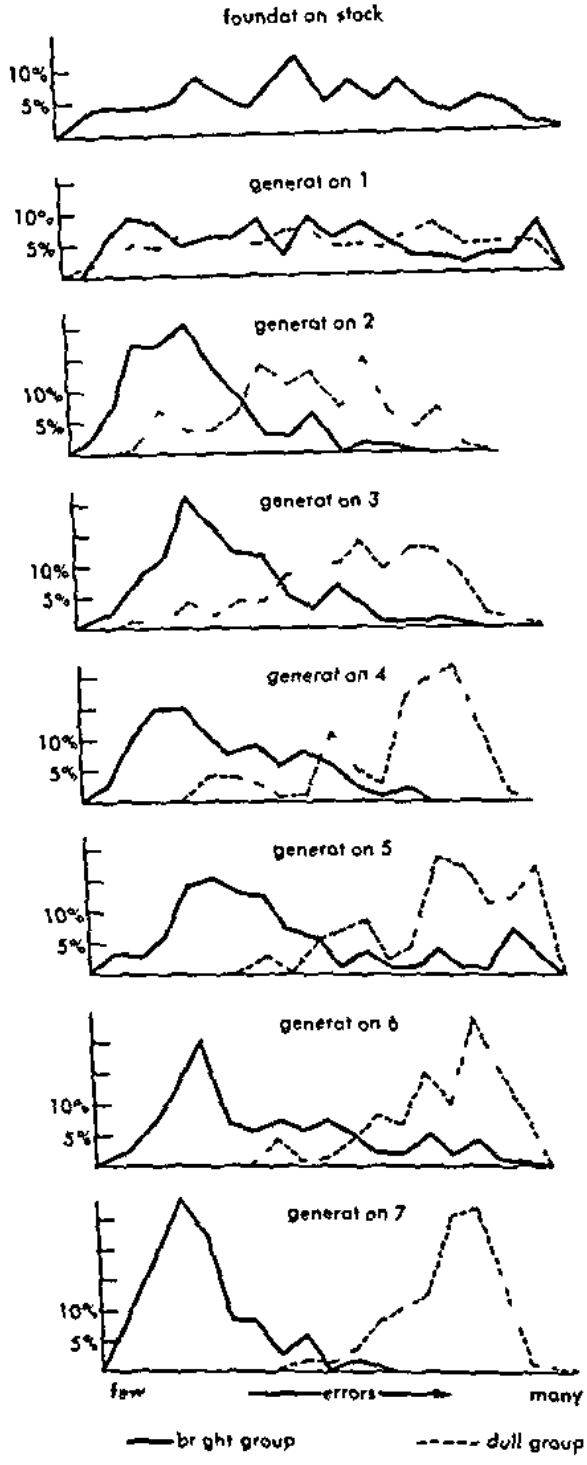


Fig 2 The gradual and systematic development of the "bright" and dull strains The vertical axis shows percentage of animals obtaining a particular error score in 19 trials in Tryon maze The bright and dull strains become more distinctly separated generation by generation until by the seventh generation only a small percentage of the dull animals make as few errors as the poorest learners of the bright strain (Modified from R C Tryon Genetic differences in maze-learning ability in rats Thirty-ninth Yearbook Natl Soc Study Educ, 1940)

an illuminated alley and a dark one The illuminated alley was sometimes to the left and sometimes to the right The correct alley was left or right dark or illuminated an equal number of times In this situation rats from the bright strain tended to make responses in terms of positional cues, that is choosing left or right regardless of whether the alley was dark or illuminated The dull rats on the other hand tended to respond to light or to dark regardless of position

The brights had been selected for excellence of performance in a maze in which only spatial cues were relevant The poor performance of the dulls in that maze did not demonstrate that they were inferior except with respect to the use of spatial cues The possibility existed that the dulls might even prove to be superior in a nonspatial type of situation and the brights might prove inferior

To determine if the bright strain did indeed differ from the dull in a general intellectual function animals from each strain were compared on a battery of nine tests Five of the tests measured learning under hunger motivation and food reward Two others required the animals to swim through a maze pathway, the reward being escape from the water General activity level was measured by recording the number of revolutions the rats turned a squirrel cage activity drum Emotionality was assessed by the amount of face washing amount of running activity and the frequency of urination or defecation in a large, brightly illuminated enclosure

The results showed that the brights were more responsive to hunger motivation and performed well in food reward situations The dulls were superior to the brights in the escape-from water problems The brights ran more rapidly through mazes but were less active than the dulls in the activity drums Furthermore most of the activity of the brights appeared just prior to feeding time another indication of the relatively great importance of food motivation for animals of this strain The brights showed more emotional responses in the enclosure and they were also observed to display signs of emotional upset in certain other test situations particularly in those involving relatively open spaces The dulls on the other hand appeared to be more disturbed by mechanical features of the apparatus such as the doors and switches which were used in recording the animal's progress through the maze

This picture is obviously not one of a clear one-dimensional difference between the strains On the contrary it would appear that the selection program had produced two lines which differed in a constellation of motivational and emotional characteristics Which parts of the constellations are fundamental to maze brightness and to maze dullness and which had been fortuitously combined during the breeding program is not known It is emphatically clear however that the terms bright and dull have definite reference only to the specific situation

employed in selection and that a truly general intelligence factor had not been isolated

The Heron study Beginning with a different foundation stock and using a maze and procedures which differed in a number of details from Tryon's W. T. Heron provided remarkable confirmation of Tryon's major result. A clear separation of two strains was evident as early as the third generation.

In addition to the total error scores for 15 trials the change in error scores from trial to trial was examined. The average number of errors declined from the first to the last trials and the downward trends were quite parallel for both strains. Nevertheless the average dull error score was higher than the average bright error score for every trial.

A distinction was also made between two different kinds of error. If an animal upon leaving a choice point turned to the incorrect alley this was designated a forward going error. A repeated entry into an incorrect alley was called a perseverative error. The dull rats made a great many perseverative errors at first and the reduction in these errors accounts almost entirely for their improvement in performance over the 15 trials. That is to say the dulls learned to avoid repetition of an error but did not learn to select the correct path. The brights in contrast made practically no perseverative errors from the beginning and their improvement was due to increasing efficiency in selecting the correct path of the two alternatives at each choice point. Dull rats were also observed to take longer than bright rats to run through the maze. Of course it takes time to make and correct an error and the dulls made more errors. This fact however did not account completely for the strain difference in time scores. When comparison was made only for trials on which the same number of errors was made by animals of both strains the difference in time scores was still apparent.

The higher activity level of bright rats was also revealed in another study. Each rat when hungry was placed in a small box into which a lever extended. Depression of the lever resulted in the delivery of a food pellet to the animal. The bright rats made many more responses than the dull rats in this situation. The tendency of bright rats to make food rewarded responses more frequently or more rapidly than dull rats suggests that the brights were more highly food motivated. This is in accord with the results obtained from the Tryon strains.

After the data on relative frequency of responding had been obtained in the lever pressing experiment *the food reward was terminated*. Now pressing the lever became an unrewarded inappropriate and in a sense an incorrect response. The maze results had shown that bright animals eliminated incorrect responses more rapidly than the dull animals and it was therefore expected that the brights would cease pressing the lever sooner than the dulls. This expectation was not confirmed. Apparently one cannot characterize the strains in terms of differences in a general ability to eliminate non-rewarded responses.

The higher activity level of Heron brights in the maze and in lever pressing is in harmony with the faster running of Tryon brights in their maze. As mentioned earlier the association of the selected characteristic such as maze learning ability with some other characteristic such as activity level provides no conclusive evidence that the two are functionally connected. However the agreement of results on both the Tryon and Heron strains reduces the chance that the association is entirely incidental. Even more persuasive evidence that activity and maze-learning ability are necessarily and functionally related is provided by a study in which two strains of rats that had been selectively bred for high and low activity levels with complete disre-

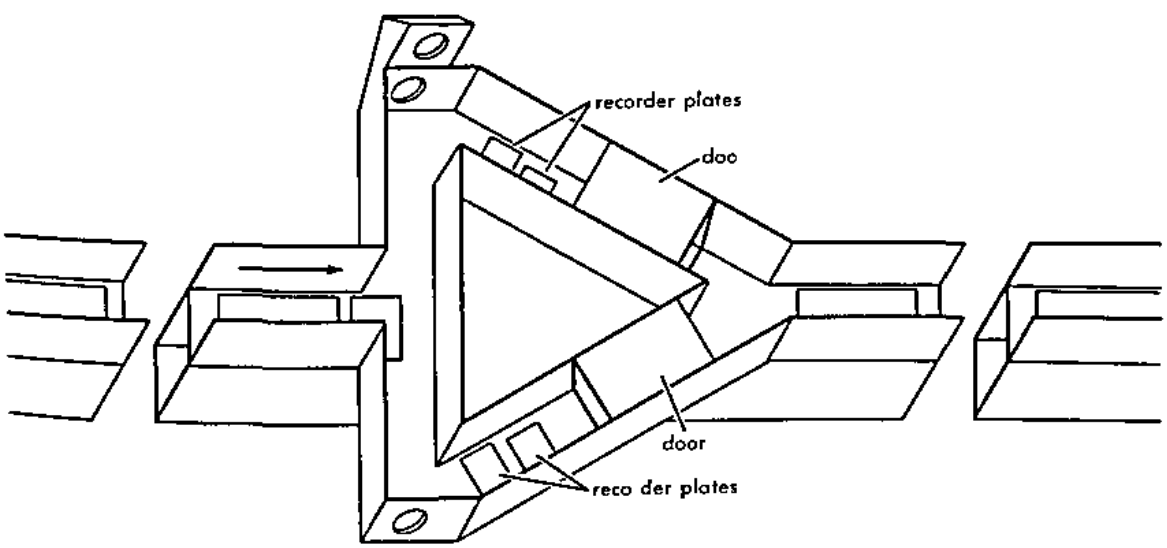


Fig. 3 One unit of Heron's 12-unit maze. (From W. T. Heron. An automatic recording device for use in animal psychology. *J. Comp. Psychol.* 16:149–158, 1933.)

gard for learning ability were tested in learning situations The activity levels were determined by performance in rotating drums Rats of the active strain learned the Heron maze more quickly than rats of the inactive strain Likewise the active rats responded more frequently in the lever pressing situation

The McGill selection program At McGill University a selective breeding program was undertaken in which an explicit effort was made to develop strains differing in rat intelligence but not differing significantly in emotional and motivational traits Selection was based on performance in an apparatus in which it was possible to alter the position and number of barriers between a starting chamber and a goal box A number of problems graded in difficulty were standardized using a heterogeneous group of rats These problems were then used in the selection study The use of progressively more difficult problems made it possible to assign to every rat a score somewhat analogous to the IQ scores in human intelligence testing

As in previous experiments differences between the two selected lines developed rapidly To determine whether emotional and motivational differences were being developed concomitantly the strains were examined on exploratory behavior food drive and defecation tendency The findings were generally negative Some differences in exploratory behavior were found but these were thought to be due to differences in learning function and therefore perhaps inseparable from brightness and dullness

Although developed only recently these interesting strains have already been helpful in adding new perspective to a controversial area For example res [illegible] ad[illegible] ma[illegible] ments using various strains of rats different from those of the original strain did not confirm this outcome In an experiment on the McGill brights and dulls it was shown that the performance of the dulls did improve when glutamic acid was given but the performance of the brights did not

MOTIVATION

In addition to the data on motivational factors obtained in the context of learning phenomena a number of studies have dealt with motivation itself

Food motivation One experiment on the genetic determination of differences in food motivation utilized mice of 15 inbred strains These strains had been selectively bred for differential susceptibility to mammary tumor and other physiological characteristics without regard to their behavioral traits Systematic inbreeding had been carried out for many generations Inbreeding reduces genetic diversity and when carried out for an extended period it results in strains within which all individuals have highly similar genotypes Individual differences that remain within an inbred strain are interpreted as due, for the most part to environmental factors If different strains are reared in similar environmental conditions differences that appear between the strains are attributable to differences in genotypes of the strains

In the experiment under consideration animals from each of the 15 strains were deprived of food for 23 hours then allowed to eat, and the amount eaten by each mouse was measured Differences among strains ascribable to genetic differences were large with the average amount eaten by the highest strain being 2¼ times that of the lowest strain The results also showed within strain variability which reflects environmental effects Furthermore the variability was greater in some strains than in others This last observation is important for it demonstrates the principle that the effectiveness of environmental forces in producing phenotypic effects depends in part upon the genotype of the animal upon which the environmental forces are acting

In another investigation of food motivation a series of studies was directed to the analysis of the genetic mechanism of food hoarding in rats The simple testing apparatus consisted of a runway extending from the door of the living cage to a bin containing food pellets The animals were kept on a feeding schedule arranged so that they were hungry prior to the daily hoarding test After being allowed to eat for a while in the home cage, each rat was given access to the runway for 20 min and the number of pellets transported to the home cage was counted

Three strains of rats brown hooded black hooded and Irish were tested The black hooded rats hoarded a much larger number of pellets than did the others The Irish hoarded less than one-fourth as much as the black hooded and the brown hooded animals were intermediate Following the trials on which the animals had been kept hungry they were tested under conditions of satiation The hoarding tendency of all animals gradually declined but even by the ninth satiated hoarding trial the black hooded animals were hoarding as much as the Irish had hoarded when hungry

Black hooded females were mated with Irish males and the F_1 offspring were found to hoard as many pellets as their black hooded parents When the F_1 animals were mated to the low hoarding Irish rats the progeny yielded hoarding scores intermediate between the black hooded and F_1 on the one hand and the Irish on the other

Locomotor activity and exploratory motivation Aside from the demonstration of differences in activity among breeds of dogs the greatest part of the research on the genetics of activity has been done with rodents Genetic influence was revealed in rats by a selective breeding program The animals were allowed to run inside rotating drums and the number of revolutions constituted the index of activity Two highly divergent strains were de-

veloped which as noted al ove also differed signifi cantly in maze and in lever pressing performance

In the foregoing experiment the rats lived in the activity cage for 21 days and were therefore thor oughly familiar with the apparatus More recently interest has centered upon activity in novel unfa miliar situations This trend has been stimulated by the growing theoretical significance of explora tory drives

A survey was made of exploratory activity in 15 stra ns of mice The apparatus was a square arena the floor of which was marked off in 36 small square subdivisions The number of squares en tered by a mouse in a 10-min interval was taken as the index of exploratory activity The average scores varied from 459 for the highest strain to 20 for the lowest strain Five strains ranging from very high to very low were then tested in a Y shaped alley maze Activity was measured by the number of different entries into each arm of the maze The rank order of the strain averages in the Y maze was about the same as on the square arena

In another study six strains were tested on the arena and in three other situations In one the time required for the mouse to crawl from one compart ment to another through a hole in the wall was re corded In another four compartments were sepa rated by barriers and exploratory activity was measured by the number of barriers climbed in a 2 min interval In the third apparatus a square area was divided into two parts a peripheral area adjacent to the walls and a central area The nu m ber of times the animal crossed into the central area in a 2 min period was recorded

A high consistency over all of the test situations was apparent Strains that had high average scores in the arena also tended to crawl quickly through the hole in the wall to climb many barriers and to cross frequently into the central area These results strongly suggest that the characteristic involved is a general one and is not restricted to any one pro cedure or apparatus

In all of the mouse studies the particular strain designated as C57BL has been one of the most ac tive Another known as the A strain has been low in activity When these two strains were crossed the F_1 hybrids were tested in the arena and found to be intermediate to their parent strains but somewhat more similar to the C57BL than to the A The offspring from the mating of F_1 animals with A strain animals constituted one backcross generation the average performance of which was between the F_1 average and the A average The average of the backcross of F_1 with C57BL animals was intermediate between F_1 and C57BL averages The average of the F_2 generation obtained by crossing F_1 animals randomly fell between the averages of the backcross generations

These results conform quite closely to the hypo thetical case of a large number of determining genes each of which contributes a small amount to the phenotypic expression

EMOTION

It is possible that differences in activity in novel situations reflect different levels of curiosity or ex ploratory drive It is equally possible that they may be due to differences in emotional states such as timidity or fear The A mice may run little and climb rarely because of fear while the high activ ity of the C57BL mice may indicate boldness or alternatively it may indicate fear motivated search for escape The particular explanation for this spe cific case must await further research The evidence relating to the inheritance of what might be broadly termed emotionality in animals is presented in two sets of observations The first is a selection ex periment and the second is a comparison of the be havior of two strains of rats

In the selection experiment the testing situation was a large brightly illuminated circular area in which rats were placed for two minutes daily for 12 days An animal s score was the number of days on which it defecated or urinated during the ob servation period and this score was taken to repre sent the state of emotionality of the animals Two extremely different strains were quickly developed An analysis of the behavior of these emotional and nonemotional strains in other situations led to the conclusions that emotional animals were less aggressive that is less likely to fight with other rats for food when hungry more timid for example hiding at the back of the home cage when the ex perimenter was near and hesitant in entering a tunnel They were more active in a rotating drum and less likely to suffer convulsions when exposed to high frequency sound

The same measure of emotionality was used in comparing tame laboratory rats of the Wistar al bino strain with the descendants of wild trapped gray Norway rats which had been reared in the lab oratory for 43 generations Even to casual observa tion the gray rats were wilder than the albinos and they also excreted more frequently in the for mal test situation It was suggested that tameness was due to the effects of a single gene which deter mines black coat color In albinos the behavioral effect is presumably expressed even though the genes determining albinism prevent the expression of black fur Some confirmatory evidence has been presented for this conclusion with respect to rats but it apparently does not hold true for mice

SOCIAL BEHAVIOR

The social behavior of several breeds of dogs and several strains of mice has been studied

Social behavior of dogs The dog was evidently one of the first animals to be domesticated by man Certain anatomical and behavioral character istics have been valued and relying upon a general understanding that like begets like for many generations men have mated animals showing the desired characteristics In effect a number of selec tion programs has produced the great variety of

dog breeds now in existence These breeds provide a valuable resource for studies on behavioral genetics

In one study pups from the same litter were placed two at a time in a pen containing one bone A pup was described as completely dominant if it retained exclusive possession of the bone for 8 or more minutes of the 10 min observation period Several litters of each of four breeds were examined Beagles basenjis cocker spaniels and wire haired fox terriers were tested and the observations were made at 5 11 15 and 52 weeks of age

At 5 weeks a relatively small proportion of the encounters resulted in complete dominance by one animal and there were no substantial breed differences By 52 weeks breed differences were pronounced with less than one half of the beagle or spaniel pairings resulting in complete dominance and nearly three fourths of the basenji and terrier pairings resulting in complete dominance by one of the two animals

This outcome is in accord with other observations on the social behavior of dogs Terrier pups have frequently been noted to persecute one of their littermates severely and in mixed litters of terriers and beagles the terriers consistently dominate the beagles

Dominance or aggression in mice A number of studies on dominance or aggression have also been conducted on mice Fighting occurs much less frequently among females than among male mice so that practically all of the research on this species has been conducted with males

In one study male mice of three strains which had been housed in separate cages were paired with each other for short observation periods and detailed records of the ensuing behavior were made A majority of such encounters resulted in active fighting In terms of ability to win fights the C57BL mice proved to be superior to the C3H which in turn were superior to the BALB/c Subsequent tests of fighting behavior between members of the same strain revealed stable dominance hierarchies in which one mouse dominated all others of his strain one mouse was submissive to all others and some intermediate animals were dominant to some but submissive to others By subjecting the most dominant animal of a strain to a series of defeats by an even more aggressive animal taken from some other group it was possible to make him submissive to the other animals of his strain which he had previously dominated Likewise by pairing a submissive animal with an even more submissive one and thus letting the first male learn to "win" it was possible to increase gradually his aggressiveness until he became the dominant animal of his strain

Males of the C57BL and BALB/c strains were reared under different social conditions Some animals were weaned at 20 days of age and kept in isolation until aggressiveness tests were given Others were also weaned at 20 days but were housed thereafter with siblings and in some cases with the father The tests were given at 100-120 days of age The aggressiveness measure was the time until onset of fighting after pairs had been placed together

In general the results showed that males which had social contacts after weaning began fighting more quickly than those without postweaning social contacts However the magnitude of effect of this environmental variable depends on the genetic variable This was shown by the fact that although the difference between animals reared alone and those reared with companions was great for the C57BL strain it did not appear at all in the BALB/c strain

The fighting in these above studies was spontaneous in the sense that there were no apparent goals for which the combatants were competing It has been shown that when a single loose pellet of food is made available to two hungry C57BL mice fighting may be elicited in both males and females If the pellet is secured to the the floor no fights occur In contrast BALB/c mice of either sex will peacefully share a loose pellet This strain difference seems to be attributable to a tendency of C57BL animals to pick up food and run with it Simultaneous efforts to move the pellet in different directions lead to fighting The BALB/c mice evidently are content to eat food where it is found

If a C57BL and a BALB/c mouse are housed together the BALB/c animal can learn to be competitive over the food However if one of these trained BALB/c mice is then placed in a cage with a naive BALB/c mouse only low intensity fighting occurs and that quickly disappears

The relationship between sexual behavior and aggression has also been studied in mice Males were housed in separate compartments of a single cage Fighting trials were begun by removing the partition separating the compartments After a series of training trials a female mouse was introduced when the partition was lifted The fighting behavior of C57BL males was delayed considerably while the males investigated the female but the BALB/c males began fighting promptly and ignored the female

These strain differences make it evident that aggression is influenced by genotype At the same time the expression of the characteristic is heavily dependent on the environmental circumstances such as whether the animals are housed together or meet only for bouts or whether competition for a goal is involved

In a study more closely approximating natural conditions young mice of the same litter were turned loose in a large room and observed periodically for several months The room contained a stand with shelves which held small cages Ramps led from the floor to the different shelves In one corner of the room was an enclosure containing food water and nesting material This enclosure had a small opening through which only one mouse

could pass at a time Four such rooms were estab lished with two containing C57BL mice and two containing DBA mice Fighting occurred among the males in both strains but was considerably less severe among the C57BL than among the DBA In the C57BL groups, the aggression assumed the forms of threats by the dominant male and avoid ance by the submissive males Females were not in volved in the conflicts Among the DBA males fighting was much more frequent and severe with females occasionally being attacked

SEXUAL BEHAVIOR

For a genetic group breed strain or species to survive behavior related to reproduction must be at least minimally effective Nevertheless sizable differences in sexual vigor have been related to genetic differences The behavior of male guinea pigs in the presence of receptive females has been observed in a series of investigations Assigning a certain number of points for the various elements of normal guinea pig sexual behavior (sniffing nibbling mounting intromission ejaculation) made it possible to assign a numerical score to each male s behavior One heterogeneous group and two highly inbred strains were studied The average vigor of males from the heterogeneous group was much greater than that of males of the inbred strains and the latter also differed from each other in pattern of sexual behavior

Effect of social isolation The effect of social isolation was then investigated some males being reared individually with their mothers until 25 days of age and completely alone thereafter and others being reared with siblings of both sexes to 25 days of age and with several females thereafter Weekly observations on sexual behavior were begun at 77 days of age The socially isolated males of the in bred strains displayed at least as much sniffing nuzzling and other types of exploration of the fe males as did the socially reared males from the same strains However socially isolated animals were much less successful in accomplishing intro mission and ejaculation Prolonged isolation after the complete adult sexual behavior had been ac quired did not reduce efficiency of performance Thus the effects of early isolation appear to be due to lack of proper experience at a crucial phase of development and not to isolation itself The per formance of animals from the genetically heteroge neous group was not adversely affected by early so cial isolation General observations had revealed a more rapid rate of maturing in the heterogeneous group and it was suggested that the experience ac quired in the company of the mother until 25 days was sufficient for the organization of the pattern of sexual behavior of these animals although 25 days experience was insufficient for the more slowly ma turing inbred strains This suggestion was tested by weaning and isolating animals of the heterogene- ous strain at 10 days of age and comparing their behavior in adulthood with animals weaned at 10 days but reared thereafter with females Under these circumstances the sexual behavior of the so- cially isolated animals was deficient

Thus the general conclusion is reached that so cial experience is necessary to the organization of sexual behavior in male guinea pigs Once again an example is provided of the important fact that the effect of environmental differences depends upon the genotype of the animals involved

A similar conclusion has been reached with re spect to female guinea pigs Various components of the female sexual behavior pattern were inhibited by deprivation of social contacts during develop ment and the magnitude of the effect was different for different strains

Genotype and reproductive success The rela tionship of genotype (genetic constitution) to re- productive success in mice has been investigated Three animals were housed together in a cage One male and a female were from an albino strain and a second male was from a black strain The coat color of the offspring showed which male had sired them In a large number of litters produced from mating arrangements of this kind 83% of the off spring were sired by albino males This result may of course be due to strain differences in such things as viability of sperm or viability of embryo How ever it is possible that behavioral differences de termined the relative success in reproduction For example the females may have preferred mates of their own strain However the albino males were observed to be quite aggressive and their repro- ductive success may have been due to domination over the black males In this connection it should be noted that in the mixed litters of terrier and beagle dogs the dominant male terriers sired all of the pups born during the experiment

While the more aggressive males at least in mice and dogs may have a higher probability of fertiliz ing females excessive aggression can seriously jeopardize the reproductive success of a social group In the experiment in which DBA and C57BL mice were released in large rooms the maternal be- havior of the DBA females was impaired in part no doubt because of the aggressive attacks made upon them by males In some cases the newborn young were eaten by the mother Comparable fail ure of maternal behavior was not noted in the C57BL females who were not subjected to repeated attacks by males

A number of behavioral differences among spe cies and subspecies of fruit flies have been de scribed Certain differences reduce the possibility of interspecific mating These differences involve the behavior of both sexes It has also been shown that within a species males differing from other males in respect to a certain gene were less able to court females successfully Analysis of the behavior of the deficient males showed that their wing flut tering which is an essential part of the courtship pattern was not continued for a sufficient period of time to elicit receptivity of the females

GENOTYPE AND OTHER TYPES OF BEHAVIOR

The genotype and its relationship to the orientation response (taxis) sound induced seizures and alcohol consumption have been investigated in a variety of animal species

Orientation responses In many animal groups the presentation of a specific stimulus will reliably elicit a stereotyped orientation response toward or away from the stimulus A common example of this class of behavior called taxis is the tendency for moths to fly toward a light *See* TAXIS

Fruit flies characteristically display positive phototaxis and negative geotaxis That is they tend to move toward light and away from the earth (upward) Selection programs have shown that both of these characteristics are under genetic influence To measure phototaxis flies were placed in a chamber which had two projecting tubes one of which was dark the other illuminated By testing the flies repeatedly it was possible to distinguish different degrees of phototaxis Selective breeding resulted in two strains Flies of one strain moved toward the light at nearly every opportunity while those of the other strain rarely or never entered the illuminated tube

In the study on geotaxis the flies were presented with a series of choices of an upward inclined vs a downward inclined tube Again two strains were developed by selective breeding—animals of one showing strong tendency to climb upward at every opportunity while animals of the other frequently moved downward

In both of these studies provisional estimates were made of the heritabilities of the characteristics that is the proportion of the total variability among individuals which can be attributed to genetic differences It was calculated that for phototaxis and geotaxis respectively one third and one sixth of the total variability could be attributed to genetic differences

Sound induced seizures If a genetically diverse group of rats or mice is exposed to an intense high pitched sound a number of animals may undergo severe convulsive seizures sometimes terminating in death A large number of studies has been devoted to the examination of the genetic basis for this convulsive disorder It was quickly discovered that some strains of rats *and mice were* susceptible to seizures while others were not Initial results gave a picture of a simple genetic basis for the condition but further research revealed a complex mechanism in both species

Not only the tendency to convulse but also the age of onset of susceptibility the severity of the seizures and the resistance to death during seizure are dependent upon genotype A *number of* biochemical substances have been shown to reduce seizure incidence in some of the susceptible strains but these same substances are ineffective in other susceptible strains These results *demonstrate* the important principle that similarity of phenotype is no guarantee of genotypic similarity Different genotypes may underly the same phenotypic character

A selection program has also been undertaken with respect to sound induced seizures in mice and from a heterogeneous foundation stock four different strains have been produced Two strains are highly susceptible to seizure but differ from each other in respect to the seizure pattern A third strain is highly resistant to seizures and a fourth strain shows susceptibility to seizure only during a short period just before reaching sexual maturity These results emphasize the complexity of the seizure phenotype

Alcohol consumption Research on the physiology of alcohol consumption in rats has revealed strain differences in the preference shown by animals for an alcohol solution as opposed to plain water While animals from both strains drank some of the alcohol solution the average amount consumed by rats of one strain exceeded that of the other strain

In another experiment mice of the C57BL strain drank almost no plain water when a 10% alcohol solution was available C3H A DBA and BALB/c mice drank plain water almost exclusively

LINKS BETWEEN GENES AND BEHAVIOR

Evidence has been presented that a wide array of behavior traits may differ in groups known to be of different ge- [illegible] been made to elu-

ence behavior

Brain anatomy and physiology One of the first suggestions was that rats which were genetically superior in maze learning were superior because they had relatively larger brains than inferior maze learners This hypothesis was tested in both the Tryon and Heron strains and while a slight tendency was found for Tryon brights to have heavier brains than the dulls, the overall weight of evidence is negative Sheer bulk of brain does not appear to determine differences in maze *brightness in rats*

A current research program is aimed at determination of the relationships among genes brain biochemistry and behavior in descendants of the Tryon strains which have been maintained without selection for a number of years In a variety of learning situations the behavior of the dulls was more predictable and stereotyped than that of the brights The search for a neurochemical distinction between the strains showed that activity of the enzyme cholinesterase (ChE) in the cerebral cortex and in the subcortical brain was greater for the brights than for the dulls Cholinesterase is part of a metabolic system thought to be of particular importance in transmission of neural impulses within the central nervous system It was hypothesized that genotype influences rate of ChE activity, more efficient neural transmission may underly the capacity for flexible and adaptive behavior

To determine if the association between ChE ac tivity and flexibility of behavior was peculiar to the Tryon animals two simultaneous selection studies were begun in which selection was for ChE level disregarding behavior The low ChE strains proved to be more rather than less adaptive than the high ChE lines The initial hypothesis obviously was in complete Nevertheless the repeated findings of ChE differences in one direction or the other in strains differing behaviorally strongly suggest that ChE is part of a metabolic system that is a crucial determinant It is now suggested that some other component of the metabolic cycle that includes ChE perhaps acetylcholine or choline acetylase may be independently inherited and that adaptive ness of behavior depends upon the ratio of ChE to this other substance

Endocrine systems In respect to the mediators of emotional behavior and sexual behavior concen tration has been on the endocrine systems rather than on the central nervous system

In the selectively bred strains of emotional and "nonemotional rats measurements were made of adrenal thyroid and pituitary gland weights Males from the emotional strain had heavier adre nal and thyroid glands than did males from the nonemotional strain Emotional strain females had heavier thyroid and pituitary glands than nonemo tional females While gland weight alone cannot be considered a definitive indicator of glandular activ ity there is a clear suggestion in these results that the thyroid gland the only one measured which dif ferentiates the strains in both sexes may be corre lated with the autonomic nervous system function involved in defecation and urination The sex dif ference in respect to adrenal and pituitary differ ences suggests an interaction of these glands with the sex glands

A comparison of laboratory rats with wild rats has led to the suggestion that domestication which has involved a decrease in savageness and in the tendency to escape has been accompanied by a re duction in function of the adrenal cortex and an earlier development of the gonads

In relation to the sexual behavior of guinea pigs a number of experiments have been directed to the role of the testes and ovaries in determining strain d fferences In general if animals of the different strains are castrated and then given overdoses of sex hormone the characteristic strain differences are not abolished Apparently the genotypic differ ences underlying the strain differences in sex drive do not simply determine level of sex hormone Rather it appears that the genotype sets a limit perhaps through neural mechanisms on the extent of each strain s sex drive Experiential or hormonal alterations can influence expression of sex behav ior up to that limit but the limit cannot be ex ceeded

The biochemistry of sound induced seizures has been particularly studied The principal defect of some seizure susceptible phenotypes is related to a fundamental energy transfer system The cycle in volving cholinesterase and the cycle involving glu tamic acid are both implicated Neurochemical dif ferences between different susceptible phenotypes reveal that the underlying genotypes differ A num ber of hormones have been found to have a protec tive function thus reducing death risk or seizure incidence

SUMMARY

The fact of genetic influence on behavior has been amply demonstrated by the studies cited above Furthermore the demonstrations have been made with respect to such a wide variety of behav ior categories as to leave no doubt that hereditary differences are fundamental to individuality

There have also been promising developments in tracing the path from genes through intermediate biochemical physiological and anatomical links to behavior

Caution must be urged against the uncritical generalization to man of the results of research on subhuman animals It is tempting to apply the sound induced seizure information to human epi lepsy and the data on alcohol consumption in mice to human cases of alcoholism The superficial simi larity cannot however be taken as a guarantee that the characteristics are the same in mice and men although it may justifiably be expected that in some cases the findings with respect to animals have some application to human conditions The prob lem of generality of findings can be answered only by direct research on man and the research on ani mals can provide the conceptual framework within which the human problems may be investigated

See PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMEN TAL [G E MC]

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Behavioral psychophysics

A branch of psychology concerned primarily with the measurement of the sensory capacities of nor mal intact animals In principle the methods are similar to those of human psychophysics the ani mal is instructed to observe a stimulus and to report what is observed The stimulus situation coupled with the past history and present physio logical state of the animal provides the necessary instructions the animal s behavioral response con stitutes the report *See* PSYCHOLOGY PHYSIOLOGI CAL AND EXPERIMENTAL

The fundamental measures used are based on the quality intensity and spatial and temporal extent of physical stimuli required to elicit some standard response and include (1) least detectable stimu

lus intensities (absolute thresholds) (2) least detectable stimulus differences (difference thresholds) and (3) stimulus equivalences (equivalence relations). Such measures map the range and degree of the animal's sensitivity to those stimuli.

The stimulus-response patterns utilized in these measures may be either innate or learned. Stereotyped unlearned behavior (such as a taxis, orientation of the whole animal in a directional field of stimulation) is particularly useful in the study of lower animals which cannot readily be taught special responses to stimuli. But the use of unlearned behavior is not confined to lower forms.

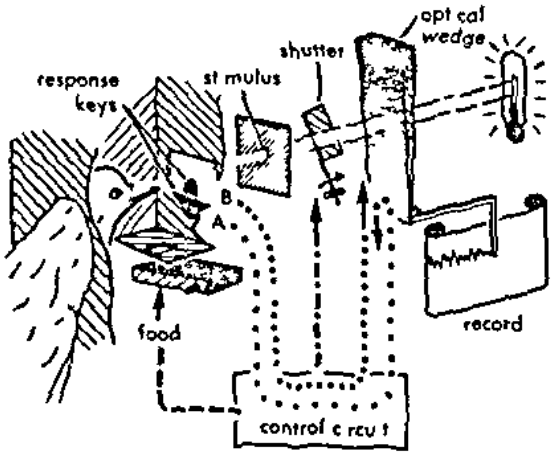


Diagram of apparatus for measuring pigeon's visual threshold. (*From D. S. Blough. A method for obtaining psychophysical thresholds from the pigeon. J. Exptl. Analysis Behavior*, 1, 31–43, 1958.)

unconditioned reflexes (such as constriction of the *pupil in response to light*) are useful indices of the effectiveness of stimuli acting on the sense organs of higher animals, including man. *See* Reflex, unconditioned; Taxis.

Such unconditioned responses, even though innately under the control of rather specific stimuli, may be brought under the control of other stimuli by classical (Pavlovian) conditioning and then used in measuring the animal's sensitivity to these new stimuli. For example, salivary secretion may be conditioned to occur in direct *response* to a sound by pairing the sound with presentation of food. *See* Reflex, conditioned.

More complex learned discriminative behavior utilizes responses which are instrumental in obtaining some reward. For example, the subject may be required to open one of two doors or to press a lever in response to some stimulus to obtain food. Such instrumental *behavior may be* conditioned to occur in response to almost any sensible stimulus simply by *reinforcing (that is* rewarding) the response only when that stimulus is present. Once such a discriminative *response* is learned, experiments may be undertaken which are comparable to human psychophysical experiments in their method, scope, and results.

Example. A procedure is devised to measure the pigeon's absolute visual threshold by instrumental conditioning. The pigeon is placed in the apparatus (see illustration) and deprived of food. Responses may be reinforced by opening the food magazine briefly. Pecking on the keys (A and B) is conditioned quickly by progressive selective reinforcement of behavior most closely approximating that response. Once established, the pecking responses are maintained by intermittent reinforcement delivered automatically.

The control circuit is then arranged so that response A moves the optical wedge and decreases the intensity of the stimulus (a small spot of light on a ground glass screen visible through an opening above the keys); response B increases the intensity. Occasionally the stimulus is automatically occluded by the shutter when response A occurs; then response B will reopen the shutter and open the food magazine, which reinforces this response. Even though response A is never reinforced directly, it is nevertheless maintained because it sometimes leads to the condition (stimulus off) under which response B may be reinforced.

Because the animal cannot discriminate between disappearance of the stimulus when it is physically occluded by the shutter and disappearance when it is the result of the intensity's being below its visual threshold, it makes response B whenever the stimulus disappears for any reason and A when it reappears. These discriminative responses thus keep the stimulus oscillating closely about the pigeon's absolute threshold. By this means the time course of changes in sensitivity during light adaptation and dark adaptation may be measured. Spectral sensitivity is measured by a set of such threshold determinations at several wavelengths. *See* Learning theories.

Significance. Psychophysics provides a means of correlating the behavior of an animal in its natural environment with the physiological processes underlying it. Even though it is complex, such be-

yses of the qualitative and quantitative relations between external physical stimuli and the discriminative responses may in turn be related to the intervening structures and processes within the animal's body, such as the physical and chemical mechanisms of the receptors which transduce the physical stimulus energy to neural activity and the subsequent transmission and integration of this neural activity by the nervous system. *See* Motor systems.

Analysis of the sensory capacities of diverse animals brings out differences and similarities which are of interest in the study of comparative psychology and comparative physiology. Some practical studies with results significant for man include

investigations of the effects of drugs diseases and adverse environmental conditions on discrimina tive behavior *See* Biophysics Chemoreception Equilibrium biological, Mechanoreceptors Phonoreception Photoreception Sensation [F R A]

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Bejel

An infectious disease of man caused by a spiro-chete It is similar to syphilis in character and oc curs among seminomadic peoples of the Middle East It is usually acquired in childhood either by direct contact or through common drinking utensils In the latter case the initial lesion is on the lips In the generalized stage lesions are par ticularly common about mucocutaneous junctions and contain treponemes in abundance Bone lesions are common while central nervous system and cardiovascular lesions are rare The serological pat tern and response to therapy are similar to those of syphilis *See* Serology Syphilis [T B T]

Bel

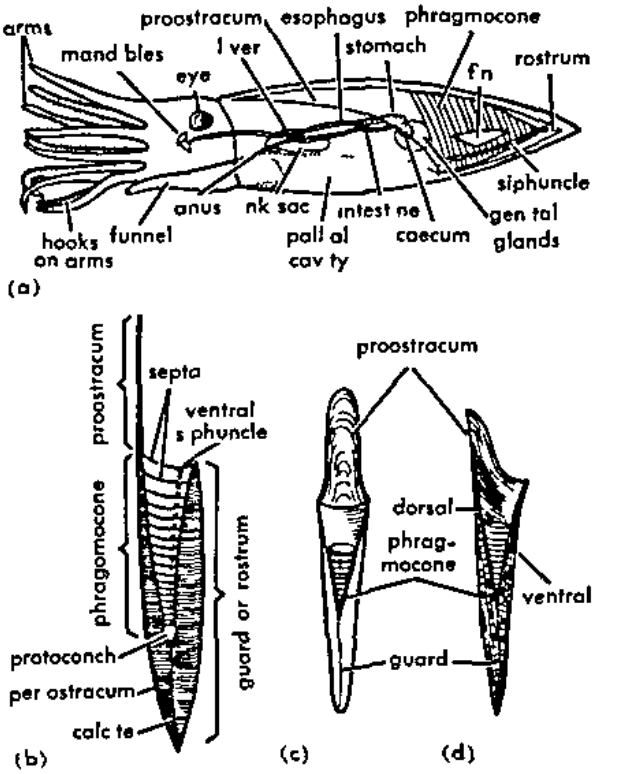
A logarithmic unit expressing the ratios of power voltage current or sound intensity The number of bels separating two power readings is the loga rithm to the base 10 of their ratio (for example two powers differ by 1 bel when their actual ratio is 10 1) while the number of bels separating two current readings or the sound pressure of an acous tical signal is twice the logarithm of the ratio of the currents

It is convenient in acoustics to express sound intensity in logarithmic units because of the wide range of pressures to which the ear is sensitive The strength of a sound is usually specified as the square root of the mean of the squares of the in stantaneous pressures measured over a period of time The sound intensity is proportional to the square of the sound pressure (*see* Sound inten sity) The measure of the level in bels of a sound is $\log (I/I_R)$ where I is the intensity of the sound and I_R is a specified reference intensity A smaller unit called the decibel equal to $\frac{1}{10}$ bel is more commonly used *See* Decibel *see also* Neper [K D K]

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Belemnoidea

An order of extinct dibranchiate cephalopods These mollusks ranged from the Upper Mississip pian through the Cretaceous The oldest known rep resentative is highly specialized although the belemnoids are considered to be the most primitive of the dibranchiates Belemnoids have a chambered shell or phragmocone which fits into a guard or



Belemno dea (a) Reconstruct on of an Upper Creta ceous belemno d *Belemnoteuth s syr ca* w th an nter nal shell cons st ng of phragmocone proostracum and rostrum (b) D agram of a belemn t d shell show ng the several important features (c) Ventral aspect of a belemn te (d) Lateral aspect of a belemnite (*R R Shrock and W H Twenhofel Pr nc ples of Invertebrate Paleontology 2d ed McGraw H ll 1953*)

rostrum the apical portion of the shell *Belemnites* is an important index fossil *See* Decapoda (Mol lusca) Dibranchia Index fossil [C B C]

Bell

A hollow metallic cylinder closed at one end and flared at the other A bell is used as a fixed pitch musical instrument or a signaling device frequently in clocks A bell is set vibrating by a clapper or tongue which strikes the lip The bell has two tones the strike note or key and the hum tone which is a major sixth below the strike note Both tones are rich in harmonics

The finer bells are made for carillons small carillons having two full chromatic octaves and large ones having four or more chromatic octaves the bell with the lowest tone being called the bourdon The Riverside Church in New York has 72 bells the largest or bourdon weighing 18¼ tons All bells of a carillon are shaped for homo

trumpet mouth—evolved from experience The how or edge has a thickness of $\frac{1}{10}$ to $\frac{1}{11}$ its diameter The contour of a new bell is formed in the molds

Sets of such measures along appropriate dimen sions of stimuli map the range and degree of the animal s sensitivity to those stimuli

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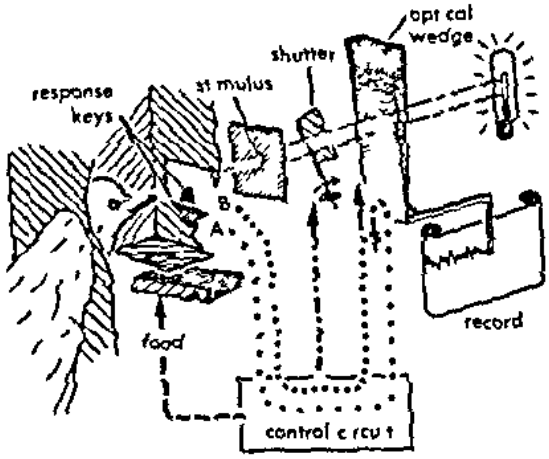


Diagram of apparatus for measuring pigeon s visual threshold (From D S Blough A method for obtaining psychophysical thresholds from the pigeon J Exptl Analysis Behavior 1 31–43 1958)

unconditioned reflexes (such as constriction of the pupil in response to light) are useful indices of the effectiveness of stimuli acting on the sense organs of higher animals including man *See* REFLEX UNCONDITIONED, TAXIS

Such unconditioned responses *even though* innately under the control of rather specific stimuli *may be brought under* the control of other stimuli by classical (Pavlovian) *conditioning* and then *used in measuring* the animal's sensitivity to these new stimuli For example *salivary* secretion may be *conditioned to occur in direct* response to a sound by *pairing* the sound with presentation of food *See* REFLEX CONDITIONED

More *complex learned* discriminative *behavior* utilizes responses which are instrumental in obtaining some reward *For example* the subject may be required to open *one of two* doors or to press a lever in response to some stimulus to obtain food Such instrumental *behavior* may be conditioned to occur *in response* to almost any sensible stimulus simply by *reinforcing* (that is rewarding) the response *only* when that stimulus is present. Once such a *discriminative response* is learned experiments may be undertaken which are comparable to human psychophysical experiments in their method scope and results

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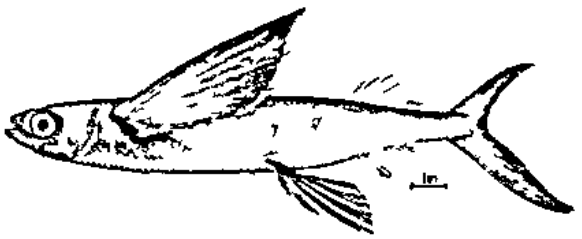
Significance Psychophysics provides a means of correlating the behavior of an animal in its natural environment with the physiological processes underlying it Even though it is complex such behavior is often found to be an elaboration of some relatively simple discriminative reaction which can be analyzed by psychophysical methods Such analyses of the qualitative and quantitative relations between external physical stimuli and the discriminative responses may in turn be related to the intervening structures and processes within the animal's body such as the physical and chemical mechanisms of the receptors which transduce the physical stimulus energy to neural activity and the subsequent transmission and integration of this neural activity by the nervous system *See* MOTOR SYSTEMS

Analysis of the sensory capacities of diverse animals brings out differences and similarities which are of interest in the study of comparative psychology and comparative physiology Some practical studies with results significant for man include

TUBIFLORALES [P D S]

Beloniformes

The needlefishes sauries halfbeaks and flying fishes This order of actinopterygian fishes al o known as the Synentognathi is distinguished by



California flying fish Cypselurus californicus (After G B Goode Great International Fisheries Exhibit on London 1883 U S Natl Museum Bull 27 1884)

the fusion of the lower pharyngeals into a single bone Other characters include the lack of fin spines an abdominal pelvic fin with six rays a pectoral fin which is inserted high on the body with the radials short and rigidly attached ab sence of mesocoracoid orbitosphenoid and opis thotic bones a ductless swimbladder cycloid scales lateral line low on side and branchiostegal rays arranged as in soft rayed fishes

Beloniform fishes date from the Eocene (? Up per Cretaceous) Modern forms are grouped in 2 suborders 4 families about 28 genera and more than 100 species Most species inhabit surface wa ters of warm seas but a few range into temperate climates and some live occasionally or permanently in fresh water especially in southeastern Asia Flying fishes have stiffened elongate rays on the paired fins that permit gliding in air No fish is ca pable of true flight *See* ACTINOPTERYGII [R M B]

Belt drive

A means for the transmission of power between shafts whose center distance is too great to make practical the use of gears or chain For economic reasons belt drives also may be used to connect shafts having moderate center distances The belt a continuous band passes over two or more pul leys ideally transmitting the same motion—except for direction of rotation in some cases—that would be produced if the pulleys were in rolling contact Flat belts may be used to transmit power between pulleys whose center distance is as much as 30 ft The axes of the pulleys may be parallel intersect ing or nonparallel and nonintersecting Belt drives depending on friction between belt and pulley are subject to some slippage between the two which makes them unsuitable for applications in which an exact velocity ratio must be maintained To maintain friction belts must be under tension which gives higher bearing pressures than would be encountered with a comparable chain or gear drive (*see* CHAIN DRIVE ROPE DRIVE)

Belts are made of leather or fabric impregnated with rubber or similar material Thin steel belts running on leather faced pulleys have been used but are not in general use Flat belts that is those having thin flat cross sections have been widely used in the past for power transmission but are be ing supplanted by unit drives and other more mod ern methods of power transmission The flat belt is usually made of tanned oxhide cemented sewed or riveted together Leather belts of one two three or four thicknesses of leather are known respectively as single double triple or quadruple belts Round leather belts may be used to trans mit small amounts of power *See* V BELT

With an open flat belt drive the pulleys have the same sense of rotation (Fig 1) The inner and outer surfaces of the belt are ordinarily of the same length and the belt of uniform thickness When the belt is stretched over the pulleys the in ner surface is compressed and the outer surface stretched At some point between these surfaces is a point where the belt is in neither tension nor com pression This neutral section is usually assumed to lie halfway between the inner and outer surfaces of flat belts The imaginary rolling cylinder with its center at the pulley center and to which the neutral section is tangent is called the pitch sur face of the pulley The effective radius of the pul ley is the radius of the pitch surface A line on the neutral section of the belt that connects the pitch

to that of the driven pulley The expression for the velocity ratio is based on the equality of the linear belt speed and the linear speed of the pulley pitch surfaces For the open belt drive of Fig 1 this linear speed is

$$-N_2\ (D_2 + t) = \pi N_3\ (D_3 + t)$$

where N is the angular speed Flat belts operate economically with linear speeds of 4000–5000 ft/min and designs should use such velocities if possible

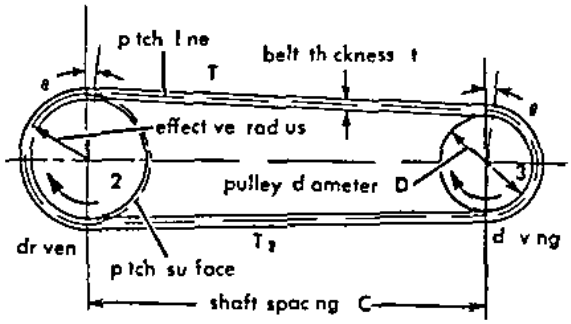
Based on this linear speed the speed ratio of two pulleys is

$$\frac{N_{\text{driving}}}{N_{\text{driven}}} = \frac{N_3}{N_2} = \left[\frac{D_2 + t}{D_3 + t}\right]$$

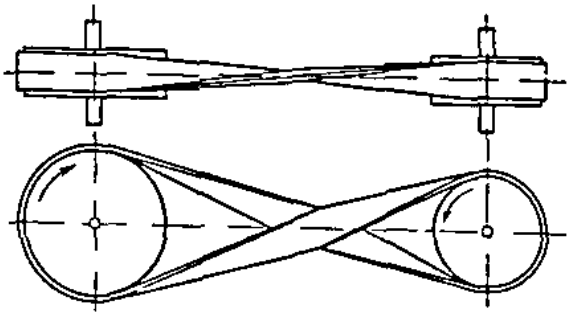
For most cases the belt thickness is small com pared to the pulley diameter and the speed ratio can be calculated as

$$\frac{N_3}{N_2} = \frac{D_2}{D_3}$$

Both preceding relations are ideal omitting slip page and creep Each element of the belt as it goes to the loose side of the and stretches when it comes on th The combined effect of creep



Fg 1 Open belt dr ve



Fg 2 Crossed belt dr ve

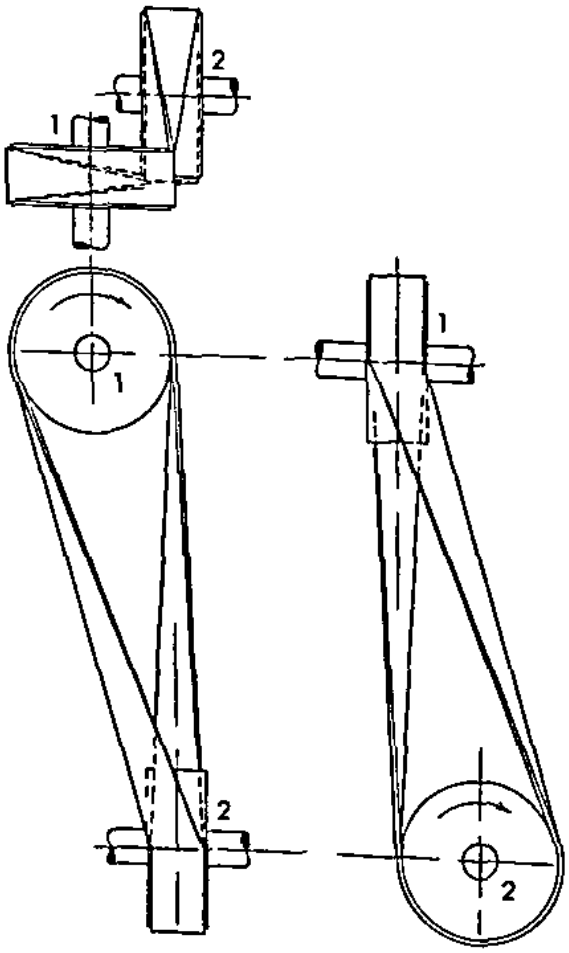


Fig 3 Quarter turn belt

make the actual speed of the driven shaft 2-4% less than the ideal value

When pulleys are to turn in opposite directions a crossed belt is used (Fig 2) The speed ratio is calculated in the same manner as for an open belt. While the crossed belt has a greater arc of contact than an open belt this advantage is somewhat offset by the increased wear due to the rubbing action where the crossing takes place Since stock pulleys are not available in all diameters it may not be possible to satisfy exact speeds and speed ratios with them *See* PULLEY

Both parts of the belt must be in tension to maintain contact between the belt and the pulleys The difference in tension between tight and loose sides of a flat belt equals the force transmitted from one pulley to another Thus the effective force transmitted is the difference between belt tensions T_1 and T_2 (Fig 1) The power transmitted to the driven pulley 2 is then neglecting belt thickness

$$P = \frac{\pi D_2 N_2}{33\,000}(T_1 - T_2) \quad \text{horsepower}$$

where N is the rpm of the pulley and D its diameter in feet

With diameters D_1 and D_2 of the pulleys and their center distance C known the length of open or crossed belts can be calculated Length L of an open belt (Fig 1) can be calculated for most purposes as

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + (D_1 - D_2)^2/4$$

In a like manner the length of a crossed belt (Fig 2) is approximately

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + (D_1 + D_2)^2/4C$$

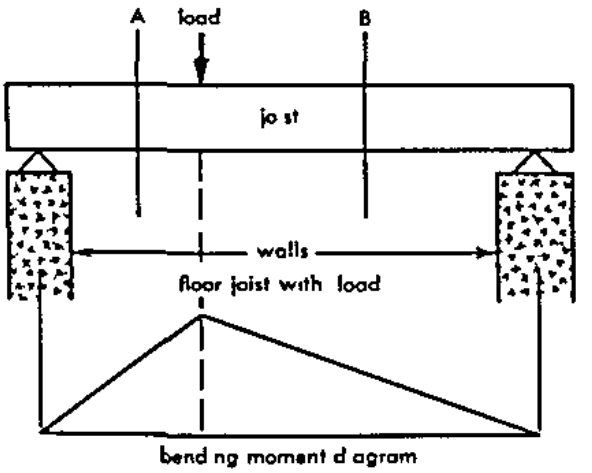
For a given center distance the length of a crossed belt will be a constant if the sum of the pulley diameters is fixed This is an important consideration where stepped pulleys are to be used

Belting can be used to connect pulleys running on nonparallel shafts if the center line of the belt, as it approaches the pulley lies on the central plane of the pulley An example is the quarter turn belt drive (Fig 3) The drive will run with the shafts at any angle so long as the preceding condition is satisfied *See* GEAR MECHANISMS ROLLING CONTACT [R C F]

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Bending moment

The algebraic sum of all moments that are on one side of a cross section of a structural member For example in the sketch of a floor joist a load on the joist tends to bend it at any particular cross section of the joist At section A A the bending moment is the reactive upward force of the left wall on the joist times the distance from wall to section A A At section B B the bending moment is



Bending moment on an end-supported joist with a concentrated load

the upward reactive force of the left wall times the distance from wall to B B plus (in the algebraic sense) the moment produced by the downward load acting at its distance from section B B The lower portion of the diagram shows the resultant bending moment at each cross section of the joist A bending moment that bends a beam convex downward is positive and that bending a beam convex upward is negative *See* LOADING TRANSVERSE SHEAR STRENGTH OF MATERIALS [F H R]

Bennettitales

An ancient order of the plant class Gymnospermae known only as fossils The plants were rarely more than 3 ft tall The tuberous stems were covered with persistent leaf bases and bore a crown of large pinnate leaves They appeared in the Late Carboniferous reached their climax in the Jurassic and became extinct in the Late Cretaceous Fossil remains have been found in all continents and particularly in Wyoming the Black Hills of South Dakota and in Mexico The most characteristic feature is the strobilus consisting of a terminal conical receptacle bearing the megasporophylls alternating with sterile scales and surrounded below by the pinnate microsporophylls with their numerous microsporangia Each megasporophyll bears a single terminal megasporangium (ovule) These bisporangiate strobili borne in the leaf axils were numerous The group probably evolved from the Cycadofilicales *See* CYCADEOIDALES EMBRYOPHYTA PALEOBOTANY PLANT KINGDOM [P D S]

Bentonite

The term first applied to a particular highly colloidal plastic clay found near Fort Benton in the Cretaceous beds of Wyoming This clay swells to several times its original volume when placed in water and forms thixotropic gels when small amounts are added to water (*see* GEL) Later investigations showed that this clay was formed by the alteration of volcanic ash in situ thus the term bentonite was redefined by geologists to limit it to highly colloidal and plastic clay materials composed largely of montmorillonite clay minerals and produced by the alteration of volcanic ash in situ Many mineralogists and geologists now use the term bentonite without reference to the physical properties of the clay On the other hand the term has been used commercially for any plastic colloidal and swelling clays without reference to a particular mode of origin *See* CLAY MONTMORILLONITE

Uses Bentonites are of great commercial value because of their important and unique properties They are used in decolorizing oils in bonding molding sands in the manufacture of catalysts in the preparation of oil well drilling muds and in numerous other relatively minor ways Since the properties of bentonites vary widely they are not all suitable for commercial use The properties of a particular bentonite determine its economic use For example the bentonite found in Wyoming is excellent for drilling muds and for foundry use but it is not useful for the making of catalysts or for oil decolorizing

Origin The occurrence of shard structures of ash as pseudomorphs in the clay often indicates the volcanic ash parent material of bentonites The presence of nonclay minerals characteristic of igneous material also provides evidence for the origin from ash

Evidence strongly indicates that the transformation of volcanic glass to montmorillonite takes place either during or soon after accumulation of the ash The alteration process is essentially a devitrification of the natural glass of the ash and the crystallization of montmorillonite The ash often contains excess silica which may remain in the bentonite as cristobalite *See* VOLCANIC GLASS

Occurrence Bentonites have been found in almost all countries and in rocks of a wide variety of ages They appear to be most abundant in rocks of Cretaceous age and younger In such material in older rocks the montmorillonite is often almost completely collapsed by compaction and metamorphism This altered bentonite swells very little and does not have the usual high colloidal properties of bentonite it is sometimes called metabentonite

Beds of bentonite show a variable thickness and can range from a fraction of an inch up to as much as 50 ft thick The color of bentonite is also variable but perhaps most often it is yellow or yellowish green When observed in the weathered outcrop bentonite tends to develop a characteristic cellular structure It shrinks upon drying and often shows a characteristic jigsaw puzzle set of fractures

Not all beds of ash in the geologic column have altered to bentonite When present bentonite is most frequently found in marine beds thus it seems certain that alteration from ash to bentonite is favored in sea water

In the United States bentonites are mined extensively in Wyoming Arizona and Mississippi England Germany Yugoslavia USSR Algeria Japan and Argentina also produce large tonnages of bentonite [F M W, R F G R]

Benzaldehyde

A colorless liquid aldehyde C_6H_5CHO boiling at 179°C and possessing a characteristic aromatic odor resembling that of bitter almonds It is produced industrially at the rate of about 2 000 000 lb annually The principal uses are as a flavoring agent and as an intermediate in chemical syntheses For discussions of chemical properties and methods of manufacture *see* ALDEHYDE

[H A S]

Benzedrine

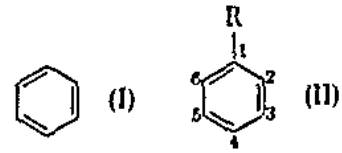
A synthetic amine also known as amphetamine that produces effects similar to those seen when the sympathetic nervous system is activated General stimulation of the central nervous system is also obtained with this compound The principal effects of benzedrine are elevated blood pressure increased heart action and relaxation of lung and gastrointestinal musculature In addition it has a stimulating effect on higher elements like the respiratory center thus making it useful in counteracting the depression caused by disease other drugs or poisons Psychic reactions to the drug vary greatly depending on the prior mental state the personality of the patient and the amount and duration of use The overuse of this drug is due principally to the mild euphoria it induces The euphoria is marked by a sense of well being or even exhilaration lessened fatigue increased desire to work and an increased confidence *See* AMINE CENTRAL NERVOUS SYSTEM SYMPATHETIC NERVOUS SYSTEM [E G S T]

Benzene

A colorless liquid inflammable aromatic hydrocarbon (chemical formula C_6H_6) which boils at 80 1°C and freezes at 5 4–5 5°C In the older American and British technical literature benzene is designated by the German name benzol In current usage the term benzol is commonly reserved for the less pure grades of benzene

Benzene is used as a solvent and particularly in Europe as a constitutent of motor fuel In the United States the largest uses of benzene are for the manufacture of styrene and phenol Other important outlets are in the production of dodecyl benzene aniline maleic anhydride chlorinated benzenes (used in making DDT and as moth flakes) and benzene hexachloride an insecticide

X ray and electron diffraction studies indicate that the six carbon atoms of benzene each with a hydrogen atom attached are arranged symmetrically in a plane forming a regular hexagon The hexagon symbol (I) commonly used to represent the structural formula for benzene implies the presence of a carbon atom at each of the six angles



(I) (II)

and unless substituents are attached a hydrogen at each carbon atom Whereas the three double bonds usually included in the formula (I) are convenient in accounting for the addition reactions of benzene present evidence is that all the carbon to carbon bonds are identical

Prior to World War II most of the benzene available commercially came as a by product of the steel industry High temperature carbonization of coal to produce metallurgical coke yields gases and tars from which benzene may be recovered Since World War II benzene formed by dehydrocyclization and dehydrogenation of petroleum hydrocarbons has become of increasing importance particularly since the Korean War In 1954 the percentage of total benzene (other than motor fuel grade) derived from petroleum was 36 per cent and this has been increasing steadily since *See* REFORMING (PETROLEUM REFINING)

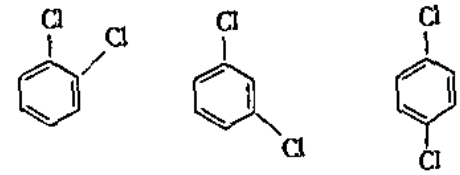
A common impurity in commercial grades of benzene of coal tar origin is the heterocyclic compound thiophene (C_4H_4S), which boils at 84°C and is difficult to remove by distillation Thiophene may be removed by preferential sulfonation by hydrogenation or by reaction with mercuric acetate

Benzene reacts chiefly by substitution (*see* SUBSTITUTION REACTION) Because of the symmetry of the benzene molecule only one monosubstitution product is possible Some typical substitution products are included in the table

Substitution products of benzene

Reagents	Formula II R =	Name of product
H_2SO_4	$-SO_3H$	Benzenesulfonic acid
$HNO_3 + H_2SO_4$	$-NO_2$	Nitrobenzene
$Cl_2 + Fe$	$-Cl$	Chlorobenzene
$C_2H_4 + AlCl_3$	$-C_2H_5$	Ethylbenzene

A large number of disubstitution products of benzene are known For any two substituents there are only three possible arrangements The groups may be adjacent to each other (ortho *o*) They may be located on carbons separated from each other by a single CH that is at positions 1 and 3 of formula II (meta *m*) or they may be at any two opposite corners of the hexagon (para *p*)



o Dichloro benzene *m* Dichloro benzene *p* Dichloro benzene

The position of substituents in trisubstituted or polysubstituted benzenes is usually indicated by

numbers For instance the trichlorobenzene in which all three chlorines are adjacent is called 1 2 3-trichlorobenzene

Benzene may also react by addition Hydrogenation in the presence of a catalyst yields cyclohexane (C_6H_{12}) a useful solvent while addition of chlorine (usually in the presence of ultraviolet light) yields benzene hexachloride ($C_6H_6Cl_6$)

Benzene is a toxic substance and prolonged exposure to concentrations in excess of 35–100 parts per million in air may lead to symptoms ranging from nausea and excess fatigue to anemia and leukopenia *See* AROMATIC HYDROCARBON

[C K B]

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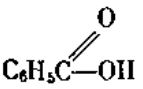
Benzidine

An organic chemical compound that is used as an intermediate in the synthesis of direct dyes for cotton It is an aromatic diamine $H_2N—C_6H_4—C_6H_4—NH_2$ also called *p p'* diaminobiphenyl with melting point 128°C. It is a very weak base with basic dissociation constant $K_b = 7.4 \times 10^{-13}$ Benzidine may be tetrazotized and then coupled with numerous amines or phenols to yield azo dyes for example Congo red by reaction with naphthionic acid (*see* NAPHTHYLAMINE) Benzidine is oxidized easily to benzidine blue the basis for sensitive tests for hydrogen peroxide and for easily reduced cations such as copper(II) or cobalt(III) Bimolecular reduction of nitrobenzene gives hydrazobenzene which rearranges in acid solution to benzidine *See* AMINE ANILINE DIAZOTIZATION

[L B C]

Benzoate

A salt or ester of benzoic acid



formed by replacing the acidic hydrogen of the carboxyl group by a metal or an organic radical In nature benzoates occur chiefly in resins and balsams Sodium benzoate one of the few food preservatives permitted by law is used extensively to inhibit the growth of microorganisms in food pharmaceuticals and cosmetics The esters characterized by agreeable odors are used in perfumes and medicines Benzyl benzoate is the most important and is used as an antispasmodic an antiseptic and in perfumes *See* BENZOIC ACID CARBOXYLIC ACID ESTER

[E H H]

Benzoic acid

The aromatic carboxylic acid with formula C_6H_5COOH Benzoic acid melts at 122.4°C boils at 250°C is slightly soluble in water and relatively soluble in alcohol and ether

Benzoic acid is found free and combined (gum benzoin many berries) in nature The acid of commerce is prepared by hydrolysis of benzotrichloride ($C_6H_5CCl_3$) using lime and iron powder catalyst by monodecarboxylation of phthalic acid using phthalic anhydride steam and zinc oxide or chromate catalyst and by oxidation of toluene using manganese dioxide and sulfuric acid or using air in the presence of a cobalt catalyst

Chemically the acid is relatively inert because of the meta directing carboxyl group Among its limited uses in direct synthesis are chlorination [using chlorine and ferric chloride (catalyst) at room temperature to give mainly *m* chlorobenzoic acid together with some 2 5 and 3 4-dichlorobenzoic acids] and nitration [with sulfuric and nitric acids to form *m* nitrobenzoic acid (the same reaction at elevated temperature gives 3 5 dinitrobenzoic acid)]

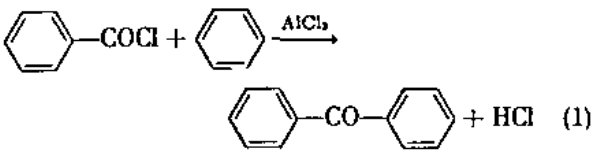
Benzoic acid is used in curing tobacco as a preservative (sodium benzoate) of foods (juices and ketchup) in dyes as a mordant in cloth printing (calico) in many esters (benzoates) and as a reference standard in volumetric analysis

Ingestion of sodium benzoate (from preserved foods) results in excretion of hippuric acid ($C_6H_5CONHCH_2COOH$) formed via enzymatically induced benzoylation of the amino acid glycine *See* BENZOATE CARBOXYLIC ACID SUBSTITUTION REACTION

[E B R]

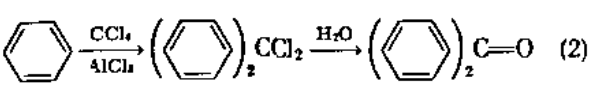
Benzophenone

A chemical compound (also called diphenyl ketone or phenyl ketone) with boiling point 305 9°C It occurs in four polymorphic forms α melting point 48 1°C β melting point 26 5°C γ melting point 45 8°C δ melting point −51°C Benzophenone is used as a constituent of synthetic perfumes and as a chemical intermediate Production in the United States in 1957 was 114 000 lb and the selling price was $1 12 per lb It is prepared by (1) Friedel Crafts reaction of benzoyl chloride and benzene and (2) Friedel Crafts reaction of benzene and



(1)

carbon tetrachloride to form diphenyldichloromethane which is then hydrolyzed to benzophenone The normal reactions of the carbonyl group



(2)

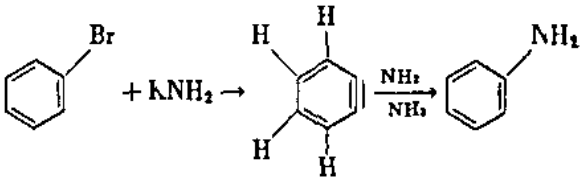
and of the benzene rings are observed in benzophenone *See* AROMATIC HYDROCARBON, KETONE

[D A S]

Benzyne

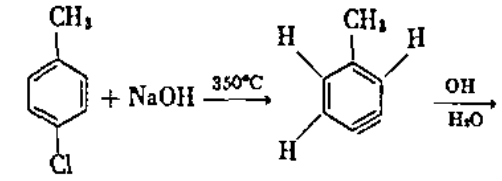
An unstable chemical intermediate of formula C_6H_4 Benzyne has not been isolated it is inferred from indirect evidence Benzyne can be formed by action of strong bases on halobenzenes

cleophilic reagents add readily to benzyne These chemical characteristics are demonstrated in the reaction of bromobenzene with potassium amide in liquid ammonia to form aniline

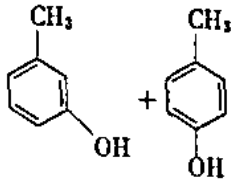


Bromo benzene — Benzyne — Aniline

This is a mechanism for nucleophilic aromatic substitution The action of bases on substituted halobenzenes sometimes gives rise to rearranged substitution products



p Chloro toluene — 4-Methyl benzyne



m Cresol (rearranged) — *p* Cresol

See ELECTROPHILIC AND NUCLEOPHILIC REAGENT SUBSTITUTION REACTION [J F B]

Bergius process

Treatment of carbonaceous matter such as coal or cellulosic materials with hydrogen at elevated pressures and temperatures in the presence of catalysts to yield an oil similar to crude petroleum F Bergius a German chemist discovered the process [illegible]

in
pla
bbl/year of liquid fuel
The [illegible]

thenes In both stages the operating temperature is in the range 380–500°C (716–932°F) and the pressure range is 200–700 atmospheres (3000–10 000 psi) The gasoline after addition of about 3 ml of tetraethyllead per gallon is suitable for aviation motors Most of the oxygen nitrogen and sulfur in the coal appears as water ammonia and hydrogen sulfide in the gaseous products If desired tar acids (phenolic compounds) and tar bases (organic nitrogen compounds) equivalent in amount to 5–10% of the moisture free and ash free coal can be extracted from the liquid product of the first stage *See* FISCHER TROPSCH PROCESS [H H ST]

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Beriberi

A disorder resulting from a deficiency of thiamine, a B vitamin incurred by persons subsisting on an unbalanced diet high in its content of milled cereals Thiamine is important in carbohydrate metabolism particularly that involving the utilization of pyruvic acid It also acts as a factor in maintaining the integrity of the normal conductivity of the nerve fiber for transmission of neural impulses *See* CARBOHYDRATE CARBOHYDRATE METABOLISM THIAMINE

Beriberi is characterized by neurologic symptoms such as tingling of the extremities and muscular weaknesses Actual inflammation of the nerve fibers occurs and this neuritis in turn leads to other alterations in reflexes in coordination and in sensory perception as well as the appearance of occasional psychic states

When beriberi occurs suddenly the symptomatology frequently centers about the heart Derangements of rhythm decreased blood pressure the appearance of valvular murmurs and electrocardiogram changes are typical These may lead sometimes precipitously to cardiac failure and death In many of these cardiac cases resulting from beriberi there is associated digestive upset and irregularity and sometimes a paralysis of the diaphragm *See* ELECTROCARDIOGRAPHY

A progressive edema of the legs which finally involves the entire body is a common occurrence in severe cases Such edema may also involve body cavities producing pleural pericardial or peritoneal fluid formation

The prognosis depends upon the severity and duration of the deficiency and is unfavorably affected by a tendency for sudden often fatal cardiac involvement to occur [E G ST]

Bering Sea

A body of water north of the Pacific Ocean 2 270 000 km² in area bounded by Siberia Alaska and the Aleutian Islands Water passages connecting the Bering Sea with the Pacific Ocean are less than 450 meters (m) deep between the islands of the eastern Aleutians In the western Aleutians depths in the passages exceed 1000 m In the north the Bering Strait is 85 km wide and 56 m deep A basin 3750 m deep occupies the southwest portion of the sea To the northeast is a wide extremely flat continental shelf Most of the shelf area is less than 100 m deep

In summer warm southwesterly winds and cloudy skies prevail in the area The sea is generally ice-free from July to October From May through August snowmelt adds large quantities of fresh water along the continents This accounts for the low salinity of the coastal waters

In winter the area is subjected to strong northerly and variable winds, low temperatures, and variable cloudiness Coastal ice begins to form in late October By February coastal ice is found in the Aleutians and sea ice extends south to 58°N (Fig 1) *See* SEA ICE

Temperature and salinity. There is little seasonal variation in the water structure below 200 m A halocline occurs around 200 m and the temperature maximum, 3 5–4 0°C, is between 250 and 400 m (Fig 2) In winter, the upper layer becomes uniformly mixed to 150–200 m, with temperatures 0–3°C and salinity about 33 parts per thousand (‰) over the deep basin Over the shelves the temperature decreases to −1 7°C under the sea ice, and freezing of the ice increases the salinity north of St. Lawrence Island to nearly 34‰

In summer, temperatures reach 8–10°C in the surface layer over the basin, and minimum temperatures occur at depths of 100–150 m except near the Aleutians The salinity increases gradually from the surface (33‰) to the halocline Over the shelf areas salinity decreases toward the coasts In the highly stratified shelf water, temperature and salinity vary from −1 3°C and 32 5‰ at the bottom west of St Lawrence Island (in Gulf of Anadyr winter water) to 12°C and 25‰ or less, at the surface near the coasts *See* HALOCLINE

Tides and currents Tides in the Bering Sea are diurnal The mean range varies from 120 cm (3 9 ft) in the Aleutians to 30 cm (1 ft) near Bering Strait Tidal currents in the narrow Aleutian passages have velocities up to 400 cm/sec (7 8 knots)

Nontidal currents tend to flow in a clockwise pattern during the period of April through October Surface water entering the sea through the Aleutians as far west as 175°E turns eastward and the speed in the narrow current along the north side of the islands reaches 50 100 cm/sec (1 2 knots) On the shallow Alaskan shelf the waters flow northward at speeds of 10–20 cm/sec but reach speeds up to 50 cm/sec near the coast A strong current continues northward through Bering Strait Speeds up to 300 cm/sec (6 knots) are observed near the eastern side of the Strait and the total transport northward averages $1\,7 \times 10^6$ m³/sec Along Kamchatka the waters flow southwestward out of the Bering Sea This outflow receives additional water from currents which set northward into the Bering Sea between 167° and 175°E (Fig 3)

The few data available indicate that in winter nontidal currents are weak and variable in Bering Strait and throughout the Bering Sea

[J F T S A]

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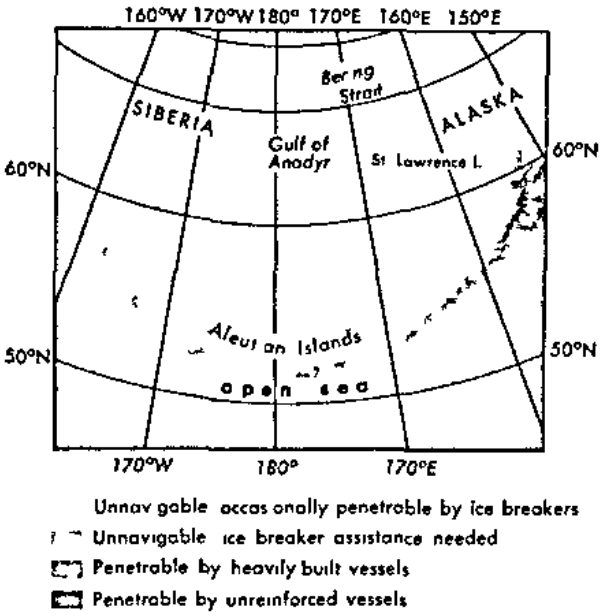


Fig 1 Southern limits of land fast and sea ice, February (*Adapted from Ice Atlas of the Northern Hemisphere U S Navy H O Publ 550, 1946*)

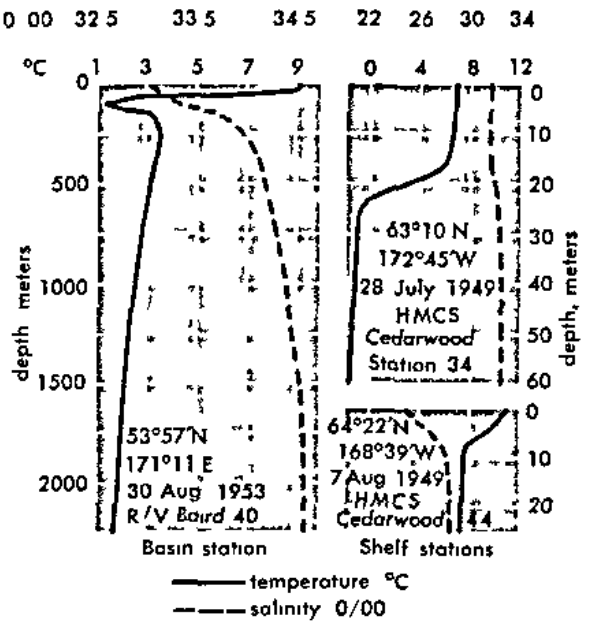


Fig 2 Vertical temperature and salinity distributions

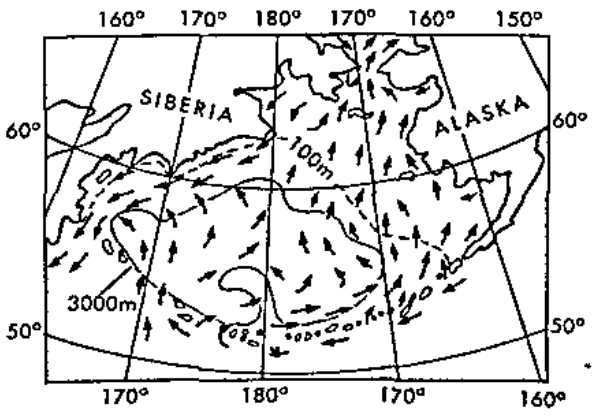


Fig 3 Surface currents, summer

Alaska Cape Spencer to the Arctic Ocean 6th ed 1955, U S Navy *Ice Atlas of the Northern Hemisphere* H O Publ 550 1946

Berkelium

Element number 97 berkelium Bk is a member of the actinide series of elements The element does not occur in the earth s crust it is prepared by



artificial nuclear transmutation of lighter elements All isotopes of berkelium are radioactive and decay *with half lives* varying from a few hours to several thousand years *Since the world s* supply of *berkelium* is of the order of millionths of a gram *its application* is usually *limited to that* of a tracer material in nuclear research or to microchemical *experiments See* ACTINIDE ELEMENTS RADIOACTIVITY

Berkelium was discovered in 1949 by S G *Thompson A Ghiorso* and G T Seaborg at the University of California in Berkeley and was named in *honor of that city* The first step in the discovery experiment was *bombardment of americium* 241 with helium ions accelerated in a cyclotron The *combination of helium* nuclei with americium nuclei followed by the loss of two neutrons gave rise to *the mass 243 isotope* of berkelium (Bk^{243}) The new berkelium isotope *was separated* from other actinide elements by an ion exchange technique and was *found to decay primarily* through capture of an orbital electron with a half life of 4 5 hours

The general pattern of this initial *experiment* was followed in the discovery of other isotopes of berkelium (mass numbers 243 through 250) *In* most cases isotopes of americium or curium served as targets for bombardment with helium *ions Subsequent* loss of one or two neutrons (and a proton in the case of curium bombard*ments*) *resulted* in formation of the new berkelium *isotopes* Some isotopes of berkelium are best prepared by irradiation of lighter elements with neutrons *in a nuclear* reactor Repeated capture of neutrons coupled with β decay to the next heavier *element* permits use of readily available isotopes *(for example* plutonium 239) as starting materials Using this approach S G Thompson and B B *Cunningham* irradiated 8 g of Pu^{239} for a period of five years and in 1958 succeeded in isolating *the first weighable* amount of berkelium as Bk^{249}

The sequence of reactions which gives Bk^{249} as well as other higher actinide isotopes is

$$Pu^{239} + n \rightarrow Pu^{240} \xrightarrow{+n} Pu^{241} \xrightarrow{+n} Pu^{242} \xrightarrow{+n}$$

$$Pu^{243} \xrightarrow[\text{decay}]{\beta} Am^{243} \xrightarrow{+n} Am^{244} \xrightarrow[\text{decay}]{\beta} Cm^{244} \xrightarrow{+n}$$

$$Cm^{245} \xrightarrow{+n} Cm^{246} \xrightarrow{+n} Cm^{247} \xrightarrow{+n} Cm^{248} \xrightarrow{+n}$$

$$Cm^{249} \xrightarrow[\text{decay}]{\beta} \boxed{Bk^{249}} \xrightarrow{+n} Bk^{250} \xrightarrow[\text{decay}]{\beta} Cf^{250} \xrightarrow{+n}$$

$$Cf^{251} \xrightarrow{+n} Cf^{252} \xrightarrow{+n} Cf^{253} \xrightarrow{+n} Cf^{254}$$

The quantity of berkelium thus produced—about one millionth of a gram—was subjected to magnetic susceptibility and spectral analysis the results confirmed the predicted electronic structure of berkelium

Initial studies of the chemical properties of the element were limited to a tracer scale These experiments indicated that berkelium possessed properties characteristic of the actinide elements a 3+ oxidation state in aqueous solution and a water soluble nitrate chloride sulfate perchlorate and sulfide Berkelium coprecipitates with lanthanum fluoride or hydroxide In contrast to neighboring actinide elements berkelium may be oxidized to the 4+ state by strong oxidizing agents such as bromate or ceric ions This behavior is interpreted as an enhanced ease of removal of the eighth electron in the 5*f* shell to attain the especially stable configuration of a half filled shell of seven 5*f* electrons

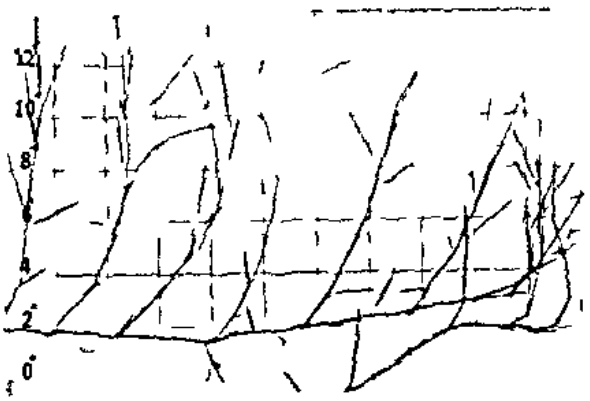
The use of ion exchange chromatography is most satisfactory for the isolation and identification of berkelium in the presence of other actinide elements When a mixture of actinide elements is adsorbed at the top of a column of cation exchange resin and a solution of a complexing agent (α hydroxyisobutyric acid is most suitable) is passed through the column the actinide ions are complexed into solution at different rates and leave the column in quite distinct fractions in reverse order of atomic number *See* ION EXCHANGE, NUCLEAR REACTION TRANSURANIUM ELEMENTS)

[S G T]

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Bermuda grass

A long lived perennial *Cynodon dactylon* native to the Old World Bermuda grass is now common in all tropical and subtropical regions and was introduced to southern United States in colonial days (see illustration) It is propagated by surface runners underground rootstocks and seed Common Bermuda grass grows 6–8 in tall it has short flat leaves and somewhat wiry stems and the flowers are borne on slender spikes 3–6 in a cluster The grass grows on any soil that is fertile and not too wet but does best on heavier soils It requires warm weather for growth and therefore is adapted t the southern half of the United States It endures hot dry periods quite well and thrives under irriga



Common Bermuda grass showing its characteristic seedheads and short leaves (From G W Burton Coastal Bermuda Grass Georgia Agr Expt Stas Bull N S 2 1954)

tion Although formerly regarded as a pest in row crops Bermuda grass is now grown as a valuable forage plant It responds strongly to such soil improvements as lime and complete fertilizers particularly those that are high in nitrogen Improved strains of Bermuda grass have been developed at Tifton Georgia of which Coastal Suwanee and Tift have been most widely used These strains are much superior to common Bermuda for both hay and pasture Under adequate fertilization and management the forage is highly nutritious and supports high production by both dairy and beef cattle *See* GRASS CROPS [H B S]

Bernoulli's theorem

The relation between fluid pressure p and fluid velocity v along a streamline in the steady flow of an incompressible inviscid fluid Bernoulli s theorem states that

$$\frac{p}{\rho} + g + \frac{v^2}{2} = H$$

with H constant along a streamline where ρ is mass density of the fluid g is acceleration due to gravity and z is vertical height It is essentially an expression of conservation of energy because p/ρ is the pressure energy per unit mass of the fluid gz is the potential energy per unit mass due to gravity and $v^2/2$ is the kinetic energy per unit mass It can also be regarded as an integral of momentum (*see* EULER S MOMENTUM EQUATION)

If all streamlines come from a space where the fluid is at rest or in uniform motion in a straight line the Bernoulli constant H is the same on all streamlines Such flows are irrotational implying the existence of a velocity potential ϕ such that the fluid velocity is given by $\mathbf{v} = \text{grad}\ \phi$ (*see* LAPLACE S IRROTATIONAL MOTION) For irrotational flows the unsteady Bernoulli s theorem states that

$$\frac{\partial \phi}{\partial t} + \frac{p}{\rho} + g + \frac{v^2}{2} = H(t)$$

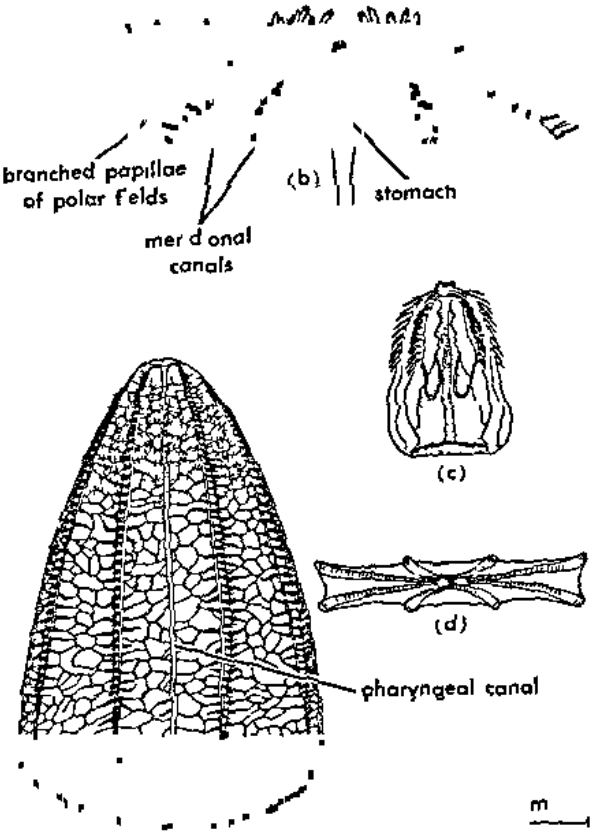
throughout the fluid The additional term $\partial\phi/\partial t$ is interpreted as the time rate of change of an impulsive pressure ϕ which would be necessary to establish the instantaneous flow from rest If the flow field is steady at some point (such as far away from a moving body in a large expanse of fluid) then H is constant that is it is not a function of time For steady flows $\partial\phi/\partial t = 0$ If the fluid is compressible but still inviscid the internal energy must be added to p/ρ giving the enthalpy per unit mass which for a perfect gas is equal to

$$\frac{\gamma}{\gamma - 1}\frac{p}{\rho} = C_p T$$

where $\gamma = C_p/C_v$ C_p is specific heat at constant pressure C_v is specific heat at constant volume and T is fluid temperature It is assumed that $p = p(\rho)$ for a perfect gas this relation is $p = k\rho^\gamma$ where k is a constant *See* CAVITATION, FLUID FLOW PRINCIPLES [A E BR]

Beroida

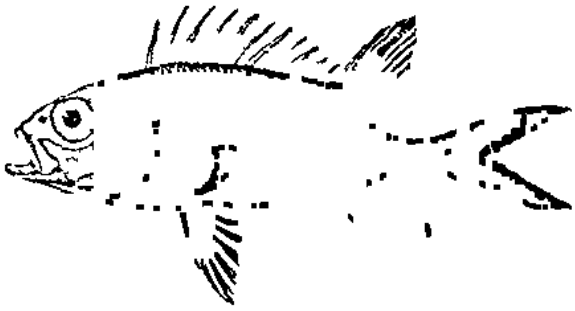
The only order of the class Nuda in the phylum Ctenophora There is no trace of tentacles in any stage of development The adults are bell shaped and have a large mouth and pharynx Meridional canals have many lateral branches The polar fields are provided with papilliform processes A common example is *Beroe* *See* CTENOPHORA, NUDA [T K]



Structure of Beroe (a) Beroë forskâli adult (b) Aboral region of Beroe enlarged (c) Cydippid larva of Beroe (d) View of Beroe from the aboral end showing great flattening

Beryciformes

An order of somewhat intermediate position among the actinopterygian fishes The Beryciformes or Berycomorphi like the Perciformes have fin spines and ctenoid scales an upper jaw which is bordered by the premaxillae a ductless swimbladder and lacking a mesocoracoid An orbitosphenoid bone is present however as it typically is in the Clupeiformes The pelvic fin is thoracic or subabdominal in position and has a spine and 3 13 (usually more than 5) soft rays the pelvic girdle is most often attached to the cleithra *See* SWIMBLADDER

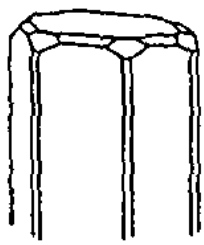


Squirrelfish *Holocentrus ascensionis* (*After* G B Goode *Great International Fisheries Exhibition London 1883 U S Natl Museum Bull 27 1884*)

The Beryciformes which are known from the Upper Cretaceous are classified into 2 suborders 12 families about 30 genera and about 100 Recent species They are cosmopolitan in tropical and temperate seas many are restricted to deep water but some are pelagic and others live in shore waters *See* ACTINOPTERYGII [R M B]

Beryl

A mineral cyclosilicate composition $Be_3Al_2Si_6O_{18}$ Beryl is of interest as a gem stone and as a source of beryllium It crystallizes in the hexagonal system and commonly occurs in prismatic crystals terminated by the basal pinacoid Small crystals may show pyramidal forms Small amounts of alkalies including cesium may be present which are reflected in the habit of the crystals Cesium beryl is usually flattened parallel to the base There is imperfect basal cleavage Hardness is 8 on Mohs scale specific gravity is 2 75 2 8 The mineral has a vitreous luster and crystals may be colorless The common color is bluish green or light yellow, more rarely emerald green pink golden yellow, or white. The transparent gem varieties are named on the basis of color Aquamarine is pale greenish blue morganite is pale pink to deep rose, emerald is deep green golden beryl is clear golden yellow *See* GEM, SILICATE MINERALS

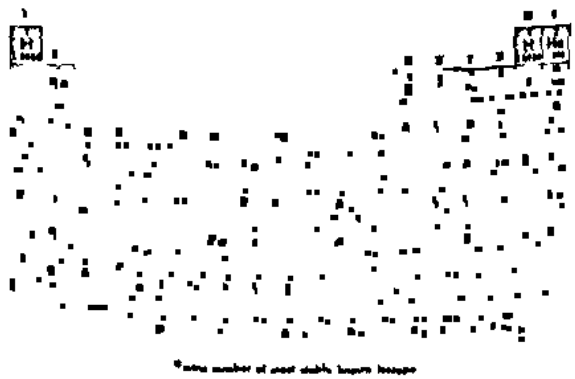


D hexagonal crystal of mineral beryl (*From* C S *Hurlbut, Jr Dana's Manual of Mineralogy, 16th ed Wiley 1952*)

Beryl is most common in granite pegmatites but is also found in tin bearing veins and in mica schists At Muso Colombia fine emeralds occur in a bituminous limestone Emeralds are also found in a mica schist near Sverdlovsk in the Ural Mountains Aquamarine is more common and is found in Brazil Madagascar Siberia and in the United States in Maine Connecticut North Carolina New Hampshire and Colorado Fine rose colored beryl has come from Brazil Madagascar, and California Beryl is the chief ore of beryllium and as such has been mined in many countries *See* BERYLLIUM [C S HU]

Beryllium

Chemical element number 4 beryllium Be has an atomic weight of 9 013 Beryllium a rare metal is one of the lightest structural metals having a



density about one-third that of aluminum Beryllium has a number of unusual and even unique properties An indication of the broad impact of beryllium in modern science is given by the variety of topics relating to it in the literature cosmological theories isotopic dating meteorological mechanisms rocket construction neutron reflection and moderation for nuclear reactors enzyme inhibition and toxicology

The widest uses of beryllium are as an alloying agent with copper and in nuclear energy The addition of 2% beryllium to copper forms a nonmagnetic alloy which is six times stronger than copper These beryllium copper alloys find numerous applications in industry as nonsparking tools as critical moving parts in aircraft engines and in the key components of precision instruments mechanical computers electrical relays and camera shutters Beryllium copper hammers wrenches and other tools are employed in petroleum refineries and other plants in which a spark from steel against steel might lead to an explosion or fire *See* BERYLLIUM ALLOYS

Beryllium has found many special uses in nuclear energy because it is one of the most efficient materials for slowing down the speed of neutrons and acting as a neutron reflector Consequently much beryllium is used in the construction of nuclear reactors as a moderator and as a support or alloy with the fuel elements *See* REACTOR NUCLEAR

Development of commercial production The discovery of beryllium in 1798 stemmed from the observation by the French mineralogist R J Hauy that the optical properties of the emerald were identical with those of the more common mineral beryl At the request of Hauy L N Vauquelin chemically analyzed beryl and emerald and proved that both substances had the same composition and contained a new element Because the salts of beryllium are sweet tasting the new element was first called glucinium The name beryllium was given by F Wohler in Germany in 1828 who simultaneously with W Bussy in France first succeeded in isolating the pure metal by fusing beryllium chloride with metallic potassium In 1898 the French chemist P Lebeau prepared beryllium of 99 5–99 8% purity by an electrolytic process Within 20 years a commercial process for beryllium production was developed by A Stock and H Goldschmidt in Germany The process involved electrolysis of the fluoride salt at temperatures near the melting point of beryllium The important ability of beryllium to age harden copper with nickel additions was discovered in 1926 by M G Corson an American metallurgist

Small scale production of beryllium and its alloys began in the United States and abroad during the late 1920s and 1930s The United States has been and continues to be the dominant producer and consumer of beryllium metal alloys and compounds

When beryllium atoms are bombarded with α particles from radium the nucleus is broken down to yield a profusion of neutrons It was this reaction which led to the discovery of the neutron in the 1930s A radium-beryllium source provided the neutrons for the studies which led Enrico Fermi to the construction of the first nuclear reactor in 1942

The possible use of beryllium as a moderator in nuclear reactors was first recognized in 1940 by C V Wilson at the University of Chicago The ability of beryllium to withstand high temperatures and corrosion makes it particularly attractive for nuclear reactors, however the brittleness of the metal and oxide present many difficulties

Certain health problems involving beryllium were recognized during the period 1933–1942 At this time a puzzling new occupational disease was reported from Germany Italy and the Soviet Union Many workers employed in the extraction of beryllium from beryl became acutely ill and about 10–20% of those affected died Many of the workers had inhaled beryllium in the form of corrosive salts such as the fluoride This acute form of beryllium poisoning produced symptoms such as chills fever painful cough and fluid accumulation in the lungs symptoms similar to those of poisoning by irritating gases such as chlorine

In 1946 a delayed form of beryllium poisoning appeared in patients who had been engaged in the manufacture of fluorescent lamps in which beryllium compounds were incorporated in the phosphors used to coat the inside of the lamp tubes In these cases workers were exposed to insoluble forms of beryllium and their illness became noticeable only after 6 months to 3 years Cases are now known in which the delayed form of beryllium poisoning called berylliosis did not appear until 15 years or longer following exposure One of the characteristic aspects of berylliosis is the appearance of lesions in the lung called granuloma

Procedures have been developed to protect those working with beryllium so that its toxicity no longer need hinder the manufacture of beryllium products

Physical and chemical properties Some of the important physical and chemical properties of beryllium are tabulated in Table 1 One of the most

Table 1 Physical properties of beryllium*

Atomic and mass properties	
Mass number of stable isotopes	9
Atomic number	4
Outer electronic configuration	$1s^2 2s^2$
Atomic weight	9 013
Atomic diameter	2 221 A
Atomic volume	4 96 cm³/mole
Crystal structure	Hexagonal close packed
Lattice parameters	a = 2 285 A
	c = 3 583 A
Axial ratio	c/a = 1 568
Field of cation (charge/radius²)	17
Density† 25° x ray (theoretical)	1 8477 ± 0 0007 g/cm³
Density 1000° x ray	1 756 g/cm³
Radius of atom (Be^0)	1 11 A
Radius of ion Be^{++}	0 34 A
Ionization energy ($Be^0 \rightarrow Be^{++}$)	27 4 ev
Thermal properties	
Melting point	1285°C (2345°F)
Boiling point‡	2970°C (5378°F)
Vapor pressure (T = °K)	$\log P$ (atm) = 6 186 + 1 454 × 10 ^4T − (16 700/T)
Heat of fusion	250–275 cal/g
Heat of vaporization	53 490 cal/mole
Specific heat (20–100°)	0 43–0 52 cal/(g)(°C)
Thermal conductivity (20°)	0 355 cal/(cm²)(cm)(sec)(°C) (42% of copper)
Heat of oxidation	140 15 cal
Electrical properties	
Electrical conductivity	40–44% of copper
Electrical resistivity	4 microhms/cm (0°C)
	6 microhms/cm (100°C)
Electrolytic solution potential Be/Be^{++}	E^0 = −1 69 volts
Electrochemical equivalent	0 01674 mg/coulomb

‡ Obtained by extrapolation of vapor pressure data not considered very reliable

striking differences between beryllium and the other main group II elements in the periodic table lies in the very small ionic radius r which is less than one half that of the next smallest cation Mg^{++}. Further Be possesses an exceptional deforming power as shown by the value of e/r^2 (e = charge) which is 17 compared to 3.3 for Mg^{++} and 1.8 for Ca^{++} and 9.2 for Al^{3+}. Beryllium shows a remarkable resemblance to aluminum in its chemical behavior.

Like aluminum beryllium forms a protective oxide skin and its stability in air even at red heat is due to this protective oxide layer. The protective influence of the film may be disrupted when the metal is placed in contact with more noble metals or alloys which may result in current flow and cause galvanic corrosion. Beryllium metal is appreciably resistant to attack by oxygen free sodium metal at elevated temperatures. It is difficult however to obtain and maintain sodium metal completely free of oxygen. The attack rate of liquid sodium on beryllium can be reduced by the incorporation into the system of an element such as calcium which forms a more stable oxide than beryllium. The resistance of beryllium metal to liquid metals is important in the design of heat transfer units in nuclear reactors.

Beryllium has a very strong tendency to form covalent compounds with a maximum covalency of 4. Its salts so uniformly have four molecules of water of crystallization for every atom of beryllium that any compound which has not may be assumed to be a complex ion formed by displacement of coordinated H_2O or to be a purely covalent substance such as beryllium acetylacetonate. Compounds of beryllium are readily hydrolyzed in water. Beryllium complexes containing donor nitrogen or sulfur atoms are decomposed by water because of the strength of the Be—O bond. In aqueous solution the chelates of beryllium with salicylic acid analogs are among the most stable.

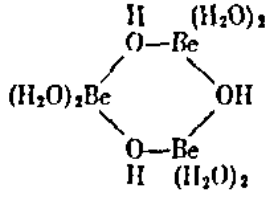
Beryllium compounds form tetrahedrons which are characteristic of many elements having the coordination number 4. This is the result of the directional characteristics of the orbital electronic distribution and intensity. Hybrid bonds of the sp^3 type giving tetrahedral symmetry such as those of carbon and silicon are found with compounds of beryllium. Because beryllium lacks d orbitals only tetrahedral compounds are formed.

The tetrahedral arrangement of the valencies of beryllium leads to optical activity of many of its compounds just as with carbon compounds. The classical example is that found by W. H. Mills and R. A. Gotts who in 1926 separated the two optical isomers of the beryllium salt of benzoylpyruvic acid.

It is of analytical importance that beryllium does not react strongly with the universal complexing agent ethylenediaminetetraacetic acid (EDTA). At pH 5.5–5.5 500 g of the tetrasodium salt of EDTA will completely bind 1 mole of magnesium or calcium but only 0.002 mole of beryllium. Also of importance in this connection is the fact that aluminum interference in the analysis of beryllium can be greatly minimized because aluminum reacts quite strongly with EDTA under conditions where beryllium does not.

Solutions of beryllium salts are acidic. In 1815 J. J. Berzelius noted that a solution of beryllium sulfate dissolves up to several molecular proportions of beryllium oxide or hydroxide. This behavior indicates the existence of beryllium hydroxo or oxo complexes. During hydrolysis when the average number of OH bound per Be^{++} exceeds unity precipitation begins. At least one polynuclear hydroxo complex is formed.

The main product of the hydrolysis is the polynuclear complex $Be_3(OH)_3^{3+}$ which is presumed to form a six membered ring three tetrahedrons being linked by sharing OH corners.



If the tetrahedrons were filled with water the complex formula would be $Be_3(OH)_3(H_2O)_6^{3+}$ as shown in the diagram.

Beryllium can form polymeric compounds as well as a class of covalent compounds which show remarkable thermal stability. Some can be distilled at temperatures above 300°C at atmospheric pressure without decomposition. Examples of these compounds include the basic beryllium carboxylates $Be_4O(RCO_2)_6$ and neutral chelate compounds of beryllium such as the well known beryllium acetylacetonate which was discovered in 1894 and which is volatile melts at 108°C. and boils undecomposed at 270°C. It is insoluble in water but is hydrolyzed on boiling and it is readily soluble in organic solvents.

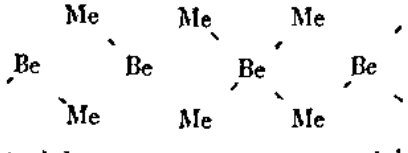
Beryllium alkyls are prepared by reaction with Grignard reagents or organolithium compounds with beryllium chloride.

$$2RMgX + BeX_2 \rightarrow R_2Be + 2MgX_2$$

Another preparative procedure involves the disproportionation of alkyl beryllium halides on heating.

$$2RBeX \rightarrow R_2Be + BeX_2$$

X ray diffraction studies show that solid dimethyl beryllium forms a polymeric chain in which each beryllium atom is attached tetrahedrally to four carbon atoms and each carbon atom to two beryllium atoms. The structure is electron deficient as are the aluminum aryls.



Each dotted line represents a half bond because there are only half enough electron pairs for the number of attachments shown.

Principal compounds The following list shows some of the principal compounds of beryllium

Acetylacetonate	Fluoride BeF_2
Ammonium beryllium fluoride	Hydroxide
Aurintricarboxylate	Nitrate $Be(NO_3)_2\,4H_2O$
Basic acetate $BeO\,Be_3(CH_3COO)_6$	Nitride Be_3N_2
Basic beryllium carbonate	Oxide BeO
Beryllate BeO_2^{2-}	Perchlorate $Be(ClO_4)_2\,4H_2O$
Beryllium ammonium phosphate	Plutonium beryllium $PuBe_{13}$
Bromide $BeBr_2$	Salicylate
Carbide Be C	Silicates (emerald)
Chloride $BeCl_2$	Sulfate $BeSO_4\,4H_2O$
Dimethyl $Be(CH_3)_2$	Uranium beryllium UBe_{13}

Many of the compounds listed are useful as intermediates in processes for the preparation of ceramics beryllium oxide and beryllium metal Other compounds are useful in analysis and organic synthesis

Nuclear properties Beryllium is the only element in the periodic table with both an even atomic number and but a single stable isotope Several radioactive isotopes can be prepared Two radioactive isotopes of beryllium Be^7 and Be^{10} are formed in the upper atmosphere as a result of intense cosmic ray activity causing spallation of the nuclei of nitrogen and oxygen A short lived isotope Be^{11} with a half life of 14 1 sec has been produced by neutron bombardment of boron *See* RADIOACTIVE SPECIES PRODUCED BY COSMIC RAYS

Neutrons are produced in many nuclear reactions involving beryllium The mixed radium beryllium source is often used as a neutron source yielding 460 neutrons per 10^6 disintegrations resulting from the reaction $Be^9(\alpha,n)C^{12}$ Photoneutrons are produced from the action on beryllium of γ rays of energy greater than 1 66 Mev according to the reaction $Be^9(\gamma,n)Be^8$ The Be^8 isotope decomposes into two α particles in less than 10^{-14} sec *See* NEUTRON

Beryllium is an excellent moderator for neutrons and compares favorably with hydrogen deuterium helium carbon and oxygen Similarly beryllium and beryllium oxide are useful as reflecting materials for nuclear reactors and the metal is useful as an alloying element and container for fuel elements

Analytical techniques Quantitative analyses for beryllium can be divided into those methods used for the assay of macro amounts (multimilligram quantities) and those used for the assay of micro or trace amounts (multimicrogram or less)

It is often necessary to remove interfering substances from a beryllium sample Numerous methods are available The use of selective complexing or chelating agents is common Metals such as copper nickel iron and calcium but not beryllium are chelated by EDTA at pH 5 5 Consequently the beryllium can be precipitated as the hydroxide as the beryllium ammonium phosphate or as one of many organic salts In specific cases such as the separation of excess copper excess ammonium hydroxide dissolves copper as a complex ion whereas beryllium hydroxide remains insoluble

Selective precipitation of foreign elements often utilizes 8 hydroxyquinoline At suitable pH in buffered media the quinolates of many metals are insoluble whereas beryllium remains in solution

Ion exchange methods especially in combination with complexing agents find many uses for separation of beryllium Beryllium absorbed on organic cation exchanger is eluted completely for example by sulfosalicylic acid at a suitable pH whereas calcium and copper remain on the cation exchanger At pH 3 5 EDTA converts most metals to anionic complexes whereas beryllium remains cationic Passage of the EDTA solution through a cation exchanger results in absorption of beryllium whereas the anionic complexes pass through

From concentrated hydrochloric acid solution numerous cations are retained by a column of an anion exchange resin while beryllium passes through unabsorbed The reverse situation is observed when the beryllium and other cations in concentrated lithium chloride are passed through an anion exchanger

Other methods of removing impurities from beryllium in analytical operations include solvent extraction volatilization and electrolysis with a mercury cathode

Analysis of beryl ore for beryllium involves a fusion with sodium carbonate followed by silicate removal In some cases it saves time to fuse beryl with sodium fluoride followed by fuming with sulfuric acid to remove the fluoride

Occurrence Beryllium is surprisingly rare for a light element constituting about 0 005% of the earth's crust It is about thirty second in order of abundance occurring in concentrations approximating those of cesium scandium and arsenic Actually the abundance of beryllium and its neighbors lithium and boron are about 10^{-5} times those of the next heavier elements carbon nitrogen and oxygen As a light element beryllium should be a great deal more abundant on earth It is believed that the beryllium nucleus is destroyed by collision with high energy protons as in the sun and other stars The scarcity of beryllium on earth has been interpreted by some to indicate that the earth passed through a stage of stellar temperatures

A summary of the natural occurrence of beryllium in various materials is shown in Table 2 More beryllium is present in the air of the larger urban centers especially coal burning communities than in rural areas

At least 50 different beryllium bearing minerals are known but in only about 30 is it a regular constituent The only beryllium bearing mineral of industrial importance is beryl a hexagonal beryllium aluminum silicate having the ideal composi

Table 2 Natural occurrence of beryllium*

Material	Concentration ppm	
	Average	Range
Earth's crust	3–6	
Soil	0 37	*0 13–0 88*
Shales		6
Bauxite		0 60
Coal	1 55	0 07 3 0
Coal ash	4 0	8000
Air	0 0002†	0 0001–0 003†
Biological		
Lung		0 00–1 98‡
Urine and blood	0 33‡	0 00

* From data summarized by J Cholak The analysis of traces of beryllium *A M A Arch Ind Health* 19 205–210 1959

† Measured in μg/m³

‡ Measured in μg/100 g

tion $Be_3Al_2Si_6O_{18}$ equivalent to 5% Be or 14 0% BeO 19% Al_2O_3 and 67% SiO_2 The precious forms of beryl emerald and aquamarine approach the ideal composition Commercial grades of beryl contain about 10–12% BeO 17 19% Al_2O_3 64–70% SiO_2 1–2% alkali metal ores and 1–2% iron and other ores

The emerald is a transparent intensely green variety of beryl The hexagonal crystals of beryl itself may be greenish bluish or rosy but in the field they tend to assume the color of the granitic rocks with which they are generally associated Occasionally they attain gigantic size up to 2 3 ft in diameter and several feet in length and weigh several tons *See* BERYL

World beryllium deposits are divided into two groups the beryl bearing pegmatite varieties of granitic rocks and the beryl bearing nonpegmatite rocks However nearly all beryllium produced has been extracted from beryl bearing pegmatites which are found in many countries The most important or potentially important areas are found in Brazil Argentina Canada the United States the Belgian Congo Rhodesia South West Africa the Union of South Africa and India

Beryllium is found in numerous minerals because the very small diameter of the beryllium ion favors its limited entry into other silicate minerals so that the formation of high concentration beryllium minerals is restricted In nonpegmatite rocks beryllium is mainly a minor constituent and only rarely do these minerals contain as much as 0 2% BeO as is found with the helvite group $(Mn\ Fe\ Zn)_4 Be_3Si_3O_{12}S$

Extraction and mining Most beryl is recovered by hand picking Hence only large crystals can be *mined Crystals* smaller than 1 in in diameter are not profitable About 100 tons of rock must be *moved in order to hand* pick ½–1 ton of beryl crystals In ore deposits where the beryl is fine *grained milling processes are required* No commercially successful concentration processes have *been perfected Flotation* methods appear most promising and semicommercial flotation procedures have been developed which have yielded 80–90% recovery of beryl from ores containing 0 5% beryl or more, but seldom exceed 70% of 0 2% beryl feed *See* BERYLLIUM METALLURGY

The total known world resources of beryl including deposits containing as little as 0 1% of beryl has been estimated at about 4 000 000 tons The estimated world s resource of beryl in deposits containing 1% beryl or the equivalent is about 200 000 tons From 1935 through 1951 the recorded world production of beryl was *49,232 tons or* about 14 times as much as the total production of the United States South America and Africa together produced about 80% of the total during this period Brazil is the world's largest producer of beryl ore producing 25 4% of the total From 1953 figures the percentage of the total production of other countries was Rhodesia, 18 9%, Argentina 16 2%, the United States, 8 0%, South West Africa 6 9% the Union of South Africa, 5 7%, Madagascar 5 5% Portugal 4 4%, Mozambique 2 9% and other 5 1%

An output of 12 500 tons of beryl was reached in 1956 Since 1941 the United States has received about 80% of world production One ton of beryl sells for $400–500 and yields about 70 lb of beryllium worth about $4200

Uses The largest uses of beryllium metal are as a reflector or moderator in nuclear reactors and as an alloying agent especially with copper

A small but important use of beryllium is in sheet or foil form as window material in x ray tubes Beryllium transmits x rays 17 times better than an equivalent thickness of aluminum and 6–10 times better than Lindemann glass This together with its high melting point makes possible the use of x ray beams of greater intensity

Beryllium oxide is used in the manufacture of high temperature refractory material and high quality electrical porcelains such as aircraft spark plugs and ultrahigh frequency radar insulators The high thermal conductivity of beryllium oxide and its good high frequency electrical insulating properties find application in electrical and electronic fields

Another use of beryllium oxide is as a slurry for coating of graphite crucibles to insulate the [illegible] of melted al[illegible] rucibles are [illegible] or reactive metals are being melted

Several salts of beryllium find limited uses Beryllium nitrate is used in combination with th orium nitrate for fabricating incandescent gas mantles Sodium beryllium fluoride is useful for the preparation of glass with a high permeability to ultraviolet rays as a flux in certain porcelain enamel and in coating of rods for welding light metals Beryllium halides and other salts find limited use as catalysts in organic chemical reactions

Lightweight very high elastic modulus and heat stability of beryllium make it an attractive material for use as construction material in aircraft and

missiles However its lack of ductility is a draw back Were it not for its toxicity and scarcity be ryllium would find use as a rocket fuel because it produces more heat energy per unit volume than any other element In multistage missiles a small weight reduction in the final stage such as might be achieved by using beryllium in place of steel permits a much larger weight reduction in the ear lier stages in terms of fuel and structure Re search in the utilization of beryllium metal and beryllium-containing materials for aircraft and mis sile uses is carried out very actively These and other still developing applications together with the continuing uses of beryllium in nuclear tech nology sustain the ever mounting production levels of beryllium

The two radioactive isotopes of beryllium Be^7 with a half life of 53 days, and Be^{10} with a half life of 2.5×10^6 years are useful in geological age determinations Beryllium 10 especially fills an im portant gap for dating purposes falling between C^{14} and the long lived nuclides (5×10^4 years to at least 10^7 years) The isotopes of beryllium are found in ground level air rain snow and sea sedi ments *See* ALKALINE EARTH METALS [J S]

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Beryllium alloys

Combinations of beryllium and one or more other metals The commercially important alloys of beryllium are of the precipitation hardening type Although beryllium has some solid solubility in copper silver gold nickel cobalt platinum pal ladium and iron and forms precipitation harden ing alloys to some degree in these systems the copper beryllium cobalt (or nickel) alloy is the only one widely used at present

The most common types of alloying occurring in beryllium systems are those based on stable com pound formation with little solid solubility How ever recent developments in dispersed phase hard ening beryllium base alloys as well as the inter metallic compounds themselves for use as light metallic materials for elevated temperature have opened up many potential uses in this area

Beryllium copper alloys The principal classes of alloys in this group are the high strength high beryllium type (1 60 2 15% Be 0 25–0 35% Co in wrought form and 2 00–2 85% Be 0 35–0 065% Co in castings) and the high conductivity low beryllium group (0 25–0 60% Be 1 40–2 60% Co as wrought alloy and 0 55–0 70% Be 2 35–2 60% Co in castings)

Age-hardenable Be-Cu alloys offer a wide range of properties because they are extremely ductile and workable in the annealed condition and very strong and hard after precipitation treatment They also have inherent characteristics of substantial electrical and thermal conductivity and good re sistance to corrosion and wear as well as to dimen sional changes and failure under cyclical loading

Beryllium copper master alloys are produced by a direct reduction of beryllium oxide with carbon in the presence of copper in an arc furnace Be cause beryllium carbide forms readily with high Be content the master alloy is usually limited to about 4 0–4 25% Be in copper The master alloy is remelted with additional copper and other ele ments to form commercial alloys Rolling billets up to 1500 lb in weight have been made by con tinuous casting techniques

Beryllium copper alloys can be fabricated by all the industrial metal working techniques to produce principally strip foil bar wire and forgings They can be readily machined and joined by brazing soldering and welding Annealing to provide high plasticity at room temperature is accomplished by heat treating from 1450–1475°F for the high Be alloys (1650–1700°F for the low Be alloys) and water quenching Precipitation hardening is ac complished by heating to 750–900°F (low Be) and 550–650°F (high Be)

After solution treating and hardening the high beryllium alloys develop tensile strengths of 165 000–180 000 psi the lower beryllium alloys 100 000–120 000 psi Up to about 20% additional strength can be obtained by cold rolling before precipitation hardening The electrical conductivi ties of low beryllium alloys can range up to 60% that of copper

Beryllium copper alloys are used widely in the electrical industry for applications such as high strength current carrying springs and welding elec trodes They also find extensive use in pressure responsive elements and bearings, and in the cast form as molds for casting plastics

Alloys with nickel and iron After annealing and cold working nickel containing 2% beryllium can be heat treated to develop tensile strength of up to 260 000 psi with 6–8% elongation and a Brinnell hardness of about 500 Be Ni alloys are used in small quantities as precision castings for aircraft fuel pumps hypodermic needles surgical instruments and matrices in diamond drill bits

Table 1 Compositions of some beryllium alloys

Alloy name	Be %	Ni %	Cr %	Co %	Mo %	W %	Fe %	Use
Nevarox	0 5	30				8	Balance	Watch springs
Contracid	0 6	60	15		7		Balance	Surgical instruments
Elgiloy	0 04	15	20	40	7		Balance	Watch springs
Ticonium	1 5	36	29 5	27				Dentures

Table 2 Properties of some beryllium intermetallic compounds

Material	Density g/cm³	Modulus of rupture psi 2500°F	2750°F
$ZrBe_2$	2 72	36 000	25 000
$NbBe_{12}$	2 91	39 000	18 000
$TaBe_{12}$	4 18	43 000	26 000

Although binary Fe Be alloys are too brittle for use beryllium containing alloys with Fe Ni and Cr exhibit high strength at elevated temperatures Some of these alloys having limited use are listed in Table 1

Alloys with magnesium and aluminum The principal use of beryllium in these alloys is as a master alloy to add small amounts of Be to castings When alloyed with magnesium in quantities as low as 0 005% beryllium reduces the flammability of magnesium and retards oxidation at the melting point The addition of 0 1 0 5% Be to aluminum refines the grain and promotes fluidity

Beryllium base alloys Dispersed phase alloys consisting of stable oxides carbides nitrides and intermetallic compounds dispersed through a beryllium matrix are chiefly characterized by their strength at elevated temperature An addition of 2% BeO nearly doubles the ultimate strength of Be at 1200°F (19 000 psi vs 10 000 psi) and 1 2% of intermetallic dispersion increases mechanical properties (tensile compression creep and rupture strength) from two to four times at 1350–1650°F

Intermetallic compounds For high temperature applications (2300–2900°F) light high strength materials have been developed The intermetallic compounds of beryllium and certain transition elements have the unusual properties of oxidation resistance to 2900°F very high thermal conductivity and specific heat high modulus and mechanical strength and thermal expansion compatible with ferrous high temperature alloys Some properties for three of these are given in Table 2 *See* BERYLLIUM INTERMETALLIC COMPOUNDS [W W BE]

Beryllium metallurgy

is used per year At present this is valued at about $375 per ton Beryl a beryllium aluminum silicate containing in commercial grades about 11–13% BeO 17 19% Al_2O_3 64–70% SiO_2 and 1–2% alkali metal oxide is the only mineral of importance used as raw material for beryllium

Because beryl ore is widely distributed it has never been found in quantities extensive enough to permit mining for itself It is therefore produced only as a by product of the mining of other minerals such as mica feldspar and spodumene Only crystals large enough to permit hand sorting are recoverable Although concentration processes have been under development for some time none has proved to be economical so far South Africa Brazil and India are the largest producers of beryl ore only a small amount is produced in the United States at the present time However, large reserves of low grade ore appear to be available if such ores may be required in the future

Two processes are used to extract beryllium oxide or hydroxide from beryl ore, and there are also two methods employed to reduce beryllium oxide to beryllium metal The two extraction methods are based on dissolving beryl as either a fluoride or a sulfate Reduction is accomplished thermally by means of magnesium with beryllium fluoride and electrolytically on beryllium chloride The thermal process is used to reduce most of the metal produced

Extraction of oxide or hydroxide In fluoride extraction finely powdered beryl is mixed with sodium fluoferrate briquetted and heated to 75°C. The chemical reaction involved is

$$3BeO\ Al_2O_3\ 6SiO_2 + 2Na_3FeF_6 \rightarrow 6SiO_2 + Fe_2O_3 + Al_2O_3 + 3Na_2BeF_4$$

The water soluble sodium beryllium fluoride is removed from the insoluble oxides by filtration after leaching The filtrate containing Na_2BeF_4 is treated with caustic soda to precipitate beryllium hydroxide The resulting hydroxide is decomposed to BeO by firing at 800°C After removal of the $Be(OH)_2$ the dilute filtrate containing NaF is treated with $Fe(SO_4)_3$ to produce Na_3FeF_6 for further beryl extraction

In sulfate extraction beryl ore is melted at 1625°C and quenched in water to destroy the orig

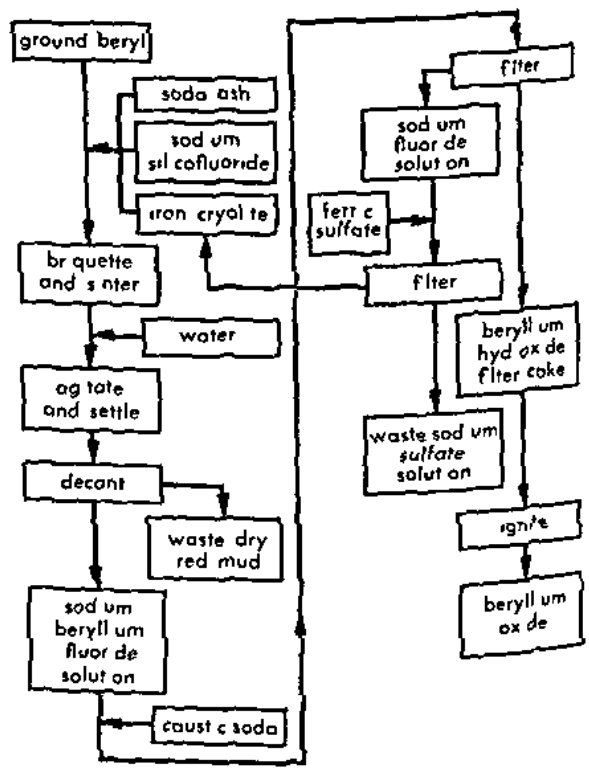


Fig 1 Flowsheet for extraction of BeO from beryl by the fluoride process (*Beryllium Corporation*)

inal crystal structure for increasing reactivity with sulfuric acid This beryl glass is heat treated fur ther to precipitate the BeO fully out of solid solu tion and thus to increase leaching yield

The heat treated frit is then ground and treated with sulfuric acid at 200–300°C The soluble beryl lium and aluminum sulfates are leached out with water and removed from the insoluble oxides

The aluminum is separated by converting it to ammonium aluminum sulfate through addition of $(NH_4)_2SO_4$ and crystallizing Chelating com pounds are added to hold iron and nickel in solu tion Sufficient sodium hydroxide is then added to convert the beryllium to sodium beryllate which is hydrolized to precipitate beryllium hydroxide

Beryllium oxide. In the manufacture of ceramic grade beryllium oxide, impure beryllium hydrox ide is generally converted to either the sulfate nitrate oxalate, basic carbonate, or basic acetate, and purified by recrystallization The purified salt is then decomposed thermally to yield beryllium oxide

The sinterability of the resulting oxide is chiefly a function of the temperature of decomposition which should be sufficiently high to complete de composition However if sinterability is desired the temperature of decomposition should be suffi ciently low to produce active surfaces Generally, calcining between 900 and 1000°C gives sinterable grade oxide whereas higher temperatures produce a more refractory oxide Beryllium oxide is pri marily employed as a refractory for the melting of reactive metals for high temperature nuclear ap plications and as thermally conducting, electrically resisting porcelains

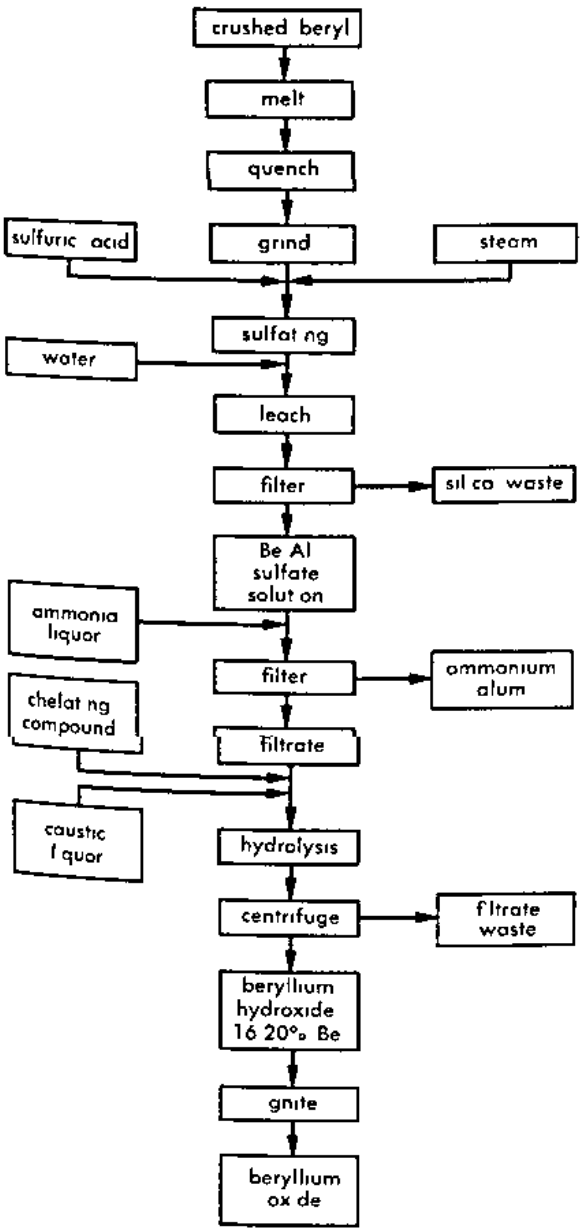


Fig 2 Flowsheet for extraction of BeO from beryl by the sulfate process (*Brush Beryllium Company*)

Beryllium metal. In thermal reduction beryl lium hydroxide or oxide is treated with ammonium bifluoride to form $(NH_4)_2BeF_4$ This solution is purified by adding lead dioxide to remove man ganese and chromium calcium carbonate to pre cipitate excess aluminum and after removal of these impurities ammonium polysulfide to pre cipitate remaining heavy elements The purified solution is evaporated and crystallized to salt which is decomposed to NH_4F and BeF_2 at tem peratures of 900–1100°C

Beryllium fluoride is mixed with magnesium in amounts corresponding to about 75% of the mag nesium stoichiometrically required and reduced at 900°C in a graphite crucible with a high frequency electric furnace After the reaction is complete the temperature is raised to about 1400°C to allow the beryllium to collect The excess BeF_2 is leached out of the slag and the beryllium pebble and MgF_2 are separated

The resulting pebbles contain slag and some magnesium and are vacuum melted for purification in a BeO crucible The metal is poured into graph ite molds to produce castings of 70–75 lb

For electrolysis beryllium chloride can be made by passing chlorine gas over BeO and carbon at 1000°C The $BeCl_2$ can be collected as a sublimate in a condenser maintained below 400°C

The electrolytic cell may consist of a nickel or stainless-steel pot serving as a cathode and a graph ite electrode as an anode A cover is provided to control atmospheric conditions in the pot

Because $BeCl_2$ is a nonconductor the electrolyte consists of beryllium chloride mixed with sodium chloride Electrolysis is carried out at about 730°C Beryllium flakes resulting from electrolysis are leached in water and dried in alcohol As in the case of pebbles thermally reduced by magnesium from BeF_2 it is generally necessary to vacuum cast the electrolytic flake to remove chlorides com pletely from the beryllium

Fabrication. Vacuum cast beryllium ingots are converted into chips by a multiple turning opera tion and the chips are attritioned between beryl lium plates into —200 mesh powder under a dry inert atmosphere to minimize oxidation The re-

sulting powder essentially cast beryllium covered by a thin film of oxide is desiral le to prevent grain growth during subsequent thermal operations and to control grain size for developing optimum me chanical properties

Consolidation of powder is most commonly brought about by hot pressing Beryllium powder is pressed with 100–500 psi in steel or graphite dies under vacuum at temperatures of 1050–1100°C The pressed metal unlike cast metal can be ma chined to high tolerances and can be used as billets for other metallurgical operations

Powder can also be canned in steel to be rolled extruded and forged Another process used chiefly for making fabrication billets is pressureless sin tering (slip casting and sintering) wherein loose powder is consolidated by heat alone under high vacuum at 1250°C *See* POWDER METALLURGY SIN TERING

Beryllium can be machined rolled forged ex truded press formed welded brazed and other wise subjected to standard metal working tech niques Generally the metal is worked either at its maximum ductility at around 400–500°C, or above the recrystallization temperature 750°C In the latter process the metal is generally jacketed in steel to provide support and to prevent oxidation *See* METAL FORMING

Uses Machined beryllium is used in modera tors reflectors and low absorption hardware in nuclear reactors It is also employed as cladding for fuel elements in gas cooled reactors (extruded tubes)

Beryllium is used in heat sink applications be cause of its high specific heat and high thermal conductivity These may involve uses in the leading edges of high speed aircraft or missiles nose cones or high energy brake disks Beryllium is also used in inertial guidance instruments where its low weight high modulus of stiffness and dimensional stability are advantageous Considerable develop ment work is also being done to provide wrought beryllium parts for aircraft and missile structures *See* BERYLLIUM BERYLLIUM ALLOYS PYROMETAL LURGY NONFERROUS VACUUM METALLURGY

[W W BE]

Beryllonite

A mineral with composition $NaBe(PO_4)$ Beryl lonite crystallizes in the monoclinic system but was originally described as orthorhombic because of a marked pseudosymmetry Crystals are tabular or short prismatic with two good pinacoidal cleavages at right angles The hardness is 5 5 6 on Mohs

[illegible] Mountain Stoneham and the second occurrence at Newry At both localities beryllonite was found in pegmatite associated with other phosphate minerals *See* BERYLLIUM

[C S HU]

Bessel functions

By definition the solutions of Bessel s differential equation

$$z\ d\ y/dz^2 + z\ dy/dz + (z^2 - \nu^2)y = 0 \quad (1)$$

Bessel functions also called cylinder functions are examples of special functions which are intro duced by a differential equation Bessel functions are of great interest in purely mathematical con cepts and in mathematical physics They consti tute additional functions which like the elemen tary functions z^n sin z e^z, can be used to express physical phenomena

Applications of Bessel functions are found in such representative problems as heat conduction or diffusion in circular cylinders oscillatory mo tion of a sphere in a viscous fluid oscillations of a stretched circular membrane diffraction of waves by a circular cylinder of infinite length or by a sphere acoustic or electromagnetic oscillations in a circular cylinder of finite length or in a sphere electromagnetic wave propagation in wave guides of circular cross section in coaxial cables or along straight wires and in skin effect in conducting wires of circular cross section In these problems Bessel functions are used to represent such quan tities as the temperature the concentration or dis placements or the electric and magnetic field strengths or the current density as a function of space coordinates The Bessel functions enter into all these problems because boundary values on cir cles (two dimensional problems) on circular cyl inders or on spheres are prescribed and the solu tions of the respective prol lems are sought either inside or outside the boundary, or both

Definition of Bessel functions The independent variable - in Bessel s differential equation may in applications assume real or complex values ν is a parameter in general also complex Its value is called the order of the Bessel function Since there are two linearly independent solutions of a linear differential equation of second order there are two independent solutions of Bessel s differential eq a tion They cannot be expressed in finite form in terms of elementary functions such as z^n sin z or e^z unless the parameter is one half of an odd in teger They can however be expressed as power

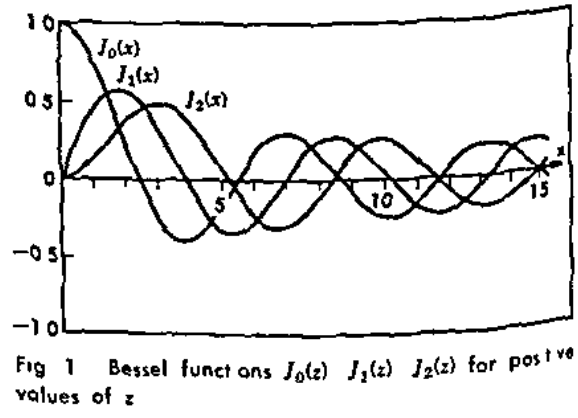


Fig 1 Bessel functions $J_0(z)$ $J_1(z)$ $J_2(z)$ for positive values of z

series with an exception for integer values of ν One designates the function defined by

$$J_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{l=0}^{\infty} \frac{(-z^2/4)^l}{l!\Gamma(\nu+l+1)} \qquad (2)$$

as Bessel's function of the first kind or simply the Bessel function of order ν $\Gamma(\nu+l+1)$ is the gamma function (*see* GAMMA FUNCTION) The infinite series in Eq (2) converges absolutely for all finite values real or complex, of z In particular,

$$J_0(z) = 1 - \frac{1}{1!1!}\left(\frac{z}{2}\right)^2 + \frac{1}{2!2!}\left(\frac{z}{2}\right)^4 - \frac{1}{3!3!}\left(\frac{z}{2}\right)^6 +$$

$$J_1(z) = \frac{z}{2} - \frac{1}{1!2!}\left(\frac{z}{2}\right)^3 + \frac{1}{2!3!}\left(\frac{z}{2}\right)^5 -$$

Along with $J_\nu(z)$, there is a second solution $J_{-\nu}(z)$ It is linearly independent of $J_\nu(z)$ unless ν is an integer n In this case $J_n(z) = (-1)^n J_n(z)$

The Bessel function of the second kind, also called Neumann function, is defined by

$$Y_\nu(z) = \frac{\cos \nu\pi J_\nu(z) - J_{-\nu}(z)}{\sin \nu\pi}$$

If $\nu = n$ this expression is indeterminate and the limit of the right member is to be taken In particular,

$$Y_0(z) = \frac{2}{\pi} J_0(z) \ln\left(\frac{1}{2}\gamma z\right) + \frac{2}{\pi}\left[\frac{1}{1!1!}\left(\frac{z}{2}\right)^2 - \frac{1}{2!2!}\left(1+\frac{1}{2}\right)\left(\frac{z}{2}\right)^4 + \frac{1}{3!3!}\left(1+\frac{1}{2}+\frac{1}{3}\right)\left(\frac{z}{2}\right)^6 - \right]$$

with $\ln \gamma = 0.577215$ (Euler's constant) There are two Bessel functions of the third kind designated as first and second Hankel functions They are defined as

$$H_\nu^{(1)}(z) = J_\nu(z) + iY_\nu(z)$$
$$H_\nu^{(2)}(z) = J_\nu(z) - iY_\nu(z) \qquad (3)$$

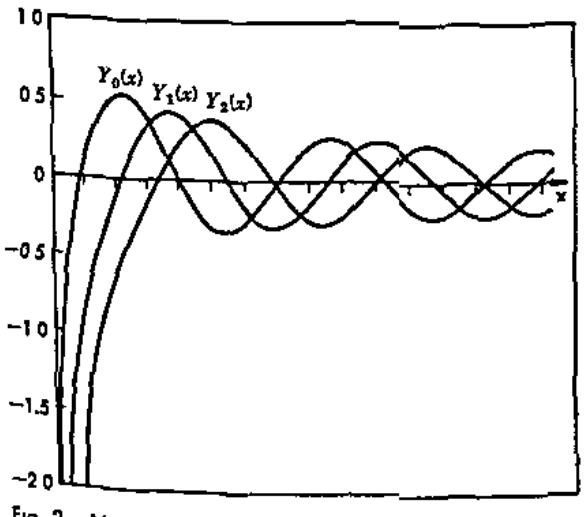


Fig 2 Neumann functions $Y_0(z)$ $Y_1(z)$, $Y_2(z)$ for positive values of z

Elementary properties. For $z = 0$ one has $J_0(0) = 1$, $J_n(0) = 0$ *if* $n = 1, 2$, *while* $Y_n(0)$ and therefore also $H_n^{(1)}(0)$ and $H_n^{(2)}(0)$ are infinite for all n The behavior of Bessel functions for small values of z is readily seen from the power series expansion (2) if ν is not an integer For integer $\nu = n \geqq 0$ one has for small z (the sign $\approx$ means approximately equal)

$$J_n(z) \approx \left(\frac{z}{2}\right)^n / n! \qquad Y_0(z) \approx \frac{2}{\pi} \ln \frac{\gamma z}{2}$$

$$Y_n(z) \approx -\frac{1}{\pi}\left(\frac{z}{2}\right)^{-n} (n-1)! \qquad (n = 1, 2, \quad)$$

(with $n! = 1\ 2\ 3 \quad n \quad 0! = 1$) The behavior of the Bessel functions for large values of $z(|z| \gg |\nu|^2)$ is given for all values of ν by the formulas

$$J_\nu(z) = \left(\frac{2}{\pi z}\right)^{1/2} \cos\left(z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)$$

$$Y_\nu(z) = \left(\frac{2}{\pi z}\right)^{1/2} \sin\left(z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)$$

$$H_\nu^{(1)}(z) = \left(\frac{2}{\pi z}\right)^{1/2} \exp\left[i\left(z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)\right]$$

$$H_\nu^{(2)}(z) = \left(\frac{2}{\pi z}\right)^{1/2} \exp\left[-i\left(z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)\right]$$

They hold not only for real positive values of z but also for complex values in the angular domain $-\pi < \arg z < \pi$ These formulas are said to be asymptotic This means that the difference of the left and right member multiplied by a certain power of z which is here $z^{3/2}$ is bounded as z goes to infinity along a straight line in the angular domain mentioned The asymptotic formulas can be used to obtain approximate numerical values of the functions for sufficiently large $|z|$ They reveal that the Bessel functions are closely related to the functions $\cos z$, $\sin z$ $\exp(iz)$ $\exp(-iz)$, respectively

The general behavior of Bessel functions can to a certain extent be inferred from the behavior near $z = 0$ and from the asymptotic behavior The functions $J_\nu(z)$ and $Y_\nu(z)$ of real positive argument z and real order ν are oscillatory in z with a period that is not quite a constant but approaches 2π as $z \to \infty$ The oscillations have however an amplitude which decreases in accordance with $(2/\pi z)^{1/2}$ as $z \to \infty$ They are used in applications to represent standing cylindrical and spherical waves The behavior of Hankel functions follows then from (3) They are used to represent progressing cylindrical and spherical waves

Figures 1 and 2 give the Bessel and Neumann functions for $\nu = 0$ 1 2 and positive values of z

The large zeros $z_{\nu,s}$ of the function $J_\nu(z)\cos\alpha + Y_\nu(z)\sin\alpha$ with α a constant are given by the asymptotic expression $z_{\nu,s}^2 \approx [(s + \frac{1}{2}\nu - \frac{1}{4})\pi + \alpha]^2 + \frac{1}{4} - \nu^2$ in which s assumes large integer values Even the first positive zero of $J_0(z)$ accurately given by this formula

2 409 as compared with the accurate value $z_{0\,1} = 2.4048$

There exist two relations between Bessel functions whose orders differ by one If $C_\nu(z)$ stands for any one of the four kinds of functions $J_\nu(z)$ $Y_\nu(z)$, $H_\nu^{(1)}(z)$ $H_\nu^{(2)}(z)$, then

$$(2\nu/z)C_\nu(z) = C_{\nu-1}(z) + C_{\nu+1}(z)$$
$$2dC_\nu(z)/dz = C_{\nu-1}(z) - C_{\nu+1}(z)$$

and hence

$$z^\nu C_{\nu-1}(z) = d[z^\nu C_\nu(z)]/dz$$
$$z^{-\nu}C_{\nu+1}(z) = -d[z^{-\nu}C_\nu(z)]/dz$$

Further properties Some differential equations can be solved in terms of Bessel functions The differential equation

$$z^2\frac{d^2y}{dz^2} + (2\alpha - 2\nu\beta + 1)z\frac{dy}{dz} + [\beta^2\gamma^2z^{2\beta} + \alpha(\alpha - 2\nu\beta)]y = 0$$

has the solutions $y = z^\alpha\,{}^\nu C(\gamma z^\beta)$ while $dy/dz^2 + (e^{-z} - \nu^2)y = 0$ has the solutions $y = C_\nu(e^{-z})$ There are series with terms containing Bessel functions whose sum can be expressed by elementary functions for example

$$\exp(iz\cos\theta) = J_0(z) + 2\sum_{n=1}^{\infty} i^nJ_n(z)\cos n\theta$$

$$1 = J_0^2(z) + 2\sum_{n=1}^{\infty} J_n^2(z)$$

$$e^{iuz} = (\pi/2z)^{1/2}\sum_{n=0}^{\infty} i^n(2n+1)J_{n+1/2}(z)P_n(u)$$

In the last formula the functions $P_n(u)$ are the Legendre polynomials There are also addition theorems of the type

$$J_0(x \pm y) = J_0(x)J_0(y) + 2\sum_{n=1}^{\infty}(\mp 1)^nJ_n(x)J_n(y)$$

Bessel functions are also useful because many definite integrals can be expressed in terms of Bessel functions Examples are

$$\pi J_n(z) = i^{-n}\int_0^\pi e^{iz\cos\alpha}\cos n\alpha\,d\alpha \qquad (n = \text{integer})$$

$$\frac{\pi}{2}x^{1/2}[J_{1/3}(2x^{3/2}) + J_{-1/3}(2x^{3/2})] = \int_0^\infty \cos(t^3 - 3tx)\,dt$$

The last integral is called Airy's integral Definite integrals containing Bessel functions can often be expressed by elementary functions for example, $\int_0^\infty e^{-t}J_0(at)\,dt = (1 + a^2)^{-1/2}$, when the imaginary part of a is between -1 and $+1$

Expansions in terms of Bessel functions In applications one often meets the problem of expanding a function in terms of Bessel functions or expressing it as an integral with Bessel functions in the integrand

The Fourier Bessel series is a generalization of the Fourier series Let z_1 z_2 z_3 be the positive zeros of $J_\nu(z)$ for some real $\nu \geqq -\frac{1}{2}$, arranged in increasing order of magnitude Then a continuous function $f(x)$ defined in the interval $0 \leqq x \leqq 1$ can be expanded into the Fourier Bessel series

$$f(x) = \sum_{m=1}^{\infty} a_mJ_\nu(z_mx) \qquad (0 < x < 1)$$

where the coefficients a_m are given by

$$[J_{\nu+1}(z_m)]^2a_m = \int_0^1 tf(t)J_\nu(z_mt)\,dt$$

The Fourier Bessel integral is a generalization of the Fourier integral Let $f(x)$ be a continuous function such that the integral $\int_0^\infty f(x)\,dx$ exists and is absolutely convergent Furthermore let ν be a real number $\geqq -\frac{1}{2}$ Then the function $f(x)$ can be represented by an integral containing Bessel functions the Fourier Bessel integral

$$f(x) = \int_0^\infty t^{1/2}J_\nu(xt)g(t)\,dt$$

where $g(t)$ the Fourier Bessel transform of $f(x)$ is given by

$$g(t) = \int_0^\infty x^{1/2}J_\nu(xt)f(x)\,dx$$

Both representations hold also if $f(x)$ has a finite number of discontinuities, except at points of discontinuity themselves

Functions related to the Bessel function In some applications Bessel functions occur with a fixed value of $\arg z \neq 0$, for instance with $\arg z = \pi/2$ that is positive imaginary z For convenience special notations are used in such cases One defines for positive x

$$I_\nu(x) = \exp(-i\nu\pi/2)J_\nu(ix)$$
$$K_\nu(x) = (i\pi/2)\exp(i\nu\pi/2)H_\nu^{(1)}(ix)$$

These functions are called modified Bessel function and modified Hankel function or MacDonald functions of order ν For real values of $\nu \geqq 0$ the functions $I_\nu(z)$ are monotonically increasing to infinity while the functions $K_\nu(z)$ are monotonically decreasing from infinity to zero as z goes through real values from 0 to ∞

Particularly in problems for which the use of spherical coordinates is appropriate one finds Bessel functions with a factor $z^{-1/2}$ They are called spherical Bessel Neumann and Hankel functions and defined by

$$\psi_\nu^{(1)}(z) = (\pi/2z)^{1/2}J_{\nu+1/2}(z)$$
$$\psi_\nu^{(2)}(z) = (\pi/2z)^{1/2}Y_{\nu+1/2}(z)$$
$$\psi_\nu^{(3)}(z) = (\pi/2z)^{1/2}H^{(1)}_{\nu+1/2}(z)$$
$$\psi_\nu^{(4)}(z) = (\pi/2z)^{1/2}H^{(2)}_{\nu+1/2}(z)$$

These functions can be expressed by elementary functions in finite form if ν is an integer In particular

$$\psi_0^{(1)}(z) = \frac{\sin z}{z} \qquad \psi_{-1}^{(1)}(z) = \frac{\cos z}{z}$$

$$\psi_1^{(1)}(z) = \frac{-\cos z}{z} + \frac{\sin z}{z^2}$$

$$\psi_{-\frac{1}{2}}^{(1)}(z) = \frac{-\sin z}{z} - \frac{\cos z}{z^2}$$

See FOURIER SERIES AND INTEGRALS [J ME]

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Beta function

A generalization of the binomial coefficient $\binom{\lambda}{n}$ to general noninteger values of λ and n The beta function is related to the Bessel and gamma functions and all are useful in mathematical analysis *See* BESSEL FUNCTIONS, GAMMA FUNCTION

Beta rays

Fast charged particles emitted from certain radioactive nuclei These particles which are all identical except for the sign of their charge are classified as *positrons* (+) *and negatrons* (−) The latter class is identical with atomic electrons The kinetic energies range from zero up to 3–5 Mev For the theory of β decay, *see* RADIOACTIVITY *See also* ALPHA RAYS, ELECTRON, POSITRON

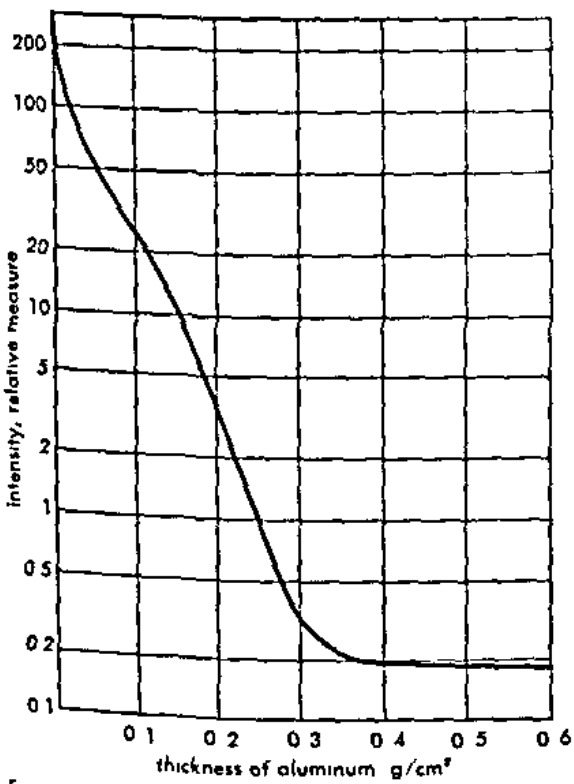


Fig 1 *The intensity of β rays from indium 116 on passage through aluminum (From J M Cork, Radioactivity and Nuclear Physics 3d ed, Van Nostrand 1957)*

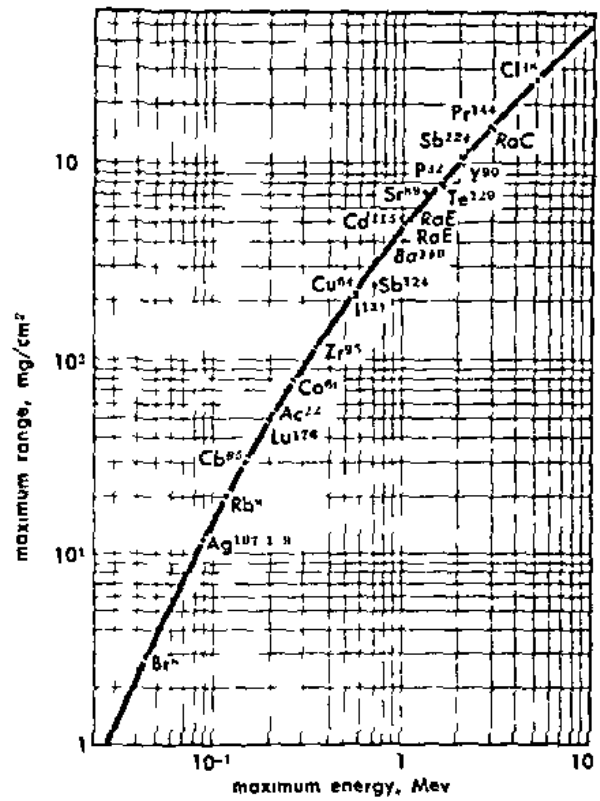


Fig 2 *The dependence of the range ρx of β rays on their energy (From K Siegbahn, ed, Beta and Gamma Ray Spectroscopy, North Holland Publishing Co, 1955)*

Interaction with matter. Beta rays, often designated β rays or β particles interact strongly with matter the particles are generally completely stopped in passing through one cm of solid material If various thicknesses of some material are placed across a beam of β rays the number of penetrating particles is found to decrease gradually to zero as the thickness increases (Fig 1) There is a definite thickness of absorber which is just sufficient to stop all the β particles This quantity, which is called the range of the β ray, is usually expressed as the product ρx(g/cm²) of density and thickness since then this "range" will be approximately independent of the material (Fig 2)

The passage of β rays through matter is macroscopically observable as heat, due to the kinetic energy dissipated This radiation also may promote certain chemical reactions and cause structural changes in materials, for instance the discoloring of glass

The track of a fast electron as observed in a photographic emulsion does not follow a straight line until the particle is stopped but zigzags in a random way because of collisions with the much heavier nuclei A β particle loses its energy by excitation and ionization of atoms and at higher energy also by emitting bremsstrahlung, or brake radiation, when scattered (*see* BREMSSTRAHLUNG) The first class of energy loss may be pic

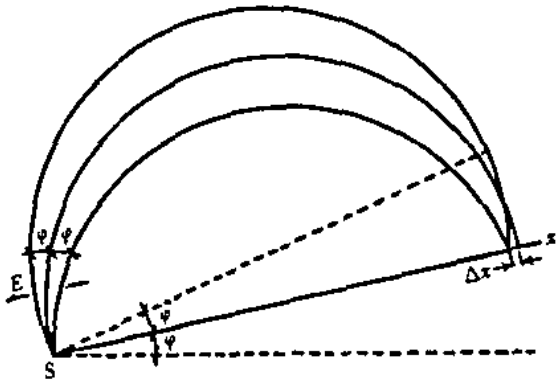


Fig 3 Principle of the semicircular spectrometer The magnetic field lines are perpendicular to the paper The dashed lines are diameters of the circular orbits

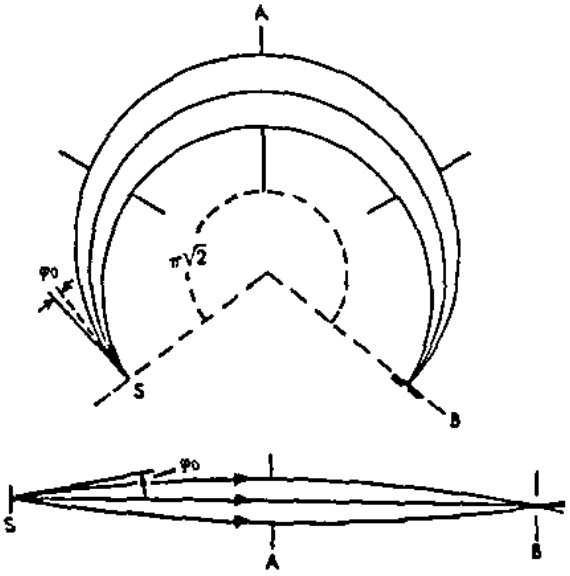


Fig 4 In the double focusing spectrometer, the beam from source S is focused on detector slit B (*From K Siegbahn, ed , Beta and Gamma Ray Spectroscopy, North Holland Publishing Co* 1955)

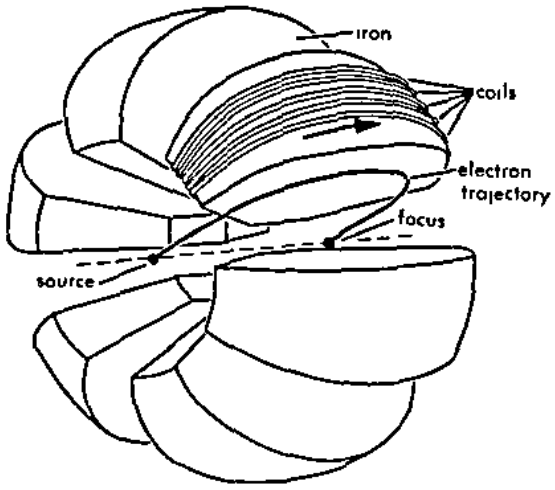


Fig 5 Orange spectrometer (*From K Siegbahn ed , Beta and Gamma Ray Spectroscopy North Holland Publishing Co , 1955*)

tured as an inelastic collision with a bound electron which thus reaches a higher energy state The energy absorbed may or may not be sufficient to liberate the electron When a β particle passes near a nucleus the electrostatic attraction deflects its path When so accelerated the electron emits one or more bremsstrahlung quanta This type of energy loss increases strongly with the atomic number of the absorber and becomes important in heavy elements at energies of a few Mev

Apart from the stopping process which proceeds similarly, negatrons and positrons behave differently in matter Usually after it has been stopped the positron combines with an atomic negatron and both vanish (annihilate) The two electron masses appear in the form of the electromagnetic energy of two photons, each of energy 0 511 Mev, which are emitted in opposite directions in order to conserve momentum Preliminary to annihilation the positron negatron pairs form bound systems, called positronium atoms *See* Positronium

Detection of beta rays. Beta detectors may function so as to produce visible tracks of the particles, as in photographic emulsions and cloud chambers, or may give a signal at the advent of each individual particle A detector may also indicate the total amount of radiation incident in a definite time All detectors work on the principle of observing the interaction with matter, in particular ionization and excitation For further information, *see* Particle detector and the articles listed therein

Beta ray spectrometers. These are used for measuring the energy or momentum distribution of β particles The energy of an electron is in principle inferred from the way it is influenced by a magnetic field If a charged particle is moving perpendicularly to the flux of a uniform magnetic field its orbit is bent into a circle of radius ρ The momentum is found to be proportional to the product $B\rho$ of radius and magnetic flux density *See* Electron motion in vacuum

A simple and generally used spectrometer is the semicircular type, shown schematically in Fig 3. From the electrons that leave the source in all directions a thin bundle (represented by an angular spread 2ϕ in Fig 3) is selected by the entrance slit E to improve resolution Particles of a definite energy move in congruent circles and are brought to a focus after going through an angle of 180° Particles of different energies come to a focus at different distances The particles may be detected by means of a photographic plate along the focal line x which permits the simultaneous recording of a large energy range The angular spread 2ϕ allowed by the finite slit width introduces a spread Δx in the position at which the particle strikes the photographic plate Alternatively a Geiger counter may be located at a fixed distance from the source and the field strength varied to focus one energy after another on a slit in front of the counter Whereas this instrument can focus a bundle of electrons divergent in the plane of the

figure it does nothing to collect particles which originally make an angle with this plane

Focusing in both directions is achieved by using a cylindrically symmetric field with a density decreasing radially as $(\rho)^{1/2}$ (Fig 4) This spectrometer can be used only with a fixed counter position

An important figure of merit for a spectrometer is its resolving power usually given by the width at half height of a peak due to electrons of a definite energy Although both instruments described have been shown to yield relative peak widths down to 0 02% the latter type realizes the same resolving power with appreciably higher transmission that is it accepts a larger percentage of the electrons emitted Most of the precise work in β spectroscopy is done with such double focusing spectrometers

There exist many types of spectrometers which make use of the focusing properties of magnetic lenses (*see* MAGNETIC LENS) They have found application especially in cases where high transmission is more important than high resolution

An instrument with exceptionally high transmission is the so called orange spectrometer (Fig 5) which essentially is a number of modified double focusing spectrometers employing a common source and a common detector [C B]

Bibliography R D Evans *The Atomic Nucleus* 1955 K Siegbahn (ed) *Beta and Gamma Ray Spectroscopy* 1955

Betatron

A device for accelerating electrons in an evacuated ring through which magnetic flux is changing The electrons are confined to the ring shaped region by a magnetic guide field which bends the electrons in a circular orbit and focuses them by means of a radial gradient of the magnetic field Both the flux through the orbit and the guide field at the orbit are varied together in such a way that the orbit radius remains constant The betatron has reached a maximum energy of 340 Mev For further information *see* PARTICLE ACCELERATOR [W K H P]

Betel nut

The dried ripe seed of a palm tree *Areca catechu* a native of Ceylon and Malaya which attains a height of 30–50 ft The nuts slightly larger than a chestnut when broken open have a faint odor and a somewhat acrid taste Betel nuts are chewed by the natives together with the leaves of the betel pepper *Piper betle* and lime The mixture discolors and eventually destroys the teeth Frequently habitual chewers of the nut are toothless by the age of 25 years The seeds contain a narcotic and produce some stimulation and a sense of well being *See* PALMALES [P D S]

Betelgeuse

Alpha Orionis a very bright cool red supergiant star spectral type M2 temperature near 3000°K Typical of the low temperature end of the supergiant sequence Betelgeuse varies in light and velocity in periods of about 6 years Because of high luminosity and low temperature it has an enormous radius (about as big as the orbit of Mars) 300 times that of the Sun The angular diameter was measured by the stellar interferometer on Mount Wilson found to be variable 0 034 to 0 047 of arc the largest among the only half dozen stars with measurable disks The mean density of the star is only 5×10 g/cm^3 In part because of its low surface gravity the atmosphere is unstable and shows outward streaming of matter at low temperature and density *See* STAR [J L CR]

Bias (electron tube)

The direct voltage used to establish the steady voltage relationship between the grid and cathode of a tube and thus to establish the operating point of the tube In most circuits the grid is made negative with respect to the cathode If the grid is biased just to the point where tube conduction stops the tube is said to be biased to cutoff and conduction occurs only when a positive input signal is applied to the grid If the tube is biased below cutoff a more positive input signal is required to cause tube conduction *See* VACUUM TUBE

The bias voltage may be established in one of several ways the particular method used depends upon the type of circuit and other factors For example the bias for a Class C amplifier is established in a different way from the method used for a Class A amplifier *See* AMPLIFIER

Grid bias In the early days of electronic circuit design a battery was connected from grid to cathode to make the grid negative with respect to the cathode This is also called fixed bias (Fig 1) This practice has long been discontinued except [illegible] be obtained

Cathode bias This method of biasing the tube is by far the most common method because it can be done so easily (Fig 2) To make the average value of the grid to cathode voltage negative the grid is grounded through a high resistance R_g and resistance R_k is inserted between cathode and ground The plate current flowing through the cath

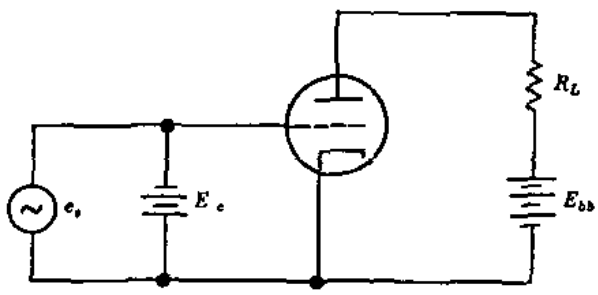


Fig 1 Fixed grid bias E_c provides the fixed bias voltage

ode circuit produces a voltage drop across R_k This makes the cathode positive with respect to ground Because the grid is grounded the grid to cathode voltage is negative The high resistance is used between the grid and ground because the input signal source also connected from grid to ground should not be loaded If biasing were the sole consideration the grid could be connected directly to ground Values for this grid resistance vary from 100 000 ohms to several megohms

Unless the cathode resistor is bypassed with a capacitor the use of cathode bias produces degeneration that is plate current variations cause the cathode potential to vary in such a way as to oppose the effect produced by the input signal The bypass capacitor C_k provides a low impedance path for these alternating components of the plate current flowing in response to an alternating input signal e_s Therefore the cathode is essentially at ground potential for alternating voltages but is above ground for direct voltages In audio amplifiers the capacitor may have a value of 10–100 microfarads depending upon the resistance of the cathode resistor and the lowest frequency expected in the input signal In rf amplifiers the capacitor can be a much smaller value An often quoted rule of thumb for choosing the size is that the capacitor reactance should be one tenth the resistance of the cathode resistor at the lowest frequency expected

Cathode bias can be used effectively for Class B amplifiers if the two tubes are identical to reduce harmonic distortion If the tubes are not identical the cathode should be bypassed

Grid leak bias If a grid resistor with a resistance of 5–10 megohms is connected from grid to ground a bias will be developed because of the flow of electrons from the grid to ground These electrons are emitted from the cathode with sufficient energy to overcome the repelling field set up by the grid and they strike the grid If the resistance is 10 megohms and the bias is 1 volt the grid current is only 0 1 microampere an extremely small fraction of the plate current In practice there is always a small grid current flowing through the grid leak resistor when cathode bias or fixed bias is used the voltage drop across the grid leak resistor being on the order of 0 1 volt

Contact bias When two dissimilar metals are placed in contact a potential difference will appear between the ends not in contact This potential is caused by the difference in work functions of the two metals and is small, on the order of 0 1 volt. The cathode and grid of a vacuum tube are made of different materials Therefore when the grid and cathode are connected together through the circuitry external to the tube, a potential difference will appear between the grid and cathode which will bias the tube [H F K]

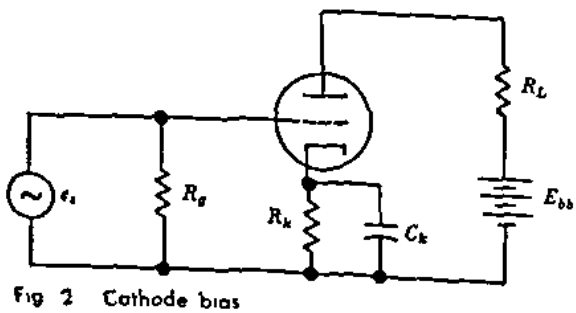
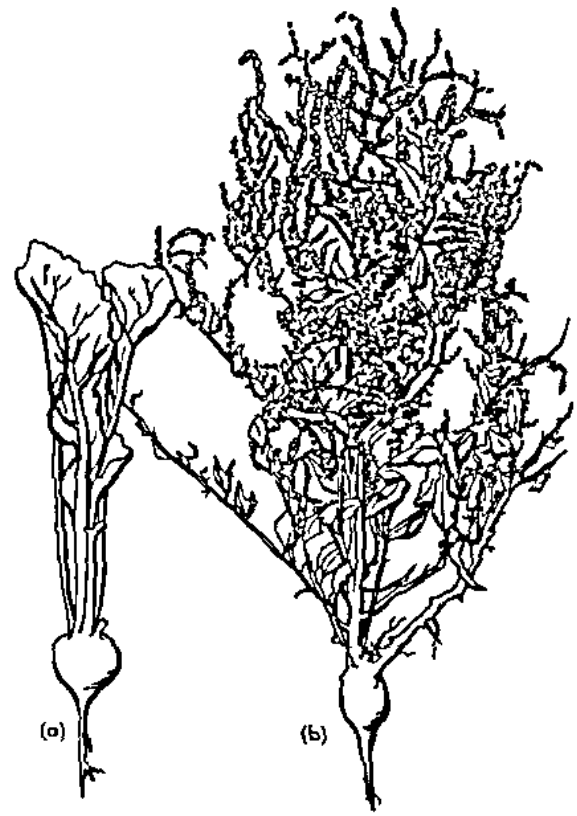


Fig 2 Cathode bias

Biennial plants

Plants which require two growing seasons to complete their life cycles During the first season the seed germinates and the seedling develops into a leafy plant which stores food in its roots At the end of the first season the aerial part of the plant dies but the root remains alive The next growing season the plant utilizing the food stored in the roots resumes growth and produces a new shoot on which flowers appear followed by fruit and seed Th , then dies , foxglove ANNUAL [P D S]



The beet a biennial food plant (a) Enlarging root during first summer (b) Utilization of reserves in production of seeds in two year-old plant (*F W Emerson Basic Botany, 2d ed , McGraw Hill, 1954*)

PLANTS, PERENNIAL PLANTS, PLANT

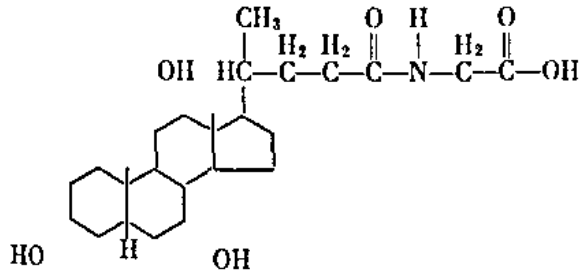
Bilateria

A major division in animal classification contrasted with the Radiata (Coelenterata plus Ctenophora), that embraces all animals with bilateral

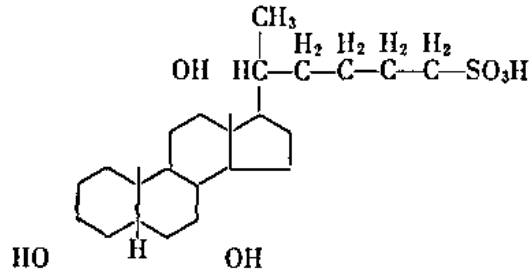
symmetry This is symmetry such that the body can be divided by one median or sagittal plane from the dorsal to ventral surface into equivalent right and left halves each a mirror image of the other It includes all phyla from the flatworms to the chordates *See* ANIMAL KINGDOM, ANIMAL SYMMETRY [TIS]

Bile acid

A steroid produced in the liver The bile acids lower surface tension promote emulsification of fat to aid in digestion and absorption of fats from the intestine The bile acids have a five carbon side chain and occur in the liver in combination through peptide linkage with glycine and taurine forming glycocholic acid and taurocholic acid respectively

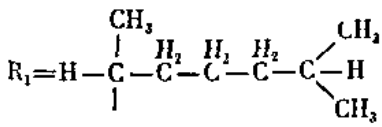


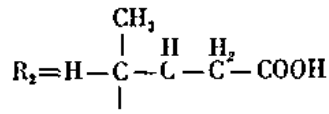
Glycocholic acid

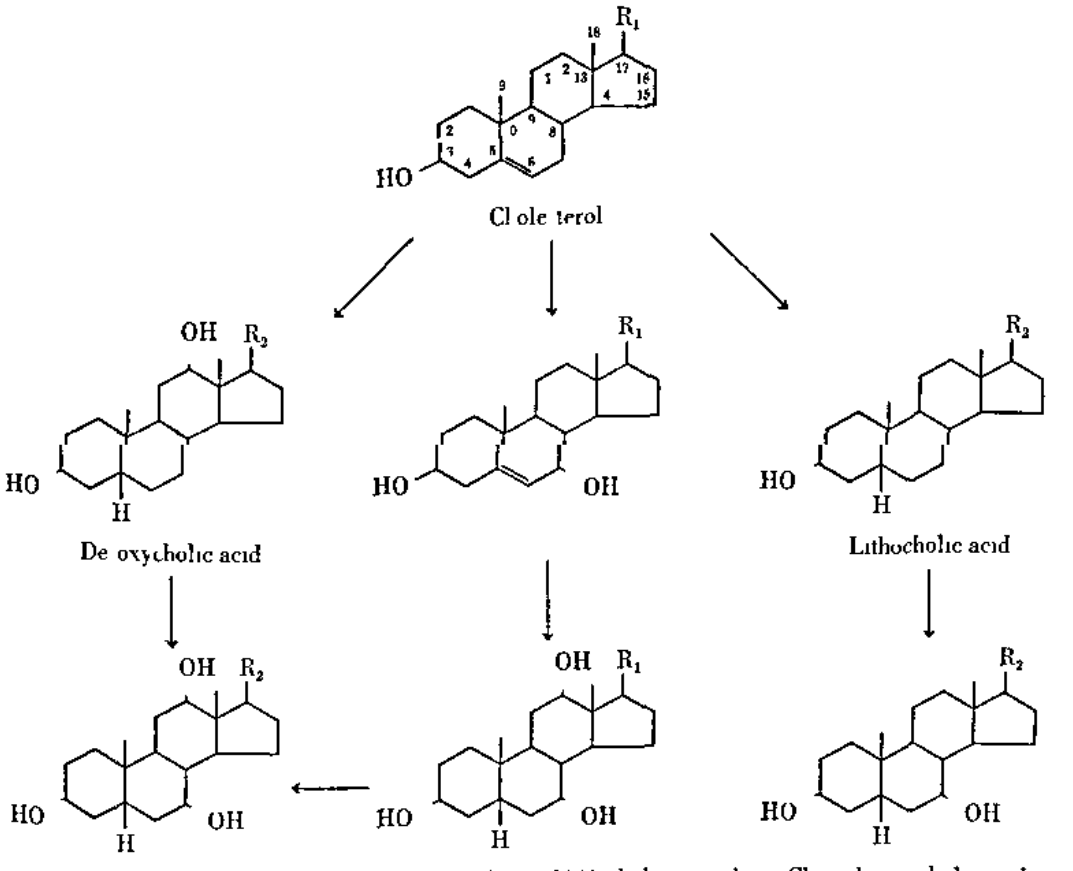


Taurocholic acid

Other bile acids are cholic deoxycholic, lithocholic and chenodeoxycholic acids The structures and probable pathways of biosynthesis from cholesterol are shown below *See* LIVER STEROID STEROL [RID]







Probable pathways of biosynthesis of bile acids from cholesterol

Bilirubin

The orange pigment of normal human bile It is produced by the metabolic degradation of senescent red blood cells brought about by the phagocytic action of the reticuloendothelial cells of the spleen liver and bone marrow Its immediate precursor is biliverdin from which it is produced by reduction It is a tetrapyrrole chain compound From the site of its formation it is transported to the liver partly as a glucuronide and partly in other forms Most or all of the bilirubin excreted in the bile is the glucuronide In the intestine the bilirubin undergoes changes by the intestinal flora to form the characteristic brown pigment of the feces stercobilin Some of the intermediates are absorbed by the intestinal mucosa carried to the liver and either reexcreted into the intestine or transported to the kidney where they are converted to urobilin which in peptide combination constitutes the characteristic pigment of urine The excretion of urochrome in man is very constant from day to day while the ratio of urochrome to creatinine excretion is closely correlated with the basal metabolism *See* LIVER PHAGOCYTOSIS SPECIALIZED TISSUE [H H MI]

Bibliography C H Gray *The Bile Pigments* 1953

Binary number system

A system in which numbers are represented as linear combinations of powers of 2 Below is shown the relationship between the binary system and the decimal system

Decimal notation	Binary notation
$3 = 1 \times 2^1 + 1$	$= 11$
$7 = 1 \times 2^2 + 1 \times 2^1 + 1$	$= 111$
$17 = 1 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1$	$= 10001$

The binary system has come into importance because of its value in computer applications *See* NUMBER SYSTEMS

Binary stars

In astronomy pairs of stars located sufficiently near each other in space to be connected by a mutual bond of gravitational attraction that compels them to describe an orbit around a common center of mass This definition encompasses in turn a diversity of objects of great intrinsic interest which manifest themselves to the observer in a variety of ways Because of their relation to each other binary stars provide a means for comparing one star to another Much information on the properties of stars has come from studies of binaries

Distinguishing features In that part of the galaxy in which we happen to be situated encounters between stars would dissolve pairs with separations exceeding 100 000 astronomical units (AU) or about half a parsec before they would have a chance to describe a revolution this represents an upper limit to the size of their orbit Binaries with separations of 10 000–100 000 AU are known Because their orbital periods (for stars of average masses) are by virtue of Kepler's third law 10 to 10 years their orbital motions are imperceptible in comparison with their translation through space within the life span of a few generations, the only way by which such binaries can reveal their identity is as pairs of stars of common proper motion

Visual binaries If the mutual separation of both components is 100 10 000 AU the orbital motion can become noticeable 150 years after such stars are first studied These are visual binaries, they can be identified by visual telescopes of sufficient resolving power These should not be confused with optical binaries which are pairs of stars that project themselves accidentally in nearly the same direction but are at widely different distances in space from each other Such optical binaries can be distinguished from real couples only in the course of time as any two stars seen accidentally close together will neither exhibit orbital motion nor share a common proper motion through space

Several thousands of visual binaries whose components are connected by the bond of mutual attraction have so far been detected among the 17 180 stars catalogued by R G Aitken The apparent separation of the closest binaries listed in 1932 and checked since by modern observing techniques is about 0 1 their orbital periods (if such a system happens to be nearby) can be as short as a few years

Whenever the apparent motion of one component of a visual binary is referred to the other the relative orbit of the two stars proves to be an ellipse with the reference star at a focus (Fig 1) This fact alone was sufficient to establish that gravitation follows the inverse square law outside the confines of our solar system

From these facts it transpires that binary stars can be visually detected only within a limited distance from the Sun at greater depths in space

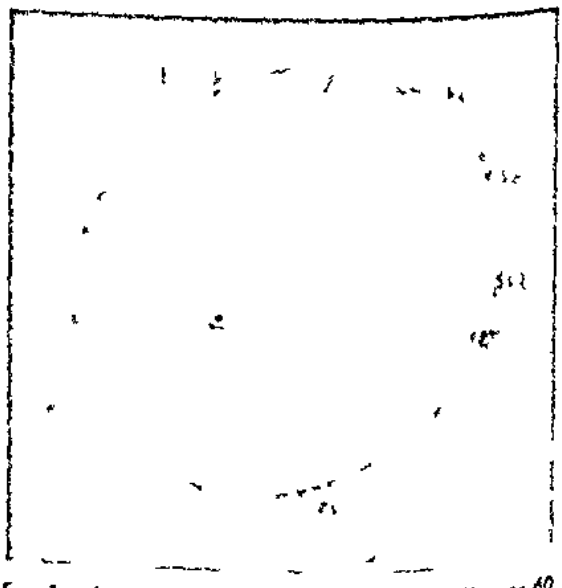


Fig 1 Apparent orbit of the visual binary Kruger 60

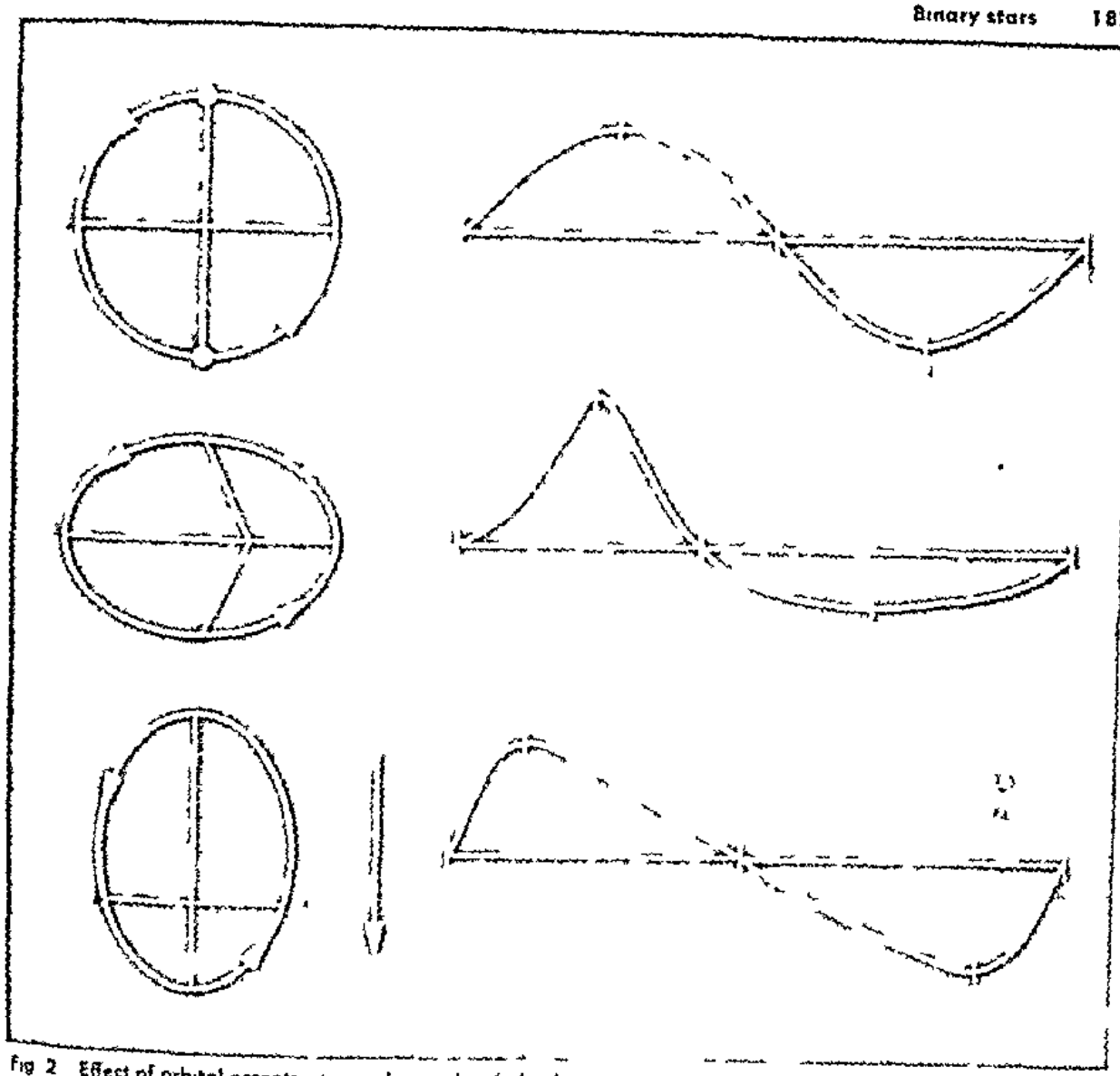


Fig 2 Effect of orbital eccentricity on observed radial velocity

than a few hundred parsecs all physical binaries are optically unresolvable

Spectroscopic binaries On the other hand the increasing proximity of the components shortens their orbital period and thus increases the absolute velocity of motion around the common center of gravity If moreover their mutual separation is less than say 10 AU the actual velocities of revolving stars can be detected from the Doppler shifts measurable on lines of their spectra

This phenomenon arises from the configuration of the components of a binary system (Fig 2) When stars A and B are in the positions 1 and 3 (conjunctions) their radial velocities in the direction of the observer are zero and the Doppler shifts of spectral lines if any will be indicative of the space velocity of the system as a whole After passing through position 1 star A begins to approach the observer and star B starts to recede The radial velocities of the stars become maximum in positions 2 and 4 (quadratures) at which time identical lines in the spectra of each component are neatly split (Fig 3) thereafter to diminish and disappear half way through a cycle A plot of observed radial velocity against phase of star B results in a sinusoid (Fig 2) The similar plot for star A would be mutually displaced in phase by half a period These curves become skew symmetrical if the orbit is eccentric Moreover the amplitudes of the radial velocity curves of both components (proportional to their distance from the center of gravity of the system) are in inverse proportion to their mass ratios

Such stellar couples which reveal their identity by periodic variation of their radial velocity are referred to as spectroscopic binaries The amplitudes of their radial velocity changes may range from a few kilometers per second for wide systems (orbital periods of several months) to many hundred kilometers per second for close systems The greater this velocity the more conspicuous the Doppler shift hence the probability of discovery of a spectroscopic binary (unlike the probability

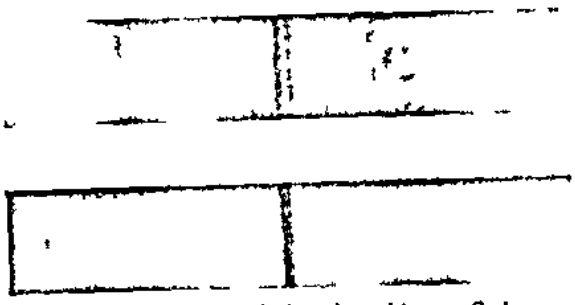


Fig 3 The spectra of the close binary β Aur gae ($P = 3.960$ days) at conjunctions (below) and quadratures (above) the latter showing the spectral lines of both components separated on account of Doppler shift

pair and the shorter its orbital period regardless of their distance in space from the observer

Over 520 spectroscopic binaries have been discovered and the elements of their orbits determined

Eclipsing binaries If eventually a system becomes so close that the absolute size of its components is no longer negligible in comparison with their separations (which may be 0 1 10 AU) and moreover their orbital plane is but little inclined to the line of sight it can happen that at the times of the conjunctions one star eclipses a part or even the entire disk of the star beyond it and half a revolution later the star formerly obscured will now eclipse its mate

The effect of such stellar eclipses for a distant observer should be a periodic variation of light from the system which can be detected and measured by suitable photometers Close couples of the stars that reveal their identity by their characteristic variation of light are known as eclipsing binaries and constitute by far the most important group of all double stars by the amount of information which they can disclose about their constituents The overwhelming part of our present knowledge of the properties of individual stars has been extracted from the observable evidence offered by eclipsing binaries

Light curves To appreciate the extent of the information available from binaries consider diverse photometric manifestations of stellar eclipses (Fig 4) Light changes to be expected if the two minima of light arise from an alternation of total and annular eclipses are shown at Fig 4*a* The duration of the eclipses from the first to the last outer contact is given by the duration of the minima the duration of the totality or annular phase is specified by that of the standstill at the bottom of the respective minimum The deeper minimum corresponds always to an eclipse of the component of greater surface brightness but whether this star is the larger or the smaller of the two must be ascertained by other analysis

Light changes to be expected if both minima are due from partial eclipses are shown in Fig 4*b* As long as the dimensions of both components are sufficiently small in comparison with their separation for their form to remain essentially spherical the total light of the system should remain sensibly constant between eclipses If however the two stars are close their mutual illumination is bound to invoke an additional variation of light between minima called the reflection effect (Fig 4*b*) If moreover the proximity of the components is such that the tides which the stars raise on each other lead to an appreciable deformation of their form the light of the system varies continuously the variation is called the ellipticity effect (Fig 4*c*)

In the foregoing examples the orbit of the components in eclipsing binary systems is circular—in which case the alternate minima are symmetrical of equal duration and separated by exactly half the period Should the orbit be eccentric the three features may break down to a varying extent (Fig 4*d*)

Each eclipsing variable must also be a spectroscopic binary (though the converse is not necessarily true) and because the light changes of a star are much easier to detect and study than variable radial velocity the number of eclipsing binaries with known periods already exceeds 2700 The effects of observational selection on the discovery of binary systems suggests that their actual total num

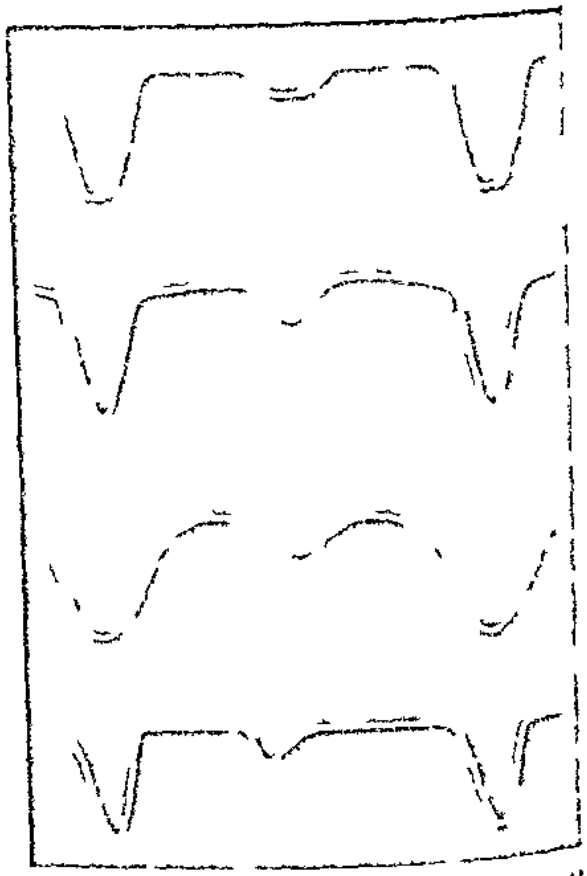


Fig 4 Light variations from eclipsing binaries (*a*) Alternation of total and annular eclipses (*b*) Partial eclipses (*c*) Tidal deformation (*d*) Eccentric orbit with total and annular eclipses

ber in our own galaxy alone is probably several hundred millions which is so many as to be quite beyond the hope of individual discovery Eclipsing close binaries are therefore no exceptional or uncommon phenomena

Information obtained from binaries With visual binaries micrometric or interferometric measurements of their relative positions permit the tracing of their apparent orbit in the sky Knowledge that the apparent orbit must represent the projection of an ellipse with one star at the focus of the relative orbit allows the reconstruction of the form of the actual orbit in space as well as its inclination to the line of sight by purely geometrical methods Many of these have been developed in the past With the aid of such methods the elements defining the visual orbits of approximately 120 binary systems have been determined The orbital planes of such systems appear to be inclined at random to the galactic plane and their semimajor axes are likewise orientated at random in space

Component masses The most interesting physical data deduced from the measurement of visual double stars are the masses of their constituent components If the apparent semimajor axis a'' of at least the relative orbit of the two stars is known in addition to the distance (parallax π) of the system the absolute dimension of the orbit equals a''/π AU and the total mass $m_1 + m_2$ of the system is from Kepler's third law $m_1 + m_2 = (a''/\pi)^3/P^2$ in solar masses where P denotes the orbital period of the respective pair in years

If however the absolute orbits of both components around their common center of mass have been established in angular units with reference to the fundamental system of coordinates and a''_1 a''_2 denote their respective semimajor axes the mass ratio of the components follows as $m_1/m_2 = a''_2/a''_1$ which opens at once the clue to the individual masses of the two stars

In practice this method is not of wide application because of the required knowledge of parallax π which for most visual binaries is much smaller than either a''_1 or a''_2 and can be significantly established only for stars within say 100 parsecs from us The total number of visual binaries that have thus furnished a knowledge of the masses of their components barely exceeds 24 as compiled by P v de Kamp K A Strand and R G Hall

With spectroscopic binaries the measured Doppler shifts furnish absolute velocities of the orbital motions therefore a knowledge of the parallax of such stars is unnecessary The measured velocities refer moreover to the absolute motion of each component around the center of mass of the system and if the lines of both components can be seen in the combined spectrum their mass ratio follows from the amplitudes of both velocity curves These amplitudes combined with the known orbital period would permit a determination of the absolute masses of the two components as well as the size of their absolute orbits provided only that the inclination i of the orbital plane to the line of sight were known but this is precisely what spectroscopic observations alone cannot specify

Component dimensions The missing data can be supplied by the photometric evidence whenever the respective system happens also to be an eclipsing variable An analysis of the observed light changes can furnish the fractional dimensions of both components (expressed in terms of their separation) as well as the value of the inclination i with considerable precision A combination of the photometric and spectroscopic elements of spectroscopic (two-spectra) binaries that happen also to be eclipsing variables then offers means for a determination of absolute masses and of the absolute dimensions of their components without appeal to their distance or particular laws of radiation Such systems (those with reliable elements have been compiled by Z Kopal and M B Shapley) are the astronomer's principal source of information concerning the masses and absolute dimensions of the individual stars and are the only source of this information of which only a minute trickle has to date been tapped available so far for massive stars Even that minute amount has provided the bulk of the observational data at the basis of all empirical mass luminosity or mass radius relations produced so far If in addition the parallax of any such system happens to be known the observed data lend themselves to a determination of effective temperatures of its constituent components

Internal composition A combination of masses and absolute dimensions of the stars obtained in this way has provided the basis for investigations of the chemical composition of stellar interiors such as the ratios of hydrogen to helium from the observed rate of energy production and the ratios of hydrogen to heavy elements from the amount of opacity hindering the light flow

Even the density distribution inside the stars can be inferred from phenomena observable in close binary systems The gravitational field emanating from invisible interiors which the opaque surface layers cannot appreciably modify is one phenomenon and radiant energy originating likewise in the deep interior and governing the distribution of brightness over the visible surface of the star is another

As long as a star is single there is no way of gaging its external gravitational field or learning about the distribution of brightness on its surface With another star in its proximity as in a binary system if their orbit happens to be eccentric information on the degree of internal density concentration can be inferred from measurable apsidal advance The variation of light induced by axial rotation of tidally distorted components or exhibited during their mutual eclipses permits us to ascertain the distribution of surface brightness over the apparent disks of the constituent stars Nonradial oscillations of tidal origin invoked by vary

ing radius vectors in close eccentric systems enable us to study the extent to which actual stellar configurations behave like perfect fluids

Stellar evolution Close binary systems supply material for studies of stellar evolution in almost all its stages When binary systems are formed (probably by simultaneous condensation of matter around two nearby centers in the parent association) their components represent objects of the same age and chemical composition Should their initial masses be unequal their evolutionary courses (such as the burning of hydrogen and later of helium) will proceed in general at different rates and the binaries as observed today confront us with the outcome

The hydrogen depletion characteristic of the post main sequence stage impels an aging star to expand in size Should this star be single there is no ready way of identifying it in this act or measuring the extent of expansion If it is the component of a close binary the combined mass envelops both stars with a dynamical barrier called the Roche limit which no component can exceed A clustering around this limit of secondary components of a class of eclipsing binaries with the system of Algol as its typical representative attests that the tendency to expand appears to be operative in such stars whose further growth has merely been arrested at the Roche limit

Another requirement of modern theories of stellar evolution is that a star in post giant stage should get rid of a major part of its mass before settling down to white dwarf stage How otherwise could there be a double star like the system of *Sirius consisting* of an early type main sequence star attended by a white dwarf considerably less massive than its mate? How otherwise could the white dwarf have overtaken its still brilliant mate in its evolutionary course unless for a major part of its past the dwarf were the more massive of the two?

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tion of the separation of their components mainly because different groups need to be studied by dif[illegible]

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tion (or common proper motion) Spectroscopic binaries can be found with modern reflectors up to distances of a few hundred parsecs but beyond this limit double stars can be detected only if they happen to be eclipsing variables

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double (or multiple) systems Beyond this limit observational material grows fragmentary but eclipsing variables have already been detected in all parts of our own galactic system (including its central bulge) accessible to observation and in some external galaxies such as the great nebula in Andromeda This indicates that their formation and existence represent processes probably operating over the entire known universe

Multiple systems Pairs of stars close or wide do not represent the only stable configurations of stars traveling together through space Multiple systems consisting of three or more stars bound by mutual attraction exist in significant numbers even among naked eye stars The structure of such systems is characteristic for whenever a symbiosis of three or more stars is encountered they invariably constitute a wide pair one or both components of which are close doubles so that if the wide pair can be resolved as a visual binary the close pair is likely to be a spectroscopic one In extreme cases triple or quadruple systems of this type may be attended by a further distant star which may itself be a close double, thus giving rise to known quintuple or even sextuple systems

Frequently the distant companion of a close binary may be too faint in comparison with the former to permit optical resolution, but it may still reveal its presence by inducing the close pair to revolve with it around the common center of gravity

The eclipsing system of β Persei (Algol) is an example of this type its close pair revolving in a period of 2 867 days is attended by a distant companion at least a hundred times fainter than the eclipsing system and revolving around the common center of gravity in a markedly eccentric orbit ($e = 0\,2$) in a period of 1 873 years Nobody has seen this third body but its presence is evidenced by observed fluctuations of the systemic radial velocity of the orbital period as well as of the apparent position of the eclipsing system of Algol in the sky and traces of it have also been noted in the combined spectrum of the system Algol is not the only eclipsing system known to be attended by a stellar companion of this type some 10% seem to possess them

An example of a quadruple stellar system among naked eye stars is ζ Ursae Majoris (Mizar) consisting of a well resolved visual pair ($a = 2\,54$) of period 59 86 years each component of which is in turn a close double The brighter one constitutes an object on the borderline between visual and spectroscopic binaries ($a = 0'05$ $P = 1\,832$ years) while the fainter is a typical spectroscopic binary with a period of 3 981 days

The star Castor (α Geminorum) represents an even more remarkable example of a sectuple system consisting as it does of an easily resolved visual double ($a = 5\,84$ $P = 340$ years) whose components are spectroscopic binaries of period 9 222 and 2 928 days This system is attended at a distance of 73′ by a much fainter stellar companion (Castor C) which is an eclipsing binary with a period of 0 814 days revolving around the center of gravity of the whole system with a period in the order of 25 000 years

The origin of the numerous double or multiple systems in the sky is not yet known with assurance but it appears probable that double and multiple stars originated concurrently with single stars from interstellar gas and dust clouds and by much the same process binary and multiple stars arising from simultaneous condensation around two or more mass centers which happened to be within the bonds of mutual gravitational attraction from the outset or possibly by the capture of one star by another in the earliest stages of a new born association while the density of stars per unit volume was sufficiently high to make capture possible But whatever may have happened at that stage it is virtually certain that the process of multiple star formation must have been terminated following the dispersal of the original association and the principal characteristic acquired then would be preserved for astronomically long intervals of time—apart from widely separated objects at the extreme fringe of double star population—at least until their components have attained post main sequence evolutionary stages with consequent loss of mass *See* STAR [Z K]

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Binaural sound

Sound that exists at the locations of the two ears In a binaural sound system sound is recorded or transmitted using two microphones mounted at the ears of a dummy human head To preserve the binaural effect the sound must be monitored by a listener wearing a set of earphones identically spaced In an ideal binaural transmission system both the amplitude and phase of the sound waves incident on the dummy s ears are duplicated at the listener s ears

Binaural systems have been made so perfect that the listener is unable to distinguish the monitored sound from the real sound For example when a person walks around the dummy head the listener upon hearing the footsteps has the compelling illusion of someone walking around him No other sound system thus far devised can even approximate such an effect

Binaural sound reproducing systems may never become popular because of the inconvenience having to wear a set of earphones during the rendition of a recording to obtain the true binaural effect *See* HEARING STEREOPHONIC SOUND [K W P]

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Binding energy, nuclear

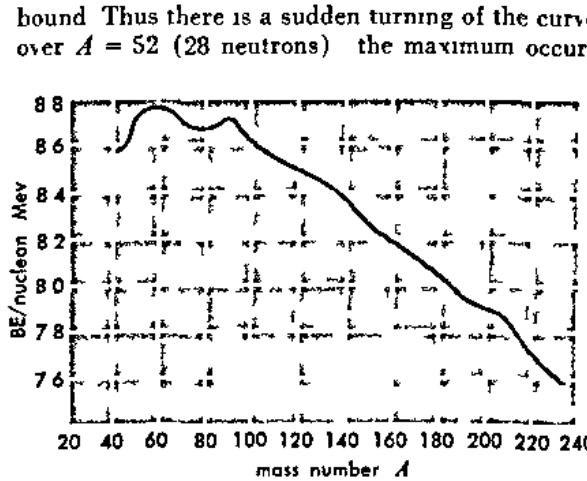
The amount by which the mass of an atom is less than the sum of the masses of its constituent protons neutrons and electrons expressed in units of energy This energy difference accounts for the stability of the atom In principle the binding energy is the amount of energy which was released when the several atomic constituents came together to form the atom Most of the binding energy is associated with the nuclear constituents (protons and neutrons) or nucleons and therefore it is customary to regard this quantity as a measure of the stability of the nucleus alone *See* NUCLEAR STRUCTURE

A widely used term the binding energy (BE) per nucleon is defined as follows

$$\text{BE/nucleon} = \frac{[ZH + (A - Z)n - {}_ZM^A]c^2}{A}$$

where ${}_ZM^A$ represents the mass of an atom of mass number A and atomic number Z H and n are the masses of the hydrogen atom and neutron respectively and c is the velocity of light The binding energies of the orbital electrons here practically neglected are not only small but increase with Z in a gradual manner thus the BE/nucleon gives an accurate picture of the variations and trends in nuclear stability The accompanying figure shows the BE/nucleon (in million electron volts) plotted against mass number for $A > 40$

The BE/nucleon curve at certain values of A suddenly changes slope in such a direction as to indicate that the nuclear stability has abruptly deteriorated These turning points coincide with *particularly stable configurations, or nuclear shells* to which additional nucleons are rather loosely bound Thus there is a sudden turning of the curve over $A = 52$ (28 neutrons) the maximum occurs



Binding energy per nucleon for atoms (*After H E Duckworth*)

in the nickel region (28 protons $\sim A = 60$) the stability rapidly deteriorates beyond $A = 90$ (50 neutrons) there is a slightly greater than normal stability in the tin region (50 protons $\sim A = 118$), the stability deteriorates beyond A = 140 (82 neutrons) and beyond A 208 (82 protons plus 126 neutrons)

The BE/nucleon is remarkably uniform lying for most atoms in the range 5–9 Mev This near constancy is evidence that nucleons interact only with near neighbors that is nuclear forces are saturated

The binding energy when expressed in mass units is known as the mass defect a term which is sometimes incorrectly applied to the quantity $M - A$ where M is the mass of the atom [H F D]

The term binding energy is sometimes also used to describe the energy which must be supplied to a nucleus in order to remove a specified particle to infinity for example a neutron proton or α particle A more appropriate term for this energy is the separation energy This quantity varies greatly from nucleus to nucleus and from particle to particle For example the binding energies for a neutron a proton and a deuteron in O^{18} are 15 60 12 11 and 20 72 Mev respectively while the corresponding energies in O^{1} are 4 14 13 76 and 14 03 Mev respectively The usual order of neutron or proton separation energy is 7–9 Mev throughout most of the periodic table [D H W]

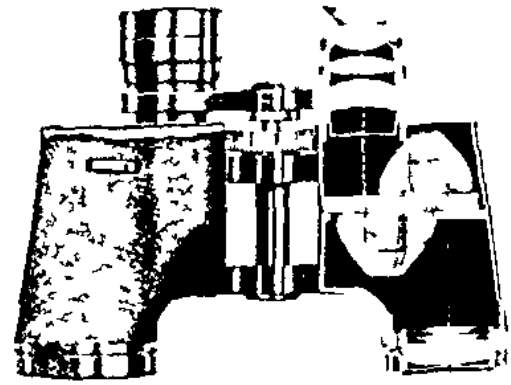
Binoculars

Optical instruments designed for use with both eyes to give enhanced views of distant objects The distinguishing performance feature of binoculars compared to monocular instruments is the depth perception obtainable

When an object is viewed with both eyes the distance of approximately 65 millimeters between the eyes requires each to view the object from different angles To bring the images onto the fovea centralis of each eye the eyes rotate inward until the lines of sight converge at the object This convergence is the signal to the brain which stimulates the sense of depth and its magnitude is the parameter from which judgment of depth is made When two objects fall within an observer's view but are located at different distances their respect[illegible]

[illegible] between convergence angles which the average adult can detect is about 30 seconds of arc which is approximately the value corresponding to an object at 500 yards The convergence angles for more distant objects are less and therefore objects beyond 500 yards cannot be resolved stereoscopically

With binoculars this range can be greatly extended Binoculars employing prism erecting systems (see illustration) can be so constructed that the distance between objectives is twice that between the eyepieces Hence if the convergence angle at an object subtended by the unaided eyes is α the angle subtended by the binocular objectives is 2α This angle in the real field of the binocular becomes $2M\alpha$ in the apparent field M being the magnification of the binocular Thus the minimum convergence angle in the real field becomes (30 sec)/$2M$ and the maximum range at which objects can be resolved stereoscopically using for example a 7 power binocular is extended to about 7000 yards



A modern high-quality prism binocular (Bausch and Lomb Optical Co)

To ensure freedom from fatigue and eyestrain for the observer the optical axes of the binocular halves must be aligned parallel to each other within a few minutes of arc A complicating factor in the maintenance of this parallelism is the hinge mechanism joining the two halves which is provided to allow adjustment of the intereyepiece distance to match the distance between the observer's eyes The accuracy to which the parts must be made and the requirement of absolute stability of parts after assembly to provide and maintain parallelism largely account for the higher cost of quality binoculars compared to monocular telescopes *See* MAGNIFICATION TELESCOPE [H E R]

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Binomial theorem

One of the most important algebraic identities which has many applications in a variety of fields The binomial theorem discovered by Sir Isaac Newton expresses the result of multiplying a binomial by itself any number of times

$$(a+b)^n = a^n + c_1a^{n-1}b + c_2a^{n-2}b^2 + c_3a^{n-3}b^3 + \cdots + c_ra^{n-r}b^r + \cdots + b^n$$

where the coefficients c_1 c_2 c_3 $\cdots$ c_r $\cdots$ are

$$c_1 = \frac{n}{1} \qquad c_2 = \frac{n(n-1)}{1\ 2} \qquad c_3 = \frac{n(n-1)(n-2)}{1\ 2\ 3}$$

$$c_r = \frac{n(n-1)(n-2)\cdots(n-r+1)}{1\ 2\ 3\cdots r}$$

The standard notation for these coefficients is $c_1 = \binom{n}{1}$ $c_2 = \binom{n}{2}$ $\cdots$ $c_r = \binom{n}{r}$ $\cdots$ $\binom{n}{r}$ is the coeff

cient of the term containing b^r in the expansion of $(a+b)^n$ It is a fraction with the numerator and denominator each containing r factors those in the denominator begin with 1 and increase by 1 those in the numerator begin with n and decrease by 1 It is easily shown that $\binom{n}{r} = \binom{n}{n-r}$

$$1\ \binom{17}{3} = \frac{17\ \ 16\ \ 15}{1\ \ 2\ \ 3} = 765$$

$$2\ (a+b)^6 = a^6 + \frac{6}{1}a^5b + \frac{6\ \ 5}{1\ \ 2}a^4b^2 + \frac{6\ \ 5\ \ 4}{1\ \ 2\ \ 3}a^3b^3 + \frac{6\ \ 5\ \ 4\ \ 3}{1\ \ 2\ \ 3\ \ 4}a^2b^4 + \frac{6\ \ 5\ \ 4\ \ 3\ \ 2}{1\ \ 2\ \ 3\ \ 4\ \ 5}ab^5 + \frac{6\ \ 5\ \ 4\ \ 3\ \ 2\ \ 1}{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}b^6 = a^6 + 6a^5b + 15a^4b^2 + 20a^3b^3 + 15a^2b^4 + 6ab^5 + b^6$$

$$3\ (2x-3y)^4 = [(2x)+(-3y)]^4 = (2x)^4 + \frac{4}{1}(2x)^3(-3y) + \frac{4\ \ 3}{1\ \ 2}(2x)^2(-3y)^2 + \frac{4\ \ 3\ \ 2}{1\ \ 2\ \ 3}(2x)(-3y)^3 + \frac{4\ \ 3\ \ 2\ \ 1}{1\ \ 2\ \ 3\ \ 4}(-3y)^4 = 16x^4 - 96x^3y + 216x^2y^2 \quad 216xy^3 + 81y^4$$

Under suitable conditions the binomial formula is valid when n is not a positive integer In this case the formula does not terminate but generates an infinite series

Much of the utility of the binomial theorem stems from the properties of the coefficients In particular the coefficient $\binom{n}{r}$ gives the number of combinations of n distinct objects taken r at a time The set of coefficients for any value of n form a distribution that has fundamental importance in the study of probability and statistics *See* ALGEBRA DISTRIBUTION (PROBABILITY) SERIES [H R C]

Bioassay

A method for quantitatively determining the concentration of a substance (or class of substances) by its effect on the growth of a suitable animal plant or microorganism under controlled conditions The substance estimated may be stimulatory or essential for growth such as a vitamin or an amino acid or it may be inhibitory to growth as for example the antibiotic penicillin In its application to the estimation of vitamins amino acids and trace elements the method is an outgrowth of studies of the nutritional requirements of animals and microorganisms Such studies have revealed that nutritional requirements of exacting microorganisms are remarkably similar to those of higher animals

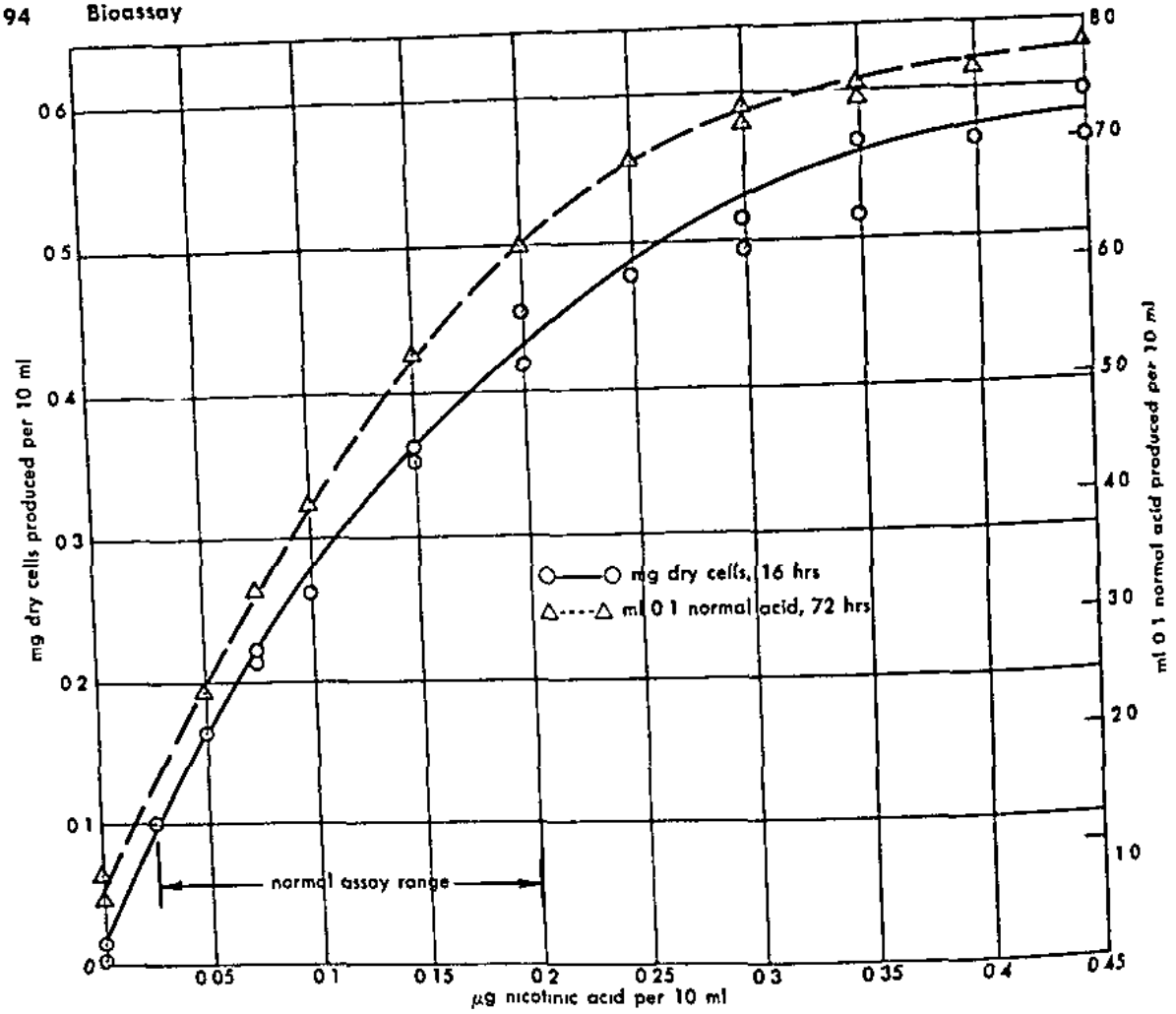
This article discusses the principles of bioassay the use of microorganisms in the assay of vitamins amino acids and antibiotics and in the standardization of disinfectants and the use of animals in bioassay

Principle Whatever organism is employed the principle involved is the same A basal diet or medium adequate in all growth requirements of the assay organism except the one to be estimated is supplied The growth response of the organism under controlled conditions is then a function within limits of the amount of the growth factor added An unknown sample is evaluated by interpolation of the growth response to known amounts of it against a standard curve established by determining in parallel the response to graded amounts of the pure test substance Methods of measuring growth response vary with the type of assay In the case of the animal assay increase in weight is the criterion used Growth response in the microbiological assay may be determined either directly by measuring turbidity dry weight of cells amount of cellular nitrogen or cell numbers or indirectly by measuring some metabolic product of the microorganisms such as CO_2 or acid

MICROORGANISM ASSAY

Use of animals for bioassay antedated use of microorganisms However the expansion of knowledge of microbial nutrition which occurred during the period 1936–1945 stimulated the development of microbiological assay methods as a routine tool for determining vitamins and amino acids in natural materials These methods possessed the required precision and were found also to be rapid convenient and remarkably sensitive for detecting the presence and for following the isolation of new vitamins or vitaminlike materials present in trace amounts in crude materials Many of these substances (nicotinic acid pantothenic acid pantetheine inositol biotin pyridoxal and pyridoxamine) were found only subsequently to be important *in animal nutrition* The development of microbiological assay methods for folic acid and vitamin B_{12} was of great aid in permitting isolation of these vitamins as well In some cases microbiological assay remains today the only rapid and specific assay available for determination of individual vitamins Microbiological assay has several advantages over animal assay It requires much less time labor and materials to perform It is consequently less expensive than animal assay and in most instances is much more precise One disadvantage of microorganisms as compared with animals as assay tools is that extraction of the vitamin from the combined forms in which most of these occur naturally is usually required to make these available to the microorganism It is generally assumed (sometimes on insufficient grounds) that animals utilize such combined forms completely This so called disadvantage of the microbiological assay as an analytical tool has proved to be an asset in that it has permitted detection isolation and quantitative determination of several hitherto unknown combined forms of the vitamins (for example pantetheine folinic acid pyridoxamine phosphate) *See* VITAMIN

Vitamin assay Microorganisms are known which require one or more of all of the water soluble vitamins except ascorbic acid Various yeasts and lactic acid bacteria have been most widely used for assay of these substances The latter group includes species in the four genera *Lactobacillus Streptococcus Pediococcus* and *Leuconostoc* and



Growth and acid production of L arabinosus as a function of nicotinic acid concentration

has been used more widely than any other organisms for assay of both vitamins and amino acids Although many modifications of the originally devised methods have been published, the methodology is similar in all cases A single procedure for the vitamin nicotinic acid (niacin) is described in detail to illustrate the general method Suitable methods for other vitamins are referred to in Table 1

1 For extraction of nicotinic acid an accurately known weight of finely ground or homogenized sample is autoclaved for 15 min in sufficient 1 N H_2SO_4 to give an estimated nicotinic acid content of 1 μg/ml of extract The cooled mixture is adjusted to pH 6 8, diluted to an estimated nicotinic acid content of 0 1–0 2 μg/ml, and filtered

2 The assay organism, *Lactobacillus arabinosus* 8014, is maintained by monthly transfer of stab cultures on a medium containing 1% yeast extract, 0 25% glucose and 1 5% agar

3. The composition of the basal medium is given in Table 2

4 The inoculum is prepared by the following *procedure. The day before the assay* is run a transfer is made from a stab of the stock culture into a sterile 10-ml aliquot of basal medium (single strength) supplemented with 1 μg of nicotinic acid

Table 1 Representative methods of assay for the water soluble vitamins

Vitamin	Test organism	References
p-Aminobenzoic acid	*Neurospora crassa* (mutant)	468[a]
Biotin	*Lactobacillus arabinosus*	393
	Saccharomyces cerevisiae	428–429
Choline	*Neurospora crassa* (mutant)	464–465
Folic acid	*Lactobacillus casei*	404–405
	Streptococcus faecalis	401–404
Inositol	*Saccharomyces carlsbergensis*	445
Lipoic acid	*Lactobacillus lactis*	[b]
Nicotinic acid	*Lactobacillus arabinosus*	364–369
Pantothenic acid	*Lactobacillus arabinosus*	385
Riboflavin	*Lactobacillus casei*	340–354
Thiamin	*Lactobacillus fermenti*	376
	Saccharomyces cerevisiae	452–457
Vitamin B_6		
Pyridoxine + pyridoxamine + pyridoxal	*Saccharomyces carlsbergensis*	438
Pyridoxamine + pyridoxal	*Streptococcus faecalis*	412–413
Pyridoxal	*Lactobacillus casei*	411–412
Vitamin B_{12}	*Lactobacillus leichmannii*	[c]

[a] Page numbers are given for P Gyorgy (ed), *Vitamin Methods*, vol I, 1950

[b] L J Reed, B G Debusk, P M Johnston, and M E Getzendaner, *J Biol Chem*, 192 851–858 (1951)

[c] *The Pharmacopeia of the United States*, 15th Revision, p 885, Mack Publishing Co , Easton, Pa , 1955

Table 2 Basal medium for determination of nicotinic acid with L. arabinosus

Constituent	Amount per 100 ml of double-strength medium
Vitamin free acid hydrolyzed casein	1.0 g
Glucose	2.0 g
Sodium acetate	1.2 g
L-Cystine	0.02 g
L-Tryptophan	0.02 g
Adenine	2.0 mg
Guanine	2.0 mg
Uracil	2.0 mg
Riboflavin	40 μg
Thiamin chloride	20 μg
Calcium pantothenate	20 μg
Pyridoxine	20 μg
Biotin	0.08 μg
Inorganic salts*	
Solution A	1.0 ml
Solution B	1.0 ml
pH adjusted to	6.8

* Solution A: 25 g K_2HPO_4, 25 g KH_2PO_4, water to make 250 ml solution. Solution B: 10 g $MgSO_4 \cdot 7H_2O$, 0.5 g NaCl, 0.5 g $FeSO_4 \cdot 7H_2O$, 0.5 g $MnSO_4 \cdot 4H_2O$, water to make 250 ml solution.

per tube. This culture is incubated for 16–24 hr at 37°C. The cells are centrifuged, washed with sterile water and resuspended in 10 ml of sterile water or saline. One drop of this suspension is used to inoculate each assay tube.

5. The assay is carried out in tipless 18 by 150 mm test tubes individually supported in a metal rack. To one series of tubes the freshly diluted standard nicotinic acid solution (0.1 μg/ml) is added as follows, with duplicate tubes at each level: 0, 0.25, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 ml. An extract of each material to be assayed, prepared as described in step 1, is similarly added in duplicate to a series of tubes in amounts estimated to supply 0.025–0.45 μg of nicotinic acid. The volume of extract added should not exceed 5 ml. All tubes are now diluted with distilled water to 5 ml, and 5 ml of the double strength basal medium is added to each tube. The culture tubes are plugged with cotton or covered with glass or metal caps and autoclaved at 15 lb pressure for 10–15 min. After cooling, each tube is inoculated with 1 drop of the inoculum suspension. The racks of tubes are incubated at 37°C for 24 hr after which the turbidity of each culture tube is measured with a photoelectric colorimeter, preferably above 560 mμ, where absorption of light due to color of the growth medium is minimized. Alternatively, incubation can be continued for 72 hr and the acid produced in each assay tube measured by direct titration with 0.1 *N* NaOH.

6. In calculating results, a standard dose response curve for nicotinic acid is prepared by plotting the average of the turbidity (recorded as optical densities or per cent of incident light transmitted) or titration values found at each level of the nicotinic acid standard against the amount of nicotinic acid present. The nicotinic acid content of the sample is determined by reference to known amounts of the test solution onto this standard curve. Only those values which fall on the rapidly ascending portion of the curve should be used. A typical standard curve obtained under these conditions is shown in the illustration.

The accuracy of the microbiological methods is usually given as ±10%. Comparative data for the same material assayed by independent reliable methods are scarce. In evaluating an assay method investigators have therefore relied on internal evidence such as the ability to secure quantitative recoveries of the added test substance and also the reproducibility of assay values. In general an assay for an essential nutrient is more accurate than one for a nutrient that is only stimulatory to growth of the test organism. *See* NIACIN.

Amino acid assay. These methods depend upon the use of microorganisms which have specific growth requirements for the individual amino acids. As in the case of the vitamins, one microorganism may be used for the assay of several amino acids. *See* AMINO ACIDS.

The basal media used for assay of amino acids resemble those for nicotinic acid (Table 2) but contain a complete assortment of vitamins and an appropriate complete mixture of pure amino acids (save for the one to be determined) in place of the hydrolyzed casein. Procedures are then entirely similar to those described for the nicotinic acid assay, and dose response curves similar to that of the graph are obtained for each of the amino acids.

The assay organisms useful for estimation of individual amino acids are listed in Table 3. L-Amino acids of demonstrated purity must be used as standards. With few exceptions, the D-isomers of the amino acids are inactive for most of the common assay organisms. The concentrations of the amino acids required to establish a standard curve are given in Table 4.

Peptides are widely utilized by certain microorganisms and may, depending upon the assay conditions and the test organism, exhibit activity which is greater than, less than, or equal to that expected from their amino acid composition. In gen

Table 3 Bacteria used for the determination of amino acids*

Name and strain no. (ATCC)	For determination of
Lactobacillus arabinosus 8014	Glutamic acid, leucine, isoleucine, valine, phenylalanine, tryptophan
Lactobacillus delbrueckii 9649	Phenylalanine, tyrosine, serine
Leuconostoc citrovorum 8081	Alanine could also be used for most other amino acids
Leuconostoc mesenteroides 8042	All amino acids except alanine
Streptococcus faecalis 8043	Glutamic acid, histidine, lysine, arginine, leucine, isoleucine, valine, methionine, threonine, tryptophan

* Adapted from E. E. Snell in S. P. Colowick and N. O.

Table 4 Concentrations of various amino acids suitable for establishing a standard curve*

Amino acid (L-form)	Assay range μg/ml	Amino acid (L form)	Assay range μg/ml
Alanine	0–25	Lysine	0–20
Arginine	0–20	Methionine	0–5
Aspartic acid	0–20	Phenylalanine	0–5
Cystine	0 5	Proline	0 10
Glutamic acid	0 25	Serine	0–10
Glycine	0–15	Threonine	0–10
Histidine	0 5	Tryptophan	0–2
Isoleucine	0–15	Tyrosine	0–10
Leucine	0 15	Valine	0–15

* From C E Snell in S P Colowick and N O Kaplan (eds) *Methods in Enzymology* vol 3 1957

eral therefore proteins should be hydrolyzed completely before they are assayed microbiologically The minimum time required for complete hydrolysis of any given protein can be determined experimentally However a generally useful procedure for acid hydrolysis of protein samples for assay is as follows the finely divided weighed sample is placed in a test tube together with a 40 fold excess of 3 *N* hydrochloric acid and the tube is sealed It is autoclaved at 15 lb pressure for 5–10 hr cooled opened and neutralized before assay Tryptophan and variable amounts of tyrosine are destroyed by acid hydrolysis modified procedures must be used when these amino acids are determined

Antibiotic assay Antibiotic assays depend upon the inhibition of growth of a susceptible microorganism They are used to standardize batches of manufactured material to test the potency of antibiotics in pharmaceutical preparations for the estimation of antibiotics (which have been administered as chemotherapeutic agents) in body fluids and for the detection of new antibiotics in culture filtrates of microorganisms and other source materials The test organisms selected in addition to being sensitive to the antibiotic being assayed should be stable (not prone to changes in sensitivity or phase) easily cultivated and preferably non pathogenic The method selected depends upon the intended purpose Only the most general methods will be outlined here

Dilution methods The substance to be tested is diluted to several concentrations and placed in a series of vessels containing a suitable liquid or solid nutrient medium Sterile technique is observed except when the incubation period is as short as 3–5 hr The vessels are inoculated with a sensitive microorganism and after incubation the lowest concentration of the substance which will just prevent or reduce to one half growth or some other easily observable function of the microorganism is ascertained

When a solid medium is used (agar streak method) several organisms are streaked on the surface of agar plates containing various dilutions of the antibiotic This method is less accurate than the broth dilution method but is useful as a rapid method of determining what organisms are inhibited and the approximate degree to which they are inhibited by the antibiotic (the antibiotic spectrum)

Diffusion methods The agar plate (cup cylinder paper disk) method is the most common horizontal diffusion method in use A petri plate (or some variation thereof) containing nutrient agar is inoculated in bulk or on the surface (by spreading an aqueous suspension of cells or a thin layer of inoculated agar) with vegetative cells or spores of a sensitive organism and partially dried at 37°C Four or five cylinders of glass, porcelain or stainless steel are spaced on the plate and filled with the solutions to be tested Absorbent paper disks may be used in place of the cylinders or depressions or holes may be made in the agar to admit the solutions The plates are incubated for a suitable period (12 16 hr at 37°C for penicillin) Clear zones appear around the point of application of the test substances where the antibiotic has diffused out to prevent growth of the microorganism The diameters of the zones are measured (with a millimeter ruler pointed dividers or calipers or specially designed projection devices) and compared with the dimensions of zones produced by known concentrations of the standard antibiotic

Turbidimetric methods These differ from dilution methods in that the response they give is a graded instead of an all or none response The growth of the test organism in a liquid nutrient medium containing various known concentrations of the antibiotic is measured photoelectrically and a standard curve is obtained by plotting the galvanometer readings versus the corresponding concentrations of antibiotic Turbidity measurements of test solutions set up at the same time and under the same conditions are referred to the standard curve for evaluation

Assay in body fluids The assay of antibiotics in body fluids presents certain difficulties The antibiotic may be present in low concentrations and limited amounts of the body fluid may be available, therefore the method must be sensitive and in some cases must be conducted on a micro scale Furthermore the antibiotic may be destroyed or its potency changed by the presence of certain constituents in normal body fluids Likewise the growth of the test organism may be affected either favorably or adversely by the constituents in blood or serum In general the difficulties may be surmounted by employing one or more of the following procedures (1) choosing a sensitive assay organism avoiding those which are inhibited or stimulated by constituents of body fluids to be assayed, (2) when a micro method is indicated, choosing a test organism which will grow on the undiluted body fluid and (3) extracting the antibiotic from interfering materials

The accuracy of these methods depends considerably upon the skill of the operator Reproducibility of assay values is the only criterion of accuracy which has been extensively used

[B M G , F E S V]

Table 5 Phenol resistance of test cultures required by the phenol-coefficient method*

Organism	Dilutions	5 min	10 min	15 min
Salmonella typhosa	1 90	+ or −	+ or −	−
	1 100	+	+	+
Staphylococcus aureus	1 60	+	−	−
	1 70	+	+	+

* − = no growth + = growth

Disinfectant standardization Disinfectant standardization has a twofold purpose first to delineate the microbicidal potency of a given product for example by relating it to that of a standard such as phenol, and second to ascertain the concentration in which the disinfectant should be used to produce the microbicidal effect expected from its use Not all bacteriological testing methods are applicable to all types of available germicides In addition to the chemical characteristics of any given disinfectant its mode of action and the particular purpose of its use will determine the testing procedure, for obvious reasons the test conditions should approach those of the intended practical application as closely as possible

Over a period of years numerous methods have been recommended for the standardization and evaluation of disinfectants both in the United States and abroad Because commerce in disinfectants is subject to regulation under a Federal statute reference will be made below to those methods which are in active use on an official level by way of furnishing some illustrative information

Phenol coefficient method The phenol coefficient method is applicable to disinfectants which are miscible with water and act upon bacteria in a manner similar to that of phenol Test organisms are *Salmonella typhosa* and *Staphylococcus aureus* of specified resistance as is shown in Table 5

The *Salmonella typhosa* phenol coefficient is calculated by dividing the greatest dilution (denominator of fraction) effective in 10 min of the disinfectant tested by the greatest dilution of phenol producing the same effect An illustrative example is furnished by Table 6

Table 6 Example of test by the phenol-coefficient method*

		Subculture tubes†		
	Dilutions	5 min	10 min	15 min
Disinfectant X	1 100	−	−	−
	1 125	+	−	−
	1 150	+	−	−
	1 175	+	+	−
	1 200	+	+	+
Phenol	1 90	+	−	−
	1 100	+	+	+

Phenol coefficient of disinfectant X = $\frac{150}{90}$ = 1 6

* Test organism *Salmonella typhosa*
† − = no growth + = growth

As a rule a disinfectant for general use must be employed in a concentration corresponding in germicidal efficiency against *Salmonella typhosa* to 5% phenol solution the figure obtained by multiplying the phenol coefficient by 20 gives the number of parts of water in which one part of the disinfectant should be dissolved (or emulsified) However, this expedient is valid only if the bactericidal adequacy of the solution can be confirmed by the use-dilution method

Use-dilution method The use-dilution method applies to testing disinfectants for use on surfaces where a substantial reduction of the bacterial contamination is not achieved by prior cleaning Test organisms are *Salmonella choleraesuis* and *Staphylococcus aureus* unlike the phenol coefficient method in which the test bacteria are acted upon in the form of suspensions in the use dilution method they are deposited in stainless steel cylinders which are then exposed to the action of the disinfectant solution under test

If the disinfectant concentration arrived at by the formula 20 times the *Salmonella typhosa* phenol coefficient is not found to be bactericidal for *Salmonella choleraesuis* by the use dilution test higher concentrations must be tested until a germicidal concentration is reached only the latter may be recommended for practical use Moreover, if the disinfectant is to be employed in hospitals or other places harboring pyogenic bacteria the dilution

satisfy this requirement

Fungicidal test The fungicidal test is applied to water miscible disinfectants intended to destroy pathogenic fungi infectious to man or animals The test organism is *Trichophyton interdigitale* which exhibits the required resistance to phenol The testing procedure resembles that of the phenol coefficient method

Sporicidal test By definition a disinfectant is presumed to free a contaminated surface or object (inanimate) of its bacterial contamination by killing the microbes present However, this requirement does not extend to bacterial spores some of which are highly resistant to the action of chemical disinfectants When a claim is made for sporicidal action the test is carried out using resistant bacterial spores of that species of spore forming bacteria which is of primary interest with respect to any particular product or condition and including the spores of *Clostridium sporogenes, Clostridium tetani* and *Bacillus anthracis* The resistance of the test spores is determined by exposure (at room temperature) to constant boiling hydrochloric acid the tolerated exposure period should be at least 5 min although many spores will resist the acid for 30 min or even longer The test of the unknown sporicide is carried out by exposing the spores on suture loops to its action for selected in

followed by transfer to subculture media and incubation to observe the results of exposure which may indicate either sporicidal potency or a lack of it the latter evidenced by germination of the surviving spores in the subculture

Available chlorine method The available chlorine germicidal equivalent concentration method is applied particularly for the evaluation of disinfectants intended for use as germicidal rinses on previously cleaned surfaces It calls for the addition of 10 increments of a specified size of bacterial inoculum (of *Salmonella typhosa* or *Staphylococcus aureus*) to a specified volume of different concentrations of the disinfectant under test with transfers made to tubes of subculture medium after the addition of each increment The results read after incubation indicate the capacity of the disinfectant to handle an increasing bacterial load before exhaustion of its germicidal principle

Many other methods have been recommended and are being used for standardization and evaluation of disinfectants particularly in connection with a variety of special uses [E G K]

ANIMAL ASSAY

Although bacteria yeasts molds and other plants are employed extensively in the performance of bioassays of antibiotics vitamins amino acids fertilizers germicides bacteriostatic agents preservatives and fungicides perhaps even greater use is made of animals for the testing of an increasingly large group of important products The species of animals used for this purpose range from mice rats hamsters and guinea pigs to higher forms including monkeys dogs cats swine and cattle Although they are not commonly considered to be animals in the more limited meaning of the word birds chickens and other fowl frogs reptiles and insects also are used for test purposes Animal assay is also used to test the comparative virulence of strains of microorganisms

Techniques Bioassays employing animals are especially essential in the testing of the efficacy and safety of medical products and in the determination of the degree of harmfulness of many products used in the home and in industry which may be potentially dangerous to man That branch of medical science dealing with the study of the action of drugs in animals is called pharmacology and that concerned with the measurement of toxic effects is called toxicology *See* PHARMACOLOGY TOXICOLOGY

Tests of this kind are not limited to those requiring the use of whole animals because especially in pharmacology many assays are best performed on isolated parts of animals which may be maintained in the living state for appreciable periods of time and which include strips of tissue or of organs suspended in appropriate liquids which supply necessary warmth oxygen and essential nutrients In the field of virology the study of viruses an entirely new technique has been developed which makes use of living cell suspensions such as may be prepared from kidney other organs and epithelial tissue In studies of cancer, suspensions of cell lines originally obtained from cancerous tissue from both human and animal sources have been maintained in a living reproductive state over long periods of time

Wherever possible more precise and less time consuming analytical methods employing physical and chemical measurements are preferred over the more complicated animal assays but for controlling the quality of many medical products and other physiologically active substances only the response produced in animals provides a realistic measurement of their true effects This is especially the case with tests designed to measure the efficacy of many therapeutic preparations including hormones vaccines toxoids antitoxins and immune serums Many times too a bioassay is to be preferred over a chemical or physical method of assay because the response produced in the test animal approximates more closely that observed in man and for toxicity studies in particular there is no substitute for suitable susceptible animals

In principle animal tests are reasonably simple and are designed to make possible the observation and measurement of a given effect or effects produced by the material to be assayed For example digitalis extract a well known heart stimulant is standardized by injecting it into the veins of pigeons in measured amounts, depending upon the potency of the product the heart of each pigeon stops after a certain number of injections has been administered The results accumulated for a number of pigeons are compared to those obtained using a standard or reference preparation and an estimate of relative potency in terms of the reference may be calculated by an appropriate statistical method Similarly a vaccine may be injected into a number of suitable animals which are subsequently challenged after a predetermined interval usually days or weeks with a virulent culture of the organism against which the vaccine is intended to produce protection The ability of animals thus immunized to withstand such a challenge is a measure of the antigenic potency of the vaccine

Statistics In carrying out bioassays it is of utmost importance that sound statistical principles be employed not only in the design of the test but also in the method for calculating the observed effect in terms of potency The application of statistical methods to this type of assay is absolutely essential because of the inherent differences in response observed in individual animals The employment of statistical analysis for bioassays is an important field of study It is equally important that good statistical methods be employed in the

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Biochemistry

The study of the substances that occur in living organisms the processes by which the substances enter into or are formed in the organisms and react with each other and the environment and the methods by which the substances and processes are identified characterized and measured

Substances The substances are so myriad that it is possible to enumerate only a few Proteins constitute a large part of most soft tissue solids and of enzymes (*see* ENZYME PROTEIN) Nucleic acids appear to carry hereditary characteristics and to govern protein synthesis (*see* NUCLEIC ACID) Their study includes that of the nucleotides which in combination form nucleic acids and coenzymes the latter combine with proteins to form some of the enzymes (*see* COENZYME) Carbohydrates function as sources of energy and also enter into the composition of tissue constituents such as the mucoproteins nucleotides nucleic acids and cellulose (*see* CARBOHYDRATE CELLULOSE) Fats and other lipids serve as sources of energy in both plants and animals and also enter into the composition of blood and tissue constituents such as the lipoproteins (*see* LIPID) Phosphorus in bones lipids nucleic acids nucleotides coenzymes and phosphorylated carbohydrate derivatives takes part in the structures of these substances and in numerous enzymic reactions (*see* PHOSPHATE METABOLISM) Sulfur is an organic constituent of the amino acids cystine cysteine and methionine of the proteins and peptides in which these four groups occur of coenzyme A of mucopolysaccharides and of brain lipids Chlorine occurs as chloride in extracellular fluids of animals and as hydrochloric acid in gastric juice Iodine is concentrated in the thyroid glands of animals and in certain sponges Among the metal elements in animals are potassium and magnesium found chiefly in cells sodium found chiefly in animal extracellular fluids iron occurring in hemoglobin cytochrome and ferritin and calcium the predominant metal in bony tissue (*see* CALCIUM METABOLISM) Metal trace elements—zinc copper manganese and cobalt—occur in animals in minute but indispensable amounts apparently as constituents of enzymes or hormones Such gases as oxygen and carbon dioxide play a continuous role in the processes of all the higher organisms and most microorganisms Minute in amount but indispensable for life are the hormones and vitamins (*see* HORMONE VITAMIN) Water constitutes the greater part of most organisms provides a medium in which other substances exist and react and itself enters into innumerable reactions such as the hydrolysis and synthesis of proteins fats and carbohydrates

Of the substances mentioned it cannot be said that there is complete knowledge of the physical and chemical properties of any even water in organisms And previously unknown biological substances are continually being discovered

Processes A L Lavoisier wrote in 1780 after experiments on oxygen consumption in man La vie est une fonction chimique The impetus given by this conception and by Lavoisier's introduction of quantitative gasometric and gravimetric methods may be said to have initiated the chemical study of processes in living organisms

This part of biochemistry includes the processes by which amino acids proteins fats carbohydrates and other substances are synthesized in plants and microorganisms Also considered are the mechanisms by which these substances are digested absorbed and transformed in animals to provide energy and to synthesize tissue and blood constituents *See* AMINO ACIDS BACTERIAL METABOLISM BLOOD BONE CARBOHYDRATE METABOLISM CONNECTIVE TISSUE ENDOCRINE SYSTEM EYE INTEGUMENT LIPID METABOLISM LIVER MUSCLE NERVOUS SYSTEM PLANT METABOLISM PROTEIN METABOLISM TOOTH

In addition biochemistry is concerned with the individual enzymic reactions that are involved in metabolic and other processes the manner in which hormones and vitamins influence such reactions and the mechanisms by which substances and energy are transferred Included too are the physical chemistry of organisms electrolytes colloids and membranes Biochemistry also considers the feedback systems by which the balances of building up and breaking down of input and outgo are maintained It takes interest also in the changes in processes that occur in disease and in infection the processes that occur in microbial and virus parasites and the interreactions between parasite and host *See* BACTERIA DISEASE VIRUS

Methods Knowledge of both the substances and the processes within the organism has been obtained by methods of separating and measuring substances determining their structure and following the course of their reactions These methods go back to Lavoisier's introduction of the analytical balance and gasometric burette to J Liebig's combustion method for carbon and hydrogen (about 1840) and to J Kjeldahl's nitrogen method (1883) In biochemistry methods have been developed for analyzing minute amounts of material Following are some types of methods used

1 Microgravimetric analyses in which weighings are made to ±0.002 mg on a Kuhlman beam balance or to ±0.0001 mg on a quartz fiber torsion balance

2 Microtitrations in which solution volumes are measured to ±1 mm^3 with the buret of J Bang or to ±0.1 mm^3 with the buret of P B Rehberg (*see* ORGANIC QUANTITATIVE ANALYSIS)

3 Photometry with visible rays 4000 to 7000 angstroms (A) in length used for micro analyses with ultraviolet rays for substances absorbing or emitting light of wavelength

A with infrared rays for analyzing substances absorbing rays above 7000 A and for determining organic structures (*see* SPECTROPHOTOMETRIC ANALYSIS)

4 Microanalyses of blood gases and gases evolved in vitro by reactions of biological organisms or substances

5 Determination of pH by hydrogen electrode glass electrode or indicator photometry (*see* HYDROGEN ION)

6 Ultracentrifugation for separation of large molecules in solution or of cell particles in suspension (*see* ULTRACENTRIFUGE)

7 Electrophoresis for separation of large charged molecules (*see* ELECTROPHORESIS)

8 Separation of dissolved substances by differential adsorption and elution called chromatography because color was originally used to identify the separated substances (*see* CHROMATOGRAPHY)

9 Chromatography of gases for separation of substances in the gas phase (*see* GAS CHROMATOGRAPHY)

10 Biological assays in which reactions of whole organisms or isolated organs are used to ascertain the presence amounts and effects of nutritional toxic or otherwise active substances (*see* BIOASSAY)

11 Synthesis of organic substances to establish their molecular structures (*see* ORGANIC CHEMICAL SYNTHESIS)

12 Isotope labelling for following atoms through *reactions for locating* elements in tissues by iso

AUTORADIOGRAPHY BIOLOGICAL OXIDATION HISTORADIOGRAPHY METABOLISM NUTRITION RADIOCHEMISTRY SPECIALIZED TISSUE STEROID

[DDVS]

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Bioclimatology

A study of the effects of the natural environment on living organisms These effects may be direct such as the influence of ambient temperature on body heat or indirect such as the influences on composition of food Only direct effects on man will be discussed in this article Natural and *artificial* elements cannot be sharply distinguished For example smoke from a lightning induced forest fire is natural but smoke from a chimney is artificial Bioclimatology encompasses biometeorology climatophysiology climatopathology air pollution and other fields The interplay between disciplines such as meteorology and physiology is emphasized

Photochemical bioclimatology Essentially this is the investigation of the effects of light from sun and sky Sunburn of the skin and the cornea of the eye is initiated by denaturization of nucleic acid and skin proteins (histidine) causing a local histaminelike action In nature the effect is restricted and is induced by ultraviolet radiation with wavelengths about 0 3 μ (micron) Racial and radiation induced pigment and a thick horny layer act as protective filters

Solar pigmentation occurs either as an aftermath of sunburn or directly The direct pigmentation is caused by ultraviolet radiation of about 366 mμ (millimicrons) wavelength

Skin carcinomas occur more frequently on facial skin exposed to the sun Proof that exposure to sun is carcinogenic comes from statistical evidence and from the results of exposing rodents to very strong artificial ultraviolet radiation

Although bacteria are easily killed with artificial ultraviolet radiation of short wavelength natural sunlight probably has very little bactericidal action because it does not contain these short wavelengths

Vitamin D is produced from natural sterols in plant and animal foodstuffs and in human skin by short wavelength solar ultraviolet radiation (0 3 μ)

It has been claimed that solar ultraviolet radiation favorably affects human circulation and general health However sunbather faddism has not been conducive to serious research It is difficult to separate the effects of ultraviolet radiation thermohygric exposure and even mental stimulation a sunbather

Most sun and sky light received by the eye is that which is reflected by clouds and surfaces The intensity of the incoming light its angle of incidence and the amount and kind (specular diffuse) of albedo control the amount of light received by the eye The specular reflections of water ice metals snow clouds and white sand are bright enough to irritate the eye Most sun goggles dampen the whole visible spectrum uniformly and eliminate ultraviolet and infrared rays

All the important ultraviolet effects mentioned above occur at about 0 3 μ near the end of the solar spectrum This ultraviolet radiation is controlled by absorption in stratospheric ozone and scattering by air molecules Dependence of ultraviolet radiation on solar and geometric altitude is pronounced Usually the scattered sky ultraviolet radiation exceeds that of the sun Snow reflects both ultraviolet rays and visible light to cause snowblindness and sunburn below the chin

Natural penetrating ionizing radiation is composed of β and γ rays from radioactive minerals including their emanations and secondary rays from cosmic radiation mainly mesons and neutrons Ionization by both effects at altitudes below 18 kilometers (km) is less than 40 milliroentgens per day probably an insignificant figure *See* ATMOSPHERE

Aerosol bioclimatology Air constituents such as oxygen partial pressure and water vapor pressure influence body chemistry

The oxygen partial pressure (pO_2) of inhaled air is vital for blood oxygenation and depend

mainly on altitude At or above an altitude of about 3000 meters the pO_2 is low enough to cause air sickness or mountain sickness Residence at an altitude of 1-2 km is supposed to have a beneficial effect on circulation but may be harmful for some heart patients

Low water vapor pressure may cause drying of the skin and of the mucous membranes of upper respiratory organs Water vapor pressure even indoors is especially low when outdoor air temperatures are low Many skin and respiratory complaints in winter are caused more by dryness than by cold

Carbon dioxide (CO_2) water (H_2O) and organic vapors emitted by man contribute to the unpleasantness of crowded and ill ventilated rooms which are also usually overheated

Ozone (O_3) is produced by solar ultraviolet radiation in the higher stratosphere by lightning and by sunlight falling on smog (Los Angeles) Stratospheric ozone is brought down by turbulence and might reach toxic levels for crews of airplanes at about 15 km altitude Ozone is blamed for some smog induced injuries for example ocular pain in Los Angeles California

Carbon monoxide (CO) unburned hydrocarbons and other by products are prevalent where there is incomplete combustion Many by products are also highly hygroscopic and serve as nuclei of condensation to cause the low humidity type of smog such as that occurring in Los Angeles High moisture smog seems typical for London

Widely discussed elements of the atmospheric aerosols are the ions which are smaller or larger particles containing one or more electrical charges For a long time beneficial or dangerous effects of an abundance of particles of one charge type have been claimed Recently these electrical space charges reportedly have influenced results of physiological tests growing of living cells and severity of hay fever attacks As a rule negative space charge of the order of 1000–10 000 ions/cm³ are reportedly beneficial These results are expected to

environment The basic equation is

$$M - C\,d\theta_b/dt + H_h = H_r + H_a + H_e + R \quad (1)$$

where M is metabolic heat production C is body heat capacity H is heat exchanged through skin R is respiratory heat exchange θ is temperature (°C), b is total body h is solar radiation r is infrared radiation s is skin a is air (convection) e is evaporation and t is time The H terms are

$$H_h = S\ \epsilon_h\ A_h \qquad H_r = h_r\ A_r(\theta_s - \theta_r)$$
$$H_a = h_a A_a(\theta_s - \theta_a) \qquad H_e = h_e\ A_e(e_s - e_a)$$

where S is solar radiant heat flow ϵ_h is absorptivity of skin (0 6 for white and 0 9 for black skin) A factors that is the respective surface areas depend on body posture and on the process involved such as radiation or convection they are always smaller than the geometric surface The terms e_s and e_a are the vapor pressures of skin and air respectively

The h factors are heat conductances at absolute temperature T

$$h_r = \epsilon\,\sigma(T_s^4 - T^4)/(\theta_s - \theta)$$

where ϵ is 0 98 (infrared absorptivity of skin) and σ is Stefan's constant 4 9 kcal m / (hr) (deg⁴) From experiments with men and using kilocalorie units (kcal) $h_a = 6\,3\sqrt{v}$ kcal (m²) (hr) (deg) for wind velocity v m sec further $h_a = 3\,3$ in calm Following from h_a

$$h_e = 1\,63\,h_a \text{ kcal (m}^2\text{) (hr) (mb) (deg)}$$

These data are valid for supine adults at sea level and refer to the heat or vapor exchanging area

For the clothed body

$$\theta_s - \theta_a = M\,A_a h + (M + H_h)\,A_a(h_a + h) \quad (2)$$

if h is conductance of clothes and if $\theta = \theta_a$ $A = A_a$ $H_r = 0$ and $d\theta_b/dt = 0$ The absorptivity of the clothing is inserted for ϵ_h If $h_a \gg h$ (strong wind thick clothes) solar heating H_h becomes unimportant

H can be measured directly with a good balance The relative skin humidity $r_s = e_s/e_s^*$ where e_s^* is saturation vapor pressure at skin temperature can be measured with a hair hygrometer or derived from H_r h_r e_a and e_s During sweating r_s is 100% otherwise it is usually below 60% If skin relative humidity is below 10% the skin may crack

Skin water transfer is accomplished by sweating and diffusion The latter corresponds usually to 1 kcal (m²) (hr) it may reverse so that water or vapor is transferred into the skin Sweat is a powerful emergency measure capable of producing $H = 600$ kcal (m²) (hr)

The respiratory heat and vapor loss is small except during hyperventilation at reduced pressure Ordinarily this loss varies little because the exhaled temperature drops as θ_a and e_a fall

Of the climatic elements S h_a (wind) and precipitation are easiest to control High values of θ_a θ and e_a are much harder to influence than low values To ensure a constant θ_b the body alters the peripheral blood flow and thus alters θ_s In cold temperatures, M is raised by work (shivering) in hot temperatures, H is raised by sweat These emergency regulations are effective only for short periods. Short time limits are set by variations of θ_b and finally θ_s (skin burn or freezing) All body controls vary with age sex health exercise and adaptation Reportedly frequent limited exposures to adverse thermal conditions particularly cold invigorate many body functions especially if exposure is combined with exercise

The most important climatic element is local air temperature in the cold wind increases the rate of body cooling For a well insulated man or house Eq (2) air temperature alone is the deciding fac

tor The house heating bill is proportional to the number of degree days that is time multiplied by $(\alpha - \theta_a)$ where α is the preferred room tempera ture about 22°C No usable formula for the cooling effect of open air on average individuals in the United States can currently be derived because clothing styles change

At temperatures greater than 25°C sweating starts Its evaporation is restricted by high values of e_a Hence the combination of θ and e_a describes livability in the heat Tests on sensation experi enced by young men exposed to different pairs of θ_a and e_a led to the effective temperature (ET) which approximately equals (θ_a + dew point tem perature) 2 The area of high ET or extreme sum mer discomfort in the United States is the Gulf Coast especially the lower Rio Grande Valley (average ET 26 27°C) In the Indus Valley ET is 28 5°C and the world maximum is in Zeila Somali Coast where ET is 29 7°C Neither tempera ture nor general climate maps indicate the locations of extreme ET areas *See* SENSIBLE TEMPERATURE

The microclimate can enhance discomfort The values of θ_a and θ are much below normal on calm clear nights especially when the terrain is concave The sun can raise the surface tempera tures of such features as sand walls and vehicles to as much as 40° above the air temperature

Statistical bioclimatology This aspect of bioclimatology investigates correlation between weather and climate phenomena and the effects on man The most important work concerns clinical data correlated with daily weather Two weather types seem to be involved Fronts central low and ascending air coincide with frequent attacks of angina pectoris and embolism Incidence of foehn and cyclogenesis to the west are found to correlate with increasing circulatory disorders mental troubles increase of accidents and kidney colic It has been claimed that there is a correlation between increased solar activity and all deaths in big cities and especially deaths from mental diseases *See* AIR MASS CHINOOK FRONT THERMOTHERAPY ULTRAVIOLET RADIATION (BIOLOGY) VITAMIN D

[K J B]

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Bioelectric model

The phenomenon of the origin of electric current in tissue can be demonstrated by a bioelectric model The following explanation is based on experimental methods The widely accepted theory of ionic permeability has never been proven and meets with many contradictions The electromotive forces (emf) arising in tissue can be explained in the same way as those arising in the galvanic batteries The emf of a galvanic cell is composed of at least two potential differences (*pd*) at the metallic electrodes Similarly an emf produced by living tissue is composed of at least two antagonistic pd located on either side of a membrane

Phase boundary potential differences These properties may be understood through the follow ing considerations A system such as

$$\text{Metal} \left| \begin{array}{c}\text{Metal salt}\\ \text{dissolved}\\ \text{in water}\end{array} \right| \left| \begin{array}{c}\text{Metal salt}\\ \text{dissolved in}\\ \text{nonaqueous}\\ \text{solvent}\end{array} \right| \text{Metal}$$

cannot produce an emf if the salt solutions are in equilibrium with the metal as well as with each other However the pd at the metal electrodes are in general not equal Consequently the total emf of the system can be zero only if a third pd exists in the center between the two salt solutions equal to 58 1 grams c_1/c_2 millivolts When employing this formula it should be considered that c_1 and c_2 are ion concentrations of the same ion in the two solvents This ratio c_1/c_2 depends on the distri bution of salt between the two solvents

For calculating the emf at the phase boundary two possibilities are considered

1 If no chemical reaction occurs at the phase boundary the pd at the boundary is independent of the salt concentration since the ratio of the concentration of an ion in the adjoining phases is constant that is the concentration ratio is deter mined by the partition coefficient Nevertheless different salts in equal concentrations may show large emf depending on the oil solubility of the salts and whether the common ion is an anion or a cation Thus for instance the system

$$+ \left| \begin{array}{c}\text{Potassium}\\ \text{chloride}\end{array} \right| \text{Guaiacol} \left| \begin{array}{c}\text{Aniline}\\ \text{hydrochloride}\end{array} \right| -$$

has an observed emf of 0 048 volt (calculated from salt distribution 0 044) or

$$- \left| \begin{array}{c}\text{Potassium}\\ \text{chloride}\end{array} \right| p\text{ Cresol} \left| \begin{array}{c}\text{Sodium}\\ \text{oleate}\end{array} \right| +$$

has an observed emf of 0 111 volt (calculated 0 115 volt)

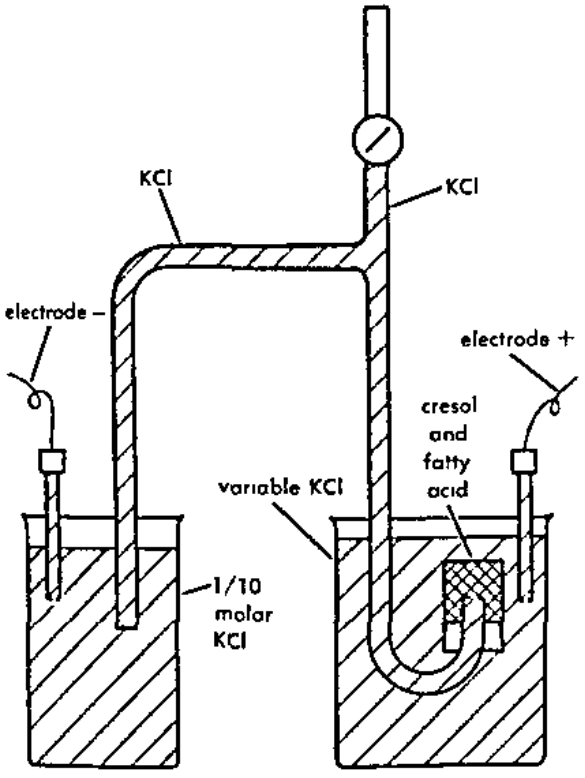
2 If a chemical reaction occurs at the phase boundary unexpected deviations from the law of partition are observed The products of the reac tion may have a different distribution than the original substances The law of partition is no longer valid a change of concentration of the aqueous solution like KCl NaCl or others leaves the concentration of the ion in the nonaqueous solu tion unaltered An example is the phase boundary between

$$\text{Aqueous KCl} \left| \begin{array}{c}\text{Mixture of cresol}\\ \text{and higher fatty acids}\end{array} \right.$$

The reaction which occurs at this phase boundary is

$$\text{KCl} + \text{Fatty acids} \rightarrow \underset{\text{(dissolved in cresol)}}{\text{Soap}} + \underset{\text{(dissolved in } H_2O)}{\text{HCl}}$$

In an aqueous solution in the absence of a water immiscible fluid (like cresol) this reaction would proceed in the opposite dir tion since soap is de composed by HCl W chemic eaction



by changing from	change of emf
1/10 to 1/50 molar KCl	0 023 v
1/50 to 1/250 molar KCl	0 032 v
1/250 to 1/1250 molar KCl	0 036 v

Fig 1 Oil cell for observing the electric effect of concentration

not the law of partition determines the distribution at the phase boundary A maximal variation of the pd with the salt concentration can be exhibited likewise with the following water immiscible substances plant cuticula, which is composed of fatty acids and higher alcohols, a precipitation membrane of copper ferrocyanide, or dried collodion membrane

Existence of phase boundary potential differences To prove the existence of these differences two batteries, each consisting of two interconnected U tubes, are set up Both systems are filled in the right tubes with a 1 molar nitrobenzene solution of an oil soluble base and acid On the left U tubes both are filled with the same solution in nitrobenzene diluted 10 times On both outer legs of one system is a ½ molar aqueous solution of sodium salicylate *In this case, the positive ion is* common to water and nitrobenzene The emf is 0 033 volt The positive pole is on the side of the higher concentration in nitrobenzene To the second system a ½ molar aqueous solution of dimethyl toluidine hydrochloride is added This leads to a reversal of polarity and the emf again is 0 033 volt These observations strikingly contradict the theory that diffusion potentials of considerable magnitude should exist at the junction of the two different nitrobenzene solutions If such a diffusion potential existed and if the interphase potential differences played no role, it would be impossible to reverse the direction of the emf by changing the two outer aqueous solutions

Nerve function The indispensability of acetylcholine esterase for nerve function has been demonstrated by D Nachmansohn but the underlying *mechanism remains unexplained The answer may* be that acetylcholine splitting is coupled with phospholipid splitting which can be shown to produce an emf of <0 1 volt nearly equal to the action potential and in the same direction, inasmuch as the negative pole is on the side of the decomposed lipid Transient reversible phospholipid splitting can be shown to be essential for nerve activation Splitting starts at the outer membrane contact surface producing the upstroke of the spike then extends across the membrane to the opposite surface to produce the downstroke of the spike This transmembrane reaction (phospholipid splitting) may be initiated by an enzyme activating ion driven into the membrane by the stimulating current (Gerard principle)

Myocardial function. The direct myocardial action of unsaturated fatty acids can be studied on a setup in which a lipoidal layer is sandwiched between two identical saline solutions This lipoidal layer is oxidized on one side and remains reduced on the other Emf may be produced by the process of oxidation provided that the lipoidal layer contains oxidizable lipids particularly linoleic acid These oxidizable lipids may be responsible for the generation of electric power Only

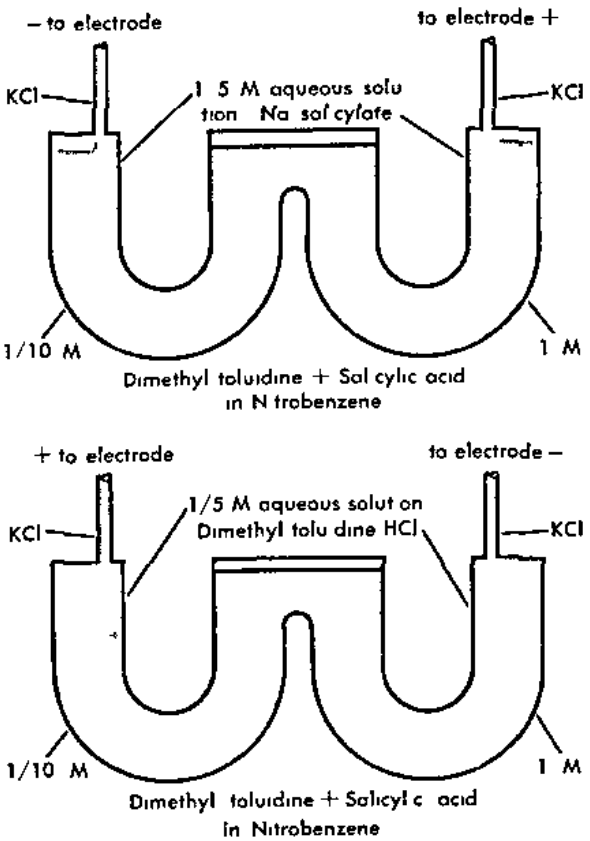


Fig 2 Reversal of polarity of an oil cell by lateral solution

heat but no electric energy is produced by oxidation (in a like setup) of soluble carbohydrates proteins or dispersed lipids Also in living tissue the oxidation of oxidizable lipids on one side of a membrane seems to be the principal source of electric energy Electric energy can be converted into mechanical energy while heat cannot be so converted according to the Second Law of Thermodynamics Since the heart is the largest consumer of electric and mechanical energy the conclusion would be that oxidizable lipids are indispensable for myocardial function

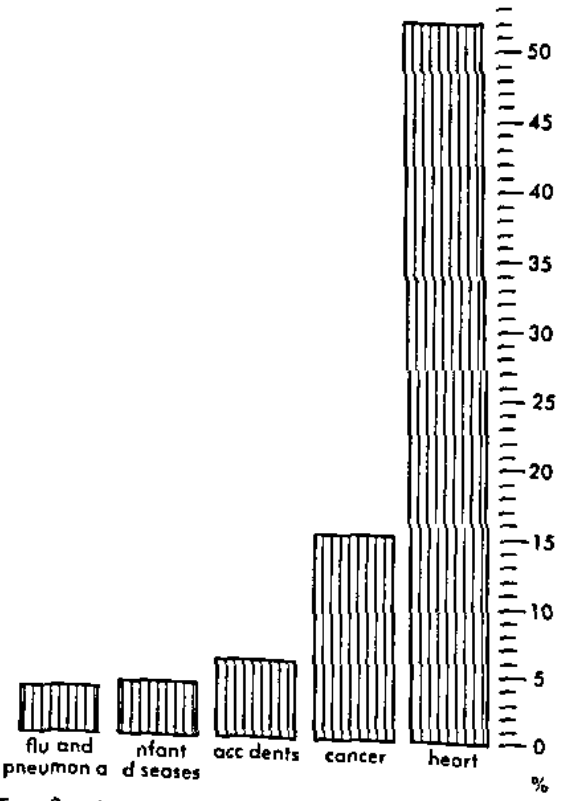


Fig 3 Incidence of five major causes of death in 1958

The high incident of death from heart disease

[R H B]

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Biogeography

The science concerned with distribution of life on the earth Plants and animals are irregularly distributed both on the continents and in the oceans Some areas have a great abundance and variety of life forms whereas others are relatively sterile Biogeographic studies are concerned with learning the manner in which living organisms are arranged on the earth and the causative factors of this arrangement All animals are dependent in the final analysis on plants to supply food Therefore the distribution of plant life is the basic component of biogeography Animal life is the secondary or dependent component

Plant geography Many factors regulate the growth of plants but of particular importance are climatic conditions and the supply of nutrient substances on which plants feed Driving across the western United States during the course of a few miles one may pass from a barren desert through wooded foothills up the slopes of a heavily timbered mountain to the crest which is above timber line and sparsely covered with low vegetation This stratification of vegetation is controlled largely by conditions of temperature and moisture which vary from the flat lowlands to the mountaintop The nature of the underlying rock from which plant nutrients are derived by weathering may strongly influence the growth of plants but the effect is less striking than that of climate (*see* TERRESTRIAL ECOSYSTEM)

Animal life in turn is stratified in conformance with the zonation of plants There are typical animals of the desert the foothills the forest zone and the alpine crest Each of these major communities of plants and animals may be called a life zone a vegetation zone a biome or a climax formation according to various systems of classification All of these communities are part of the temperate region of the world To the north is the boreal region which extends generally from the North Pole to the latitude of southern Canada and south of the temperate region is the tropical region extending from the Equator roughly to central Mexico The Southern Hemisphere may be similarly divided into biotic regions and these in turn into vegetation zones or communities *See* COMMUNITY PLANT GEOGRAPHY POSTGLACIAL VEGETATION AND CLIMATE

As an example of the subdivision of a landscape into component types Fig 1 shows the distribution of vegetation zones in Mexico This country spans the border of the temperate and tropical regions the vegetation zones are arranged correspondingly in two series *See* CLIMAX PLANT FORMATIONS

Tropics The greatest variety of plant life exists in the tropics especially in wet forested areas In southeastern Mexico for example there are tall dense rain forests made up of many species of trees stratified in layers The trees are heavily laden with climbing vines and with epiphytic plants such as orchids and bromeliads The ground beneath has

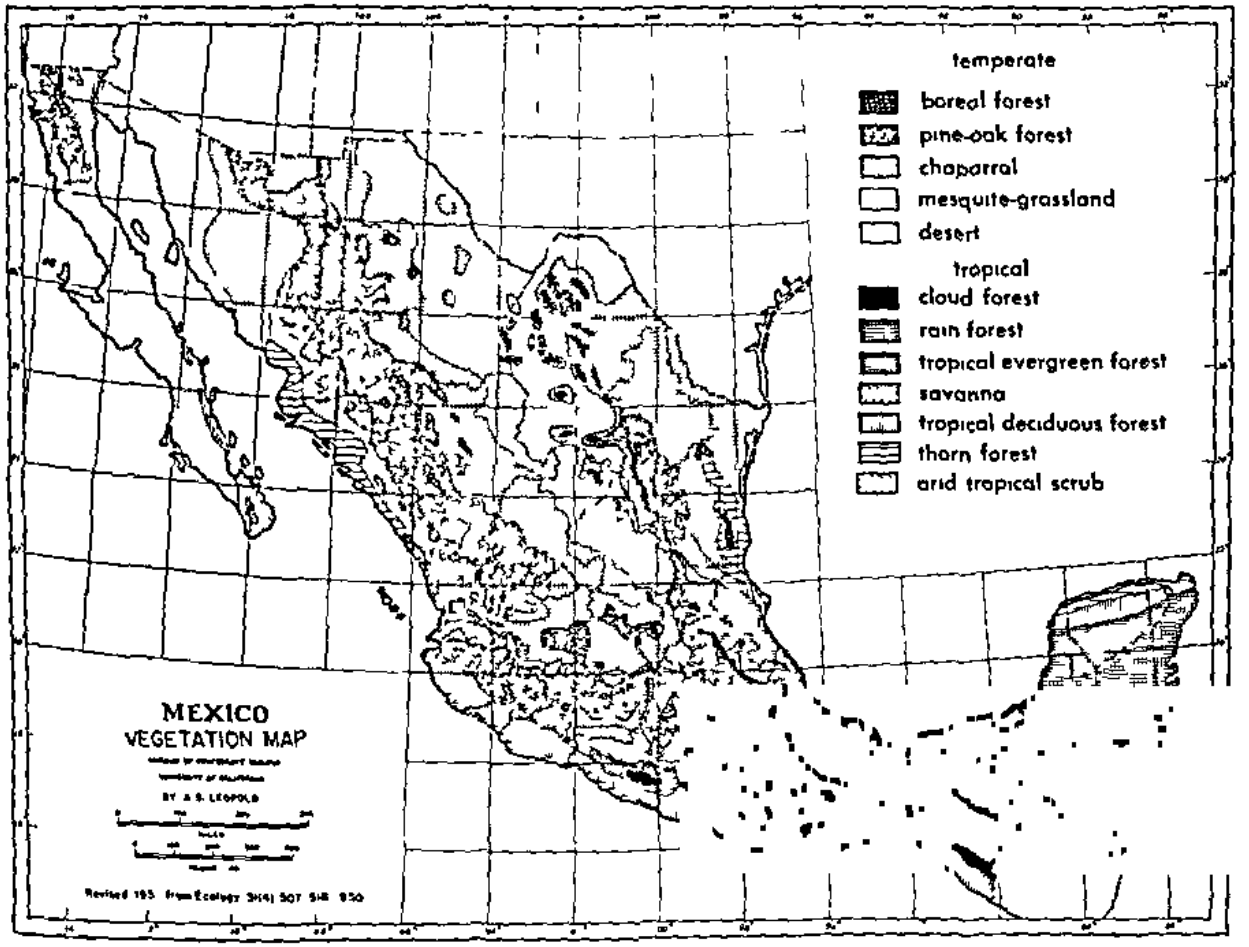


Fig 1 Vegetation zones of Mexico (*Museum of Vertebrate Zoology Univ of California*)

a complex flora of shrubs, herbs, and lesser plants On a few acres there may be hundreds of different kinds of plants In general as one proceeds north or south from the tropics the variety of plant life decreases and fewer kinds dominate the vegetation In polar latitudes, as on islands of the Arctic or Antarctic seas floras are very simple

Temperate zones Within temperate zones al though the variety of plants is less than in the tropics the total mass of vegetation may be as great at least in wet climates The coniferous for ests of coastal Washington or the original hard wood forests of Ohio or central Europe were as massive as the great tropical rain forests of Mex ico or the Philippines

Arid zones Arid zones in any region of the world support relatively little vegetation for the ob vious reason that lack of water limits plant growth The sparse development of plants in polar regions may be due as much to frozen ground which creates a physiologic drought condition for plants, as to the cold itself

Changes in distribution The distribution of plants on the surface of the earth is never static, but is constantly changing with shifts in climate with emergence and submergence of land masses, and with such surface disturbances as volcanic ac tivity or geologic erosion As environmental condi tions change floras tend to migrate and in so doing some species become extinct and new species evolve Certain floristic communities have moved long distances in geologic time During the Cre taceous period redwood trees dominated a rich for est in the American arctic Redwood fossils are found abundantly along the Colville River in northern Alaska Cold and drought of subsequent periods pushed the redwood flora southward, both in the Americas and in Asia so that now redwoods are found in California and in China but not in their original northern homeland *See* POPULATION DISPERSAL

Thus the study of plant geography must consider the historic background of plant communities as well as problems of ecologic adaptation to existing conditions *See* PALEOBOTANY

Animal geography. As stated in the discussion of plant geography, terrestrial animal populations are distributed largely in accordance with vegeta tion patterns Every kind of animal is to some de gree specific in the type of habitat it requires The distribution of individual species of animals often conforms rather closely with the distribution of par ticular vegetation zones As an example Fig 2 shows the range of the Montezuma quail, *Cyrtonyx montezumae*, in Mexico Reference to the vegeta tion map (Fig 1) will show that this quail occu pies principally the pine-oak vegetation zone In fact the association is so close that the Montezi

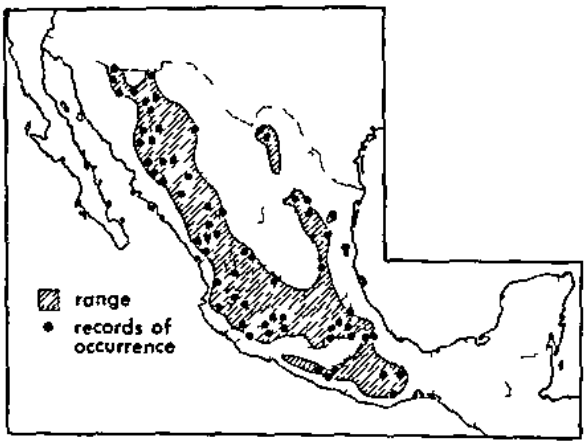


Fig 2 Range of the Montezuma quail (*Cyrtonyx montezumae*) in Mexico

quail may be taken as an avian indicator of pine oak vegetation

Not all animals are as specific as the Montezuma quail in their habitat requirements Most species are adaptable enough to occupy two or more vegetation zones although they may achieve highest density in one favored plant association But in all the world there is no known animal that is completely nonspecific in its environmental needs Requirements for particular types of food shelter or cover and amounts of water are the main components of habitat that limit the range and locally the density of every kind of animal

Some animals make seasonal use of different habitats by migrating Thus many species of migratory birds nest in northern boreal zones in summer but return southward to temperate or even tropical habitats in winter On a more local scale some species of both birds and mammals migrate vertically in mountainous terrain that is upward in summer and downward in winter The device of seasonal migration permits utilization of environments that are only habitable part of the year

Distribution in time In geologic time whole faunas have moved up or down the continental land masses in response to major climatic changes As is true of the plants many cases of discontinuous distribution of families or orders of animals are best explained on the basis of past movements Thus the marsupials are found in Australia and nearby islands and [illegible] The most [illegible] by the [illegible] in [illegible] ments to the present areas of proliferation when the northern climate became too severe for their existence The ranges of other animal groups have been similarly altered over geologic time *See* PALEONTOLOGY

Oceanic distribution Animal life in the oceans is distributed as irregularly as on land The temperature of the water and the concentration of mineral nutrients varies with air temperature ocean currents and especially with points of upwelling of enriched waters from the ocean depths In favorable waters floating microscopic plants and animals collectively called plankton are abundant and serve as rich pastures for larger organisms which in turn feed the fishes and even large mammals like baleen whales Fish eating birds seals and porpoises thrive in turn Areas rich in oceanic life are situated as a rule in cold currents and along continental shelves Thus the great oceanic fisheries of the world and the centers of whaling are mostly in northern or southern waters and not in equatorial latitudes *See* MARINE ECOSYSTEM, SEA WATER FERTILITY

Human biogeography The distribution of human populations on the earth bears a close relationship to the distribution of natural plant and animal life Throughout history man has thrived best in areas that are highly productive of foodstuffs By and large the most favorable habitats for man are situated in the temperate regions of the world where climates are moderate and soils are rich The highest development of agricultural and pastoral industries today is in the regions of temperate climate and moderate rainfall Various human societies however have become adapted to many specialized environments Eskimos and Lapps for example live successfully in the icy northern wastelands Incas and Sherpas in towering mountains and Mayans and Pygmies in wet tropical lowlands

Unlike most other animals man has to a considerable degree altered his environment in supplying his needs Thus forests have been cleared for crops deserts irrigated with water brought from distant mountains marshes filled and cities built thereon Foodstuffs ores and fuels are transported all over the world The system which we call civilization has become so complex that many people lose track of the fact that it still depends upon the function of natural resources just as it always did Urban dwellers in particular come to think that industry supports us forgetting what supports industry

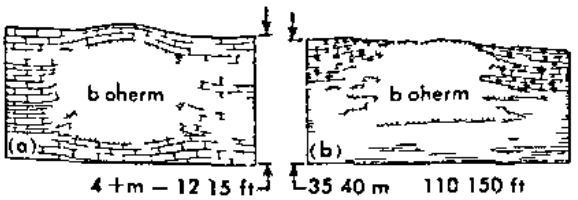
Through blind destruction of agricultural soils and exploitation of other resources many past civilizations have become impoverished or have even destroyed themselves Since Biblical times the rich lands of the Mediterranean region have largely been reduced to semideserts The glory that was the Mayan Empire persists only as ruins overgrown with jungle The great experiments of civilization have not been unqualified successes In the last analysis man is still an animal dependent upon many natural features of the environment for his welfare He can modify and use these features but he cannot with impunity destroy them *See* ECOLOGY HUMAN

Perhaps the outstanding aspect of human biogeography today is the explosive increase of population since 1900 Modern medicine has reduced the normal death rate among people and technological improvements have intensified the processes of resource extraction permitting for the moment at least more people than ever before to live upon

the earth How long the resources of the earth will support such spiraling demands is conjectural *See* ECOLOGY, APPLIED [A S L]

Bioherm

An organic reef composed of fragmental bioclastics the major percentage of which are of marine origin and are not found in growth position The concentration of these bioclastics is due to intense localized organic activity or to local aggregation by waves and currents so as to form rigid mounds or submarine bars which are wave resistant as a result of cementation in situ by living calcareous algae and physicochemical precipitation of calcite Their prime characteristics are that the structure is unstratified or poorly stratified composed of bioclastics and thicker than surrounding time-equivalent nonbioclastic or biostromal strata Bioherms may be of any size and shape and in any stratigraphic position from Cambrian to Recent but they are *usually* associated with topographic irregularities or the break in slope between the shelf and basin within the light zone of ancient seas *See* BIOSTROME, ORGANIC REEF



Bioherms (a) A small stumplike mass of cavernous dolostone in the midst of thin bedded dolomitic limestone of Middle Silurian age near Lomira Wisconsin There has been prominent steepening of the initial dip around the periphery of the structure because of differential compaction in the surrounding calcareous muds (b) Coelenterate bioherm lying in the midst of shale and thin bedded cherty limestone of Middle Silurian age at Wabash Indiana (*From R R Shrock Sequence in Layered Rocks McGraw-Hill 1948*)

The term bioherm is applied by some geologists (E R Cummings and R R Shrock 1928) to any domelike moundlike lenslike or other circumscribed mass built exclusively or mainly by sedentary organisms and enclosed in a normal rock of different lithologic character but it seems preferable to restrict its usage to masses of fragmented debris which were moved out of growth positions before the broken fragments were cemented together This in fact seems to be the case for the greater part of rock bodies to which the term has been applied [S A W E]

Bibliography P E Cloud Jr Facies relations of organic reefs *Bull Am Assoc Petrol Geologists* 36 2125 2149 1952 E R Cummings and R R Shrock Niagaran coral reefs of Indiana and adjacent states and their stratigraphic relations *Bull Geol Soc Am* 3 579–620 1928 T A Link Theory of transgressive and regressive reef (bioherm) development and origin of oil *Bull Am Assoc Petrol Geologists* 34 263–294 1950

Biological effects of sound waves

Sound is a mechanical disturbance in an elastic medium The physical parameters describing the acoustic disturbance may undergo periodic or transient changes at any given site The disturbance can propagate as wave motion and thus transfer energy from one portion of the medium to another In the frequency range below 15 000 or 20 000 cps (the upper frequency limit of human hearing) a sinusoidal periodic disturbance is designated by the term sonic (the term sonic has however been used by some authors to designate the entire acoustic frequency spectrum) above 15 000 or 20 000 cps the waves are termed ultrasonic Since the first biological sound generating or sound receiving organs or both were developed by organisms sound *waves have been vital to the transfer of information* from one organism to another as well as from the environment to the organism (either as environmentally generated sound or as sound generated by the organism and reflected from objects in the environment) The sound transmission and reception by biological systems has not been limited to the sonic range as defined arbitrarily by the frequency limit of human hearing The use of sound frequencies up to 150 000 cps by organisms has been studied One example of the use of sound in the 40 000-cps range is that employed by the bat in its avoidance mechanism These animals employ an ultrasonic guidance system by detecting ultrasonic energy reflected by objects in the environment as a result of short bursts of sound emitted by the animals Another example is the system employed by porpoises in the gathering of food and avoidance of obstacles These animals employ a pulse echo system in their water environment *See* PHONORECEPTION SOUND

Sound wave parameters Sound waves in fluids are partially described by changes in the physical *parameters listed in Table* 1 For *fluids with appreciable* viscosity other important parameters must be introduced in order to describe adequately the changes in the medium produced by the acous

Table 1 Parameters for sound waves in fluids

Term	Symbol	Units (cgs system)
Free field sound velocity	c	cm/sec
Intensity	I	ergs/(cm²)(sec)
Time	t	sec
Linear coordinate	x	cm
Density	ρ	grams/cm³
2π times frequency	ω	1/sec
Sound pressure (amplitude)	p (P)	dynes/cm²
Particle displacement (amplitude)	ξ (D)	cm
Particle velocity (amplitude)	$\dot{\xi}$ (U)	cm/sec
Particle acceleration (amplitude)	$\ddot{\xi}$ (A)	cm/sec²

example of a mechanism resulting in conversion of acoustic energy into heat is that resulting from heat conductivity in fluids This results in non adiabatic heating in the medium and consequent loss of acoustic energy as heat Relaxation effects may be important in various ranges of the frequency spectrum These mechanisms are operative whenever a time interval comparable to the period (inverse of the frequency) of the acoustic disturbance is required for the transfer of energy from external degrees of freedom of the medium to internal degrees of freedom Another inadequacy also the result of viscosity in the use of the parameters of Table 1 to describe an acoustic disturbance in a fluid arises from the fact that shear disturbances may be important and that the single scalar pressure cannot then be used to describe the stress distribution in the medium In such circumstances one resorts to the use of a stress tensor Similarly in such cases it is convenient to introduce the concept of a strain tensor However for the purpose of this article it will be convenient to restrict the discussion to considering the changes in the parameters of Table 1 and to introduce the acoustic absorption coefficient

All the propagation parameters listed in Table 1 satisfy the same type of wave equation which for plane waves with wavefronts perpendicular to the x axis takes the form

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

where the pressure parameter has been inserted and where it is assumed that the amplitude of the disturbance is sufficiently small that nonlinear effects can be neglected

For an acoustic field it is not necessary to specify or measure all the parameters listed in order to describe the field completely As indicated in the table the particle velocity and particle acceleration are time derivatives of the particle displacement and the particle velocity can be expressed (for sinusoidal time variations) in terms of the space gradient of the pressure as

$$\xi = -\frac{1}{\omega\rho}\frac{\partial p}{\partial x}$$

Therefore if the spatial distribution of the pressure amplitude is measured all the other parameters can be derived However if the pressure amplitude is measured at an isolated site or along a single direction it is generally not possible to derive the value of the particle velocity at this site since the space gradient of the pressure could not be derived from the measured values Since the acoustic intensity I is defined as the time average power transfer per unit area across an interface in the medium it is equal to the time average product of the pressure and particle velocity Therefore the sound intensity is expressible as

$$I = \frac{\int_0^\tau p\xi\, dt}{\tau}$$

and for a plane wave

$$I = P^2/2\rho c = \rho c U^2/2$$

This quantity is a space vector and in a plane-wave field it is normal to the wavefronts In many cases particularly when focused beams are used (for instance in the irradiation of deep tissue structures) it is important to specify the values of for example the pressure amplitude and the particle velocity amplitude if a complete determination of one of these variables over the focal region is not made or if the relation between pressure amplitude and particle velocity amplitude is not that characteristic of a plane wave ($P = \rho c U$)

Biological applications The earliest studies involving the irradiation of biological systems with sound waves of sufficient intensity to modify their structure or function or both were initiated in the early 1920s and since that time a variety of biological systems have been irradiated to produce a spectrum of effects The sound waves used in these investigations have been produced in the sonic range by for example devices employing moving coils in a magnetic field For the ultrasonic fre-

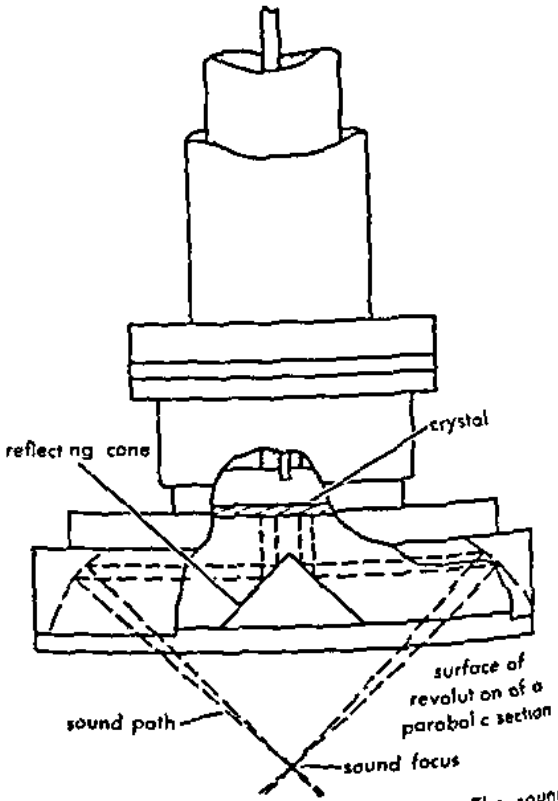


Fig 1 Reflector type focusing irradiator The sound waves emanating from the circular crystal plate impinge on a 90° included angle cone from which surfaces they are directed to a surface of revolution generated by a section of a parabola Focusing is obtained by reflection of the waves from this surface

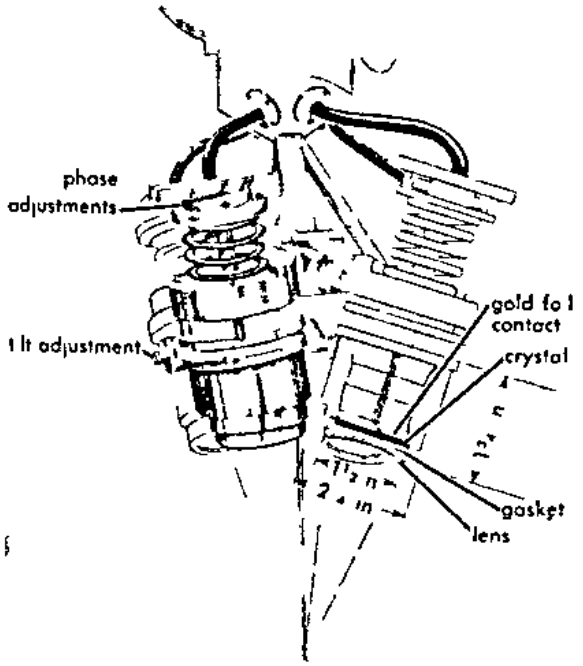


Fig 2 Four beam focusing irradiator Each beam is individually focused by means of a lens and the beams are brought into coincidence and adjusted in phase to yield a maximum sound level at the focal region

quency range the magnetostrictive effect (for transducers to operate up to about 100 kilocycles) and the piezoelectric effect (in crystals used in devices operating from a few kilocycles to the high megacycle range and in certain ceramics used in transducers to operate in the range from a few kilocycles to a few megacycles) have been employed in acoustic transducers Both lens and reflector systems have been used to focus the sound emitted by such transducer elements Two such devices for use in the megacycle frequency range are illustrated in Figs 1 and 2 These schematic diagrams illustrate the construction and principles of operation of such transducers

The acoustic properties of some biological tissues have been investigated These properties include the acoustic velocity from which the specific acoustic impedance can be derived Specific acoustic impedance is defined as the product of the density and the free field sound velocity Table 2 lists some of these materials and the corresponding values for the velocity and specific acoustic impedance Physiological saline and castor oil are included for purposes of comparison because saline is useful as a medium for transmitting the sound from the transducer to the tissue structures The fraction of an acoustic wave reflected (in medium 1) at normal incidence from a tissue interface is a function of the ratio of the specific acoustic impedances, that is the pressure reflectivity is given by

$$\frac{P_{\text{reflected}}}{P_{\text{incident}}} = \frac{(\rho_2 c_2/\rho_1 c_1) - 1}{(\rho_2 c_2/\rho_1 c_1) + 1}$$

where $\rho_1 c_1$ is the specific acoustic impedance of medium 1 in which P_{incident} pertains and $\rho_2 c_2$ is the specific acoustic impedance of medium 2 (the tissue)

The acoustic energy reflected at an interface in soft tissue can be used to determine by ultrasonic means the macroscopic structure of the soft tissue without adversely affecting the biological system The positions of the larger blood vessels muscle fat and skin interfaces and skeleton can be visualized in three dimensions and consequently changes in soft tissue structures caused by disease or accident can be detected that is the presence of tumors calcification and foreign bodies of any material It is expected that this use of ultrasound will become extremely important in medical diagnosis in the near future

The extent to which a sound wave incident on a plane interface is refracted is determined by the angle of incidence and the values of the acoustic velocities in the two media The refraction of acoustic waves at tissue interfaces enters into the determination of the accuracy of placement of the focus of an ultrasonic beam in deep tissue structures If the magnitude of the refraction is known it can be included in the computations for determining

Table 2 Velocity and acoustic impedance of some biological tissues

Species	Tissue	Condition	Temp °C	Frequency Mc	Velocity m/sec	Specific acoustic impedance g/cm² × sec × 10⁵
Man	Limb (mostly muscle)	In vivo	Body	2 5	1540 (mean value)	1 63
Man	Liver	Refrig	24	1 8	1570	
Man	Fat	Refrig	24	1 8	1476	
Man	Skull bone	Fresh	Body	0 8	3360	
Dog	Brain	Fresh	24	2 5	1515	1 56
Dog	Muscle	Fresh	26	4 12	1592	
Hog	Brain		24	2 5	1506	1 55
Castor oil			25		1466 5	1 395
Physiological saline (0 9% NaCl)			25		1515 3	1 520

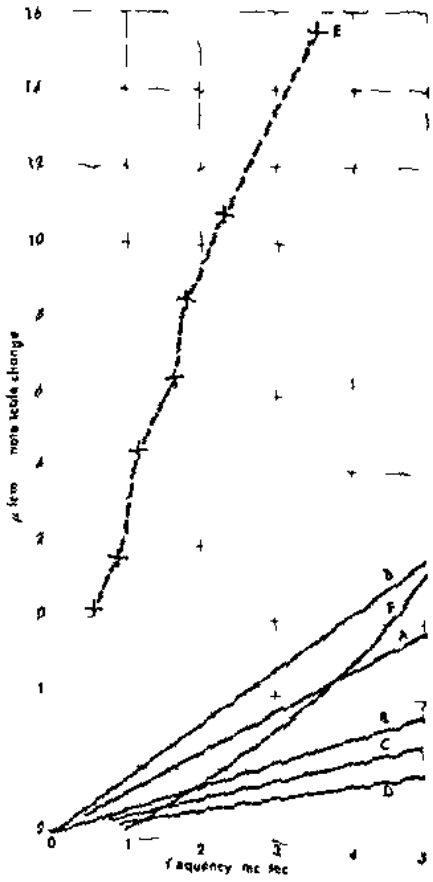


Fig 3 Ultrasonic intensity absorption coefficient per centimeter as a function of the frequency for various tissues in the temperature range 25–30°C and for castor oil at 30°C A beef heart B beef liver C, hog brain (white matter) D hog fat E human skull bone F castor oil

the placement of the transducer relative to the site to be irradiated whereas if it is unknown or not taken into account it introduces an error into the placement of the focus

The ultrasonic absorption coefficient which is sho[illegible] absorption coefficient for intensity is twice that for acoustic pressure amplitude or other linearly related acoustic parameter and it is commonly specified per unit of path length that is

$$I / I_0 = e^{-\mu x}$$

where μ is the intensity absorption coefficient per unit of path length in the medium I_0 is the acoustic intensity at $x = 0$ and I is the acoustic intensity after the wave has traveled a distance x in the medium The absorption coefficient as thus defined is proportional to the frequency over a wide range for the soft tissue structures which have been studied This dependence is not that characteristic for liquids (see for example the absorption coefficient curve for castor oil in Fig 3) The dependence of the absorption coefficient of bone upon frequency is different from that of soft tissue as indicated by the curve for bone given in Fig 3 The absorption coefficient is important in determining the smallest size of focal region which can be attained in deep tissue structures and in determining the temperature distribution which will exist in tissue structures as a result of the passage of the sound It will probably also play an important role in deriving information on macromolecular structures and their distribution in tissue It is already apparent from measurements made on different species of proteins that these molecules have different absorption coefficients

Cavitation is the term applied to the formation of gas or vapor filled cavities in a liquid because of the presence of the sound field These cavities are caused by the negative pressures generated in the medium on alternate half cycles of the acoustic disturbance At any given hydrostatic pressure the minimum sound level necessary to produce cavitation is a marked function of frequency The intensity threshold for cavitation increases as the frequency increases, that is higher sound levels are required at higher frequencies in order to produce cavitation The threshold can also be altered considerably by appropriate processing of the liquid that is by degassing or by subjecting it to a high hydrostatic pressure before subjecting it to the sound This dependence upon frequency for water as a medium is shown by the graphs of Fig 4 Interfaces of various materials presented to the passage of a sound wave in a liquid display a wide range of minimum sound intensities which will initiate cavitation at the various surfaces depending on the degassing of the liquid and the surface preparation An interface can considerably lower the minimum sound intensity needed to initiate cavitation from that which would be observed within the volume of a liquid No cavitation is observed in animal tissues (brain muscle) which have been studied in vivo for acoustic intensities as high as 1500 watts/cm² at a 1 Mc sound frequency

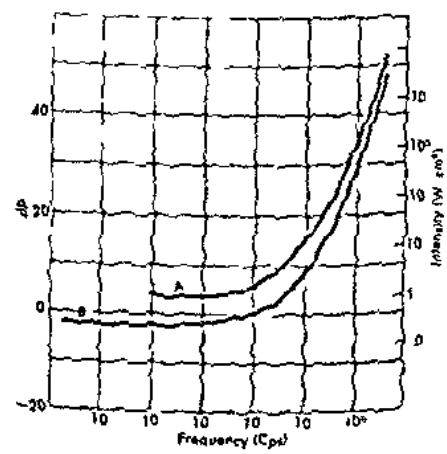


Fig 4 Minimum sound intensity (in watts per square centimeter) to initiate cavitation as a function of the frequency for A distilled filtered and degassed water and B fresh tap water These curves are for cavitation initiated by a focused sound field in the body of the fluid so that interfaces are not present at regions of high sound intensity

Cavitation is extremely undesirable if it is not being employed to produce a specific effect since it interferes drastically with the passage of the acoustic waves In addition it may be accompanied by pressure and temperature disturbances of large amplitude at sites in the medium where the vapor filled cavities collapse *See* CAVITATION

It is possible to produce changes in biological systems by subjecting them to acoustic fields of sufficiently high level or intensity Effects may be caused by heating resulting from sound absorption by cavitation and its associated temperature and pressure phenomena and by so-called mechanical action (for example frictionlike forces exerted between macromolecular species and imbedding media) No detailed mechanical mechanisms that is correlation of a particular field variable or combination of variables with a disruption of specific bonds have yet been formulated to explain specific biological changes but such research is in progress An example of this is the attempt to explain the mechanism of the selective action of appropriate dosages of high level ultrasound on specific tissue components of the central nervous system Since a variety of mechanisms for producing changes is possible in order to explain the results produced by sound in a specific case it is necessary to investigate the possible roles of each of these factors

In much of the earlier work concerned with the action of high intensity ultrasound on biological systems precision instrumentation was not employed so that the acoustic field conditions of irradiation were unknown and thus not reproducible from one type of experiment to another and in many cases were not reproducible with the same equipment These early experiments were concerned with the irradiation of such biological systems as whole fish suspensions of bacteria enzymes viruses and unicellular and multicellular organisms Mammalian tissue including human was irradiated at relatively low intensity levels The criterion employed in irradiating humans was the requirement that the patient experience no pain (in the skin or underlying tissue) under conditions of continuous irradiation This criterion which limits the intensity to the range of 1 to 5 watts/cm^2 depending on the frequency employed and the rate of movement of the irradiator automatically excludes the possibility of discovering selective actions which appear only at higher sound levels

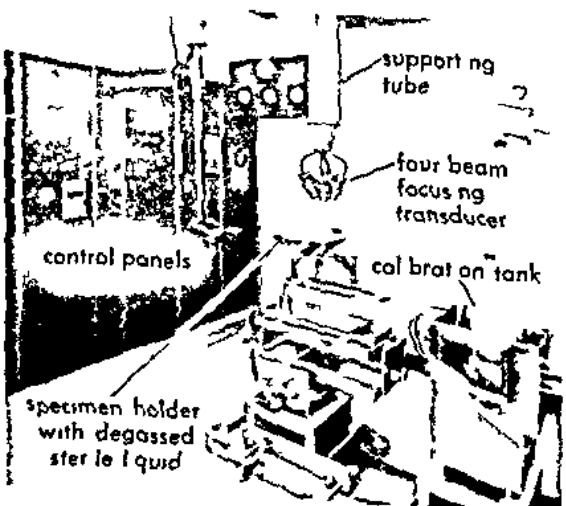
As a result of this work at low sound levels therapeutic devices capable of producing ultrasonic intensities of a few watts per square centimeter of unfocused acoustic radiation at frequencies of the order of 1 Mc were manufactured and used in the treatment of disorders of the human such as periarthritis of the shoulder joint disorders involving limited range of motion rheumatoid spondylitis pain caused by postoperative neuroma in patients who have had amputations and intervertebral disk syndrome and in the treatment of sports injuries such as semilunar cartilage damage muscular and tendon sprains and torn or ruptured muscles The beneficial therapeutic effects are usually the result of heating produced in the tissues but evidence also exists which indicates that nonthermal effects also have some influence The actions or effects of the sound—of interest in the therapy of the disorders indicated—are of a nondestructive nature

It was only in 1958 with the advent of precision machines (both focusing and nonfocusing types) that a wide range of selective irreversible (permanent) effects of high intensity ultrasound on the central nervous system were discovered and then quantitatively reproduced In most of the early work with the destructive action of sound on biological materials suspended in liquid media cavitation played the major physical role in causing the observed changes With precision equipment now in use it is possible to induce either permanent or temporary changes of a selective nature in specific tissue components of the central nervous system for example The effects of precisely controlled high intensity ultrasound on tissue other than that of the central nervous system have not been studied to the same extent as those characteristic of the brain and spinal cord Thus it is not possible to indicate at present the range of selective changes which might be possible in other tissue structures since such studies have not yet engaged the attention of investigators In the case of the central nervous system the results are quite striking under appropriate dosage conditions Neural components in both white and gray matter are more susceptible to the action of ultrasound than are the blood vessels and supporting tissue The blood vessels are more resistant than the neural components in both white and gray matter so that the operation of the neural elements in a region can be completely interrupted without disruption of the vascular system or interruption of blood flow in the same region Some work has been reported on changes induced in the blood brain barrier by appropriate ultrasonic irradiation conditions but the dosage limits to obtain a specific change have not yet been reported The neural components (nerve fibers) of white matter are more susceptible to the action of the sound than are the neural components of gray matter This makes it possible to produce a lesion in which a complex shaped fiber tract is completely interrupted without damage to neighboring or surrounding gray matter that receives an equal dosage of the ultrasound Since the ultrasound can be focused it is possible to induce changes at any desired depth in the brain at a specific site or in specific structures without adversely affecting tissue intervening in the path of propagation from the surface or port of entry of the sound to the site undergoing irradiation It is also possible to induce changes of a temporary nature in neural components of the central nervous system by appropriate choice of ultrasonic irradiation parameters Such changes can be used to obtain three dimensional functional maps of brain operation by sweeping the focus of the sound through the tissue structures and observing the relations between stimuli input to the animal and the

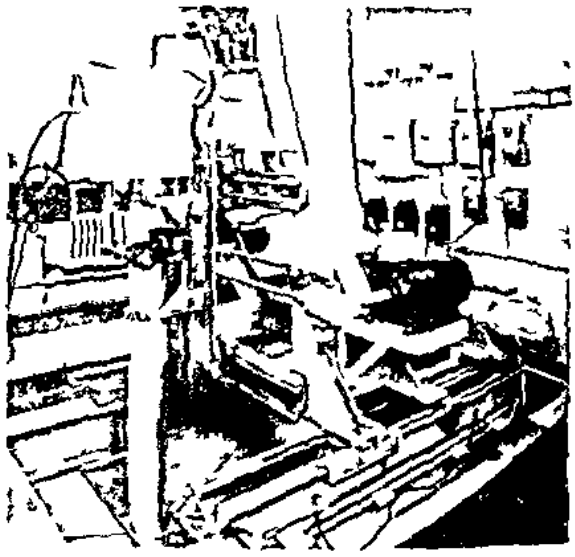
output responses (for example an overt act or the occurrence of an electric event) The instrumentation necessary for such neurophysiological and neuroanatomical investigations is quite elaborate one such instrumentation arrangement is shown in Figs 5 and 6

In Fig 5 the four beam focusing transducer is supported on the tube which projects through the ceiling of the irradiation room This tube is moved about by a positioning system housed in the room above The holder supports the head of the animal (in any desired orientation) with a metal container positioned over the skull The metal container supports the degassed sterile liquid which is used as the medium to transmit the ultrasound from the focusing transducer to the brain The four beam transducer dips into the degassed water of this tank and the acoustic output and field pattern are determined by utilizing a thermocouple probe mounted in this tank The control panels provide controls for positioning determination of ultrasonic dosage observation of electrical activity of the central nervous system and other auxiliary instruments Closed circuit television systems permit the positioning of the focus of the transducer by exhibiting on picture tubes a portion of the scales mounted on the position system in the room above

As a result of basic research on experimental animals over the past decade it has been possible to apply focused ultrasound to the treatment of various neurological disorders in the human Such work with humans has been in progress since the year 1958 The methods used are a modification and elaboration of those used on experimental animals In the case of the human it is possible since the patients are irradiated while awake to interview and examine the individual during the process of irradiation A bone flap can be removed at the initial application and irradiation can subsequently be carried out any number of times without the necessity of repetitive surgery It is thus possible to follow and modify the symptoms and



Fg 5 Apparatus for precis on ultrason c rad at on of t ssue (central nervous system) at h gh sound levels



Fg 6 V ew of coord nate posit on ng system for support ng and moving the ultrasonic transducer Ths structure s housed above the irrad at on room llus trated

signs of a variety of disorders by producing changes at precisely controlled arrays of sites in various structures of the brain The disorders which have received attention to date include parkinsonism athetosis intractable pain and phantom images

Some work has been accomplished on the effects of high intensity ultrasound on tumor tissue but this work is in relatively early stages as compared with that on the central nervous system Favorable effects on some types of tumors have been reported from the use of a high intensity unfocused beam covering a large volume of tissue simultaneously The use of high intensity ultrasound in the irradiation of deep tumors is in the early stages and only a small amount of work has been accomplished in this area *See* BIOPHYSICS THERMOTHERAPY

[F J F WIF]

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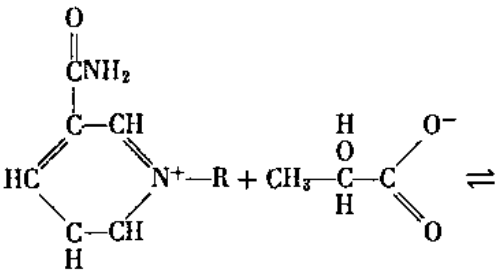
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Biological oxidation

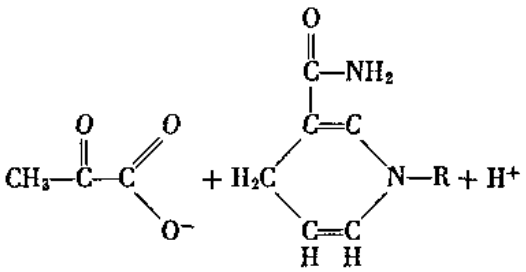
The class of chemical reactions by which hydrogen atoms or electrons are transferred from one molecule to another in the living cell Reactions of this type catalyzed by enzymes are the major source of energy in the animal kingdom and may also serve purely degradative or synthetic functions The principal sources of hydrogen and electrons are specific metabolic breakdown products of the major foodstuffs fats carbohydrates and proteins The molecules which accept the hydrogen in the initial reactions are the respiratory coenzymes respectively flavin adenine nucleotide (FAD) and the di and triphosphopyridine nucleotides (DPN and TPN) Most of the energy made available by the oxidation of foodstuff or substrate occurs not in the initial reduction of coenzyme but in the subsequent transfer of the hydrogen to molecular oxygen This is a stepwise process in which hydrogen or electrons are transferred in a series of oxidation reduction reactions from one respiratory

Reactions at the substrate level The structure of DPN is

It is the nicotinamide ring on this molecule that is alternately reduced and oxidized A typical reaction is the oxidation of lactate to pyruvate Only the nicotinamide ring of DPN is shown in detail

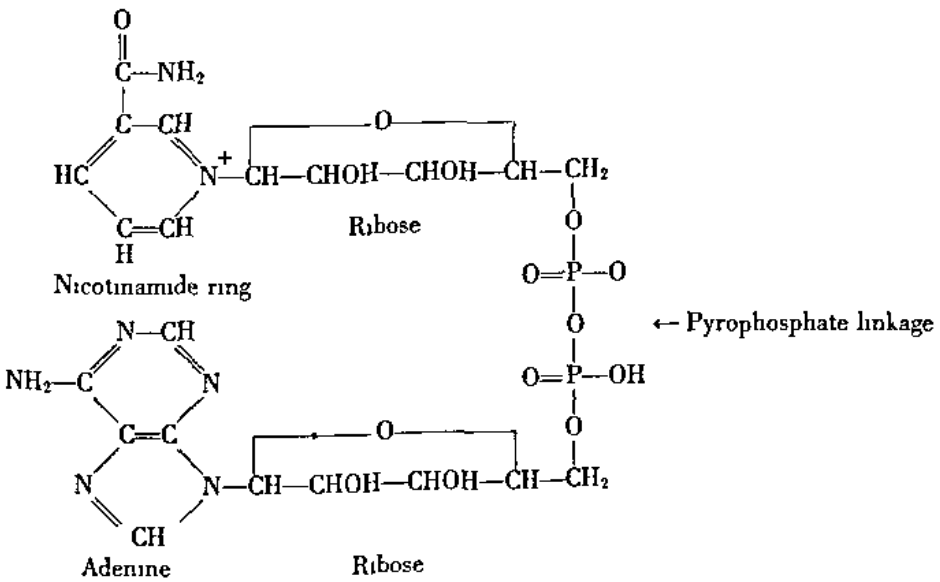


Nicotinamide ring Lactate



Pyruvate DPNH + H+

The substance which donates hydrogen or electrons is said to be oxidized and the one which accepts the hydrogen is said to be reduced Thus proceeding from left to right the lactate is oxidized and the DPN is reduced to DPNH In the presence of the enzyme the reaction goes in both directions and reaches an equilibrium The equilibrium is strongly in favor of lactate in this case Complete oxidation of lactate to pyruvate occurs only when the DPNH is reoxidized by another oxidant There are hundreds of reactions of this type in nature differing *in the nature of the substrate oxidized by pyridine* nucleotide and each catalyzed by a specific enzyme In all pyridine nucleotide reactions the nicotinamide group accepts a hydrogen atom plus one

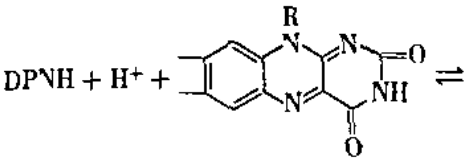


Nicotinamide ring Ribose ← Pyrophosphate linkage

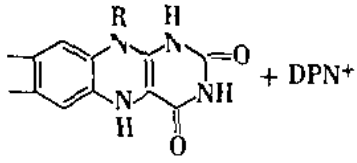
Adenine Ribose

electron from the substrate and one hydrogen ion is transferred to the solvent

Respiratory enzymes A second group of enzymes catalyzes the reoxidation of DPNH by FAD



FAD



Flavineadeninenucleotide reduced ($FADH_2$)

The isoalloxazine ring of FAD accepts a hydrogen atom plus an electron from DPNH and picks up a hydrogen ion from the solvent In such reactions the equilibria are usually far to the right that is the complete oxidation of DPNH to DPN is favored Subsequent steps in the transfer of hydrogen from substrate to oxygen involve the participation of a group of respiratory enzymes called the cytochromes In these reactions an iron atom coordinated in a porphyrin group on the cytochrome protein accepts one electron and is reduced from the ferric (Fe^{3+}) to the ferrous (Fe^{2+}) state

$$FADH_2 + 2\ \text{Cytochrome}^{3+} \rightarrow FAD + 2\ \text{Cytochrome}^{2+} + 2H^+$$

There are two points of importance in this reaction (1) it is electrons that are transferred and the hydrogen enters the solvent as hydrogen ions (2) two cytochrome molecules are needed to oxidize one molecule of $FADH_2$ As a consequence of the latter requirement the FAD must exist at least transiently in the form FADH This form is termed a free radical or semiquinone and is characterized by the presence on it of an unpaired electron Subsequent steps in the transport of electrons involve the transfer of electrons from one cytochrome molecule to another in the sequence, Cyt c → Cyt b → Cyt a → O_2 The last step is represented by the equation

$$O_2 + 4Cyt\ a^{2+} + 4H^+ \rightarrow 4Cyt\ a^{3+} + 2H_2O$$

and involves atomic

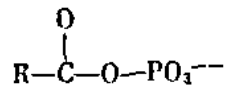
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the flow of hydrogen and electrons from substrate to oxygen by the reactions outlined above is analogous to the flow of electrons from the negative to the positive terminal of a storage battery and may be harnessed to perform work In order to do this the energy liberated in an oxidation step must be first utilized in the conversion of orthophosphate ions to reactive or energy rich phosphate anhydrides The best known and simplest example occurs in the oxidation of glyceraldehyde 3-phosphate represented by the abbreviated formula RCHO

$$RCHO + \text{Enzyme} + DPN \rightleftharpoons RCO\text{—Enzyme} + DPNH + H^+$$

$$RCO\text{—Enzyme} + HPO_4^{--} \rightleftharpoons RCO\text{—}OPO_3 + \text{Enzyme}$$

The enzyme in this case performs the auxiliary function of forming a reactive ester with the acyl group formed in the aldehyde oxidation The chemical bond energy of the aldehyde is retained in the acyl enzyme intermediate and also in the product that is formed when the acyl group is transferred from the enzyme to a phosphate ion The product has the structure



and is thus a reactive mixed carboxyl phosphate anhydride A second enzyme catalyzes the transfer of the phosphate group from the above product to adenosine diphosphate (ADP) to form adenosine triphosphate (ATP) The latter compound constitutes the "energy currency" of the cell Its breakdown by loss of the energy rich phosphate is utilized in the performance of both chemical and mechanical work *See* ADENOSINEDIPHOSPHATE (ADP) ADENOSINETRIPHOSPHATE (ATP)

When the DPNH transfers its hydrogen and two electrons through the respiratory enzyme chain at least three more molecules of ATP are formed from ADP and inorganic phosphate The flavoproteins and cytochromes in the respiratory chain occur in complex lamellar structures called mitochondria visible in all cells The detailed mechanism of phosphate esterification during the latter hydrogen and electron transfer steps is the subject of widespread investigation It is believed that accessory substances containing a benzoquinone structure are interspersed between the respiratory enzymes of the mitochondria and act as sites of phosphorylation prior to ATP formation

Methods The entire respiratory chain of enzymes remains intact and functional in isolated cells or in mitochondria isolated therefrom The oxidation of a test substrate may therefore be followed quantitatively by measuring manometrically the decrease in oxygen pressure with time that occurs when tissue slices or cell fragments are shaken with substrate in a closed vessel Many of the individual enzymes particularly those which catalyze the reduction of DPN have been isolated by standard methods of protein fractionation and crystallized in pure form The reduction and oxidation of all of the known respiratory enzymes and coenzymes are associated with specific changes in the optical absorption spectra Therefore it is possible to follow individual reaction steps with purified enzyme systems by placing the reaction vessel in a spectrophotometer Similar methods may also be used with intact cells if suitable electrical and mechanical devices are employed to correct for turbidity and for nonspecific absorption It has been

possible to isolate specific cytochromes and flavoproteins from mitochondria and these substances continue to participate in oxidation reactions but the ability to utilize oxidative energy in ATP formation is lost when the mitochondria are fragmented beyond a certain level *See* METABOLISM MITOCHONDRIA [S F S]

Biological productivity

The quantity of organic matter (in the form of living flesh stored food and waste products) accumulated during a given time also known as the biological production rate Gross productivity is the integrated total including that lost to other organisms by death excretion and other physiological phenomena Net productivity is the balance (positive or negative) between the amount of organic matter present on two successive occasions Productivity may be referred to a population of a single species a group of species such as those sharing a trophic level in a food chain or an entire community or ecosystem In the ecosystem the primary productivity is the gross photosynthesis by the plants Some authors would restrict the term to primary productivity by plants because actual production of organic matter occurs only through photosynthesis and chemosynthesis Thus F Odum substitutes the term assimilation for production by nonphotosynthetic organisms Most authors follow the more general definition above *See* COMMUNITY ECOSYSTEM, FOOD CHAIN

Energy and matter in the ecosystem The synthesis and breakdown of organic matter involve two separate but related activities namely change of biomass and flow of energy These may be studied at the organizational levels of the species the trophic level and the whole community The paths of matter and energy through the system are quite separate and failure to recognize this has caused much confusion in the past *See* BIOMASS

Circulation of matter Substances built up by photosynthesis may be broken down by the plant in respiration, they may be passed on to herbivores or decomposer organisms which in turn may break them down by oxidation or hand them on to later members of the food chain A given atom of carbon or phosphorus, for example may be (and as studies with radioactive isotopes have shown usually is) reused many times within a single organism and by other members of the community and its fate is therefore quite unpredictable

Energy pathway The path of energy through the system on the other hand is subject to a strict balance sheet The primary production of energy by photosynthesis (plus imports from other communities plus exploitation of past reserves such as muds and fossil fuels) must equal the losses by respiration of all the members of the community (plus losses to other communities and to reserves) Once liberated by oxidation of fuel energy is irretrievably lost to the system and it is this strict quantitative relationship between photosynthesis and respiration rates which makes energy the universal currency for productivity measurement in ecological systems Comparisons between members of a trophic level between levels and between communities can be made in calories and provide a generally applicable measure of activity or importance

Productivity Current practice is to restrict the meaning of productivity (rate of production) to the rate of accumulation of material as measured in biomass per unit time When used without qualification productivity may mean either dry weight of organic matter or of carbon and may refer to either gross or net productivity the basis should always be specified Productivity is sometimes used to mean the annual yield to man of some natural or artificial biological system which he exploits, such as a fishery or a corn crop It is even used to indicate the instantaneous weight of crop present Some authors have redefined productivity simply as the rate of energy accumulation (for example F P Odum who does not however adhere to this usage subsequently)

It is essential first that the sense in which such terms are used should be understood in every case and second that some general agreement about their meaning should be accepted It is suggested here that productivity be used only in the sense of a rate of production that it be confined neither to energy nor to matter and that the units always be specified that it be clearly distinguished from standing crop (which is an instantaneous quantity, not a rate and is a poor indicator of productivity and of productive capacity) and that the term yield be used to denote that proportion of the product which is exploited by a particular human harvesting operation The term production should not be used as a substitute for either yield or standing crop

Efficiency The ratio between the amount of energy contained in the living matter of a species or trophic level during a given period and the energy liberated from it during the period is quite variable The loss of energy by respiration during a complete life cycle is always much greater than the body energy content of an individual (although heavy mortality of young stages may reduce the proportion for whole populations) Soil arthropods consume their body energy content about 12 times during their life and trout about 5 times Thus from the standpoint of the community the energy content of a trophic level at one time is unimportant compared with the energy loss by respiration from that level When measurements are made at intervals of 1 year and the community is stable, so that standing crops do not change much from year to year the static energy content of a level may be ignored On the other hand when the exploitation by man of the energy content of flesh (usually sertel rate) is considered the proportion of energy contained therein at any one time is of predominant interest

Terms such as efficiency are used in many senses and no correct use can be specified Efficiencies are ratios either of mass or energy and they may be

compared either within or between trophic levels In fishery practice they are given the special meaning of the percentage of that food which is not used for metabolism but which appears as increased body weight The usual meaning of the expression when not qualified is the percentage of biomass which is handed on as flesh to subsequent trophic levels as compared with that which is assimilated that is the ratios of production of successive levels Many efficiencies are enumerated by E P Odum and B Patten

The losses at each successive level are reflected in the discrepancies in size between the steps of the energy and biomass pyramids over all photosynthetic efficiency is about 1% and the proportion of plant food taken by herbivores is seldom more than 50% Productive efficiency increases to the order of 10% at the herbivore level and is perhaps higher at carnivore levels A generalization accorded to R Lindemann states that there is a progressive increase in efficiency of this kind but there are still hardly enough figures for reliable generalization Even so the lesson for human exploitation of ecosystems is clear that the lower the trophic level which can be used the greater will be the yield cereals are produced more abundantly than meat and herbivores such as the herring are more abundant than carnivores such as trout

Measurement of productivity Practical measurements of productivity have been made in the case of single species populations subject to human exploitation such as those by E Allen for trout and some relatively simple whole communities in fresh water by H T Odum and J Teal Less complete studies are available for marine areas and for terrestrial habitats Figures for productivity of agriculture and fisheries are given by K Kalle and E Odum and a few approximate but representative figures are given in the table

Methods of measurement vary greatly In the case of human crops the annual yield is a measure of net productivity provided the crop is not being shared with other (pest) organisms Gross primary productivity of aquatic plankton can be measured by adding the oxygen consumption measured in a dark bottle to the oxygen production measured in a clear one An alternative method which gives discrepant results still subject to controversy is C Nielsen's use of the rate of uptake of carbon from bicarbonate labeled with C^{14} Primary productivity in aquatic environments can also be measured over limited periods by the rate of uptake of nutrients and of synthesis of chlorophyll The gross productivity of whole communities can be arrived at by the consideration of respiration rate measurements and the combination of biomass and caloric content determinations through the food chain [A MC]

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Some representative figures of biological productivity

Type of productivity	Rate kcal (m²)(yr)
Marine	
Solar energy reaching surface of North Sea (55°N lat.)	884 000
Gross productivity organic matter	
North Sea	360
Sargasso Sea	800
Long Island Sound	4 700
Coral reefs	26 600
Fish yield	
North Sea fisheries	2 3
Tropical seas maximum	192
Fresh water	
Gross productivity	
Temperate lakes oligotrophic	1 020
Temperate lakes eutrophic	3 060
Florida stream Silver Springs	25 600
Fish yield	
German rivers	1 9
German carp ponds maximum	3 8
Chines fish ponds maximum	27
Land	
Deserts gross productivity maximum	700
Temperate grassland gross productivity maximum	14 000
Yield of temperate crops (edible part only)	
Wheat Europe	890
Potatoes, Europe	2 280
Sugar beet Europe	3 240
Timber Europe	1 000
Alfalfa United States	372
Carrot (very productive) Europe	2 250
Asparagus (low productivity) Europe	140
Yield of tropical crops	
Sugar cane	16 100
Banana	24 000
Cassava	34 800
Meat	
Beef United States*	29 8
Beef Germany†	10 8
[illegible]	16 8
[illegible]	67 5
Nematoda	220
Collembola	1 000
Microorganisms after manuring	250
Microorganisms without manuring	373
	25

* E P Odum *Fundamentals of Ecology* Saunders 2d ed 1959
† K Kalle *Deut Hydrograph Z* 1(1) 1948
‡ Very approximate

Biological specificity

Although all living cells contain hundreds of potentially reactive chemical substances their metabolic and developmental reactions do not occur at random but follow instead orderly patterns that give rise to the unique characteristics of the individual and of its species The guiding principle is termed biological specificity, examples abound in all areas of biology *See* CELL (BIOLOGICAL)

Specificity may originate, first, at a chemical level A most important example is the structural *correspondence (presumably in an inverse comple* mentary sense) between an enzyme and the sub strates whose reaction it catalyzes Analogous rela tions govern the specific reactions between antigens and antibodies Again, the specificity of fertiliza tion of an egg by sperm or pollen is universally important in preserving the unique characteristics of animal and plant species although occasional hybrids can be produced as exceptions In addi tion to chemical determinants, the specificity of re production may also be governed by anatomical or behavioral characteristics of the plant or animal which minimize cross matings between separate species *See* ANTIGEN ANTIBODY REACTION EN ZYME, FERTILIZATION, SPECIATION

The relations between two or more widely diver gent species may also be precisely ordered as in parasitism Thus with negligible exceptions a given pathogenic microorganism will infect either an animal or a plant, but not both Within each kingdom further elements of host specificity ex ist some microorganisms being adapted to para sitize only one species, such as man Certain para sites for example schistosomes malaria organisms, and wheat rust require multiple defined animal, insect, or plant hosts, in alternation, if their life cycles are to be completed Some associations may not be unfavorable to either partner The ferti lizations of Smyrna figs, yuccas, and certain or chids require particular insects for pollen trans fer The association of algae and fungi in lichens is also a nonrandom one *See* LICHENS MALARIA PARASITOLOGY, SCHISTOSOMIASIS, WHEAT

[H P T]

Biologicals

Biological products used to induce immunity to various infectious diseases or noxious substances of biological origin The term is therefore much more restrictive than the words themselves imply because it is usually limited to immune serums antitoxins vaccines, and toxoids that have the effect of providing protective substances of the same general nature that a person develops natu rally from having survived an infectious disease or having experienced repeated contact with a biologi cal *poison* As a matter of governmental regulatory convenience certain therapeutic substances which have little to do with conferring immunity have been classified as biological products primarily be cause they are derived from human or animal sources and are tested for safety by methods similar to those used for many biological products

Immune serums. One major class of biologicals includes the animal and human immune serums All animals including man develop protective substances in their blood plasma during recovery from many (but not all) infectious diseases or following the injection of toxins or killed bacteria and viruses These protective substances called antibodies usually are found in the gamma globulin fraction of the plasma and are specific in the sense that they react with and neutralize only substances *identical or closely similar to those* that caused them to be formed Thus serum containing anti bodies induced by injections of diphtheria toxin will neutralize diphtheria toxin but not tetanus toxin *See* BIOLOGICAL SPECIFICITY *See also* AGAMMA GLOBULINEMIA, ANTIBODY, ANTIGEN, IMMUNITY

Antibody containing serum from another animal is useful in the treatment or prevention of certain diseases of humans when it is given by intramuscu lar or intravenous injection The use of these pre formed "borrowed" antibodies is called passive immunization to distinguish it from active im munization in which each person develops his own antibodies Passive immunization has the advantage *of providing immediate protection, but it is rather* temporary because serum proteins from other ani mals and even from other humans are gradually destroyed in the recipient

Types Serums which contain antibodies active chiefly in destroying the infecting virus or bacte rium are usually called antiserums or immune serums, those containing antibodies capable of neutralizing the secreted toxins of bacteria are called antitoxins Immune serums have been pre pared to neutralize the venoms of certain poisonous snakes and black widow spiders they are called antivenins

Because all products used for passive immuniza tion are immune serums or the purified globulins from such serums they are named to indicate the diseases that they treat or prevent the substances that they inhibit or neutralize the animal from which they came and whether they are whole serums or the globulin fractions thereof Thus there is for example, antipertussis immune rabbit serum antipoliomyelitis human gamma globulin diphtheria antitoxic globulin (horse) and tetanus antitoxin (bovine purified) *See* GAMMA GLOBULIN

Preparation The general methods of preparation of various immune serums and antitoxins differ only in details Horses cows, goats or rabbits are in jected with slowly increasing amounts of either the virus, bacterium, bacterial toxin, or venom as antigens against which immunity is to be developed These agents are usually treated with chemicals to *render them noninfectious or nontoxic before in* jection Injections are given over several months and the animals respond by producing relatively large amounts of specific antibody against the in jected material When the antibody concentration has reached a high level in the blood the animals are bled and the blood is allowed to clot The liquid serum can be separated from the blood cells after the clot has contracted In modern practice this serum is almost always fractionated chemically to obtain the concentrated antibody globulin frac tion free of albumin and other nonantibody frac tions Therefore a small volume contains the anti bodies from a much larger volume of serum The antibody globulin solution is then sterilized by

filtration through a bacteria proof filter and a small amount of a preservative antibacterial chemical is added to protect the solution from bacterial contamination during administration

Each lot of immune serum or globulin concentrate is tested to make certain that it is sterile free of fever producing impurities (pyrogens) and free of accidentally introduced poisonous materials In addition each serum is tested to determine the antibody concentration in the serum Although methods vary depending upon the type of immune serum the potency of antitoxins is usually measured by determining the amount that is required to protect mice or guinea pigs which have been injected with a standard amount of the corresponding toxin When the protective dose of the unknown serum is compared to the protective dose of a standard antitoxin containing a known number of units of antitoxin per milliliter it is possible to calculate the number of units of antitoxin activity in the serum or globulin concentrate that is being tested The dosages of antitoxins are usually specified in units rather than volume *See* BIOASSAY PHARMACEUTICALS TESTING

The potencies of immune serums against viruses and bacteria are usually measured by their ability to protect animals from the fatal effects of a standard amount of the living infectious agent This method of testing is not as precise as the measurement of an antitoxin so that a minimum potency is usually established for each kind of serum and each new lot is required to equal or exceed the protective effectiveness of a reference immune serum The dosages of antibacterial or antiviral immune serums or globulin concentrates are usually expressed in milliliters

Disadvantages The use of animal immune serums for prevention or therapy in humans has certain disadvantages The serum proteins themselves may cause the production of specific antibodies in the person who receives the immune serum and thus he may become allergically sensitized to the serum protein of this animal species Therefore a second dose of serum from the same species of animal given weeks months or years later may cause an

hypersensitivity by injecting a tiny amount of serum into the skin of the patient A positive reaction indicating hypersensitivity is evidenced by the rapid development of itching inflammation and swelling at the site of the injection *See* HYPERSENSITIVITY

A second and less acute type of reaction resulting from the injection of animal immune serum is so-called serum sickness About 4–10 days after the administration of serum the patient develops fever urticarial (hivelike) rash and sometimes joint pains These reactions are not ordinarily fatal

Many people have significant amounts of measles and poliomyelitis antibodies in their serums as a result of recovery from either the clinical diseases or inapparent infections Therefore the globulin concentrates from normal pooled human serums collected at random have sufficient antibody to be useful in preventing these infections in persons who have been exposed Such human serum proteins do not produce the allergic hypersensitivity problems that often follow the passive transfer of animal serum

Active immunity production Products used to produce active immunity constitute the other large class of biological products They contain the actual toxins viruses or bacteria that cause disease but they are modified in a manner to make them safe to administer Because the body does not distinguish between the natural toxin or infectious agent and the same material when properly modified immunity is produced in response to injections of these materials in a manner very similar to that which occurs during the natural disease Vaccines are suspensions of the killed or attenuated (weakened) bacteria or viruses Toxoids are solutions of the chemically altered specific bacterial toxins which cause the major damage produced by bacterial infections Biological products producing active immunity are usually named to indicate the disease they immunize against and the kind of substance they contain thus typhoid vaccine diphtheria toxoid tetanus toxoid and poliomyelitis vaccine *See* DIPHTHERIA POLIOMYELITIS, TETANUS TOXIN BACTERIAL TYPHOID FEVER

Safety measures It is most important that vaccines and toxoids be altered in a way to make them safe but not so drastically altered that they will no longer produce immunity Certain strains of smallpox virus yellow fever virus and the tubercle bacillus have been attenuated so that although they can still undergo limited multiplication in the body they will not produce progressive infection or symptoms of disease Vaccines made from these strains are called attenuated vaccines Other viruses are rendered completely noninfectious by the addition of small amounts of formaldehyde and bacteria may be killed with formaldehyde phenol or mercurial compounds Vaccines made from these killed infectious agents are called killed vaccines Typhoid vaccine pertussis (whooping cough) vaccine and polio vaccine are examples of this type of product Many bacterial toxins can be made nontoxic by incubation at 37°C with small amounts of formaldehyde These altered toxins are called toxoids and will stimulate the body to produce antitoxin capable of specifically neutralizing the toxin Diphtheria toxoid and tetanus toxoid are the two most common toxoids used to immunize humans *See* SMALLPOX TUBERCULOSIS, YELLOW FEVER WHOOPING COUGH

Vaccine preparation Bacterial vaccines are usually prepared by growing specially selected strains in suitable culture media harvesting the bacteria from the media and suspending them in saline A killing agent is added to the bacterial suspension

and is allowed to act at about 37°C until no bacteria remain alive The suspensions are then diluted with physiological saline solution to a standard density of bacteria correct for the particular kind of vac cine These suspensions after testing for sterility lack of abnormal toxicity and immunizing potency are ready for use Because viruses must be grown in the presence of living cells these agents are inoculated into embryonated eggs live animals or cultures of living cells growing in bottles in the laboratory The egg fluids animal tissue juices or the supernatant fluid of tissue cultures then contain the viruses As with bacteria treatment with form aldehyde destroys the infectivity of viruses and these virus containing solutions may be used for immunization after suitable tests to ensure safety sterility and potency

Toxoids With certain toxoids the addition of a small amount of alum aluminum hydroxide or aluminum phosphate precipitates the toxoid mole cules and changes the solution to a suspension that is more effective when injected than the original toxoid solution These precipitated toxoids may be given in smaller amounts to produce equal or greater immunity than that caused by the plain toxoid Alum precipitated diphtheria toxoid is widely used in preference to plain toxoid

Multiple immunization Because it is frequently expedient to immunize people simultaneously against several diseases various immunizing agents have been combined so that they can be given in a single series of two or three doses A combination of pertussis vaccine diphtheria toxoid and tetanus toxoid with alum added has become very widely used as an immunizing agent for small babies Vaccines against three types of poliomyelitis have been added to this mixture Combinations of ty phoid vaccine and tetanus toxoid have also been used to immunize adults and other combined vac cines will probably be introduced as they are de veloped

The combination of a large number of different immunizing agents within a single immunization dosage is an exceedingly complex problem because dosage volume must be kept small and the various agents must be compatible This has resulted in much research on purification and concentration of antigens to reduce their volumes and eliminate toxic impurities Tetanus and diphtheria toxoids and influenza and poliomyelitis vaccines have been considerably purified and chemical fractions of various pathogenic bacteria are now being used as immunizing agents

Veterinary use Because livestock and pets as well as human beings require protection from in fectious diseases there is an extensive assortment of veterinary biological products Many of these are vaccines and toxoids prepared in the same way as are products for human use although vaccines prepared from attenuated living viruses and bacte ria are frequently employed There hav tensive trials in human beings of pc vaccines containing living attenuated polio viruses Although this vaccine is similar in principle to several of the vaccines used to immunize animals its administration is rather unusual because it is given orally rather than by injection It establishes an intestinal infection just as does virulent poliomye litis virus but it does not appear to cause infection of nerve tissue

Blood derivatives In addition to products for active and passive immunization a few other sub stances of human or animal origin are also classed (mostly for regulatory convenience) as biological products One group of these is normal human blood plasma and its derivatives Whole plasma and serum albumin are used to combat hemorrhage and shock and other fractions are used in the treatment of hemophilia and for their clotting properties Although they do not produce immunity to infec tious diseases these substances require testing for sterility safety and freedom from pyrogens as do the immune serums

Diagnostic agents Another group of biological products consists of a miscellany of reagents used in the diagnosis of infectious diseases These in clude immune serums for the serological typing and identification of pathogenic bacteria and vi ruses and various antigens for the detection of antibodies in patients serums as a means of assist ing in diagnosis In addition to these substances used in the laboratory diagnosis of disease certain extracts of bacteria fungi and plant and animal tissue have been prepared for injection into the skin to detect allergic hypersensitivity In certain diseases such as tuberculosis and brucellosis the patient usually becomes hypersensitive to certain components of the infecting organism Extracts of these organisms injected into the skin of such a person will cause inflammation whereas no reac tion will occur in a person who has not been in fected Patients who are allergic to various plant and animal substances will also react to skin tests with extracts of the appropriate substance These skin tests therefore are of assistance in the diag nosis of various infectious diseases and allergic hypersensitivities *See* IMMUNOLOGY SKIN TEST

[W F V]

Biology

A division of the natural sciences dealing with life Biology is the science of living organisms in con trast to the physical sciences which are concerned with inanimate matter Biology is the broad gen eral field of knowledge concerned with the study of all aspects of living things which can be ap proached by the methods of natural science Be cause the field is so broad in scope it has been divided into two main divisions botany and zool ogy each with a large number of specialized branches No one worker can know the entire field of biology thoroughly Specialized sub divisions of biology pertaining to both plants and animals in

ogy cytology genetics evolution and ecology The term biology embraces those principles of wide t application to the origin growth and development structure function evolution and distribution of plants and animals *See* ANIMAL BOTANY MICRO BIOLOGY PLANT ZOOLOGY [C B C]

Bioluminescence

The emission of light visible to the human eye by various living organisms In the plant kingdom only two orders exhibit bioluminescence the luminous bacteria and the luminous fungi whereas among animals some 40 to 50 different groups produce light

Basically bioluminescence is chemiluminescence that is light for which a chemical reaction supplies the energy It differs from the incandescence of a burning candle where chemical energy (of combustion) is also involved but only to raise the temperature to a high value With luminescence visible light appears at a low temperature

Luminescence in plants Luminous representatives of the plant kingdom the bacteria and the fungi do not require a stimulus for light emission Their steady glow depends only on temperature pressure and changes in salt content or in pH of the medium *See* CELL (PRESSURE TEMPERATURE EFFECTS) Odour

in refrigerators or on flesh of various land animals They are of the rod coccus or vibrio shape and may be distinguished by the general methods used in bacteriology (*see* BACTERIAL LUMINESCENCE)

Luminous fungi are fairly numerous in both tropical and temperate climates In the mushroom the fruiting body the mycelium or both may be luminous When the mycelium penetrates dead wood the phosphorescent wood *or fox fire* of forests appears Its steady light is a well known sight when the season has been especially damp and humid

Luminescence in animals With a few exceptions animals light only on stimulation For instance the phosphorescence of the sea is caused by a ship s movement through water or by electrical or thermal stimulation In a multicellular organism this stimulus is provided by nerves the flash of a firefly is an example

In the animal kingdom these groups are known to be self luminous *radiolarians* dinoflagellates hydroids medusae siphonophores pennatulids ctenophores nemertines various polychaetes earthworms nudibranchs pulmonate snails gastropods bivalves squid decapod ostracod copepod and schizopod crustaceans millipedes centipedes Collembola Diptera Coleoptera ophiuroids enteropneusts tunicates elasmobranch and a large number of teleost fishes

Most of these forms are marine The only true fresh water luminous animal is *Latia* a limpet from New Zealand The larva of a firefly an aquatic glowworm that breathes by tracheal gills may also be classed in this category It is not known why the deep fresh water lakes such as Lake Baikal in Siberia are destitute of luminous species whereas the depths of the ocean contain many luminous animals

Single cells may be luminous as in the case of bacteria or dinoflagellates The best known of the latter is *Noctiluca* which is responsible for much of the light of the sea Observed with a microscope at night the light is seen to be in points not diffuse It arises from small granules scattered throughout the protoplasm and appears only on stimulation Granules within cells are associated with luminescence in multicellular animals also The light may come from isolated patches of cells on the surface of the body a definite multicellular gland or a very complicated luminous organ like an eye Sometimes present are accessory structures for focusing light such as a reflector a lens or both or color screens to deflect the light These lanterns are best developed among the deep-sea shrimp squid and fish

In many cases an animal will be reported luminous because of some reflecting material on the body The eye of a cat seems to luminesce but the effect always results from a reflecting tapetal layer in the retina and is absent in complete darkness Other animals become luminescent through infection with luminous bacteria which eventually cause their death This has been reported among sand fleas fresh water shrimp millipedes mole crickets may flies midges caterpillars and ants

Symbiosis An animal can also harbor luminous bacteria as symbionts in special glands the bacteria receive nutrients from the host and the animal can use the bacterial light as if it were actually self luminous Such species may be considered bioluminescent with the reservation that the light is bacterial in origin

The most interesting case of symbiosis occurs among two fish of the Banda Sea in Indonesia *Photoblepharon* and *Anomalops* Both genera possess an oval luminous organ under the eye that is well supplied with blood vessels and contains many bacteria emitting continous light The *Photoblepharon* can shield the light by drawing up a *black* fold of skin like an eyelid over the light organ The *Anomalops* has a hinge muscle at its front end to rotate the light organ so that the bacterial light is turned inward and only the black surface of the organ exposed to view Thus these fish can flash their light like fireflys as they swim through the sea and may use it in some sort of signaling system Other species of fish contain glands with long ducts filled with luminous bacteria which can be squeezed into the sea like a true secretion Some species of squid also harbor luminous bacteria that are presumably symbiotic They do not appear in every individual of the species

Chemical basis Chemiluminescence is usually slow oxidation not nearly so rapid as in a flame Bioluminescence also in most cases utilizes molecular dissolved oxygen Luminous bacteria fireflies



(*Top*) Photograph shows a plate of fish and shrimp taken by artificial light
(*Below*) Photograph taken by the light of luminous bacteria present on the seafood (*Photographs by H Johnson*)

(*Lower left*) Photograph of luminous mushrooms taken in artificial light (*Lower right*) The same mushrooms photographed utilizing their luminescence (*Photographs by Y Haneda*)



or *Cypridina* become dark when the oxygen is removed and luminesce when it is returned A few forms *the ctenophores for example will luminesce* in complete absence of dissolved oxygen They probably contain oxygen bound in some stable form

The photogenic substances may be produced and remain within the cells during light production (intracellular luminescence) as in the firefly or may be excreted into the sea water (extracellular luminescence) as in the ostracod crustacean *Cypridina*

An understanding of the chemical problem of bioluminescence involves isolating the photogenic

level to a higher energy level On the electron s return to the ground level this energy is emitted as a quantum of light

The bioluminescence mechanism is best understood in the ostracod crustacean *Cypridina* the firefly and certain luminous bacteria The fundamental reaction is the oxidation of a relatively simple dialyzable heat stable compound luciferin in the presence of a thermolabile enzyme luciferase This was formulated in 1886 by the French physiologist Raphael Dubois It can be demonstrated by mixing two extracts from the luminous organ In one a cold water extract luciferin has been removed through oxidation in the process of luminescence and luciferase remains in the other luciferase has been destroyed by heating and after cooling luciferin is left When the two extracts are combined light is emitted The reaction has been demonstrated in only eight of the many groups of luminous organisms (*Cypridina* fireflies bacteria worms shrimps limpets and fish) No doubt failure with other organisms has been due to lack of other substances in the extracts or possibly to the

the conditions for luminescence appear to be the simplest Only luciferin luciferase and oxygen dissolved in water are necessary *Cypridina* luciferin has been crystallized and its elementary composition has been given as $C_{21}H_{26\ 28}O_2$ 2HCl but its detailed structure is unknown although it is probably a chromopeptide *Cypridina* luciferase has been purified but its mode of action is also unknown The isoelectric point is 3 28 and the molecular weight about 45 000 The reaction may be written

$$\underset{\text{Luciferin}}{LH_2} + \underset{\text{Luciferase}}{E} + \tfrac{1}{2}O_2 = \underset{\text{Oxyluciferin}}{L} + E + H_2O + \text{light}$$

The excited molecule is unknown

In the firefly luciferin and luciferase can be demonstrated but adenosine triphosphate (ATP) and Mg ions as well as dissolved oxygen are also necessary Firefly luciferin has also been crystallized Its composition is $C_{13}H_{12}N_2S_2O_3$ but the structure is unknown The function of the ATP in presence of Mg ions is apparently to *form active firefly luciferin* (corresponding to *Cypridina* luciferin) which then oxidizes in presence of firefly luciferase with light emission as follows

$$\underset{\text{Luciferin}}{LH_2} + ATP = \underset{\text{Active luciferin}}{LH_2AMP} + \text{Pyrophosphate} + H_2O$$

$$LH_2AMP + \tfrac{1}{2}O_2 + \underset{\text{Luciferase}}{E} = ELAMP^* + H_2O$$

$$ELAMP^* = L + AMP + E + h\nu$$

where $h\nu$ is quantum of light and the asterisk indicates *the possible excited molecule*

Firefly luciferase has been crystallized as long needles It behaves like a euglobulin with a molecular weight of about 100 000 Its functions are to catalyze LH_2AMP (active luciferin) formation and to bring about light emission

In luminous bacteria luciferin appears to be a complex of reduced flavin mononucleotide (FMNH) and a long chain aldehyde (RCHO) Light will appear when bacterial luciferase a flavoprotein enzyme is mixed with $FMNH_2$ and RCHO The reactions appear to be

$$FMNH\ RCHO + \tfrac{1}{2}O = FMN + RCOOH + H_2O + \text{light}$$

The excited molecule is unknown

Bacterial bioluminescence In the living bacterial cell which emits light at a constant rate there must be a mechanism for continually forming $FMNH_2$ and aldehyde The continuous supply of aldehyde is not yet understood but the reduction of FMN is accomplished by reduced diphosphopyridin nucleotide (DPNH) in the presence of DPNH oxidase

$$FMN + DPNH + H \rightarrow FMNH_2 + DPN$$

The $FMNH_2$ is thus ready to emit more light in the presence of aldehyde and luciferase A steady state is attained in the bacterial cell in the presence of oxygen but if the oxygen is removed $FMNH_2$ accumulates and a temporary flash of luminescence occurs when oxygen is readmitted The light intensity then returns to the steady state level These conditions can be imitated in a test tube with aldehyde FMN DPNH and a cell free extract of bacteria

Thus the luciferins and luciferases of the three best known luminous organisms are chemically very different They will not interact with each other but the luciferin of one genus of fireflies *Photinus* will give light with the luciferase of another genus of fireflies *Photuris* and vice-versa

An examination of various organic chemiluminescent compounds shows that these also may be very different structurally Further their mechanism of light production may be very different Moreover the color of the chemiluminescence may vary from red (metalloporphyrin compounds) or yellow (dimethyldiacridinium nitrate) to blue (aminophthalichydrazide) with intermediate colors In

the same way the colors of bioluminescence may be red in the railway worm yellow in the firefly or blue in *Cypridina* The remarkable railway worm of South America 2 in long is actually a larva or an adult wingless wormlike female (the male is a winged beetle) of the genus *Phrixothrix* related to the fireflies It has a row of yellowish green luminous spots on each side of its body segments and a red light on the head thus giving the appearance of a railroad train traveling backward hence the native name *ferrocarril*

Spectroscopically all chemiluminescences or bioluminescences are broad bands of continuous light without lines having maxima in various regions of the visible spectrum Bioluminescent light is like any other kind of light It can be reflected refracted polarized and so on but is not polarized as emitted

Periodicity It is obvious that the bioluminescence of any organism can be of no value in the daytime In fact certain species of luminous animals for example the dinoflagellate *Gonyaulax* have developed a rhythm of luminescence corresponding to night and day When kept in darkness or in dim light continuously *Gonyaulax* luminesces (when stimulated) only when it is night outside During the day *Gonyaulax* luminescence is very weak This periodicity may last 10 days or more in constant dim light

Other luminous organisms for example the ctenophores exhibit no marked periodicity but their light emitting reactions are completely suppressed in sunlight or in any bright light However the animals recover the ability to luminesce if kept in the dark for some 20 minutes

The above instances are exceptions Many forms can luminesce day and night except that reflex stimulation to luminescence is frequently less functional during the daytime

Evolution and luminescence It would appear from the distribution of luminescence in the animal kingdom that the various groups scattered haphazardly from Protozoa to fish must have arisen independently in evolution and have made use of quite different chemiluminescent compounds It is not uncommon to find one species in a genus of dinoflagellates luminous and a very closely allied species nonluminous And in the plant kingdom one variety of the mushroom *Panus stipticus* found in Europe is nonluminous while the American variety *Panus stipticus phosphorescens* is luminous Intercrosses are fertile and the heredity is Mendelian (with luminescence dominant) but complicated by lethal factors

Some slight change in the chemistry of an organism could have given rise to a luminous species during the course of evolution It has been known for a long time that nonluminous or dim mutants will occasionally appear among luminous bacteria A genetic analysis of these mutants has indicated that some lack the enzyme luciferase in others something must interfere with production of flavin mononucleotide since addition of flavin to the cultures will increase their brightness Finally in a third variety something interferes with aldehyde production since the addition of minute amounts of a long chain aldehyde to these dark cultures will immediately cause them to luminesce

Once the chemical reactions for luminescence have appeared natural selection will operate to develop more and more complicated structures provided the light is useful to the organism There are many uses to which the light may be put In deep-sea forms living in perpetual darkness it would seem that the light organ must be used for actual illumination or the pattern of light organs helps in recognition of the species, or the opposite sex In the firefly there is no doubt but that the various types of flashing shown by different species act as signals between male and female Such may also be the case in other luminous forms

The light may be a lure to catch food as in the deep sea angler fish which has a lantern on a tentacle The light is dangled just before the mouth where any attracted organism can be easily engulfed Luminescence may also be a warning The sudden turning on and off of a bright light might scare away predacious forms allowing the animal to escape in the subsequent darkness

Uses can be suggested for the luminescence of many luminous species but it is more difficult to prove that the suggestions are correct from actual studies in the field It is hardly possible to imagine a use for the light of so many of the marine plankton forms which merely float at the surface of the sea They exhibit no special behavior pattern and are blown hither and thither by the wind The most puzzling situation occurs among luminous fungi and bacteria Does the light of a fungus prevent animals from eating the fungus? Can this be the value to the fungus? Who can suggest a use for bacterial light? It must be supposed that among bacteria light production is a chance phenomenon merely accompanying some of the necessary reactions in the cell These reactions are in fact a link in the respiratory mechanism although not a necessary link as indicated by the growth of luminous bacteria at higher than optimum temperature Under these conditions light emission does not occur but growth of the colonies may be marked *See* CHEMILUMINESCENCE, ELECTROLUMINESCENCE FLUORESCENCE LUMINESCENCE PHOSPHORESCENCE *see also* CTENOPHORA (E N H)

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Biomass

The dry weight of living matter including stored food present in a species population and expressed in terms of a given area or volume of the habitat Biomass is an expression used chiefly in relation

to food chains For example a comparison of herbivores feeding on grass should include cows as well as leafhoppers and weight of flesh is a fairer basis for comparison than numbers of individuals *See* FOOD CHAIN

Measurement The conversion of census figures to biomass strictly requires data on age distribution of weight and mortality but these vary with biotic and physical factors and with season and have been computed only for some fish populations The synthesis of biomass figures for whole communities is usually based on adult animals only

Metabolic rate The ultimate criterion of biological productivity is metabolic rate and this is not simply related to biomass Smaller species have higher metabolic rates per unit mass according to a $^{3}/_{4}$ power law in general but there are many exceptions to this law Also some forms such as the molluscs contain nonliving minerals (an objection which can be overcome by measuring total body nitrogen and converting results to weight of protoplasm) The biomass of a species at a given time (which is a measure of standing crop) is a poor index of productivity As an example the biomass of marine animals is lower in tropical than arctic plankton of equal productivity but the rate of synthesis and breakdown of organic matter is higher Again metabolism is faster at some seasons than at others and restriction of nutrients may result in accumulation of biomass but reduction in productivity

Biomass pyramids Biomass pyramids can be constructed on the same lines as pyramids of numbers to summarize the biomass structure of communities Excellent examples are given by E Odum who shows that the shape of the pyramid depends upon whether the community is self contained (as regards primary production of food substances) or imports or exports matter to or from the different trophic levels of the food chain [A MC]

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Biome

A complex biotic community covering a large geographic area and characterized by the distinctive life forms of important climax species of plants and animals A life form is the common morphological features that characterize a group of organisms On the land a biome is identified by the life form of the dominant climax plants as well as by the distinctive types of vegetation and landscape in which they grow In the ocean the life forms of the predominant animals serve as the criterion The biome incorporates all serial (successional) as well as climax stages of the community and its distribution is controlled by climate or in the ocean by other physical factors of the environment Principal terrestrial biomes are the temperate deciduous forest, coniferous forest woodland chaparral tundra grassland desert tropical savanna and tropical broad leaved forest Principal marine biomes are the pelagic the barnacle-gastropod brown algae the sea urchin large snail the bivalve annelid the coral reef and the abyssal benthic

Terrestrial biomes are divisible into plant associations which are distinguished by distinctive combinations of climax dominant species For instance the temperate deciduous forest biome includes the beech maple oak hickory and other associations Both terrestrial and marine biomes are divisible into animal biociations A biociation is distinguished by the distinctiveness of the predominant animal species Some of the biociations within the temperate deciduous forest biome are the North American deciduous forest with white tail deer and black bear among its predominant animals the European deciduous forest, with the European bison and red deer and the Eurasian deciduous forest with the Manchurian tiger musk deer and true wolf *See* COMMUNITY ECOLOGY [S C K]

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Biometrics

The application of mathematical and statistical methods to describe and analyze data concerning the variation of biological characteristics obtained either from observation or experiment The concept of a population and the samples derived from it are discussed in the following paragraphs

A population or universe is a technical term meaning a collection of events or objects with certain characteristics A population may be finite or infinite It may exist in physical form or may be abstract and conceptual Examples of a population are income of all families in the United States height of all college boys outcome of throwing a die an infinitely large number of times all possible offspring of a specified type of mating and so on The population must be precisely identified and defined in any study

An observation technically means recording the actual value of the characteristic of a member or element of the population under investigation Such a value is an observed value A complete recording of the values of all the members of a (finite) population is called a census while a partial recording consisting of only a limited number of observations (for example n) is called a sample A sample may be large (n large) or small (n small) In most practical cases a complete examination of a population is unattainable and one must be satisfied with the study of a limited number of observations based on one or more samples From any specified population many samples can be drawn which although from the same population may consist of quite different observed values These actually observed sets of values are usually referred to as data

Random sample refers to a sample wherein each member is drawn at random from a population At random means the complete lack of any systematic

the same way the colors of bioluminescence may be red in the railway worm yellow in the firefly or blue in *Cypridina* The remarkable railway worm of South America 2 in long is actually a larva or an adult wingless wormlike female (the male is a winged beetle) of the genus *Phrixothrix* related to the fireflies It has a row of yellowish green luminous spots on each side of its body segments and a red light on the head thus giving the appearance of a railroad train traveling backward hence the native name *ferrocarril*

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Table 1. Frequency table

Class limits, in	Midpoint y	Frequency f	Relative frequency f/n
59–61	60	4	0 010
61–63	62	12	0 030
63–65	64	50	0 125
65–67	66	102	0 255
67–69	68	120	0 300
69–71	70	78	0 195
71–73	72	28	0 070
73–75	74	4	0 010
75–77	76	2	0 005
Total		400	1 000

quick recognition of the distribution of height is gained In practical calculations, the height of the f students in a class is taken to be the midpoint of that class The mean and standard deviation are then calculated as follows

$$\bar{y} = \frac{1}{n}\Sigma fy = 67.50 \text{ in}$$

$$s^2 = \frac{1}{n}\Sigma f(y-\bar{y})^2 = \frac{1}{n}(\Sigma fy^2 - \bar{y}^2) = 7\,07 \text{ in}^2$$

$$s = \sqrt{7\,07} = 2\,66 \text{ in}$$

The standard error of the sample mean from $n = 400$ observations is $s_{\bar{y}} = s/\sqrt{n} = 2\,66/20 = 0\,133$ in In calculating s^2 in this example n is used for simplicity instead of the correct $n-1$ since n is large and it makes little difference whether 400 or 399 is being employed

Histogram and frequency polygon A frequency table may be converted into a diagram for easy visual inspection of the distribution The diagram most commonly used is a series of rectangles of

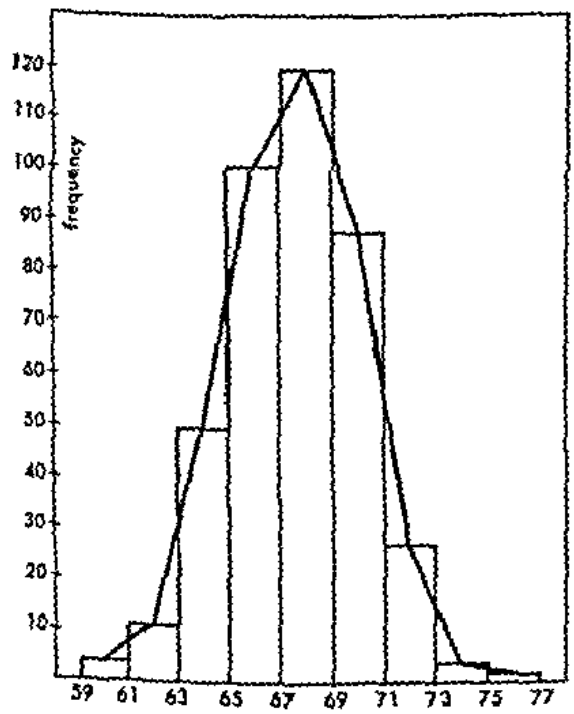


Fig 1 Histogram and frequency polygon

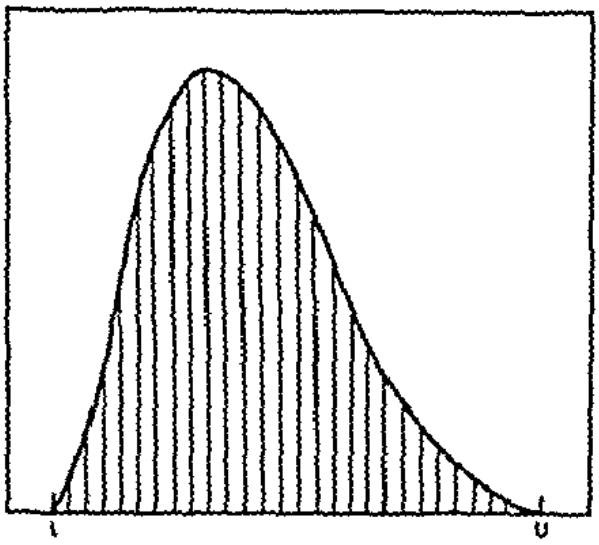


Fig 2 Frequency curve

equal width corresponding to the equal class intervals, and height proportional to the class frequency or relative frequency Such a series of rectangles is called a histogram (Fig 1) If all individuals in a class are assumed to have the same midpoint value these midpoints may be plotted against their corresponding frequencies These points lie in the middle at the top of the rectangles Two adjacent points may be connected by a straight line The resulting series of straight lines is called a frequency polygon If the variate such as height, takes only certain discrete values, a bar or solid column may be erected at each value with the height proportional to the frequency The result is a bar graph Even in such a case one may still use the frequency polygon to help trace the change in frequency from class to class

Frequency curve Although the data are condensed into a frequency table which consists of a limited number of classes with arbitrary class limits it is recognized that such a variate as height really changes continuously and may assume any value within a certain range If there are a very large number of observations (theoretically infinitely large) and the class interval becomes infinitely narrow the frequency polygon will approach a smooth frequency curve as a limit (Fig 2). Therefore in all theoretical work dealing with a continuous variate the distribution (of height for example) in the entire population will be described by a mathematical expression which, when plotted will assume the shape of the frequency curve Such a mathematical expression is called the density function The relative frequency between two values a and b is the area under the frequency curve and is bounded by the ordinates $y = a$ and $y = b$

Mode and median The mode is the value of the variate at which the frequency is the hi[illegible] is the most frequently occurring val[illegible] ate For example, for the heigh[illegible] male students the modal value is

the midpoint of the modal class 67–69 in For a continuous distribution the modal value is that at which the frequency curve reaches its peak If there is one peak in the frequency curve the distribution is said to be unimodal If there are two peaks the distribution is bimodal The median is such a value of the variate that half of the observation are greater and half are smaller than it Thus the median height in the example is approximately 67 53 in assuming that the 120 individuals are uniformly distributed in the 67–69 class and applying linear interpolation Then 200 students are taller and 200 students are shorter than 67 53 inches For a continuous distribution the vertical line erected at the median divides the entire area under the frequency curve into two equal halves The ratio of standard deviation to mean is called the coefficient of variability (c v)

Normal distribution Normal distribution refers to a symmetrical bell shaped frequency distribution (Fig 3) Many distributions in nature are approximately of the normal shape It may be shown that if a variate y such as height is influenced by a large number of factors each exerting independently a small effect on y and if these effects are additive the resulting distribution of y will approach the normal shape as a limit If a large number of measurements are taken repeatedly of an object these measurements will not be identical no matter how carefully taken but will assume more or less varying values which are again normally distributed For this reason the normal distribution is also known as the distribution of errors Large deviations are comparatively few while small deviations may occur quite frequently It is the most useful distribution in both theoretical and practical statistics for in many cases a normal population may be assumed and when the population is *not* normal the statistics calculated from repeated random samples (sampling distribution) *assume* approximately the normal form A normal distribution has two parameters the mean μ and the variance σ^2 (or standard deviation σ) When these two values are specified the normal curve is uniquely determined In terms of standardized units the mean is zero and variance is unity whatever the actual values of μ and σ^2 are Since the normal distribution is symmetrical mean = mode = median the area under the normal curve between the mean μ and $\mu + \sigma$ is approximately 0 34 and so the relative frequency of the y values within the interval $\mu \pm \sigma$ is approximately 0 68 or 68% At the y values $\mu \pm \sigma$ the curve twists from a concave to a convex one The relative frequency within the interval $\mu \pm 1\,96\sigma$ (slightly less than 2σ on either side of the mean) is 0 95 and thus that outside the same interval is 0 05 with 0 025 under each tail The areas or relative frequencies of the normal distribution have been tabulated in various ways but always with the standardized *unit* as the independent variable

Confidence interval The sample mean $\bar{y}$ from n observations is almost normally distributed even though the y population may not be normal itself

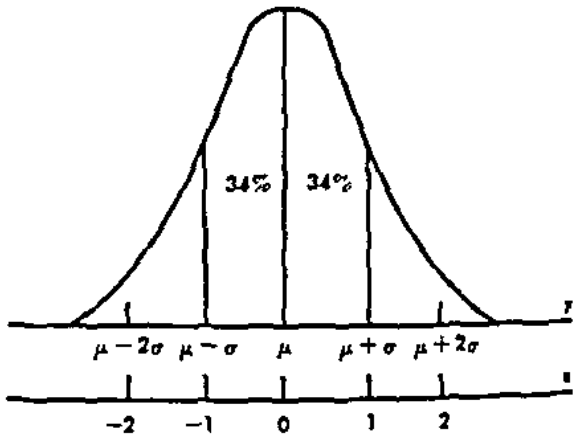


Fig 3 Normal distribution

This is true especially when the population is unimodal and the size of the sample is moderately large The facts that $E(\bar{y}) = \mu$ and $\sigma_{\bar{y}}^2 = \sigma^2/n$ make possible certain statements about the population mean The normal deviate for the variate $\bar{y}$ (not y) is

$$u = \frac{\bar{y} - \mu}{\sigma_{\bar{y}}}$$

Then the probability is 0 95 that the *following* inequality holds

$$-1\,96 < \frac{\bar{y} - \mu}{\sqrt{\sigma^2/n}} < +1\,96$$

The inequality may be written

$$\bar{y} - 1\,96\sqrt{\sigma^2/n} < \mu < \bar{y} + 1\,96\sqrt{\sigma^2/n}$$

in which the limits vary from sample to sample while the central item μ remains constant In repeated sampling these varying limits will "catch" or cover the population mean 95% of the time This gives an interval estimate of μ For practical calculation s^2 may be substituted for σ^2 The values $\bar{y} \pm 1\,96\sigma_{\bar{y}}$ are called the 95% confidence limits and the width between these two limits is called the 95% confidence interval The 95% confidence in this example is arbitrary Other degrees of confidence may be chosen

Test of hypothesis This is also known as a test of significance Assume that $\bar{y}$ and s^2 have been calculated from a moderately large sample *and* that instead of using $\bar{y}$ as an estimate of the population mean, one may want to test the hypothesis that the population mean is equal to a certain fixed value for example, m If m is indeed the population mean then the normal deviate for the variate $\bar{y}$ is

$$u = \frac{\bar{y} - m}{\sqrt{\sigma^2/n}}$$

s^2 may be substituted for σ^2 in practical calculations for large samples The probability that this u value will lie between $-1\,96$ and $1\,96$ is 0 95 and that it will lie outside this interval is $\alpha = 0\,05$ if m is the true population mean The rule of testing is that if $|u| > 1\,96$ it is regarded as an unusual

phenomenon hardly consistent with the hypothesis In such an event the hypothesis is abandoned and the difference $y - m$ is said to be statistically significant at the $\alpha = 5\%$ significance level Instead of the normal deviate 1 96 and the corresponding probability of 0 05 used as an example here other significance levels may be chosen The testing of a hypothesis results either in its acceptance or rejection In so doing either a type I or a type II error may be committed

Type I and type II errors If $|u| > 1\,96$ is employed as the criterion to reject the hypothesis $\mu = m$ which happens to be true the probability of this wrong rejection is $\alpha = 0\,05$ This type of error is called the type I error It is the error of attribution of false significance On the other hand the hypothesis itself may be untrue Suppose that the true mean is M, and yet it is hypothesized that it is m Ideally the untrue hypothesis should be rejected However the distribution with mean M overlaps with the distribution with mean m and the sample may well yield a value of u within the interval $-1\,96$ and $1\,96$ In such a situation the untrue hypothesis would not be rejected This error is called type II error the error of failure to detect significance The probability of committing a type II error depends upon among several other things the value of M The greater the difference between M and m the less probability of committing the second type of error The two types of error cannot be committed at the same time In any particular test if significance is declared only the risk of committing an error of type I is run and if the hypothesis is retained only the risk of committing an error of type II is run With proper balancing of the two types of error in a long series of similar tests the first kind of error is sometimes committed and the second kind of error committed other times but one will be correct in rejecting the wrong hypothesis and accepting the right hypothesis most times The increase of sample size can reduce both types of error

Difference between two means Suppose that there are two independent samples of sizes n_1 and n means y_1 and y_2 and variances s_1^2 and s_2^2 To determine if these two means can be considered significantly different one sets up the hypothesis that the two population means are equal $\mu_1 = \mu_2$ A hypothesis of this nature is called a null hypothesis because it assumes the absence of differences Now consider the new variate $d = y_1 - y_2$ If the null hypothesis is true the expected value of d is

$$E(y_1) - E(\bar{y}_2) = \mu_1 - \mu_2 = 0$$

and the variance of d is

$$\sigma_d^2 = \sigma_{\bar{y}_1}^2 + \sigma_{\bar{y}_2}^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

Hence the normal deviate for the variate d is

$$u = \frac{d}{\sqrt{\sigma_d^2}} = \frac{(\bar{y}_1 - \bar{y}_2)}{\sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2}}$$

The procedure of testing the significance is the same as discussed previously except that the variate d is being considered and the particular hypothesis being tested is that its mean value is zero

Student's t distribution Since σ is unknown s may be used in its place for large samples without introducing serious error However in small samples *the value of s varies from sample to sample* too much to be taken as a constant Student's t is the ratio of a deviation to its varying sample s In other words it is a normal variate standardized in terms of the sample standard deviation The distribution of t closely resembles that of u being bell shaped with zero mean, but is lower in the middle *portion and higher in the two tail regions than the* normal curve The exact dispersion of the t distribution depends on the number of degrees of freedom which is $n - 1$ for samples of size n The areas under the t curve have been tabulated for various degrees of freedom at various significance levels.

Student's t test If the σ in a previous expression *for u is replaced by the corresponding s the* resulting standardized unit is the t value

$$t = \frac{(\bar{y} - m)}{\sqrt{s^2/n}}$$

To test the hypothesis that the population mean is equal to m based on a sample of only $n = 14$ observations where s^2 has 13 degrees of freedom the absolute value of t has to be equal to or greater than 2 16 (instead of 1 96 for the u test) at the same $\alpha = 0\,05$ significance level Confidence intervals may be constructed in the same way as before using the appropriate t value instead of the u value

If the two population variances σ_1^2 and σ^2 are not equal there is no simple method to test the significance of the difference $y_1 - y_2$ in comparing two sample means If the two variances and the two sample sizes do not differ too much it may be assumed that the population variances are equal and a pooled estimate of the common variance from the two samples may be obtained by calculating

$$s^2 = \frac{\Sigma(y_1 - \bar{y}_1)^2 + \Sigma(y_2 - \bar{y}_2)^2}{(n_1 - 1) + (n_2 - 1)}$$

Then

$$t = \frac{(\bar{y}_1 - \bar{y}_2)}{s\sqrt{1/n_1 + 1/n_2}}$$

with degree of freedom $= n_1 + n_2 - 2$ For example if $n_1 = 15$ and $n_2 = 12$ so that the degree of freedom is 25 the absolute value of t has to be equal to or greater than 2 06 (instead of 1 96 for the u test) at the same $\alpha = 0\,05$ significance level In the special case where the observations of the two samples are paired the n differences for the n pairs are then regarded as the n observations of one sample and the t value (with $n - 1$ degrees of freedom) may be calculated to test the null hypothesis that the true difference is zero When the number of degrees of freedom is large the t distribution becomes the u distribution

Two tail and one tail tests The examples given above for both u and t tests are two tail tests because the significance of a difference is being tested whether one is larger than the other or vice versa If one is interested only in testing if $\bar{y}$ is greater than m and uses $u = +1.645$ as the criterion the probability of reaching a wrong rejection of the null hypothesis is $\alpha = 0.05$ which is the area under the right hand tail of the normal curve Testing the significance of difference in one direction only is called a one tail test Both types of tests are in common practice depending upon the nature of the problem

Analysis of variance Analysis of variance is a method of comparing the differences between several sample means It is a more general tool than the t test This method is used most frequently in analyzing experimental data Suppose there are k groups (or k samples) and in the first group there are n_1 observations with mean y_1 in the second n_2 observations with mean y_2 and so on the total number of observations being $n_1 + \quad + n_k = N$ with the general mean $\bar{y}$ If the k populations from which the k samples are derived have the same variance a pooled estimate of the common variance σ from the k samples is given by

$$s^2 = \frac{\Sigma(y_1 - \bar{y}_1)^2 + \quad + \Sigma(y_k - \bar{y}_k)^2}{(n_1 - 1) + \quad + (n_k - 1)}$$

which has $N - k$ degrees of freedom On the null hypothesis that the k population means are equal another estimate of the common variance may be obtained from the k sample means by calculating the following quantity

$$s_m^2 = \frac{n_1(\bar{y}_1 - \bar{\bar{y}})^2 + \quad + n_k(\bar{y}_k - \bar{\bar{y}})^2}{k - 1}$$

which has $k - 1$ degrees of freedom The sum of squares in the numerator of s^2 and s^2 add up to the total sum of squares for the N observations as a whole $\Sigma\Sigma(y - \bar{\bar{y}})^2$ and so the degrees of freedom in the denominators are $(N - k) + (k - 1) = N - 1$ If the variates are normally distributed the ratio of two independent estimates of the same variance has a sampling distribution known as the F or variance ratio distribution Thus to test the null hypothesis that the k population means are equal the ratio $F = s^2/s$ is calculated and the table is consulted for the F value with $k - 1$ degrees of freedom for the numerator and $N - k$ degrees of freedom for the denominator If the observed F is greater than the tabulated F the null hypothesis is discarded and the significance of the differences between the k means is assumed When there are only two samples the F test is equivalent to the t test for $F = t^2$ in such a case

Linear regression Very frequently the variate y under investigation is influenced by another (sometimes uncontrollable) variate x For example the yield (y) of a crop may be influenced by the amount of rainfall (x) during the growing season When the pairs of values (y x) are plotted in rectangular coordinates the points form a scatter diagram (Fig 4) If these points show a linear trend a straight line running among these points may be fitted to represent the trend Such a line is called the linear regression line The problem is how to draw that line other than freehand

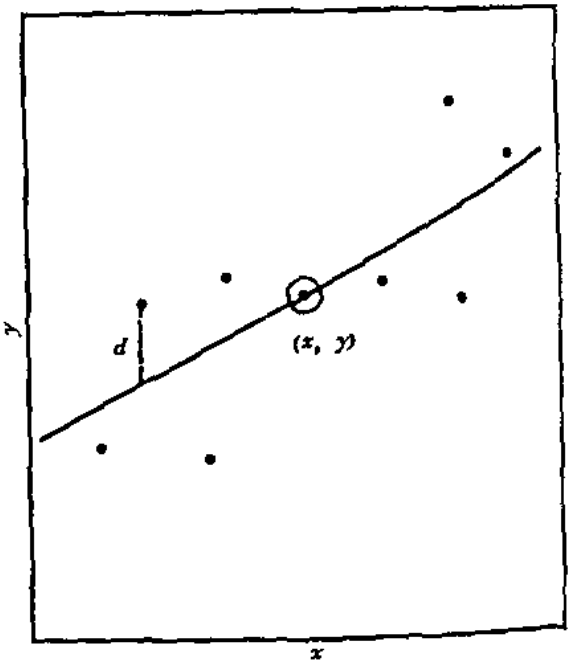


Fig 4 Scatter diagram and linear regression

Method of least squares This is a method for fitting a straight line to a series of points For the given value $x = x$ the observed $y = y$ while the y value on the straight line is $y' = y'$ Then $d = y - y'$ is the vertical distance from the observed y to the y' on the straight line The method of least squares requires that the straight line should be drawn such that $\Sigma d = \Sigma(y - y')^2$ is as small as possible The equation of the straight line is $y' = a + bx$ where a is the intercept on the y axis and b, the slope of the line is known as the regression coefficient of y on x The least square solutions are

$$a = \bar{y} - b\bar{x} \qquad b = \Sigma(y - \bar{y})(x - \bar{x})^2$$

The regression coefficient is in terms of the number of y units per x unit for example 2 lb/sq in This line passes through the central point $(\bar{y}\bar{x})$

Residual variation of y Substituting these values of a and b in the straight line equation y' is obtained Since these y' values are determined by the regression line their variation is measured by $\Sigma(y' - \bar{y})^2$ with one degree of freedom accounted for by the variation of x The deviation $d = y - y'$ from the regression line the residual is regarded as the random error of y Hence the estimate of $\sigma^2 = \sigma^2_{y.x}$ free of x influence is

$$s^2 = s_{y.x} = \Sigma(y - y')^2/(n - 2)$$

For practical calculation the individual y' values and the individual distances d need not be obtained for

$$\Sigma d = \Sigma(y - y')^2 = \Sigma(y - \bar{y})^2 - b\,\Sigma(x - \bar{x})^2$$

Significance test for b The sampling variance of b is $\sigma^2/\Sigma(x-\bar{x})^2$ To test the hypothesis that the true regression coefficient is β, the following expression may be calculated

$$t = \frac{b-\beta}{\sqrt{s^2/\Sigma(x-\bar{x})^2}}$$

This follows Student's t distribution with $n-2$ degrees of freedom To test the hypothesis that y is not linearly influenced by x β is set equal to 0

Analysis of covariance This is a combined application of linear regression and an analysis of variance Suppose that the effects of three fertilizers on corn yield (y) are studied The significance of the treatment effects may be tested by the analysis of variance method Now suppose that a complicating factor intervenes the number of plants (x) known as the concomitant variate in general varies from plot to plot for reasons other than the treatments applied so that the comparison of the yield between the three fertilizer groups may be partially blurred or distorted by the influence of x To correct for the influences of x the regression coefficient of y on x and the residual variation of y free from the influence of x are first found and then the F or variance ratio test is applied

Correlation A correlation problem considers the joint variation of two measurements neither of which is restricted by the experimenter Examples [illegible] of the relation

Both variables are observed as they naturally occur neither variable being set at prescribed levels For n pairs of observed values $(y\ x)$ the following quantity is defined as the correlation coefficient between y and x

$$r = r_{xy} = \frac{\Sigma(y-\bar{y})(x-\bar{x})}{\sqrt{\Sigma(y-\bar{y})^2 \quad \Sigma(x-\bar{x})^2}}$$

This value ranges from $+1$ to -1 If the points in the scatter diagram are close to a straight line r will be close to $+1$ or -1 depending on the direction of the line If the points are scattered without a linear trend r will be close to zero The r and b coefficients are related and always have the same sign Indeed

$$b = r\frac{s_y}{s_x} \quad \text{or} \quad r = b\frac{s_x}{s_y}$$

The quantity $\Sigma(y-\bar{y})(x-\bar{x})/(n-1) = s_{xy}$ is called the covariance of y and x Thus $r = s_{xy}/s_x s_y$ for a sample and the population correlation is defined as $\rho = \sigma_{xy}/\sigma_x\sigma_y$ Testing the null hypothesis $\rho = 0$ is equivalent to testing $\beta = 0$ and the same t test may be used Or from the relation $\Sigma(y-\bar{y})^2 = (1-r^2)\ \Sigma(y-\bar{y})^2$ the test may be rewritten

$$t = \frac{r}{\sqrt{(1-r^2)/(n-2)}}$$

The definition of r being symmetrical with respect to y and x measures the mutual association of the two variates The interpretation of r is another problem The existence of a significant r value does not imply a causal relationship between y and x Both variates may be influenced by a common factor or factors omitted from consideration in this discussion

Path coefficients are regression coefficients with respect to standardized variates When y and x are standardized the regression equation of y on x will be $y = p_{y\,x}x + e$ where $p_{y\,x}$ is called the path coefficient from x to y In this simple case $p_{y\,x}$ is simply r_{yx} since the latter is the standardized covariance One application of the path method is the deduction of the chain property of correlation under certain simple conditions Suppose that $y = p_1x + e_1$ where $x = p_2z + e_2$ the ps being path coefficients and the es random errors Substitution gives $y = p_1p_2z + e$ Hence the path coefficient from z to y is the product of that from z to x and that from x to y Also $r_{yz} = r_{yx}r_{xz}$ Next consider a standardized multiple regression equation $y = p_1z_1 + p_2z_2 + e$ Since every variate has unit variance one obtains $1 = p_1^2 + p_2^2 + 2p_1p_2r_{12} + \text{Var}\ (e)$ The term p_1^2 is called the coefficient of determination of z_1 on y and so on Another application is the analysis of correlation between two variates which are linear functions of other common variables Suppose that in Fig 5

$$x = b_1z_1 + b\ z_2 + b_3z_3 + e_1$$
$$y = c_1z_1 + c_2z_2 + c_3z_3 + e_2$$

where the es are uncorrelated with the zs or among themselves and the bs and cs are path coefficients

$$\begin{aligned} r_{xy} = \text{cov}(x\,y) &= b_1c_1 + b_1r_{12}c_2 + b_1r_{13}c_3 \\ &= b_2c_2 + b_2r_{21}c_1 + b_2r_{23}c_3 \\ &= b_3c_3 + b_3r_{31}c_1 + b_3r_3\ c_2 \end{aligned}$$

where for brevity r_{12} is the correlation between z_1

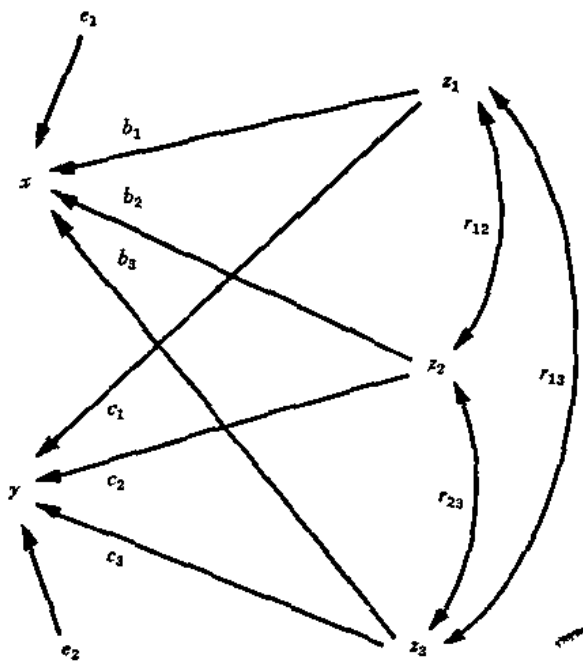


Fig 5 Path coefficients

and z_2. Thus the total correlation r_{ux} has been analyzed into nine components corresponding to the nine different ways x and y are connected in the accompanying diagram. A correlation line has two arrowheads and can be used in both directions. When the common causes (z_1 z_2 z_3) are uncorrelated $r_{ux} = b_1c_1 + b_2c_2 + b_3c_3$. The general theorem is that the total correlation between two variates is the sum of all paths by which they are connected. To apply the method of path coefficients in practical problems the relationship of the variates must be specified prior to the evaluation of the various paths. The path method has been highly successful in certain types of genetical problems where the causal relationship is known. *See* Population genetics.

Binomial population and sampling. In biological and medical research variates are frequently dealt with that fall into either of two categories, for example alive or dead, ill or well, male or female, and generally with or without a certain trait. This is known as a binomial variate. A complete description of a binomial population requires only one parameter, such as the proportion P of individuals with the trait, for then the proportion of those without the trait is $Q = 1 - P$. The statistical device of handling such a variate is to let $y = 1$ for individuals with the trait and $y = 0$ for those without it. Then the population mean is $\mu = P \times 1 + Q \times 0 = P$ and the population variance is $\sigma^2 = P(1-\mu)^2 + Q(0-\mu)^2 = P(1-P) = PQ$.

If a random sample of n observations is taken from a binomial population the observations will take the form $y = 0\ 1\ 1\ 0\ 1\ 0\ 0\ 0\ 1$. The sample total is a, the number of ones in the sample, and the sample mean is $\bar{y} = a/n = p$. The variance of $\bar{y}$ is σ^2/n, which may be estimated by pq/n. When n is large the sampling distribution of $\bar{y}$ is nearly normal if P is not close to zero or unity. In determining how large a sample is "large" the usual working rule is that nP and nQ should be greater than 5, so the largeness of a sample depends on both n and P. For large samples the test of significance follows the general procedure of the normal test. For example, to test the hypothesis that the population mean is P the formula

$$u = \frac{p - P}{\sqrt{PQ/n}}$$

is used. The u test is appropriate here because the hypothesis of mean P implies the population variance PQ.

Suppose that there are two samples. The observed results are a $n_1 = p_1$ for the first sample and b $n_2 = p_2$ for the second. The null hypothesis $P_1 = P_2$ implies equal variance for the two populations and the pooled estimate of the common variance is pq, where

$$p = \frac{a + b}{n_1 + n_2}$$

the over all proportion from the two samples. Then the null hypothesis ($P_1 = P_2$) may be tested by calculating the normal deviate

$$u = \frac{p_1 - p_2}{\sqrt{pq(1/n_1 + 1/n_2)}}$$

On the other hand, if the hypothesis to be tested is $P_1 - P_2 = D$, then the u test should be modified

$$u = \frac{(p_1 - p_2) - D}{\sqrt{p_1q_1/n_1 + p_2q_2/n_2}}$$

since the two populations with different mean values necessarily have different variances.

For small samples from a binomial population the sampling distribution is given by the expansion of $(P + Q)^n$. The exact probabilities of obtaining certain sampling results may be thus calculated. The values of these probabilities have been extensively tabulated for various values of P and n.

Poisson distribution. If P of a binomial population is very small then the occurrence of a member with the trait is considered a rare event. A rare event can be observed only in a very large sample. If n is so large that $nP = m$ is some finite value then the sampling distribution is given by the expansion of e^m in powers of m, each term being divided by e^m so that the total probability is unity. Many empirical observations of natural and experimental events conform with this distribution. The mean number of events is m and its variance is also m. When m is 5 or less the distribution is skewed but when it is larger it becomes more symmetrical. In some fields of application if the observed number of events is a, $\sqrt{a}$ is taken as the standard error of the observed number.

Chi square test. The quantity χ^2 is the sum of several independent squared normal deviates. In the analysis of frequency data the χ^2 test is a generalization of the previous test for binomial data in two respects: (1) it extends to a multinomial population where each observation may fall in one of several classes, and (2) it furnishes a comparison between several samples instead of only two. The χ^2 as a generalization of u is analogous to F as a generalization of t.

The calculation of χ^2 for testing the goodness of fit may be illustrated as shown in Table 2. According to a certain genetic theory the breeding should yield 9/16 red, 6/16 sandy, 1/16 white. To test this theory the number of pigs is divided into three classes in the proportions 9, 6, 1. Then

$$\chi^2 = \sum \frac{(f - f')^2}{f'} = \frac{25}{63} + \frac{19}{42} + \frac{4}{7} = 2.135$$

If there are k classes the χ^2 has $k - 1$ degrees of freedom because the total number of observations is the same for the two sets of frequencies. In this example degrees of freedom $= 3 - 1 = 2$. If the genetic hypothesis is true the probability that the χ^2 with 2 degrees of freedom should exceed 5.99 (read from χ^2 table) is 0.05. The statistical reasoning for the test of significance is the same as for

Table 2 Data for χ^2 calculation

Color of pig	Observed number f	Expected number f	Difference $f-f$
Red	58	63	−5
Sandy	49	42	7
White	5	7	−2
Total	112	112	0

fore Since the χ^2 in question is smaller than 5 99 the hypothesis is retained the observed results not being contradictory to the genetic theory The χ^2 test is a one tail test It does not prove that the theory is the correct one It is conceivable that the observed results are also consistent with some other hypothesis However as the class frequencies become larger the test becomes more discriminating When an expected class frequency is 5 or less the χ test is not applicable and a more exact method if available should be employed Several small classes may be pooled to form one larger class

Contingency table (2×2) If the observed frequencies are classified dichotomously according to two different characteristics simultaneously as exemplified by the following four fold table it may often be desirable to know if the two characteristics are independent of each other

Table 3 Contingency table

	Inoculated	Not inoculated	Total
Dead	a	b	$a+b$
Alive	c	d	$c+d$
Total	$a+c=n_1$	$b+d=n_2$	$a+b+c+d \quad N$

If the characteristics are independent the proportions of inoculated and not inoculated should be the same among the dead and the alive or stated alternatively the proportions of dead and alive should be the same among those inoculated and those not inoculated In such a case the expected frequency in the inoculated dead cell should be $a' = (a+b)(a+c)/N$ and so on Then $\chi = (a-a')^2/a' +$ which simplifies to $\chi^2 = N(ad-bc)^2/(a+b)(c+d)(a+c)(b+d)$ Since the expected frequencies are calculated on the basis of the marginal totals this χ^2 has only one degree of freedom At the 0 05 significance level and for 1 degree of freedom the critical value is $\chi^2 = u^2 = (1\,96)^2 = 3\,84$ The χ test for independence in a 2×2 table is equivalent to the u test for the hypothesis $P_1 - P_2$ for two binomial samples

The test for independence may be extended to contingency tables of any size for example m rows times k columns The expected frequency of the cell in the third row and the second column for example is equal to third row total times second column total over the grand total The χ^2 may then be calculated in the usual manner It has $(m-1)(k-1)$ degrees of freedom For a $2 \times k$ table the χ^2 test is equivalent to testing the hypothesis that the means of the k binomial populations are equal

Maximum likelihood method There are many methods of estimating a parameter which underlies the probability of an event The most efficient method of estimating is known as the maximum likelihood method the principle of which may be illustrated by the following example

Suppose that p is the (unknown) probability of success (and $q \quad 1-p$) in a trial (for example hitting a ball recovery from an illness or germination of a seed) and that the individual is allowed a second trial if the first one is a failure The observed frequencies for the three possible outcomes are $a \quad b \quad c$ as shown in the table The principle of maximum likelihood says that the value of p should be so chosen that the probability of observing such a set of frequencies is maximum The chief drawback of this powerful method is that in most cases and especially when there are two or more parameters to be estimated explicit expressions for the estimates are unobtainable and for a solution one must resort to iteration methods Calculation of the variances is even more tedious

Table 4 Estimation by maximum likelihood method

	Probability	Observed number of occurrences
1st trial success no 2d trial	p	a
1st trial failure 2d trial success	qp	b
1st and 2d trials failure	q^2	c
Total	1	n

Transformation The four statistical tests (u t χ^2 F) are all based on the normal distribution If the variate y is not normally distributed often a change of scale renders the new variate $z = f(y)$ approximately normal so that the standard tests may be employed on the new variate Such a change of scale is called a transformation of variables There is no rule of thumb as to how a variate scale should be changed to render it normal and to equalize the variances of two or more samples The following are some of the commonly used transformations

Logarithmic Probably the most frequently used transformation is $z = \log y$ or $\log (y+c)$ If the new variate z is normal then y is said to be log normal a special name for the original distribution of y It may be shown that if the measurement y is influenced by a large number of factors acting multiplicatively (instead of additively) then y has a log normal distribution A logarithmic transformation also changes the original exponential relationship with another variable into a linear one which is much easier to handle statistically

Angular For samples from a binomial population the mean $y = p$ and its variance pq/n are correlated The ps of several samples cannot be averaged in the usual manner because each has a different variance The angular transformation is to replace the proportion p by an angle θ such that $p = \sin^2 \theta$ The variance of θ depends on n only Then the angular values can be treated by standard statistical methods The square root transformation

accomplishes the same purpose for a Poisson distribution

Probit This is the normal deviate plus five $(u + 5)$ to avoid negative numbers Suppose that $p = 13\ 20 = 0\ 65$ is the observed proportion of deaths in a group of 20 animals treated with a certain dose of drug The assumption is that the individual le thal dose level is normally distributed Then the area $p = 0\ 65$ under the left side of the normal curve is set off by an ordinate at $u = 0\ 385$ or a probit value $5\ 385$ The probit transformation thus replaces a proportion (area) by its corresponding normal deviate (abscissa value) plus 5 The reason for doing this is that the mortality curve for proportions against dosage is sigmoid in shape but the mortality curve for probits against dosage is linear (The dosage may be replaced by log dosage

the all or none type See ANALYSIS OF VARIANCE HUMAN GENETICS STATISTICS

[C C L]

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Biophysics

A hybrid science involving the overlap of physics chemistry and biology A dominant aspect is the use of the ideas and methods of physics and chemistry to study and explain the structures of living organisms and the mechanisms of life processes

Many eminent scientists of previous generations such as *Count A Volta H von Helmholtz* and J L M Poiseuille were really biophysicists because they made important contributions to both biology and physics Helmholtz and his contemporaries explicitly planned to explain biological phenomena in terms of the physical sciences Nevertheless the recognition of biophysics as a separate field is recent

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sea These tools are peculiarly adapted to the study of problems of great current importance to medicine problems related to virus diseases can

physical) environment have been thrust upon man Study of biological processes at every level molecular or macroscopic continues to reveal the complex physical and chemical basis of life demanding the development of physical thought for the special task of interpreting physical measurements on living systems As a result biophysics departments and research programs in many universities which provide opportunities for study at undergraduate graduate and postdoctoral levels have been established and the Biophysical Society has been organized

There are several areas within biophysics the major ones being molecular biophysics radiation biophysics physiological biophysics and mathematical or theoretical biophysics

Molecular biophysics currently the most active division has to do with the study of large molecules and particles of comparable size which play important roles in biology Favorite physical tools for such research are the electron microscope the ultracentrifuge and the x ray diffraction camera Conspicuous success has been achieved in the study of viruses and in the investigation of nucleic acid, the substance which is involved in hereditary mechanisms

Radiation biophysics consists of the study of the response of organisms to ionizing radiations such as α β γ and x rays and to ultraviolet light The biological responses are death of cells and tissues if not of whole organisms and mutation either somatic or genetic Somatic mutations represent changes in nonreproductive cells and might lead to uncontrolled or cancerous growth Genetic mutations involve changes in the germ cells which can be transmitted to future generations

Physiological biophysics called by some classical biophysics is concerned with the use of physical mechanisms to explain the behavior and the functioning of living organisms or parts of living organisms and with the response of living organisms to physical forces The questions of how nerve impulses are transmitted what the mechanism of muscle contraction is what the visual mechanism is how one hears tastes smells or feels and why living cells are able to ingest some substances and excrete others have been studied and in part at least answered by physiological biophysicists Closely related matters are the changes in normal functioning of organisms including the human body when the physical environment is changed Of particular importance in the space age are the changes brought about by subjecting the individual to high accelerations

Mathematical and theoretical biophysics deal primarily with the attempt to explain the behavior of living organisms on the basis of mathematical and physical theory Biological processes are being examined in terms of thermodynamics hydrodynamics and statistical mechanics Mathematical models are being investigated to see how closely they simulate biological processes *See* BIOLOGICAL EFFECTS OF SOUND WAVES, BIOPHYSICS MATHEMATICAL BIOPOTENTIALS AND ELECTROPHYSIOLOGY BONE (BIOPHYSICS) MICROMANIPULATION MICROSCOPE MUSCLE (BIOPHYSICS) MUSCULAR SYSTEM OXIMETRY, PROTOPLASM, RADIATION BIOLOGY RESPIRATION EXTERNAL SKELETAL SYSTEM SPACE BIOLOGY SYMBALLOPHONE THERMOREGULATION THERMOTHERAPY

[M A L]

Biophysics, mathematical

The science of applying physicomathematical methods to biological phenomena with the purpose of gaining a better understanding of the mechanisms of those phenomena It is more generally known as mathematical biology Mathematical biophysics stands in the same relation to experimental biology as mathematical physics to experimental physics Mathematical biophysics is concerned with the development of mathematical theories of different biological phenomena to explain those phenomena both in their qualitative and quantitative aspects

Cells and cellular aggregates One of the most important phenomena in biology is that of cell division (*see* CELL DIVISION) Through it life spreads on earth through it multicellular organisms develop from the ovum Numerous suggestions have been made as to the possible causes of cell division One attractive explanation stated that cell division was due to electrical forces It appears however that the forces calculated from known electrical charges in general are not sufficient to overcome the known mechanical strength of the cell and thus cause division

A particularly promising possibility seemed to be that of the so-called diffusion drag forces Every living cell is a seat of numerous metabolic reactions A number of substances flow into a cell from outside and a number of others flow outwards The transport of those substances occurs generally by diffusion Physicomathematical considerations lead to the conclusion that a stream of diffusing molecules exerts a 'drag force' on the molecules of the substance through which the stream moves Hence as a result of diffusion of various metabolites a complex system of forces is established inside the cell and in its immediate vicinity It is possible to calculate those forces approximately from known rates of flow A mathematical study shows that generally not only are such forces sufficient to produce cell division but under certain conditions they will produce it The theory leads to a number of quantitative conclusions One of them is that the average size of cells should be about 3×10^{-3} cm which is in agreement with observation Another conclusion is that the linear dimensions of cells should vary as the inverse cubic root of the rate of oxygen consumption other conditions being equal This seems to be roughly verified Finally the theory leads to an equation which describes the rate of elongation of a dividing cell providing the cell was originally spherical A consequence of the theory is that after elongating such a spherical cell will develop a constriction at the "equator" taking the shape of a dumbbell This constriction or "neck" should decrease in diameter until the cell breaks in two The theory leads to an equation which describes the shape of the curve obtained by plotting the diameters of the constriction against time All those conclusions have been verified with reasonable accuracy in experiments with dividing demembranated *Arbacia* eggs Such experiments were suggested by the theory

Thus the diffusion drag force of cell division leads to a correct quantitative description of some gross aspects of cell division It is however quite inadequate for the explanation of the important fine details of mitosis (*see* MITOSIS) Other factors must be considered and a number of theoretical studies are being made to investigate those other factors

A theory of cell respiration has been developed as a by product of the above mentioned studies This theory leads to equations which express the rate of oxygen consumption of some cells in their dependence on the oxygen concentration in the surrounding medium The agreement of those equations with available experimental data is good *See* BIOLOGICAL OXIDATION

The diffusion drag forces may account also for the interaction between cells The development of a mathematical theory of such interaction throws light on the structure and properties of different cellular aggregates A possible mathematical approach to some embryological phenomena is thus provided

A number of mathematical studies of phenomena of circulation have been made on such problems as propagation of pulse waves and the effects of branchings of blood vessels on this propagation The problem of exchange of metabolites between capillaries and tissues has also been the subject of several mathematical studies Problems related to electrocardiography electroballistography and electroplethysmography have also been studied mathematically The problem of retention of particulate matter in respiratory passages as well as problems related to the removal of malarial parasites from the blood stream are among many others studied in mathematical biophysics *See* BIOPOTENTIALS AND ELECTROPHYSIOLOGY

Excitation and conduction in peripheral nerves By assuming the presence in the nerve fiber of two factors one of which causes excitation the other inhibition and by postulating simple differential equations for the variation of those two factors under the action of an electric current, pertinent equations have been derived These describe the relation between the intensity of different types of stimulating currents such as constant current alternating current condensor discharge and others and also the duration of the current required to produce excitation Those equations agree very well with experimental data An interpretation of the two factors as the concentrations of potassium and calcium ions combined with definite assumptions about the structure of the membrane of the nerve fiber leads to a mathematical theory concerning effects of different physicochemical factors on phenomena of excitation *See* NEUROPHYSIOLOGY

Conduction of the excitation along the nerve fiber presents a number of interesting mathemati

cal problems Different aspects of conduction have thus been studied A simple expression for the velocity of conduction has been derived which is in fair agreement with available data

The central nervous system The central nervous system of a human consists of some 10^{10} neurons with most intricate interconnections An attempt to develop a mathematical theory of the central nervous system proceeds along the following lines

It is assumed that the central nervous system consists of a very large number of "elements" of two kinds The first kind of element the so called excitatory ones have the property of becoming excited under the action of appropriate factors and the capability of transporting that excitation from one such element to another if the two are in contact The second kind the inhibitory elements are also capable of excitation but when excited they inhibit the excitation in the elements of the first kind if in contact with them Excitation and inhibition are considered to be due to some unspecified corresponding excitatory and inhibitory factors in analogy with the theory of excitation in peripheral nerves Both excitation and inhibition are considered to be continuous variables and the simplest possible equations are assumed to govern the interaction between different elements Different arrangements of excitatory and inhibitory elements are conceived and then studied mathematically and the properties of such arrangements are derived It is found that those properties are both qualitatively and quantitatively similar to many known properties of the central nervous system

This circumstance is the more remarkable since later experimental studies clearly showed that the laws of interaction assumed to hold for the abstract 'elements' are different from the laws of interaction of actual neurons The former are assumed to be continuous while the latter are found to be discontinuous The paradox is resolved by showing mathematically that when one deals with large groups of neurons which interact discontinuously the average effect of those discontinuous interactions appears as a continuous one This is just like the average result of the discontinuous impacts of gas molecules against the walls of a container which results in an apparently continuous gas pressure Thus the elements of the mathematical theory actually correspond to aggregates or groups of neurons those aggregates interacting with each other

The simplest possible arrangement of excitatory elements is a linear chain The mathematically derived equations which describe the properties of such a chain show that the time between the stimulation of the 'afferent' end of the chain and the arrival of excitation to the 'efferent' end decreases with increasing intensity of stimulation The equation which describes this relation is found also to describe quite accurately the decrease of reaction times in humans with increasing intensity of stimulation

The study of more complicated arrangements of elements leads to mathematical expressions which describe, sometimes with great accuracy, other phenomena in the central nervous system Thus theories of discrimination, learning psychophysical judgments and even of esthetic perception have been developed They all agree with experimental data Mathematical theories of the perception of "Gestalts" have also been developed as well as theories of abstraction, logical thinking and rational problem solving *See* LEARNING THEORIES NERVOUS SYSTEM

General mathematical principles. All the previously mentioned developments are based on what may be called construction of physicomathematical or mathematical models of various biological phenomena No general principles similar for example to Newton's laws of motion or the principles of thermodynamics in physics have been mentioned Two general biological principles however have been formulated

The first principle deals with problems of organic form that is with problems of shape of plants and animals Any organism may be considered as a system which performs certain specified functions such as locomotion production of energy and digestion of food The performance of those functions depends largely on the shapes and sizes of the different parts of the organism in other words on its form The principle states that the shapes and sizes of the different parts are such as to offer the greatest possible economy in the material of which those parts are made and also economy of energy expenditure necessary for the performance of the functions considered This is the principle of optimal design

A number of consequences are derived mathematically from this principle For example it follows that in quadruped mammals the width of the trunk or body should vary approximately as the ½ power of its length The frequency of breathing should vary approximately as the inverse cubic root of the mass of the animal A similar relation must hold for the frequency of the heart beat Those relations are actually found to hold The diameter of the aorta and the size of capillaries as well as some other characteristics of the arterial system can be fairly accurately calculated on the basis of this principle A mathematical description of the gross shape of different plants such as trees and shrubs is made possible

Another general principle emphasizes the important relational aspects of biological phenomena and brings into focus the unity of the organism and of the organic world as a whole A paramecium moves towards food in response to a stimulus It ingests that food digests it excretes the indigestible parts and assimilates the rest A higher animal though much more complicated in structure performs essentially the same functions Though those functions are quantitatively different in a paramecium and in a higher animal they stand in all animals in the same relation to each other Similar considerations apply to plants Higher organisms can be mapped in a many to one manner by reference to simpler ones The mathematical formula-

tion of this principle requires the use of topology and theory of sets (*see* TOPOLOGY) The principle of biotopological mapping states that to every organism there corresponds an abstract topological space and that all those spaces are obtained from each other by the same transformation A consequence of the principle is that in higher animals and men emotional disturbances may lead for example to gastrointestinal or cardiovascular disturbances This is a well known fact Another consequence is that some animals secrete substances that are used to catch food, an example is the spider web The principle also requires among other things that unicellular organisms should exist which produce antibodies when stimulated by appropriate antigens and that some plants at least must show phenomena similar to the production of antibodies Those consequences have not yet been verified experimentally but together with other conclusions they indicate new directions for experimental research *See* BIOPHYSICS [N R]

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Biopotentials and electrophysiology

Biopotentials are the voltage differences existing between various parts of living systems The mechanisms involved in their genesis the consequences of their existence the changes which occur in them from time to time and the currents which they drive constitute the dominant bulk of the subject matter of electrophysiology This article considers resting potentials and their analysis action potentials and other phenomena concerned with bioelectricity

Resting potentials Nonpolarizable electrodes contacting different parts of biological systems usually show that relatively steady voltage differences exist between them and that current can be drawn For instance the cell interior the cytoplasm is electronegative with respect to normal extracellular fluid during the resting state This type of biopotential called the resting potential membrane potential or transsurface potential ranges up to about 100 millivolts (mv) and seems to exist entirely across the thin surface layer of the cell Examples are found in such diverse cells as the coenocytic marine algae *Valonia Halicystis* and *Nitella* which generate potentials up to about 80 mv between the cell sap and the outside medium in muscle cells of the frog where resting potentials are 70–80 mv in nerve fibers where resting potentials are 70 80 mv in the squid and lobster and in nerve cell bodies where potentials in the spinal cord of the cat for example are of the order of 70 mv Voltage differences also exist across cell sheets Frog skin exhibits a potential difference of 20–90 mv with the inside positive Intestinal mucosa salivary glands and renal tubules show similar potential differences There are also voltages between whole organs such as those which change with ovulation and between body regions such as those which change with growth and development These latter types of potential however are smaller than those measured across cell surfaces or cell sheets

Resting potential analysis Although none of these resting potentials is well understood perhaps most is known about that across the single cell surface almost as much about the potential across frog skin and less about the others

Technical advances Major insights into the single cell resting potential have been gained because of a few very effective technical advances It is for instance possible to insert one or more microelectrodes into the cell interior with so little damage that the cell survives and simultaneous measurements of transsurface current and voltage are possible in the living system under controlled conditions Radioactive isotopes have permitted better understanding of the relationship of the potentials and changes in them to the ionic composition of the cell and its environment The versatility speed and sensitivity of electronic devices have permitted maximum exploitation of the microelectrodes and radioisotopes Although these methods are now supplied to many cells and even to cells in the essentially intact living animal the availability of certain isolable large cells such as the giant axon of the squid (up to about 0 7 mm in diameter) has made many pioneer experiments easier

Research areas The major problems involving single cell resting potentials concern (1) the physicochemical source of the potential in molecular or submolecular terms (2) properties of the container that is the structure of the cell that are important for the potential found across its surface and (3) the energy source for the work done to generate the potential These problems are discussed in the following section

Voltage source The source of the voltage across the cell surface has been the subject of much speculation Only three possibilities will be considered

1 The potential is due to oriented dipoles at the cell surface macromolecules are positioned there with an inwardly directed negative and an outwardly directed positive end (*see* DIPOLE) Although there almost surely are such oriented dipoles it is difficult to explain how a sheet of dipoles could yield prolonged current flow

2 The potential is an expression of the difference between intracellular and extracellular potassium concentrations There is approximately 10–50 times more potassium (K) inside the cell than outside Hence potassium ions (K^+) continually tend to diffuse out Their companion anions possibly proteins or phospholipids cannot diffuse out beyond the cell surface film Therefore across the boundary layer there will be a small spatial separation between these charged particles with a greater number of positively charged potassium ions just outside and a greater number of negatively charged anions just inside Such a spatial separation of charge could give rise to the resting potential across the surface the polarity being negative inside

If this is the case the potential should obey the formulation

$$E = \frac{RT}{nF} \ln \frac{[K^+]_{\text{inside}}}{[K^+]_{\text{outside}}}$$

where E is the potential measured in mv R the gas constant T the absolute temperature n the valency change F the Faraday ln the natural logarithm and [K] the potassium ion concentration RT nF at 18°C is 58 Certain tests immediately suggest themselves Supporting this proposition the potential is found to be nearly linear function of the absolute temperature T and quantitatively to match fairly well the value predicted from the potassium concentration ratio as determined by direct chemical analysis Also under certain conditions the voltage does change by the predicted 58 mv when the potassium ratio is changed tenfold by varying the outside potassium concentration However the agreements are only approximate sometimes the relationship between voltage and potassium ratio holds only outside the physiological range of potassium concentration and there is considerable question about whether the potential changes as it should when intracellular rather than extracellular potassium is experimentally changed

It may therefore be concluded that the intracellular extracellular potassium ratio plays a major role in setting the level of the cellular resting potential but the mechanism of its generation is still a matter of question

3 The potential is an expression of a difference in transsurface movements of K and sodium (Na) *Just* as K is known to be more concentrated inside the cell so Na is known to be more concentrated *outside* This is not as was once thought because Na cannot enter but because the cell accumulates K *and continually* removes the Na which leaks in A difference in transsurface movements of these ions *could result in a potential* dynamically maintained by the Na extrusion mechanism Such a potential would *depend partly upon* K distribution but not exclusively so and would be variable to the extent that the Na *extrusion* mechanism functioned more or less efficiently

Cell structure Whatever *its genesis* the cellular resting potential seems to exist entirely across the thin cell surface thought by *some to be the* so called cell or plasma membrane and considered to be about 100 A thick If so *then in some* sense there is a voltage gradient across this membrane of about 100 mv/100 A or about 100 000 *volts/cm* In trying to understand the potential it is important to consider what is known about the cell *surface* structure which can support such a steep *voltage* gradient In addition the molecular composition and architecture of the cell surface are of interest because (1) damage to this region *causes* the resting potential to disappear whereas major disruption of the cell interior as by *stirring* with a microelectrode has little or no immediate effect (2) damage to this region destroys *the ability* of the cell to conduct the signals called impulses and (3) damage to this region destroys the ability of the cell selectively to accumulate or exclude certain substances If the damage is great enough the cell dies

In electrical terms the cell is known to consist of a low resistance interior, separated from a low resistance fluid environment by a barrier of relatively high resistance and very high capacity The high conductivities of the cytoplasm and external medium are due to the presence of salts Because of this core conductor construction the analogy between the tubular axon and semitubular muscle cell on the one hand and a submarine cable on the other is an obvious one However when compared to the copper wire in a cable the cellular core is a poor conductor (50–100 ohm cm specific resistance) The cell surface insulation could store a great amount of electrical energy in its large capacity of about 1 microfarad/cm², but it is leaky in comparison with cable insulation having a resistance of only a few thousand ohms per square centimeter Therefore the cell although qualitatively analogous to the submarine cable is a quantitatively poor analog Nonetheless these core conductor properties are important in the physiological behavior of the cell

Information about cell surface structure comes from a number of sources mainly permeability chemical analytical birefringence x ray diffraction and electron microscope studies There are one or more bimolecular leaflets of tangentially oriented protein molecules associated with radially arranged lipid molecules probably mainly phospholipids cholesterol and cerebrosides incorporating water and calcium at sites still not clearly known. In vertebrate nerves these layers are wrapped around the axons except for small ones in a jelly roll fashion interrupted every few millimeters along the long axis at so called nodes of Ranvier In invertebrate axons these surface layers are differently arranged Interestingly similar lipid protein leaflets exist in such diverse structures as the rods and cones of the eye chloroplasts of plant cells at the surface of and probably within *mitochondria* and diffusely throughout the cell in the so called endoplasmic reticulum It may be that this ubiquitous structure serves as an orienting skeleton for enzymes and their substrates Most likely it is the phospholipid component whose integrity is somehow essential for maintenance of the resting potential An example of such a structure is found in the myelin sheath of nerve (see illustration) *See* CHOLESTEROL, LIPID, MICROSCOPE ELECTRON X RAY DIFFRACTION

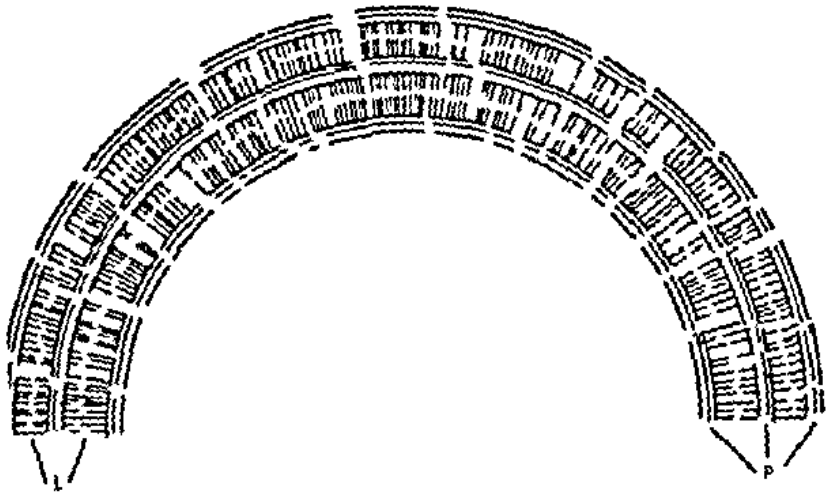
Energy source Concerning the source of the work done to generate the potential the energy source must ultimately be metabolic oxidations However the precise links or devices for coupling

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cules must be synthesized and incorporated in or



Orientation of lipid (L) and protein (P) components of the myelin sheath deduced from polarized light analysis (*From A. Engstrom and J. B. Finean, Biological Ultrastructure*, Academic Press, 1958)

derly fashion. This process and prevention of their degradation into random disorder require metabolic energy, and just as the potentials disappear after death and metabolic arrest, so do the resistance and capacity of the surface structure disappear. If the potentials depend on ion segregations, then work must be done to prevent the ions from simply diffusing in accord with their concentration gradients. This might be achieved by metabolic synthesis of selective ion binders or of carriers for so-called active transport against a concentration gradient. At the present it may be concluded that the energy sources for biopotential genesis are ultimately metabolic, but reliable details are few. *See* BIOLOGICAL OXIDATION; CELL (BIOLOGICAL); METABOLISM.

Action potentials. Another type of bioelectric potential is the action potential, a transient change in the cellular transsurface potential which is propagated along the surface of the cell and its processes. Although it has been investigated most extensively in nerve and muscle cells, the action potential probably occurs in some form in all cells; it is even seen in certain plant cells such as *Nitella*, but its function there is unknown. It is the propagated signal or unit of information by means of which communication is achieved between receptors (sense organs) and effectors (muscles, gland cells) via the central nervous system, between one part of the nervous system and another, and between the nervous system and other organs. It also travels along the surface of the muscle cell and somehow leads to contraction. It is characteristically initiated by a decrease in the resting potential. *See* NERVOUS SYSTEM.

In general, the following events seem to occur as the cell is stimulated to go from the resting to the excited state and back again. The stimulus consists of a reduction in the resting potential (depolarization). This is commonly produced in the laboratory by a voltage pulse (fraction of 1 msec) opposing the resting potential, as in the region of an applied cathode (an anode increases the resting potential, that is, hyperpolarizes). The depolarization must occur rapidly enough and last long enough or the tissue accommodates, and threshold depolarization will not be reached. At first the potential across the cell surface decreases in fairly linear relation to the applied cathodal pulse; this decrease spreads along the surface of the axon decaying roughly exponentially with distance from the cathode (length constant, order of a few millimeters) and roughly exponentially with time (time constant, order of 1 msec). Such behavior is expected from a core conductor, and the cable equations applicable to the submarine cable apply here too. The spread of the potential change along the cell surface is called electrotonic spread or electrotonus. When the resting potential reduction exceeds a few millivolts, however, this progressive reduction ceases to be a linear function of the applied pulse and starts to become greater than the equations predict and to last longer. This is the so-called local response. The cell is no longer behaving simply as a passive core conductor but to its core conductor behavior it is adding an active, although not yet propagated, response. When this local response increases sufficiently and the depolarization is about 20% of the resting potential, there suddenly appears an all-or-nothing type of change which is no longer graded as the local response was. Threshold for excitation is said to have been reached. The transsurface potential suddenly falls locally to zero, reverses by about 30 mv so that the inside of the cell goes momentarily positive relative to the outside, and then returns, after a few quantitatively minor oscillations (after potentials), to the initial resting level. This cycle of events—the sharp fall, transient reversal, and recovery of the transsurface potential—occurs in 1 msec or less and is called the action potential. When the transsurface potential changes in this way at any locus on the cell or its processes, then the voltage change and current both spread electrotonically ahead of this active region just did in the region of the applied cathode.

rent flowing ahead of the active region decreases the resting potential of the adjacent region to which it spreads and normally the current is more than enough by about six to ten times to reduce the potential of the adjacent region sufficiently so that it too becomes excited and goes through an identical cycle of events in turn exciting the region downstream from it Thus self propagation is achieved A wave of reversible depolarization travels along the cell surface with a finite conduction velocity Because nerve fibers (axons) may extend from cell bodies in the central nervous system for several feet as in the leg of man a signal can be conducted in this fashion between the central nervous system and a distant organ

An integral event during the action potential cycle is a local reversible fall in transsurface resistance from a few thousand to about 25 ohms cm The electrical capacity on the other hand changes very little if at all Because the cell contains ions in solution not metal wires all current must be carried by ions not by electrons The momentary fall in transsurface resistance therefore means that for an instant ions can move more freely across the cell surface These ion movements largely prevented during rest are in fact the action current whose flow through the transsurface resistance produces the action potential It is not yet known what molecular changes suddenly and reversibly permit these transsurface ion movements but as noted above a critical reduction in the resting potential seems to be part of the essential triggering mechanism The ions which move are known and the association of specific ones with the several phases of the action potential has been demonstrated Thus inward movement of sodium ion is that part of the action current associated with depolarization and reversal of the transsurface potential whereas outward movement of potassium reaching its maximum later in time is that part of the action current associated with repolarization or recovery Essentially similar events seem to characterize the muscle-cell action potential but this is not true of all cells Thus in *Nitella* the action current involves mainly an outward movement of chloride ions and in certain secretory cells activity is accompanied by a transient hyperpolarization rather than by depolarization

Other problems The above account supplies some of the concepts essential for general understanding and outlines the most recent advances and currently central problems In addition certain other matters concerning bioelectric phenomena may be mentioned

For instance in no case is it known in molecular terms how a receptor organ converts the energy of a stimulus such as light sound taste and touch into nerve impulses It is known that a potential difference the generator potential much like the graded local response is produced at the junction between the receptor cell and the axon leading from it to the central nervous system and when this is sufficiently large it initiates propagating action potentials in the axon However how the stimulus produces the generator potential is not understood

At certain other junctions as between the terminal twigs of motor axons and muscle cells (neuromuscular junction) or between axons and nerve cells (synapse), or between axons and gland cells there is evidence that transmission of excitation across the junction is not simply by electrotonic spread as described for axonal propagation At these junctional regions the impulse coming down the axon seems to liberate a chemical a so-called neurohumor or chemical mediator of activity which diffuses across the junction and depolarizes the second order cell this cell then again propagates impulses electrically as before The electric organs of certain fishes contain some junctions at which transmission is electrical and some at which a chemical mediator is involved

The nervous system is also capable of inhibitory action Inhibition seems to be produced by hyperpolarization rather than by depolarization and by changes in conductance of the cell resulting in shunting the action current to a higher threshold region This too may involve release of an intermediating chemical a chemical mediator of inhibition

See BIOPHYSICS ELECTROPHYSIOLOGY (HEART) MOTOR SYSTEMS REFLEX UNCONDITIONED *see also* ELECTROCARDIOGRAPHY, ELECTROENCEPHALOGRAPHY [J M T]

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Biosphere

The life zone of the earth The biosphere is by analogy with the atmosphere hydrosphere and lithosphere consists of the outer sphere of the earth that is inhabited by living organisms It includes the lower part of the atmosphere the entire hydrosphere down to its maximum depth (10 863 m) soils and the lithosphere to a depth of about 2 km where some bacteria occur in conjunction with petroleum deposits The term has also been used to designate the total quantity of

living matter on the earth but such usage should be discontinued The concept of the biosphere was introduced by J B Lamarck and later defined by E Suess in 1875 Because of the great geological activities of *Homo sapiens* the modern biosphere is sometimes referred to as the anthroposphere or noosphere *See* BIOSPHERE GEOCHEMISTRY OF *see also* ATMOSPHERE HYDROSPHERE LITHOSPHERE

[J R S]

Biosphere, geochemistry of

Many geochemical processes occurring at or near the earth's surface within the limits of the biosphere are regulated either directly or indirectly by the biochemical activities of living organisms (*see* BIOSPHERE) Quantitative studies of biochemical processes from a geochemical point of view form the subject matter of biogeochemistry a field of investigation that may be regarded as a synthesis of the bio- and geochemical aspects of oceanography limnology soil science and terrestrial ecology

The two main objectives in biogeochemistry are to obtain data on the chemical composition of living organisms and to elucidate the roles played by organisms in the geochemical cycles of the elements Both phases of the subject are in early stages of development There are 350 000 and 1 200 000 described species of plants and animals respectively now in existence and it is thought that about 500 000 extant species remain to be discovered The total number of extant and extinct species is estimated to be between 50 000 000 and 4 000 000 000 Only 1% of the described species of living plants and 0 2% of the described species of living animals have been subjected to chemical analysis Most of those analyses have been limited to one or a few chemical elements

The importance of living organisms in geochemical processes was first appreciated by J B Lamarck J Liebig E Suess and other investigators of the nineteenth century but it was not until the beginning of the twentieth century that biogeochemical data were systematically accumulated into a coherent body of information The first comprehensive studies were undertaken by V I Vernadsky (1863–1945) of the Soviet Union who is regarded as the modern founder of the subject Other leaders in the field have been A P Vinogradov (Soviet Union) G Bertrand and D Bertrand (France) and F W Clarke and G E Hutchinson (United States)

LIVING MATTER IN THE BIOSPHERE

Living matter occurs in the biosphere wherever water exists in the liquid state in conjunction with a source of energy for metabolism Some of the extreme conditions under which certain species maintain permanent populations are listed in Table 1

The fundamental distinction between organisms with regard to geochemical activities and importance results in two classes (1) those organisms that contain chlorophyll pigments and utilize the energy of visible light for the synthesis of energy rich organic compounds (pigmented algae photosynthetic bacteria and higher plants) and (2) those lacking the photosynthetic apparatus (viruses nonphotosynthetic bacteria fungi and animals) Those without chlorophyll derive their energy for metabolism from the respiratory oxidation of food materials in the form of organic and in some cases inorganic compounds

Table 1 Conditions under which living organisms are known to reproduce in nature

Factor	Minimum	Maximum
Temperature	−2°C (organisms in polar seas)	85°C (blue-green algae in hot springs)
Hydrostatic pressure	Not determined	1070 atm (deep-sea forms)
pH	1 7 (the diatom *Pinnularia*)	12 0 (blue green algae in Kenya lakes)
E_h	0 50 volts (marine sedimentary bacteria)	0 83 volts (aerobic organisms)
Salinity	Very low as in rain water	220 parts per thousand (halophytic bacteria and *Artemia salina*)

In separate parts of the biosphere fairly distinct communities of organisms can be recognized for example the plankton communities of natural waters coral reefs sphagnum bogs spruce fir forests and steppes Because there is an exchange of energy and matter between the living community and the nonliving environment the complex is often studied as a unit called an ecosystem The physical dimensions of an ecosystem may range from a puddle of water to a maximum which is the entire biosphere The passage of energy through an ecosystem can be conceived as proceeding through a series of trophic (feeding) levels (*see* BIOMASS) The following trophic levels are recognized photosynthetic plants herbivorous animals and microorganisms of decay primary carnivores and higher carnivorous levels Under steady state conditions the rate of energy production by one trophic level must necessarily exceed the rate of energy utilization by a succeeding trophic level This is in accordance with the second law of thermodynamics as applied to steady state systems It follows that for the biosphere as a whole green plants tend to be of greater geochemical importance than consumer organisms in terms of both biomass and metabolism However photosynthetic plants are unable to maintain permanent populations at depths greater than 100 m in the hydrosphere or greater than a few meters (in the case of plant roots) in soils because of the lack of light In such environments all biochemical activity is the result of animals and nonphotosynthetic microorganisms This situation exists in the more peripheral parts of the biosphere

The linear dimensions attained by living organisms lie between the limits of 10^{-8} cm in the case of viruses and 10^{4} cm for sequoia trees given taxonomic group the rate of unit weight of tissue tends to in thirds power of the weight There

variation from one taxonomic group to another and many exceptions to this general rule are known The over all result is that per unit weight smaller individuals tend to respire and also to increase in mass at faster rates than do larger individuals Thus under maximal growth conditions a virus population will double its weight in a matter of minutes bacteria in less than 1 hour small animals in days or weeks and larger forms in months or years As a consequence small individuals tend to be more active geochemically than their biomass might suggest

Although the total mass of living matter in the biosphere has never been accurately estimated its probable value is $n \times 10^{17}$ g live weight (where n is any small integer) which corresponds to $20n$ mg per cm^2 of earth surface The amount of carbon dioxide annually fixed in photosynthesis in the entire biosphere is probably equivalent to 7×10^{16} g of carbon with the true value not less than one half nor greater than twice this amount This rate approximately corresponds to a 0 1% efficiency in the utilization of the visible light energy that actually reaches the earth s surface Photosynthesis by marine plants accounts for at least two thirds of the total photosynthesis in the biosphere The greatest amount of photosynthesis on land occurs in forests followed in decreasing order by cultivated land steppes and deserts *See* Biological productivity Ecology Ecosystem Photosynthesis

INFLUENCE OF LIVING MATTER

As a result of enzymatic action many chemical reactions occur at low temperatures within the bodies of living organisms that would otherwise proceed only at slow rates in the biosphere Prime examples are photosynthesis and the formation of nitrates from molecular nitrogen by the combined action of nitrogen fixing and nitrifying microorganisms In spite of the small mass of living matter in the b

sion rates to transport certain elements from the lower soil layers to the surface and to accelerate the decomposition of some minerals and rocks by the excretion of carbon dioxide and polyvalent organic compounds that act as ligands (chelating agents) In addition many of the physical and chemical characteristics of soils and aquatic sediments are determined by the activities of microorganisms such as pH oxidation potential E_h and texture

The concentrations of certain elements in plants and animals may exceed those in the media of growth
One of
of vana
of vana
0 01% live weight whereas sea water contains 0 0000002% vanadium The extensive deposition of foraminiferan and radiolarian oozes on the sea floor emphasizes the importance of these forms in the deposition of $CaCO_3$ and SiO_2 respectively Evidence of the former activity of organisms in the biosphere is provided by acaustobioliths (inorganic bioherms) such as reef limestones and by caustobioliths (organic accumulations) such as oil shales and deposits of coal and petroleum *See* Marine sediments

Considerable indirect geochemical evidence as well as more direct indications from the occurrence of fossil microorganisms in Precambrian deposits indicate that the biosphere has been in existence for some 1 600 000 000 years and possibly for twice that length of time As a result of evolutionary processes both the numbers and kinds of species have been changing from time to time New environments have been occupied and even biologically created in the process The quantitative importance of living organisms in the biosphere is quickly appreciated when it is realized that a weight of water equivalent to that present in all the oceans ($1 4 \times 10^{24}$ g) is decomposed by photosynthetic plants once every 10 000 000 years The supply of oxygen in the earth's atmosphere a characteristic that serves to differentiate the earth from all other planets with the possible exception of Mars has been derived mostly from photosynthesis resulting from a lack of balance in the biospheric carbon cycle The total amount of carbon photosynthetically incorporated into green plants during the history of earth is approximately 10^{16} g an amount which is equivalent to 1/50 of the weight of the globe It is estimated that about 10^{15} g of this carbon still persists in the form of fossil organic compounds in coal petroleum and organic shales

Following the appearance of *Homo sapiens* in the biosphere both direct and indirect geochemical changes have arisen as a result of land clearing water conservation practices road construction combustion of fossil fuels mining operations, and extinction and redistribution of species The term anthroposphere (or noosphere) has been used to designate the modern biosphere in which human changes play a significant part As a result of atomic fission processes both in weapons testing and in nuclear reactors new biogeochemical problems have arisen The radioactive nuclides present in atomic fallout and in low level reactor wastes are accumulated by organisms the nuclide enrichment factors sometimes amount to as much as 100 000 times the environmental concentrations In general the radioactive nuclides most concentrated by organisms are those of elements that occur in the environment in physiologically limiting concentrations This is the case for example in the accumulation of P^{32} by phytoplankton and some vertebrates in the Columbia River (USA) below the level of the Hanford atomic energy plant

CHEMICAL COMPOSITION OF LIVING MATTER

A living organism can perhaps be best described in general terms as a complex colloidal system enclosed and separated from the environment by a semipermeable membrane with enzyme controlled

feedback mechanisms that serve to maintain and reproduce the entire system A characteristic which serves to distinguish the living or once living from the nonliving is the molecular asymmetry of biological matter, certain enantiomorphs (optically active isomers) predominate Thus D-glucose is the only known biological enantiomorph of glucose and in proteins all the amino acids appear to be of the L series In chemical syntheses a racemate (50 50 mixture of D and L isomers) is usually produced *See* AMINO ACIDS, GLUCOSE

Elements in living matter Excluding technetium promethium astatine francium and the transuranium elements all of which are either very rare or nonexistent in nature there are 88 elements that could conceivably enter into the composition of living matter Of this number 71 have been identified but the data for three of these (niobium zirconium and tantalum) are questionable and need confirmation Among the elements still undetected in living matter are four of the noble gases (helium, neon krypton and xenon) that undoubtedly occur there as atmospheric contaminants, all the platinum metals (ruthenium rhodium palladium osmium iridium and platinum), and seven other elements of atomic numbers in the range 49 91 (indium tellurium hafnium rhenium polonium, actinium and protactinium) It is improbable that any of the unidentified elements is completely excluded from protoplasm

The major biological elements hydrogen (H) carbon (C) nitrogen (N) and oxygen (O) comprise 96 99% of the live weight of nonskeletal tissues These elements enter into the composition of the four main groups of protoplasmic molecules namely water (89 4% O and 10 6% H by weight) proteins (51 3% C, 22 4% O 17 8% N and 6 9% H by weight) carbohydrates (49 4% O 44 4% C and 6 2% H by weight) and lipids (69 0% C 17 9% O and 10 0% H by weight) In terms of the number of atoms the abundance of elements in living matter decreases in the order hydrogen > oxygen > carbon > nitrogen Skeletal or supporting structures may be composed of organic compounds such as cellulose lignin chitin and sclero proteins or inorganic compounds such as calcium carbonate silicon dioxide and calcium phosphate

Concentrations of elements The average percentage composition of terrestrial vegetation is listed in Table 2 for those elements that have been studied in sufficient detail The concentration of a minor element in living matter provides no indication of its physiological importance or necessity Concentrations of essential elements may vary by a factor of 100 000 or higher Some elements of unknown function occur in very small amounts The cow liver cell for example contains only some 23 atoms of radium probably in nonessential sites The protistan *Euglena gracilis* on the other hand requires only 5000 molecules per cell of the essential cobalt containing vitamin cyanocobalamin (vitamin B_{12})

Several attempts have been made to construct a biological classification of the elements but no single satisfactory tabulation has yet been discovered The biological elements are generally those of low atomic weight however iodine with an atomic weight of 127 is a notable exception Partly as a result of the high percentage of water in living tissues there is actually more resemblance between the cosmic abundance of elements and the abundance of elements in living matter than there is between that of living matter and the lithosphere Perhaps the best documented relationship is that discovered by G E Hutchinson for elements of constant valence as shown in Fig 1 The elements enriched by plants relative to the upper part of the lithosphere are those with either a high or a low

Table 2 The average percentage by weight of elements in terrestrial vegetation*

Element	Percentage	Element	Percentage	Element	Percentage
O	70	Fe	2×10^{-2}	Br	1×10^{-4}
C	18	Mn	7×10^{-3}	Mo	5×10^{-6}
H	10 5	F	3×10^{-3}	Y†	4×10^{-6}
Ca	0 5	Ba	3×10^{-3}	Ni	2×10^{-5}
N	0 3	Al	2×10^{-2}	V	2×10^{-5}
K	0 3	Sr	2×10^{-2}	Pb	2×10^{-5}
Si	0 15	B	1×10^{-2}	Li	1×10^{-5}
Mg	7×10^{-2}	Zn	3×10^{-4}	U	1×10^{-6}
P	7×10^{-2}	Rb	2×10^{-4}	Ga	3×10^{-6}
S	5×10^{-2}	Cs	2×10^{-4}	Co	2×10^{-6}
Cl	4×10^{-2}	Ti	1×10^{-4}	I	1×10^{-6}
Na	2×10^{-2}	Cu	1×10^{-4}	Ra	2×10^{-12}

* Modified slightly from a tabulation by G E Hutchinson

† Data are given for yttrium and the rare earths

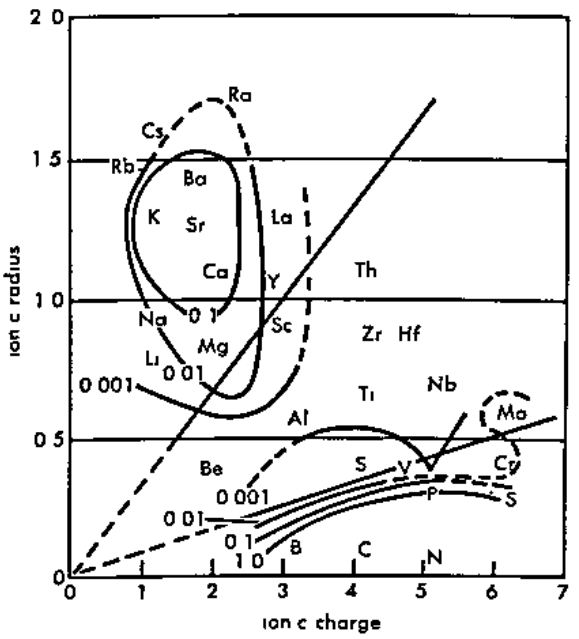


Fig 1 A plot of ionic radius vs ionic charge for elements of constant valence Curved lines show ratios of average concentration in terrestrial plants to the concentrations in the accessible lithosphere (*From Goldschmidt in G E Hutchinson The biogeochemistry of aluminum and of certain related elements Quart Rev Biol, 18(4) 337 1943*)

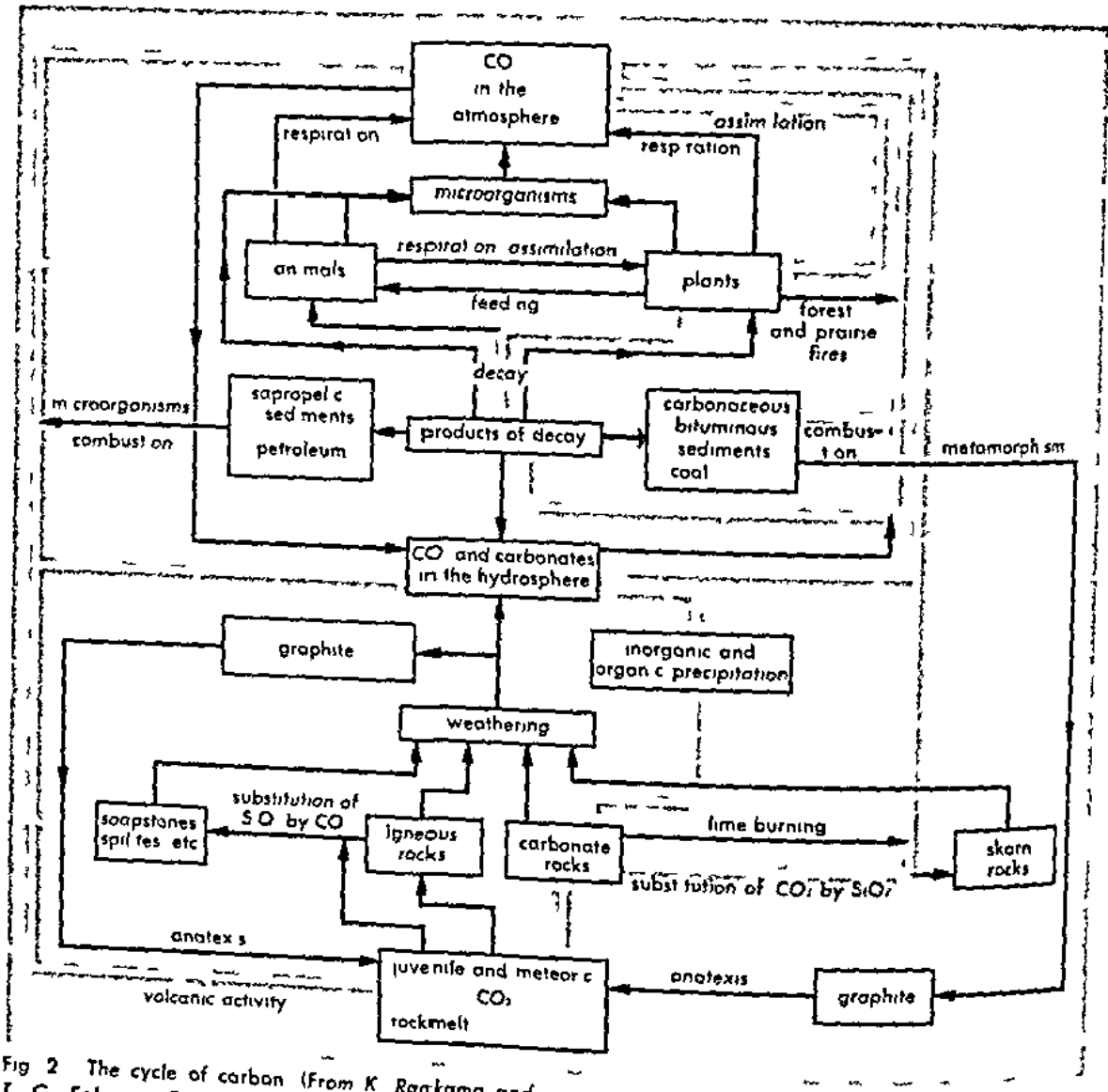


Fig 2 The cycle of carbon (*From K Rankama and T G Sahama Geochemistry University of Chicago Press 1950*)

ionic potential (ratio of ionic charge to radius) The basis of the rule is water solubility The elements in the upper left group of Fig 1 form soluble cations in water those in the lower right group form anionic complexes with oxygen that are soluble in water whereas the elements in the central group tend to form insoluble oxides

The chemical composition of single species populations cannot be taken as a completely invariable characteristic although it is approximately so Chemical composition changes with genetic constitution growth and environmental conditions The availability of many soil elements for plant growth depends upon the pH of the soil the state of the element concentration and many other factors The ability of plants to reflect subsoil concentrations of certain elements has been used as a basis of biogeochemical prospecting for subsurface ore deposits In the nickel rich areas of the southern Ural Mountains some abnormal forms of *Anemone patens* may contain up to 8 times more cobalt and 50 times more nickel than the same species growing on normal soils Biogeochemical prospecting has been similarly used for copper, lead, selenium and uranium deposits *See* GEOCHEMICAL PROSPECTING

Trace elements and isotopes. Many of the trace metals are incorporated into protoplasm by forming complexes with ligands such as proteins porphyrins amino acids mucopolysaccharides and other polyvalent compounds Among metals of the first transition series there exists a stability sequence for the metal ligand complexes that is largely independent of the nature of the ligand namely

$$Mn^{++} < Fe^{++} < Co^{++} < Ni^{++} < Cu^{++} > Zn^{++}$$

It has occasionally been suggested that specific isotopes of some elements may be essential for living matter, but there is no evidence for such a concept A fractionation of isotopes does occur in most biological processes with a preferential ac

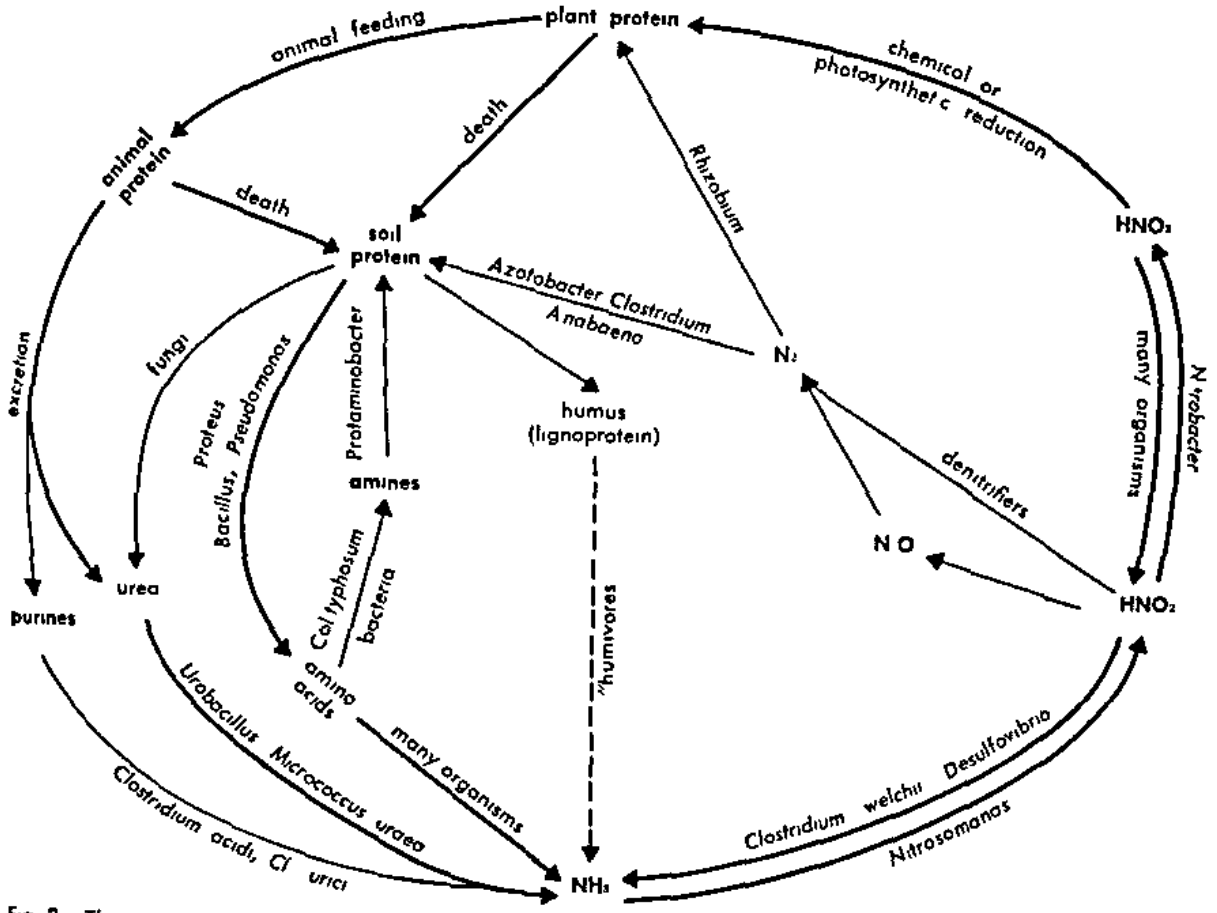


Fig 3 The nitrogen cycle in the biosphere (*From K V Thimann, The Life of Bacteria, Macmillan, 1950*)

cumulation of the lighter members in the pairs $C^{12} - C^{13}$ and $S^{32} - S^{34}$ Isotope ratios of natural materials provide useful data in determining the mode of origin of certain deposits, and in the case of $O^{16} - O^{18}$ in carbonate shells, in determining paleotemperatures *See* GEOLOGIC THERMOMETRY, PALEOBIOCHEMISTRY

BIOGEOCHEMICAL CYCLES OF ELEMENTS

Primary elements. Each of the primary elements of living matter (hydrogen carbon, nitrogen, oxygen, phosphorus) constitutes more than 0 5% of the weight of the living body

Hydrogen occurs in nearly all biological compounds Molecular hydrogen is both produced and oxidized by different kinds of bacteria Hydrogen sulfide and methane are also metabolized under anaerobic conditions The basis of many enzymatic oxidation reactions is a dehydrogenation

Carbon is unique in that it forms more compounds *than all* the other elements combined The cycle of carbon in the biosphere is shown in Fig 2 Photosynthetic plants reduce carbon dioxide during photosynthesis to organic carbon compounds that are ultimately converted back to carbon dioxide in plant and animal respiration Because some carbon compounds are not readily attacked by animals and microorganisms there is a slight but steady loss of carbon to sediments a process that has led to the accumulation of coal and petroleum deposits *See* COAL PETROLEUM (ORIGIN) Much of the carbonate deposition in the oceans is mediated by calcareous organisms such as corals, mollusks brachiopods, and some bacteria and algae Carbonates may be indirectly precipitated from natural waters by a rise in pH following periods of intense phyto

sil fuels This appears to have led to a 9% increase in the carbon dioxide content of the atmosphere in the period 1900–1960

Oxygen is an essential element for all organisms however, certain microorganisms are adapted to an anaerobic existence which in some cases is facultative, and in others, obligate The oxygen produced by green plants during photosynthesis is used in plant and animal respiration, the over all reaction (proceeding to the right) being a reversal of photosynthesis

$$(CH_2O)_n + nO_2 \rightleftharpoons nCO_2 + nH_2O + 106n \text{ kcal}$$

The oxygen produced during photosynthesis arises from the decomposition of water

The geochemical cycle of nitrogen is outlined in Fig 3 In most plant tissues nitrogen averages 2–6% of the dry weight whereas in animals and some bacteria the corresponding value is 6–13% for ash free weights *Azotobacter*, some blue green algae, and *Rhizobium* in association with plant

roots convert molecular nitrogen into organic compounds Hutchinson estimates that the total annual biological fixation of nitrogen amounts to $n \times 10^{1}$ g of nitrogen or approximately $n/5$ g of nitrogen per cm² of earth surface The return of molecular nitrogen to the atmosphere is accomplished by a number of facultative anaerobic bacteria that convert nitrates and nitrites into molecular nitrogen The most important biological forms of nitrogen are proteins and nucleic acids The predominant excreted forms of nitrogen in terrestrial animals are uric acid and urea whereas in aquatic forms the nitrogen is usually excreted as ammonia

Phosphorus usually forms 0 2 1 0% of the dry weight of plant and animal tissues Many organic phosphorus compounds occur biologically (for example phosphoproteins phospholipids carbohydrate phosphates and nucleic acids) In all these compounds the phosphorus occurs as phosphate esters Phosphate is taken up from natural waters by algae and bacteria when the concentrations are only a few parts per 1 000 000 000 parts of water The concentrations of phosphate in both waters and soils are low enough to be limiting to plant growth Because of erosion and agricultural practices about 10^{3} g of phosphorus is annually delivered to the sea This is largely a unidirectional process because only $n \times 10^{9}$ g of phosphorus is annually removed from the sea mostly in the form of guano deposited by marine birds

Secondary elements The other essential elements for living organisms in approximate order of *decreasing* concentration by weight are sodium calcium magnesium sulfur chlorine potassium iron silicon vanadium zinc boron fluorine manganese cobalt copper and iodine

Among the alkali metal cations sodium (Na) occurs primarily in circulating fluids whereas potassium (K) is located *intracellularly* The biological K/Na ratio is usually higher than in the growth medium Lithium is a minor and variable constituent of living matter Rubidium on the other hand *is a normal* constituent behaving

[illegible] fluids The only known biological chlorine compound is the antibiotic chloromycetin Iodine is concentrated from sea water by brown and red algae where it may occur in concentrations of 1% of the live weight In sponges corals and the thyroid glands of vertebrates iodine occurs in the form of iodinated amino acids Bromine occurs biologically as bromide and also in the form of organic compounds Fluorine enters the apatite lattice of bones and teeth

Calcium is biologically the most important member of the alkaline earth family occurring as skeletal matter in the form of carbonates (aragonite and calcite) and as phosphate (hydroxyapatite) Calcite *skeletons are* generally rich (2 28%) in $MgCO_3$ whereas aragonite skeletons usually have less than 1% Corals and some red and brown algae accumulate strontium (Sr) preferentially to calcium (Ca) from sea water but most plants and animals are characterized by higher Sr/Ca ratios in their diets than in their bodies Sr^{90} is the most serious of the radioactive fallout nuclides because it has a long biological residence time as well as a long physical half life Sr^{90} fallout is apt to be most serious in areas of calcium deficient soils Magnesium is an integral part of the chlorophyll molecule and is also required as a cofactor in enzymatic phosphate reactions Radium is accumulated by some plants Marine animals (especially fish) appear to contain less radium than marine plants

Boron in the form of borates is essential for the growth of higher plants but its function is unknown Silicon is primarily a skeletal element It is accumulated by diatoms radiolarians some sponges and some terrestrial plants Copper is accumulated from sea water by certain molluscs and crustaceans where it occurs in the form of the respiratory pigment hemocyanin Copper is also known to participate in some enzyme reactions but ionic copper is decidedly toxic to most forms of life when it is present in appreciable concentrations

The geochemical cycle of sulfur is markedly affected by biological reactions The photosynthetic sulfur bacteria have a photosynthesis based on the metabolism of sulfur compounds Hydrogen sulfide is generated during the anaerobic decomposition of plankton Selenium is selectively accumulated by some land plants such as *Astragalus* but it is otherwise toxic to plants and animals

Aluminum is the third most abundant element in the lithosphere but it is scant in most living tissues One exception is *Lycopodium alpinum* which may contain up to 33% Al_2O_3 in its ash

Vanadium manganese iron and cobalt appear to be indispensable but only for some species in the cases of the ferrides vanadium and cobalt Iron occurs biologically in a number of organic compounds the most important of which are hemoglobin and the respiratory enzymes (cytochromes) The geochemical cycle of iron is influenced *directly* by the deposition of hydroxides by the iron bacteria and indirectly through changes in pH and E_h conditions Manganese is a cofactor for some enzymes and vanadium appears to play some role in photosynthesis Vanadium also occurs in the form of vanadyl porphyrins in petroleum

The other elements of the periodic table are so far as is known neither essential for organisms nor present therein in appreciable amounts The geochemistry of such elements may be secondarily influenced by biological events as in the precipitation of heavy metals by organic sediments rich in hydrogen sulfide [J B S]

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Biostrome

A bedded structure or layer (bioclastic stratum) composed of any calcite and dolomitized calcareous fossil fragments distributed over the sea bottom as finite lentils independent of or in association with bioherms or other areas of organic growth Fragmental bioclastic layers may be of any thickness are found in sedimentary rocks ranging from Cambrian to Recent are typically developed on marine shelves and platforms within the zone of light penetration and are deposited under sedimentary controls similar to those involving the distribution of quartzose sand on the sea floor *See* BIOHERM, COQUINA, ORGANIC REEF [S A W E]

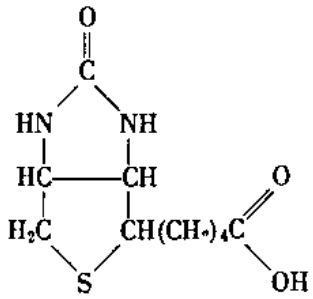
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Biotic isolation

The occurrence of organisms in isolation from others of their species Many organisms live in aggregations or social groups Among many others however there appears an opposite tendency toward relative isolation with each individual or pair living by itself separated by at least a small distance from others of its kind Thus in a desert shrubs may grow widely scattered each with its roots occupying the soil in an area around it A shrub seedling which begins to grow within the root area of another shrub is more likely to die because of failure to obtain sufficient water from the soil than one growing in the open space between other shrubs The shrubs consequently grow not in clumps but in isolation from each other with a more regular spacing in which the distances between individuals may be more even than in a random distribution In many animals a breeding pair may isolate themselves occupying a definite territory from which others of the species are excluded (*see* TERRITORIALITY) Such biotic isolation provides each individual or pair with a living space from which it can obtain food or water and nutrients more or less free from competition with others of its species *See* ECOLOGIC INTERACTIONS POPULATION DISPERSION [R H W]

Biotin

A vitamin widespread in nature whose deficiency causes dermatitis and other disturbances in animals and man It is only sparingly soluble in water (0 03 g/100 ml H_2O at 25°C) It is stable in boiling water solutions but can be destroyed by oxidizing agents acids and alkalies Under some conditions it can be destroyed by oxidation in the presence of rancid fats Its structural formula is shown below



Biotin

Biotin's occurrence in nature is so widespread that it is difficult to prepare a natural deficient diet Studies of egg white injury resulted in the discovery of biotin deficiencies in animals Raw egg white contains a protein avidin which combines with biotin to form an indigestible complex The feeding of large amounts of raw egg white has been used in producing experimental biotin deficiencies Heating of egg white denatures avidin destroying its biotin complexing ability Although the avidin

commonly used

Biotin deficiency in animals is associated with dermatitis loss of hair muscle incoordination paralysis and reproductive disturbances Biotin deficiency produced in human volunteers by feeding large amounts of egg white resulted in dermatitis nausea depression muscle pains anemia and a large increase in serum cholesterol

Biotin occurs in nature mainly in bound forms One of these isolated from yeast biocytin is ϵN biotynyl L lysine Biocytin can replace biotin as a growth factor for many organisms Although the metabolic role of biocytin is unknown its structure

some microorganisms because the bacteria require aspartic acid for growth and the oxaloacetic acid produced by biotin containing enzymes can be converted by transamination to aspartic acid (*see* VITAMIN B_6) Biotin is also involved in deamination of some amino acids aspartic acid $\rightleftharpoons NH_3$ + fumaric acid Some microorganisms require oleic acid if biotin is not supplied Biotin may be important for oleic acid synthesis or vice versa Under normal conditions biotin is synthesized to such a degree by intestinal bacteria that a dietary source

is probably not necessary Most diets contain 25 50 μg per day but 2 5 times as much are excreted in the urine and feces *See* COENZYME [S N F]

Industrial synthesis The structure of biotin was established and the vitamin synthesized by V du Vigneaud and coworkers

The synthesis represents a masterpiece of technical chemical management of a very complicated synthesis *meso* Dibenzylaminosuccinic acid is reacted with phosgene to close the imidazolidone ring The two carbocyclic groups enable closing the adjacent thiophanone ring by reduction and sulfonation A three carbon chain is then introduced by reaction with ethoxypropylmagnesium bromide Upon closing a third (thiophanium) ring resolution of the optical antipodes is possible A malonic ester condensation providing the necessary side chain is followed by dibenzylation saponification, and decarboxylation giving the naturally occurring dextrorotatory biotin *See* VITAMIN [R MF]

Biotite

The most abundant and widely distributed species of the mica group of minerals also called black or magnesium iron mica Its chemical composition is variable

$$K_2[Fe(II)\ Mg]_{6\ 4}[Fe(III)\ Al\ Ti]_{0\ 2}(Si_{6\ 5}Al_{2\ 1})O_{20\ 22}(OH\ F)_{4\ 2}$$

Biotite itself is of no commercial importance but *vermiculite which* expands (exfoliates) upon heating *has widespread* application as lightweight concrete and plaster aggregate insulation plant growing medium and lubrication

Biotite grades into phlogopite and no sharp division exists between the two Some types contain little Mg others are rich in Fe(III) Ti or Mn a few contain Li The variety lepidomelane is a dark colored iron rich biotite containing Fe(II) Fe(III) or both It is common in syenites and nepheline syenites The variety siderophyllite is rich in Fe(II) with little Fe(III) *haughtonite* another varietal name refers to biotite *rich in* both Fe(II) and Fe(III) Meroxene is that variety *in which the* optic plane is parallel with the *b* axis *of the crystal* in contrast to anomite which has the optic plane normal to the *b* axis

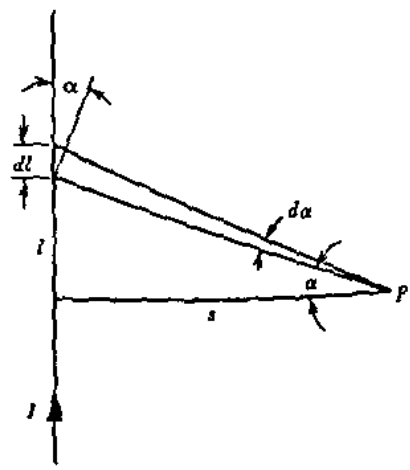
The color ranges from black to dark *brown* or green Unaltered basal cleavage sheets (easy and perfect) are both flexible *and elastic* The hardness is 2 5–3 specific gravity 2 8 3 2 Polymorphism is extensive 1 layer monoclinic 2 layer monoclinic 3 layer hexagonal 6 layer triclinic 18 layer triclinic and 24-layer *triclinic* It is strongly pleochroic in brown less commonly *in green*

Biotite an important *rock forming* mineral may be an essential constituent of *both intrusive* and extrusive igneous rocks ranging in composition from gabbro to granite It is *especially* common in granite granodiorite and *syenite* In porphyritic extrusive rocks biotite appears *chiefly as* phenocrysts very rarely in the matrix Many pegmatites also contain biotite in large *amounts* in coarse flakes or rough crystals It is also formed under moderate grade metamorphic conditions appearing commonly in schists and gneisses of both sedimentary and igneous parentage in some cases associated with such species as muscovite kyanite sillimanite garnet potash feldspar oligoclase and quartz Under weathering conditions biotite alters more readily than muscovite, hence it is much less common in clastic sedimentary rocks Biotite is readily transformed to chlorite during which change by product magnetite and sphene may also be produced Much of this chloritization is the result of low grade hydrothermal action Some biotite is transformed, probably mainly also under hydrothermal conditions first to hydrobiotite and then to vermiculite *See* MICA, SILICATE MINERALS [E W H]

Biot-Savart law

A law of physics which states that the magnetic flux density (magnetic induction) near a long straight conductor is directly proportional to the current in the conductor and inversely proportional to the distance from the conductor There is also a law in fluid dynamics bearing this name it is concerned with vortex motion, and bears a close analogy to the law discussed in the present article

The field near a straight conductor can be found by application of Ampere's law (*see* AMPERE'S LAW INDUCTION MAGNETIC) Consider any element *dl* of the current carrying conductor (see illustration) The contribution of this element to the flux



Biot-Savart law

density at point *P* is perpendicular to the plane of the paper and directed into the paper

The flux density *B* at point *P* is found by summing up the contributions of all elements of the conductor from one end to the other All the contributions are in the same direction at *P*, and hence the vector sum is the simple integral taken from one end of the wire to the other The limits of the angle α are chosen to represent this sum For a wire of any length the lower end is represented by $\alpha = \alpha_1$ and the upper end by $\alpha = \alpha$ If *l* is the

current μ_0 the permeability of free space and s the distance of P from the conductor

$$B = \int dB = \frac{\mu_0}{4\pi} \frac{I}{s} \int_{\alpha_1}^{\alpha_2} \cos \alpha \, d\alpha = \frac{\mu_0}{4\pi} \frac{I}{s} (\sin \alpha_2 - \sin \alpha_1)$$

For the special case of an infinite straight conductor that is one that is long in comparison to s $\alpha_2 = 90°$ and $\alpha_1 = -90°$ Then

$$B = \frac{\mu_0}{4\pi} \frac{I}{s} [\sin 90° - \sin (-90°)] = \frac{\mu_0}{4\pi} \frac{I}{s} (1 + 1)$$

or

$$B = \frac{\mu_0}{2\pi} \frac{I}{s}$$

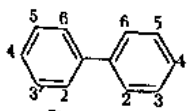
This relation was originally developed from experimental observations by J Biot and F Savart and is known as the Biot Savart law

The magnetic flux density B near the long straight conductor is at every point perpendicular to the plane determined by the point and the line of the conductor Therefore the lines of induction are circles with their centers at the conductor Furthermore each line of induction is a closed line This observation concerning flux about a straight conductor may be generalized to include lines of induction due to a conductor of any shape by the statement that every line of induction forms a closed path [K V M]

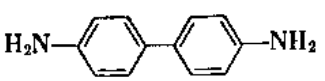
Bibliography F W Sears *Principles of Physics* vol 2 1951 R L Weber M W White and K V Manning *Physics for Science and Engineering* 1957

Biphenyl

A colorless hydrocarbon (melting point 80 0°C boiling point 254 9°C) also called diphenyl or phenylbenzene which crystallizes as small plates Although small amounts are present in coal tar the biphenyl of commerce is obtained by the pyrolysis of benzene One successful scheme has been to pass benzene vapor through molten lead at temperatures of about 750°C Under these circumstances about 10% of the benzene is converted to biphenyl Since the unreacted benzene may be recycled the yield is good



B phenyl



Benzidine

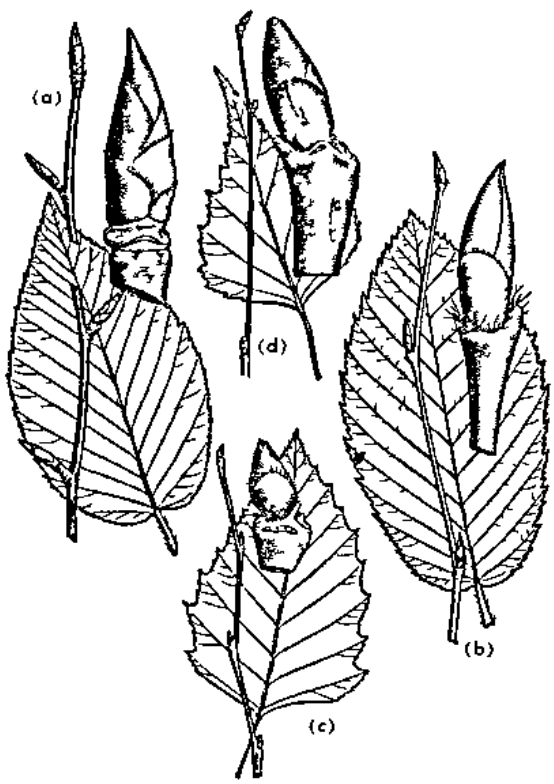
Biphenyl undergoes substitution in the 2 and 4 positions in the nitration reaction and in position 4 in the Friedel Crafts or sulfonation reaction Hydrogenation of biphenyl yields cyclohexylbenzene and bicyclohexyl

The most important derivative having the biphenyl nucleus is benzidine an intermediate in the manufacture of dyes but benzidine is not usually prepared from biphenyl Certain biphenyl derivatives having large groups at the 2 2 6 6 positions are restricted in rotation about the central bond and have been resolved into optical antipodes (*see* OPTICAL ACTIVITY) The high thermal stability and low vapor pressure of biphenyl make it a valuable heat transfer medium which can be used without high pressure equipment Biphenyl is used for this purpose either alone or mixed with diphenyl ether In certain applications it is chlorinated or alkylated to produce agents superior to the parent hydrocarbon Biphenyl possesses some antifungal activity and paper for wrapping oranges is sometimes impregnated with it *See* AROMATIC HYDROCARBON POLYNUCLEAR HYDROCARBON

[C K B]

Birch

About 40 species of deciduous trees of the genus *Betula* order Fagales distributed over much of North America in Asia south to the Himalaya and in Europe (*see* FAGALES) The sweet birch *B lenta* the yellow birch *B alleghaniensis* and the paper birch *B papyrifera* are all important timber trees of eastern United States The yellow and the paper species extend into Canada The gray birch *B populifolia* is a smaller tree of the extreme northeastern United States and adjacent Canada Both sweet (black) and yellow birches can be recognized by the wintergreen taste of the bark of the young twigs A flavoring similar to oil of wintergreen is obtained from the bark of the sweet birch The paper and gray birches can be easily identified by their white bark The bark of the paper birch



(a) Sweet b rch *Betula lenta* (b) Yellow b rch *B alleghaniensis* (c) R ver b rch *B nigra* (d) Gray b rch *B populifolia* (*From A H Graves Illustrated Guide to Trees and Shrubs rev ed Harper 1956*)

peels off in thin papery sheets a characteristic not true of the gray birch The river birch *B nigra* is a less common tree of wet soil and banks of streams and is important as an ornamental and for erosion control The hard strong wood of the yellow and the sweet birches is used for furniture boxes baskets crates and woodenware Yellow birch plywood is used in airplane construction The European birches *B pubescens* and *B pendula* are the counterparts of the paper and gray birches in the United States The European birches are also cultivated in America *See* FOREST AND FORESTRY TREE [A H G]

Bird

Any member of the class Aves subphylum Vertebrata Birds are rather closely related to reptiles in their general structure but are distinguished by the presence of feathers All living birds have horny beaks instead of teeth and the caudal vertebrae are telescoped into a special tailbone the pygostyle All birds are warm blooded and lay eggs *See* AVES [J D B]

Birefringence

Birefringence also called double refraction is the splitting which a wavefront experiences when a wave disturbance is propagated in an anisotropic material In anisotropic substances the velocity of

electromagnetic waves

In birefringent materials either the separation between neighboring atomic structural units is different in different directions or the bonds tying such units together have different characteristics in different directions Many crystalline materials

cules become anisotropic when stretched or compressed Solutions of long chain molecules become birefringent when they flow This first phenomenon is called photoelasticity the second streaming birefringence *See* PHOTOELASTICITY

For each propagation direction with linearly polarized electromagnetic waves there are two principal displacement directions for which the velocity is different These polarization directions are at right angles The difference between the two indices of refraction is also called the birefringence When the plane of polarization of a light beam does not coincide with one of the two principal displacement directions the light vector will be split into components parallel to each direction At the surface of such materials the angle of refraction is different for polarized parallel to the two principal

For additional birefringent ice and LARIZED LIGHT P Po II B]

Birthmark

The common term for several types of skin lesions which are present at birth or appear sometime later

Two major types are recognized the cellular and the vascular nevi Both are abnormal benign growths of some tissue component native to an area which result from faulty development Most are pigmented and the color depends upon the amount of pigment or blood present and the nearness to the surface of the skin

Pigmented nevi or common moles vary from natural flesh color through a range of increasing pigmentation to dark brown or black Any site may be involved but nevi of the face excite more attention for obvious reasons

Almost everyone has at least a few moles and the vast majority are of no consequence either medically or cosmetically Their size ranges from a few millimeters to several centimeters they may be flat or elevated smooth or rough and other features can be present Rarely is a tendency toward malignant change seen so that moles which deepen in color and show increases in size or other changes should be evaluated promptly The common hairy brown mole is least prone to show malignant changes especially if present on the legs from childhood

Vascular birthmarks are either developmental abnormalities of blood vessels or benign neoplasms which arise postnatally Capillary hemangiomas consist of local overgrowths of small blood vessels localized in delimited beds so that they are said to have a single vessel for supply and drainage of the tufts Port wine stains are forms of this lesion which appear as large plaquelike areas of red to blue discoloration on the face or trunk

A strawberry hemangioma is typically a soft raised nodule of varying size which often regresses spontaneously in childhood These may be congenital or may appear during the first few weeks of life

Cavernous hemangiomas consist of large dilated vessels which frequently have smaller vessels with in them Although they occur as birthmarks on the skin they are also found in deeper tissues such as the liver brain and other organs

Other forms of birthmark are known but occur much less commonly than the types mentioned *See* ONCOLOGY TUMOR [E G ST]

Bismuth

The metallic element of atomic number 83 and atomic weight 208 99 belonging in the periodic table to group Vb which also includes nitrogen phosphorus arsenic and antimony It is the most metallic element in this group in both physical and chemical properties The only stable isotope is that of mass 209 The electron configuration of the incomplete shells (*O* and *P*) is $5s^2$, $5p^6$ $5d^{10}$ $6s^2$ $6p^3$

Uses The main use of bismuth is in the manufacture of low melting alloys many of them melt

ing below 100°C These low melting alloys are used in fusible elements in automatic sprinklers, special solders, safety plugs in compressed gas cylinders, and automatic shutoffs for gas and electric water heating systems Some bismuth alloys, which expand on freezing are used in castings and in type metal Bismuth and its alloys are often added to molten iron, steels, and aluminum alloys to produce castings and forgings which can be machined more readily Because bismuth has a low neutron absorption cross section, low melting point and high boiling point its application to reactor technology as a reactor coolant is being tested Another important use of bismuth is in the manufacture of pharmaceutical compounds Various bismuth preparations have been employed in the treatment of skin injuries, alimentary diseases such as diarrhea and ulcers, and in the treatment of syphilis The oxide and basic nitrate are perhaps the most widely used compounds of bismuth The trioxide is used in the manufacture of glass and ceramic products while the basic nitrate is used in porcelain painting to fire on gilt decoration



Occurrence. It is estimated that the earth's crust contains about 0 00002% bismuth It occurs in nature as the free metal and in ores such as the sulfide bismuthinite (also known as bismuth glance), and as the oxide, bismite The principal ore deposits are in South America Bismuth also occurs as a minor constituent in a number of lead copper, and tin ores

Production. Because its melting point is low bismuth may be obtained from its native ores simply by heating them, this treatment melts the bismuth which flows off the ores The procedure of liquation was formerly used as was also reduction of oxide ores by carbon or reduction of sulfide ores with iron At present however the primary source of bismuth in the United States is as a by product in the refining of copper and lead ores Bismuth remains with the copper or lead after smelting It is removed from lead by electrolytic refining crystallization, and by the Betterton Kroll process During the electrolytic refining the bismuth remains in the anode sludge In the crystallization process, lead crystallizes first from the alloy as it is cooled leaving a molten alloy enriched in bismuth The Betterton Kroll process depends upon the formation of calcium bismuth and magnesium bismuth compounds whose high melting points and lower densities permit them to be removed from the lead bath The enriched bismuth dross is freed of calcium, magnesium and lead by chlorination

Physical properties Bismuth is a grey white, lustrous hard brittle, coarsely crystalline metal It is one of the few metals which expand on solidification the expansion being 3 3% The thermal conductivity of bismuth is lower than that of any metal, with the exception of mercury Of all metals, bismuth is the most diamagnetic and has the greatest Hall effect The vapor consists of a mixture of monomer, Bi, and dimer, Bi_2

Table 1 Physical and mechanical properties of bismuth

Melting point °C	271	
Boiling point °C	1630	
Heat of fusion, kcal/mole	2 51	
Heat of vaporization kcal/mole	42 6	
Vapor pressure mm Hg	1	917°C
	10	1067°C
	100	1257°C
Density g/cm³	9 80	20°(solid)
	10 03	300°(liquid)
	9 91	400°(liquid)
	9 66	600°(liquid)
Mean specific heat cal/g	0 0294	0– 270°C
	0 0373	300–1000°C
Coefficient of linear expansion	13 45 × 10^{-6}/°C	
Thermal conductivity cal/(sec)(cm²)(°C)	0 018	100°(solid)
	0 041	300°(liquid)
	0 037	400°(liquid)
Electrical resistivity μohm cm	106 5	0°(solid)
	160 2	100°(solid)
	267 0	269°(solid)
	128 9	300°(liquid)
	134 2	400°(liquid)
	145 3	600°(liquid)
Surface tension dynes/cm	376	300°C
	370	400°C
	363	500°C
Viscosity centipoise	1 662	300°C
	1 280	450°C
	0 996	600°C
Magnetic susceptibility cgs units	1 35 × 10^{-6}	
Crystallography	Rhombohedral a_0 = 4 7457 A	
Thermal neutron absorption cross-section, barns	0 032 ± 0 003	
Modulus of elasticity, lb/cm²	4 6 × 10^6	
Shear modulus lb/cm²	1 8 × 10^6	
Poisson s ratio	0 33	
Hardness Brinell	4–8	

Chemical properties. Bismuth is inert in dry air at room temperature although it oxidizes slightly in moist air It rapidly forms an oxide film at temperatures above its melting point, and it burns at red heat forming the yellow oxide, Bi_2O_3 The metal combines directly with halogens and with sulfur selenium and tellurium, however, it does not combine directly with nitrogen or phosphorus

Bismuth is not attacked at ordinary temperatures by air free water, but it is slowly oxidized at red heat by water vapor Bismuth does not dissolve in nonoxidizing acids but does dissolve in nitric acid and in hot concentrated sulfuric acid The fo

tion of intermetallic compounds involves mainly the strongly electropositive metals

Principal compounds of bismuth Almost all compounds of bismuth contain trivalent bismuth However bismuth can occasionally be pentavalent or monovalent Compounds of bismuth previously regarded as being in the 2+ or 4+ state have not been verified Sodium bismuthate and bismuth pentafluoride are perhaps the most important compounds of Bi(V) The former is a powerful oxidizing agent and the latter a useful fluorinating agent for organic compounds Bismuth trihalides can be prepared by the reaction of the corresponding hydrogen halide on Bi_2O or by direct union of the elements All the trihalides except the trifluorides are rapidly hydrolyzed in contact with water the corresponding oxyhalide being formed Bismuth trioxide is obtained by burning the metal or by heating the basic carbonate sulfate or nitrate It dissolves in acids but is insoluble in dilute alkali hydroxides At red heat the oxide can be reduced easily to the metal Bismuth hydroxide $Bi(OH)_3$ is precipitated by hydroxyl ion from bismuth salt solutions It is difficult to obtain in a pure state since it is colloidal in nature The sulfide Bi_2S_3 is formed when hydrogen sulfide is passed through a bismuth salt solution and is soluble only in a concentrated acid It is not very stable and decomposition to the elements takes place slightly above 100°C Bismuth nitrate $Bi(NO_3)_3 \cdot 5H_2O$ is obtained by dissolving bismuth in nitric acid and evaporating the solution When the crystals are heated bismuthyl nitrate BiO(NO) is formed The sulfate $Bi_2(SO_4)_3$ is prepared by heating the metal or its chloride or nitrate in concentrated sulfuric acid evaporating the solution and heating the resulting crystals to 350°C The hydride bismuthine (BiH_3) is not stable and decomposes slowly even at ordinary temperatures or instantaneously on heating

Analytical In the conventional qualitative analysis scheme bismuth a member of the copper series is precipitated with H S and the precipitate is dissolved in nitric acid Addition of base yields a new precipitate which upon addition of sodium stannite solution is converted to metallic bismuth For quantitative determinations bismuth may be precipitated and weighed as the sulfide or oxychloride or precipitated as the hydroxide and weighed as the trioxide *See* Alloy Antimony Arsenic [S J Y]

Table 2 Properties of some bismuth compounds

Compound	Color	Density g/cm³	Melting point °C	Boiling point °C	Heat of formation kcal/mole
BiF_3	Gray white	5 32	727	>700	−?16
$BiCl_3$	White	4 75	232	447	−90 6
$BiBr_3$	Yellow	5 69	218	461	71
BiI_3	Gray black	5 7	408		−16
Bi_2O_3	Yellow	8 9	817		−138
$Bi(OH)_3$	White	4 4	100 (decomposes)		
Bi_2S_3	Black	7 39	685 (decomposes)		

Bison

More commonly called the American buffalo *Bison bison* a large North American member of the family Bovidae Bison were once the most common



of all big game mammals but are now reduced to a few protected and managed herds in the western United States and Canada Both sexes bear large hollow permanent unbranched horns on massive skulls The bison has a prominent hump between the shoulders and is somewhat taller at the shoulders than at the rump Long shaggy blackish brown hair covers the forepart of the animal the remainder of the body is covered with short woolly hair of somewhat paler color

The Indian buffalo *Bos bubalus* is a distinctly cowlike animal except for the heavy based broadly curving horns which may reach a length of 12 ft It is a water dwelling animal of southeastern Asia and the Philippines It is widely domesticated in this region and utilized as a draft animal and for meat milk and hides The similar cape buffalo *Bos caffer* has more typical bovine horns which may grow 3 ft long It is found throughout eastern Africa and is also domesticated *See* Artiodactyla [J D B]

Bit

A contraction of binary digit in the binary number system and thus a 0 or 1

By extension the term bit may refer to a position in a binary coded alphabetical or numerical character representation For example the international teletype code is a five bit code the five bits 11010 represent C

In digital computers the output of a bistable device such as a relay electronic flip flop or a magnetic core is either of two stable states and may be labeled 0 or 1 *See* Digital computer

In information theory a bit is a unit of measure of the information content of a message or of the capacity (in bits/sec) of a channel *See* Information theory [R J S]

Bitumen

A term used to designate naturally occurring or pyrolytically obtained substances of dark to black color consisting almost entirely of carbon and hydrogen with very little oxygen nitrogen and sulfur Bitumen may be of variable hardness and volatility ranging from crude oil to asphaltites and is largely soluble in carbon disulfide *See* ASPHALT AND ASPHALTITE [I A B]

Black

The opposite extreme from white in the series of achromatic colors Blackness is a relative term applied to surfaces that uniformly absorb large percentages of light of all visible wavelengths A black object in sunlight absorbs a large percentage of the light but it may reflect a larger absolute quantity of light to the eye than a white object in the shade Black may also be used to refer to invisible light ultraviolet rays for example may be called black light if they fall on fluorescent materials that thereby emit visible light *See* COLOR VISION WHITE [L A B]

Black body

An ideal energy radiator which at any specified temperature emits in each part of the electromagnetic spectrum the maximum energy obtainable per unit time from any radiator due to its temperature alone A black body also absorbs all the energy

[illegible] es of real es—a ra n and a

radiator which absorbs all incident radiation Neither case is completely realized in nature Carbon and soot are examples of radiators which for practical purposes absorb all radiation Both appear black to the eye at room temperature hence the name black body Often a black body is also referred to as a total absorber Such a total absorber constitutes a standard for the radiation of non black bodies since Kirchhoff's law demands that the black body radiate the maximum amount of energy possible in any wavelength interval For an extended discussion of black body radiation and Kirchhoff's law *see* HEAT RADIATION *See also* GRAY BODY [H G S P J W]

Black Sea

The Black Sea and the Sea of Azov form an almost isolated body of water which extends far into the greatest continental area of the world Europe and Asia There is only a narrow connection with the Mediterranean Sea by way of the Bosporus and the Dardanelles This is about 3000 kilometers (km) from Gibraltar the nearest point on the Atlantic Ocean The surface area is 413 488 km² The greatest depth is 2243 meters (m) and the average depth is 1197 m

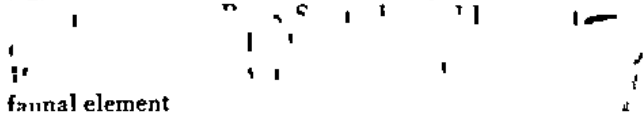
Geologic history The whole Black Sea Caspian Sea region has been subjected to an increasing degree of isolation from the open sea since late Tertiary time During early and middle Miocene time this great salt sea was a part of the vanishing Thethys By the late Miocene in the Sarmatian Basin the halobiotic elements of the Mediterranean disappeared and in the Pliocene the Pontic Sea was completely isolated By the end of the Tertiary there was an alternate opening and closing of the connection with the Mediterranean accompanied by fluctuations in the salinity of the waters

Hydrochemical conditions The present surface circulation is characterized by two main cyclonic (counterclockwise) currents This system of circu

(Fig 1) The surface water of the Black Sea flows through the Bosporus channel (width about 4 km depth 40–90 m) into the Sea of Marmara At the same time denser water from the deeper layers of the Sea of Marmara flows northward (downslope) along the floor of the Bosporus into the Black Sea basin

As a result of the isolation and the shallow depth of the sill which connects with the Mediterranean considerable amounts of free hydrogen sulfide H_2S are present below depths of about 180 m Near the bottom the H_2S content increases to about 6 2 cm^3/liter Thus all the deeper parts are uninhabitable for higher forms of life these being limited to a shallow zone at the surface The 0 5 cm^3/liter H_2S layer lies about 50 m below the lower limit of plankton Only anaerobic bacteria are present in the deeper parts A large part of the organic material produced in the open sea sinks into the anaerobic zone Most of the detritus reaches the bottom The high content of nitrogen ammonia and phosphorus results from the breaking down of this material In addition large amounts of sediments are brought into the Black Sea each year by rivers The biomass of the microorganisms in the central part of the sea is greatly reduced at the upper H_2S limit or at depths of about 150 m but is present in considerable amounts from this level to the bottom (Fig 2)

Plankton and zoobenthos Diatoms make up 79% of the plankton Their numbers are greatly increased in the spring up to 20 000 000/liter In summer there is a mass development of dinoflagellates (up to 48 000/liter) The zooplankton which has only a small number of species here as compared with the number in the Mediterranean is influenced by the low salinity of the surface waters (Fig 3) A similar reduction in species of the zoobenthos is noted Thus a number of groups represented in the Mediterranean are absent and only a few representatives of other groups have penetrated to the Black Sea The deepest zone of



faunal element

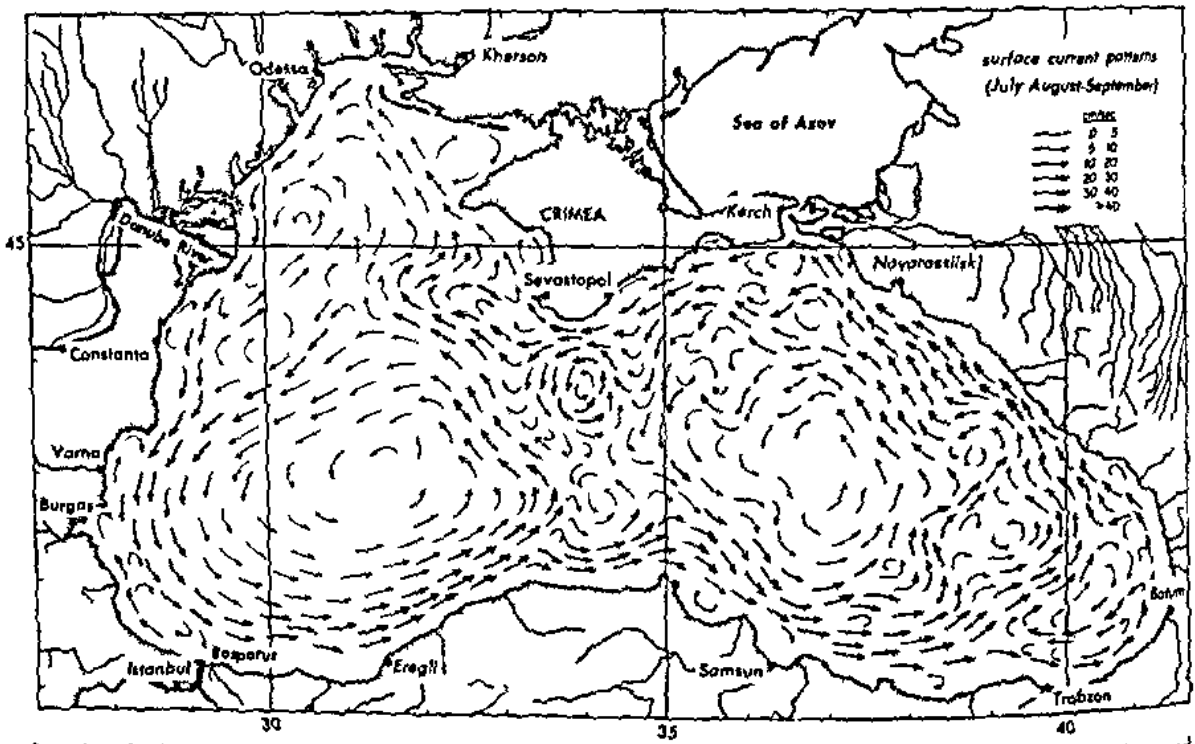


Fig 1 Surface-current patterns of the Black Sea in midsummer (*From G Neumann, 1942, as used in J W Hedgpeth, ed , Treatise on Marine Ecology and Paleoecology, vol 1, Geol Soc Am Mem 67, 1957*)

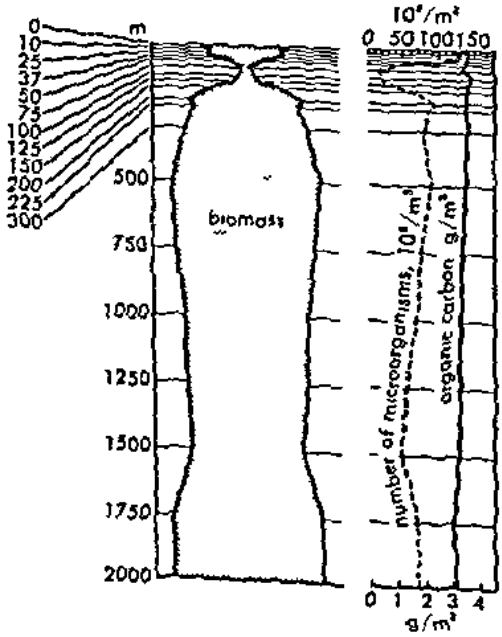


Fig 2 Vertical distribution of microorganisms in the Black Sea from surface to 2000 meters (*From A E Kriss, 1953, as used in J W Hedgpeth, ed , Treatise on Marine Ecology, vol 1, Geol Soc Am Mem 67, 1957*)

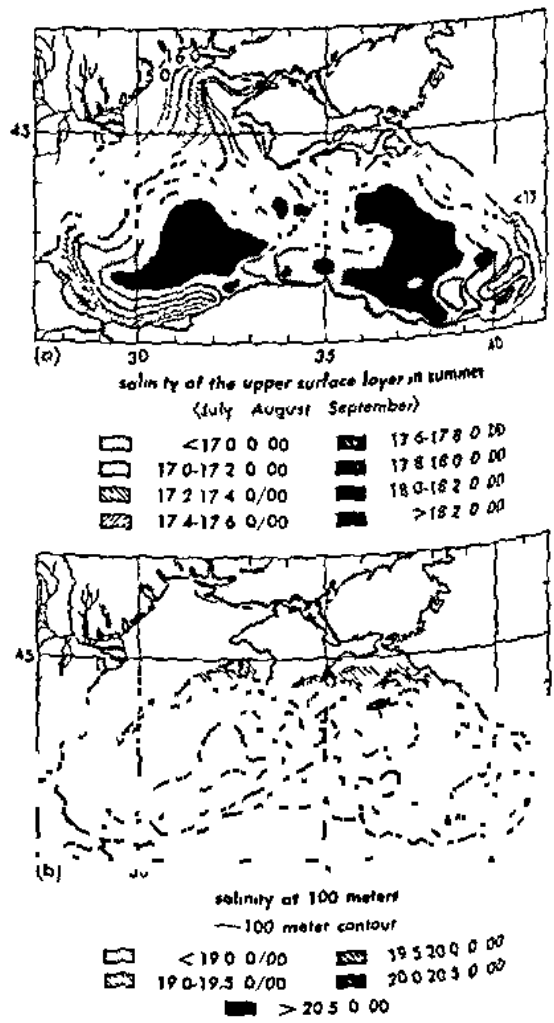


Fig 3 Salinity distribution in the Black Sea (a) At the surface (b) At 100 meters (*From G Neumann, 1943, as used in J W. Hedgpeth, ed , Treatise on Marine Ecology and Paleoecology, vol 1, Geol Soc Am Mem 67, 1957*)

Relict faunas There is a still greater reduction in faunal forms from the Black Sea to the Sea of Azov At the present time the forms of Mediterranean origin are most abundant in both species and individuals Associated with the Mediterranean forms is a relict fauna of special zoogeographic interest According to some Russian authors 119 species of animals occurring in the Azov Black Sea basin were derived from the Caspian Sea in comparatively recent (post Pleistocene) times The relict fauna of the Black Sea is not therefore directly derived from a Sarmatian Sea whose autochthonous fauna became separated by geological processes into two large regions but represents a reinvasion from a previously isolated region Only 18 of these Caspian species (primarily fishes) occur in the open Black Sea Of special interest as refuges for relict elements of the Sarmatian and Caspian fauna are the limans (drowned estuaries of rivers) and the lagoons with their varying degrees of salinity Indeed the Sea of Azov (37 600 km^3) can be taken as a big shallow lagoon (greatest depth 13 2 m) connected with the Black Sea by the Strait of Kerch Its hydrography is controlled by the inflowing waters of the Don It is characterized by an average salinity of 11 $2^0/_{00}$ and a marked productivity of plankton and fish but with greater seasonal differences of the biomass Bacteria *Desulfovibrio aestuarii* are present in enormous concentrations in certain bottom zones of this sea *See* BIOLOGICAL PRODUCTIVITY MARINE ECOSYSTEM MARINE MICROBIOLOGY ZOOGEOGRAPHY [H C]

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Black shale

A laminated to fissile black clay shale that is rich in organic matter or iron sulfide The coloring matter in individual shales is carbon hydrocarbons or finely divided iron sulfide *See* SHALE

Types of black shale The widespread Chattanooga shale of the central United States is representative of one common type The shale is fissile phosphatic highly radioactive and locally rich in marcasite and pyrite It contains abundant fossil organisms among which are conodonts shagreen granules of sharks phosphatic brachiopods plant spores *Callixylon* and the sporelike organism *Tasmanites* The Chattanooga shale was deposited on a broad stable platform in shallow stagnant marine water (Fig 1) Its age is Late Devonian

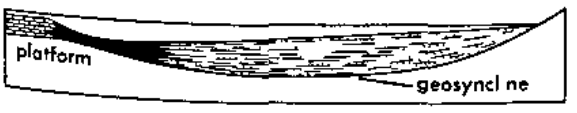


Fig 1 Hypothetical section across a geosyncline showing black shale deposits overlying stable platform on the left (*From C O Dunbar and J Rodgers Principles of Stratigraphy* Wiley 1957)



Fig 2 Specimens of black shale showing carbonized impressions of Ordovician graptolite colonies on bedding planes natural size (a) *Climacograptus* Mohawkian (b) *Phyllograptus* Canadian (*From R C Moore Introduction to Historical Geology 2d ed McGraw Hill 1958*)

and perhaps Early Mississippian Similar black shales are the Kupferschiefer (Permian) of Germany the Rhinestreet shale (Upper Devonian) of western New York and the Hunsruck shale (Lower Devonian) of Bundenbach Germany

Some black shales have been termed graptolite shales from the fact that bedding planes are covered by the carbonized remains of the external skeletons of graptolites (Fig 2) These shales are black carbonaceous and platy to fissile Examples all Ordovician in age are the Schaghticoke Deepkill and Normanskill shales of New York the Polk Creek shale of Arkansas and Oklahoma and the Dictyonema bed of western Europe The sediments from which these shales were derived are believed to have been deposited in fairly deep quiet marine water *See* GRAPTOLITHINA

Cyclic Pennsylvanian sedimentary sequences (cyclothems) commonly contain a black shale unit typically situated between the two marine limestones of the cycle Some such shales are the shale at the base of the Oak Grove limestone in Illinois Hushpuckney Muncie Creek Quivira and Heebner shales of Kansas and the Anna and Excello shales of Oklahoma and adjacent states These shales are black and fissile they contain spherical phosphatic concretions and are highly radioactive Their or

ganic contents include conodonts and concretions which enclose phosphatic brachiopods, shark remains and small cephalopods The deposits are typical of those in shallow lagoons *See* CYCLOTHEM

Sedimentary characteristics. Black shales are the characteristic rock of starved basins, such as the Midland Basin of western Texas These basins are cut off from supplies of normal clastics and are thought to receive wind blown dust and minor quantities of water borne clastics Accumulation was exceedingly slow and the portion of the sedimentary column which these shales represent is significantly thinner than that of correlative units The sediments are almost barren of organic content *See* SEDIMENTATION (GEOLOGY)

Black shales occur in sediments laid down on the margins of platforms and thus lie in the belt between the platform carbonates and the basin sandstones The Smithwick shale of central Texas and the equivalent black shale facies of the Atoka formation of eastern Oklahoma are examples The shales are fissile, are low in organic content and have tongues that extend into the adjacent arenaceous and calcareous facies *See* FACIES (GEOLOGY)

Bituminous black shales are those colored by hydrocarbons Some of these shales are rich enough

River shale (Eocene) of the Rocky Mountain region The Mowry shale contains many fish scales and numerous beds of bentonite *See* OIL SHALE

[C C BR]

Blackberry

Those species of the genus *Rubus*, plant order Rosales having fruits that persist on the receptacles The plants are upright or trailing shrubs, usually thorny with perennial roots and biennial canes (stems) Horticulturally these fruits derived from species native to or introduced into the United States are classified as upright and trailing blackberries and black fruited and red fruited dewberries the latter being closely related to the raspberry, with which there are a few hybrids Propagation of the upright types is by suckers and root cuttings, for the dewberries and trailing blackberries, propagation is by tip layers *See* ROOT (BOTANY), STEM (BOTANY)

Blackberries are grown in home gardens over most of the United States except for the coldest parts of the Great Plains area and the hottest part of the South Commercial production is extensive in many states the annual value of the crop usually exceeds $3 000 000 The upright types are grown in the North whereas the more tender dewberries and trailing blackberries are grown in the

and North Carolina Although the fruit is sold fresh for dessert purposes or canned, and is made into jelly or jam quick freezing is the largest outlet for the crop



Blackberry, a short-cluster garden variety (*From L H Bailey, ed., The Standard Cyclopedia of Horticulture vol 1, Macmillan, 1937*)

For diseases of blackberry *see* RASPBERRY, *see also* FRUIT GROWING (SMALL); ROSALES [J H CL]

Blackbird

In America any of several birds of the family Icteridae which are black, or mainly black The name in Europe is used for a thrush *Turdus merula*, the male of which is black

In the United States the name blackbird is applied to the rusty blackbird and Brewer's blackbird, which are solid black; to the purple and bronzed grackles often called crow blackbirds which are glossy purple or greenish blue, to the



The red winged blackbird, *Agelaius phoeniceus* length to 9½ in (*From E L Palmer, Fieldbook of Natural History, McGraw-Hill, 1949*)

yellow headed blackbird and to two species of red winged blackbirds In all blackbirds of the United States the males are more brilliantly marked than the females which tend to be dull in color females are frequently mistaken for sparrows All such blackbirds are of moderate size and tend to gather in flocks especially in the fall All are migratory Most of them are valuable insect destroyers during the summer they eat weed seeds and unharvested grain in the fall *See* PASSERIFORMES [J D B]

Blackleg

An acute usually fatal disease of cattle and occasionally of sheep goats and swine but not man The infection is caused by *Clostridium chauvoei* (*Clostridium feseri*) a strictly anaerobic spore forming bacillus of the soil

The disease is also called symptomatic anthrax or quarter evil The characteristic lesions in the natural infection consist of crepitant swellings in involved muscles which at necropsy are dark red dark brown or blue black Artificial immunization is possible by use of blackleg aggressin or whole culture bacterin Animals surviving an attack of blackleg are permanently immune *See* BACILLACEAE IMMUNITY [L S M]

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Blacksnake

Any of several snakes most commonly one of the eight subspecies of the racer *Coluber constrictor* The varieties differ widely in color but most commonly they are bluish black above paler slate to whitish below The scales are smooth and shiny Some racers are tan greenish or blue gray They are found over most of the United States The racers are swift runners on the ground and are adept at climbing Their principal food is rodents making them highly beneficial Some of the whip snakes genus *Masticophis* are sometimes called blacksnakes This is especially true of the gray and black subspecies of the coachwhip *M flagellum* Still another snake *Elaphe obsoleta* the pilot blacksnake or rat snake of the eastern United States is included in the general term blacksnake The pilot blacksnake is relatively large up to 8 ft in length *See* REPTILIA SNAKE [J D B]

Blasting

The process of loosening or fragmenting solid materials such as rock masonry or hard clays through the use of explosives to permit their excavation Blasting consists of drilling and cleaning blast holes loading the holes with a suitable explosive and igniter or detonator stemming the hole (tamping sand or clay over the charge so that its explosive force will not be dissipated) and firing or setting off the charge For a discussion of drilling *see* CONSTRUCTION METHODS For a discussion

like the safety fuse it detonates all at once and detonates any cartridge next to it Although it is set off by an electrical blasting cap its safety advantage is that the number of caps is reduced to a minimum Because they are more expensive than blasting caps detonating fuses are used primarily in deep and large boreholes where one fuse line will replace many electrical blasting caps

Explosives such as ammonium nitrate must be detonated by special primers or small charges of dynamite which are detonated by electrical blasting caps or detonating fuses

Large tunnel and quarry blasts require that the charges be detonated in sequence The holes near an exposed face detonate first followed by progressive detonation of adjacent holes This provides for equal burden on each hole improves fragmentation and reduces the amount of explosives required Sequence firing is accomplished with delay caps or detonating fuses There are two types of delays regular delays with delay intervals of 1 2 seconds per detonation and millisecond delays with delay intervals of 25–100 milliseconds per detonation Millisecond delays provide greater fragmentation but throw the blasted material farther The latter is undesirable in tunneling and regular delay caps are preferred in this specific application [W H]

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Blastoidea

A class of extinct Pelmatozoa which arose in the Ordovician and flourished during Carboniferous times The symmetrical bud shaped theca comprised 13 rigid plates arranged in 3 horizontal rings of 3 basals 5 radials and 5 deltoids There was often a jointed aboral stem The ambulacral grooves were carried on 5 lancet plates lying in notches in the radial and deltoid plates Series of lateral plates margined the lancet plates on either side and each lateral plate supported a brachiole (see illustration)

Each brachiole carried a branch of the ambulacral groove Underneath the ambulacra the radial and deltoid plates were thrown into vertical pleats whose folds termed hydrospires hung into the coelom The reverse folds on the upper side opened to the exterior via pores The hydrospires probably served as respiratory organs because water entering via the pores could traverse the folds and emerge through 5 or 10 spiracles at the adoral pole In later forms the anus became incorporated into one of the spiracles Blastoids did not survive the Permian *See* CRINOIDEA PELMATOZOA [H B F]

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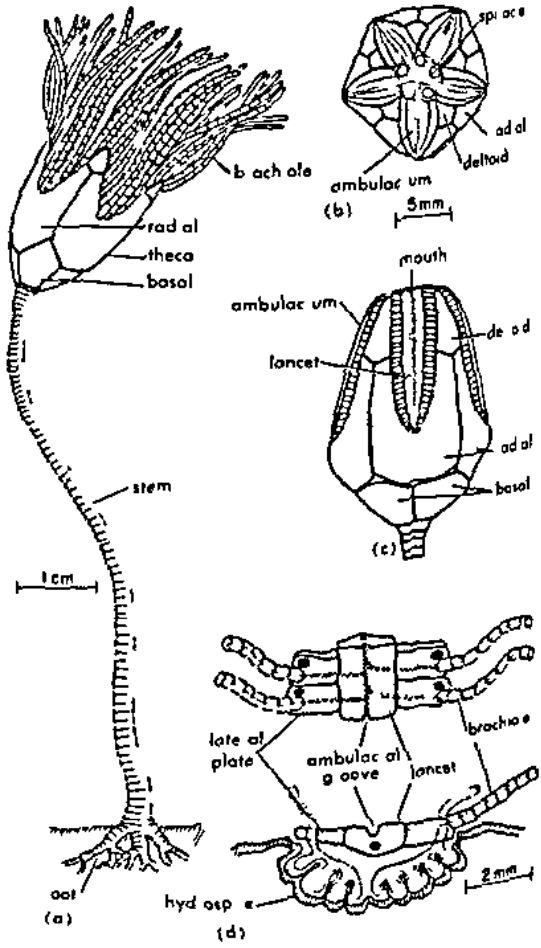
Blastomycosis

A term for two infectious yeastlike fungus diseases of man North American and South American blastomycosis

North American blastomycosis is seen in the United States and Canada It is caused by *Blastomyces dermatitidis* a diphasic fungus Diphasic or dimorphic fungi have a mycelial saprophytic phase and a yeastlike parasitic phase in warm blooded animals Although this organism has not been isolated from nature there is little doubt that it resides in the soil or on plants

There are two recognized forms of North American blastomycosis cutaneous and systemic Some investigators believe that the cutaneous form, in most instances is a clinical manifestation of the disseminated form The route of entry in systemic blastomycosis is usually the respiratory tract Most patients with this form of the disease will have pulmonary lesions from which the organism has disseminated to the viscera central nervous system bones and skin

B dermatitidis grows well on Sabouraud's medium and on blood agar When grown at room temperature it is a white cottony mold but when cultured at 37°C it acquires the tissue phase—a single budding yeast possessing a thick double refractile wall



A blastoid *Pentremites* (a) Whole animal (b) Adoral aspect of theca (c) Lateral aspect of theca (d) Details of ambulacral region in surface view and section

Treatment of North American blastomycosis is not encouraging although use of 2 hydroxystil bamidine has resulted in recovery in some instances of pulmonary blastomycosis A regimen in which the patient is desensitized and given iodides has also been satisfactory in some instances

South American blastomycosis (paracoccidioido mycosis) is seen primarily in Brazil although it has been reported from other countries in the Southern Hemisphere The etiological agent *B brasiliensis* (*Paracoccidioides brasiliensis*) is a diphasic fungus acquired from an exogenous source in nature yet unknown

There are several clinical forms of this disease The most common is the lymphangitic form Unlike North American blastomycosis there is massive en largement of lymph nodes in the neck region The organism appears to enter the mucous membranes of the nasopharynx without development of an ulcer at the site of entry

B brasiliensis grows on Sabouraud s medium and blood agar It is a mold at room temperature and a multiple budding yeast when incubated at 37°C

The most successful treatment of this disease has included the use of sulfadiazine or sulfamera zine and a polyvalent vaccine *See* ASCOMYCETES MYCOLOGY MEDICAL YEAST

[L D H]

Blastulation

The formation of a segmentation cavity or blasto-coele within a mass of cleaving blastomeres and re arrangement of blastomeres around this cavity in such a way as to form the type of definitive blastula characteristic of each species The blastocoele originates as an intercellular space which some times arises as early as the 4- or 8 cell stage Thus blastulation is initiated during early cleavage stages and formation of the definitive blastula is thought to terminate cleavage and to initiate gas trulation Accordingly cleavage and blastulation are simultaneous events which follow activation of the egg and precede the next major step in develop ment namely gastrulation Initially the diameter of the blastula is no greater than that of the acti vated egg subsequently it increases *See* CLEAV AGE EMBRYONIC GASTRULATION

The blastula The blastula is usually a hollow sphere Its wall may be only one cell thick in many species but in others it is several cells in thick ness In eggs which contain considerable amounts of yolk the blastocoele may be eccentric in posi tion that is shifted toward the animal pole The animal portion of its wall is always completely divided into relatively small cells whereas the vegetative portion tends to be composed of rela tively large cells and may be incompletely cellu lated in certain species The blastocoele contains a gelatinous or jellylike fluid which originates in part as a secretion by the blastomeres and in part by passage of water through the blastomeres and intercellular material or both into t

The chemical nature of this secretion appears to vary in different species In some it is said to be albuminous in others to contain polysaccharides It also contains certain salts It possesses a viscos-ity which renders it visible when released from the blastocoele by puncture of the wall of the latter however the viscosity changes with time The pH of this substance may be the same as that of sea water or it may be more alkaline It usually stains in preserved material and stains most vividly dur ing concentration of blastocoele fluid in those spe cies where the blastocoele becomes reduced in size during gastrulation until it is eventually crowded out of existence If fluid is withdrawn from the blastocoele with a hypodermic needle the wall of the blastula crumples but the quantity of blasto-coele fluid is quickly restored to normal as is the shape of the blastula The volume of blastocoele fluid can also be reduced osmotically by placing blastulas in sucrose sea water whereupon the diam eter of blastulas decreases Both of these observa tions indicate that blastocoele fluid exerts con siderable pressure on the wall of the blastula and that the coherence of blastomeres must be con siderable to resist this pressure Cells and inter cellular substance provide this structural stability although the latter is often reinforced by an exter nal elastic hyaline membrane Permeability of the wall of the blastula changes during blastulation in certain species At first it is freely permeable to all dissolved substances but as the cells become smaller with each succeeding cleavage permeabil ity of the wall is reduced and the fluid in the blasto-coele becomes increasingly cut off from the ex ternal environment For example the wall of the developing blastula of sand dollar eggs is freely permeable to large molecules such as those of sucrose up to the tenth cleavage but thereafter this permeability is lost

Blastular wall The wall of the blastula is a mo saic of cellular areas each of which will normally produce a certain structure during subsequent development In other words each area of cells in the wall of the blastula has a certain prospective fate which will be realized in normal development In blastulas of some species the outlines of these several areas can be determined directly because the cytoplasm of cells within one area may be colored orange yellow that in another area light gray and that in still another area dark gray This is the case in the blastula of the tunicate *Styela* but this is an exceptional situation In most cases it is necessary to determine the prospective fate of each cellular area indirectly by marking experi ments that is by staining cells in each area with a vital stain determining by observation what organ or organs are formed from each stained area and with the aid of this information constructing a prospective fate map secondarily on the surface of the blastula (*see* FATE MAPS EMBRYONIC) This does not mean that each of these areas would develop independently into the structure in

tula It merely means that these several cellular areas are so related to one another spatially in the blastula stage that they can be shifted subsequently in an orderly way by the morphogenetic movements of gastrulation into appropriate positions which will enable them to cooperate in the formation of tissues and organs through processes of self differentiation or interaction or both Thus the events of blastulation appear to be necessary prerequisites for the succeeding period in development namely gastrulation The blastocoele appears to be essential in many species to provide a space into which certain of the special cellular areas of the wall of the blastula can move en masse or individually during gastrulation [R L W]

Bleaching

The purification and whitening of textile materials Because cellulosic and wool fibers require different treatments they will be discussed separately

Cellulosic fibers The impurities in raw cotton constitute 6–11% of the cotton They are made up of nitrogenous matter (protoplastic residues) mineral matter (calcium and magnesium salts) pectic material (mainly calcium and magnesium pectates) waxes (a complex mixture of wax alcohols free fatty acids and esters of wax acids) and an *unclassified* mixture of pigments and resins

Some of the impurities can be removed by water steeping some by acid steeping some by alkali *boiling* Most of the waxes must be removed by emulsification in hot alkali (the waxes are the most *difficult* to remove and are the cause of much of the trouble in the dyeing and finishing of cotton *goods*)

Scouring Impurities are removed by scouring and a good scour is essential to the *subsequent production of a good white* by bleaching Scouring *is done by boiling with alkali in a kier (a large closed pressure vessel)* using either the lime boil *or caustic boil* process The lime-boil process con*sists of several steps boiling* under pressure with *lime water rinsing* steeping in dilute acid rins*ing and repeating the steps* The goods *must be* uniformly packed in the *kier* avoiding air pockets and the hot alkaline liquor *circulated through* the fabric Some faults may arise *from poorly* controlled scouring If *the cloth wet with hot alkali* comes into contact with *an air pocket oxidation* will take place with the formation of *oxycellulose* Careless steeping *in dilute acid may form hydrocellulose in spots If* the goods come into contact with some hot metal *part of the kier scorching in* spots will occur The emulsion must be completely removed [illegible]

[illegible] sodium hypochlorite *are of any importance* Calcium hypochlorite (bleaching *powder*) is made by passing chlorine gas into *wet lime It is stabilized* for shipping and storage by keeping an excess of lime in it When it is *stirred* into water the excess lime forms a sludge on the bottom and the supernatant liquid contains calcium hypochlorite and calcium chloride and is saturated with lime This liquid can be taken off and used as such or sodium carbonate may be added to it this will form sodium hypochlorite and precipitate $CaCO_3$ This is a simple method for making sodium hypochlorite but it can also be made by the electrolysis of common salt When an electric current is passed through a solution of sodium chloride chlorine is formed at the positive electrode and sodium hydroxide at the negative The mixture of these two will react to produce NaOCl Both calcium and sodium [illegible] solution will

$$NaOCl + HOH \rightarrow HOCl + NaCl$$

Because this is an equilibrium reaction an excess of alkali in the solution will retard the formation of HOCl Real bleaching is an oxidation reaction caused by oxygen liberated from HOCl Therefore the rate of bleaching must be connected with the formation and decomposition of HOCl This means that the rate can be controlled by adjusting the pH (acidity or alkalinity) of the bleach bath *Most commercial bleaching* is done in a bath where the pH ranges from 5 to 9 However when cotton is immersed in a neutral (pH = 7) bleach liquor the oxidation of cellulose is favored and it proceeds rapidly Because this must be kept at a minimum most bleachers will keep the bath away from the *neutral point* at a pH above or below Bleaching is strictly an oxidation reaction in which both coloring material and cellulose are oxidized Overbleaching will cause trouble because the fiber itself may be damaged in a way that may not become apparent until after considerable use Most of this damage occurs near the end of the bleaching period one way to decrease the damage *is to* remove the goods before bleaching is completed and hang them in the air Air contains CO_2 (carbon dioxide) which will slowly react with the hypochlorite left in the goods to form HOCl which will gradually complete the bleaching The other product will be either Na_2CO_3 or $CaCO_3$ (insoluble *in* suspension) Either of these will decrease *the* chances for cotton to be hydrolyzed by acid

Acetate rayon is sensitive to high *temperature* and is damaged in alkaline baths Hence *such* bleaching is done in acid baths at a pH of 4.5–5.5 *See* HYPOCHLORITE

Chlorite bleaching Sodium chlorite ($NaClO_2$) may be used for bleaching cotton Its *activity is* due to chlorine dioxide (ClO_2) which is liberated most readily at low pH values high *temperature* and high concentration Although even in acid *solutions* chlorite is not as strong an oxidizing *agent* as sodium hypochlorite in alkaline medium *chlorite* has some advantages over hypochlorites *for* bleaching The most important of these is the absence of any degrading effect on cellulose *even in* hot acid solutions Whereas strict controls must be exerted in hypochlorite bleaching to avoid oxidation of the cotton *these are not so necessary in*

chlorite bleaching because it appears that differences in pH time temperature and concentration are of little significance The activity of the chlorite and therefore the rate of bleaching may be increased by mixing it with hypochlorite in the ratio of 1 chlorite to 1 5 hypochlorite in terms of available chlorines The hypochlorite does not liberate chlorine but reacts with chlorite to form ClO *See* CHLORITE.

Peroxide bleaching Bleaching with hydrogen peroxide has become more and more popular It has certain advantages over hypochlorite bleaching Less handling of the goods is required and it may be thought of as a universal bleach since its use is not restricted to one class of fibers

Hydrogen peroxide may be made by the bleacher from solid sodium peroxide or it may be purchased in concentrated liquid form and then diluted when used as a bleach The latter is to be preferred because of fire danger and personal hazards in the handling of sodium peroxide Liquid hydrogen peroxide is usually sold in 10- 20- 100- and 130-volume strengths This method for designating the strengths of peroxide baths is used in all peroxide bleaching It is based on the volume of oxygen that can be released by one volume of the peroxide For example a 10-volume H O will release 10 times its volume of oxygen and a 100-volume H_2O_2 will give 100 times its volume of oxygen On a percentage basis the 10-volume H O contains 3% H O_2 and the 100-volume 30% H O The strength is sometimes expressed in terms of the grams of active oxygen available A 10-volume H O contains 14 g available oxygen per liter It must be stored in a cool place away from sunlight Since they decompose quite readily all commercial peroxides are stabilized by the addition of acid

Bleaching with peroxide is practical only within a certain temperature range (80–85°C) At lower temperatures the action is too slow and at higher temperatures oxygen is lost by too rapid evolution The pH of the bath is also important in neutral baths the action is too slow to be practical so peroxide bleaching *is always carried out in alkaline* baths Certain compounds exert a stabilizing effect on H O_2 even in alkaline medium The most important one is sodium silicate which retards the decomposition of H_2O considerably On the other hand H O is very sensitive to certain metals especially copper or even alloys of copper As a result of this activation considerable oxycellulose may be formed during bleaching The use of iron lead or aluminum in bleaching equipment is practicable providing silicate is present

A typical peroxide bleach uses a 0 5–1 volume H O bath containing silicate and NaOH at about 85°C If the goods are thoroughly rinsed after washing no loss in tensile strength need be expected

Continuous scouring and bleaching processes have been investigated For example in one process only about 2 hours is required from gray cloth to the fully bleached product It consists of impregnating the cloth with about 3% NaOH squeezing steaming at 100°C in a hot air tube for a short time and then storing at high temperature for about one hour It is then impregnated with 0 5 volume H O heated to 100°C, and again stored for about an hour *See* PEROXIDE

Wool The amount of bleaching required by wool is very small compared with the bleaching of cotton and other vegetable fibers Hypochlorites yellow and damage wool Therefore the coloring matter in scoured wool is removed by a reduction reaction in either of two ways bleaching with sulfur dioxide or bleaching with hydrogen peroxide

Sulfur dioxide bleaching is known as stoving Wet wool is looped over poles in a gas chamber in the center of the floor of which is placed a pan of sulfur The sulfur is ignited and the chamber is closed and left for about 12 hours The amount of water in the wool must be controlled so that none of it will accumulate at the lower ends of the loops In such cases irregular bleaching results will be obtained This method yields a very brilliant and flashy white but unfortunately it is not permanent the color gradually reverts to the original creamy yellow

The white obtained by peroxide bleaching is not quite as good as the SO white but it is permanent The result is actually a pinkish white which may be improved by a subsequent mild treatment with SO or immersion in a bisulfite solution Peroxide bleaching is always carried out under alkaline conditions Therefore the H O bath is neutralized usually with sodium silicate and brought up to a pH of 7 2 7 4 or even as high as 9 The ordinary strength of peroxide is 1 2 volume The goods are entered at 50°C and allowed to steep overnight The time may be shortened if a higher pH is used However care must be used because of the well known sensitivity of wool to alkali The concentration of H O and the temperature must also be controlled Above a 4-volume H O wool tends to become gelatinous and above 50°C it is seriously damaged *See* FIBER NATURAL OXIDIZING AGENT TEXTILE TEXILE CHEMISTRY [B E H]

Blimp

A name originally applied to nonrigid airships and usually implying small size Early blimps contained about 100 000 ft^3 and were only a fraction of the size of the rigid airships of that period The nonrigid pressure type airship however did not stay small but each succeeding model built was substantially larger *than its predecessor until* ships with volumes of approximately 1 500 000 ft^3 were operational in the U S Navy (Fig 1) With the advent of these larger sizes it appears that the name blimp is tending to be replaced by the more general term airship However the principles of construction of these ships are basically the same regardless of the size

Main envelope The fabric of the main envelope or pressure hull is usually made up of two or three plies of cloth impregnated with an elastomer at least one of these plies is placed in a bias direction with respect to the others This tends to make the

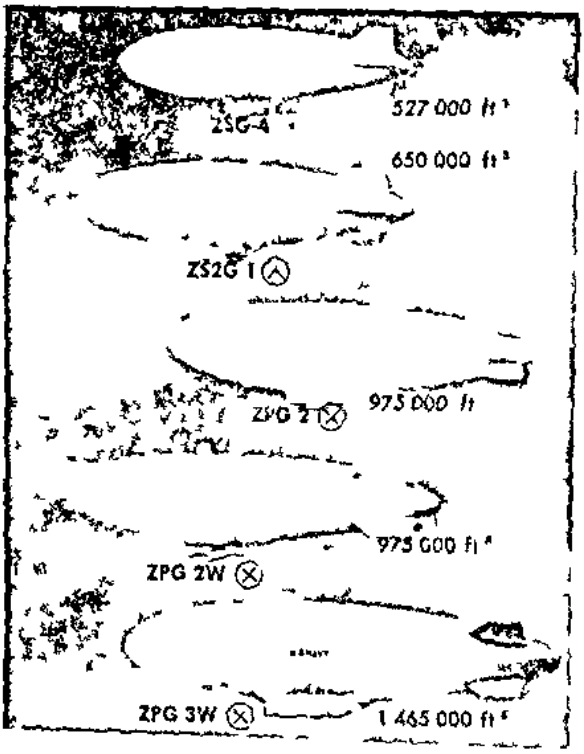


Fig 1 Five of the most recent nonrigid airships Diagrams following designations indicate empennage configurations (Goodyear Aircraft Corp)

fabric more resistant to shear loads and results in a stabilized structure The materials used for the envelope must be light in weight extremely strong and resistant to gas diffusion Chronologically the fibers and elastomers used were (1) cotton and rubber (2) cotton and neoprene (3) Fortisan rayon and neoprene (4) nylon and neoprene and (5) Dacron and neoprene Each newly developed material improved some property required of envelope structures and these improved fabrics along with advancements in assembly techniques permitted the increase in size of the pressure type airship to fulfill any possible need

The airship envelope is a symmetrical airfoil in the form of a body of revolution circular in cross section and elliptical along its longitudinal axis the curve of which for example can be satisfied by the formula

$$y = R\sqrt{1-\left(\frac{x}{a}-0.2\right)^2}\left(1.02062-0.21263\,\frac{x}{a}\right)$$

where y is ordinate from centerline, R is maximum radius (ordinate) x is distance from maximum diameter (positive to rear) and a is one half of the envelope length

A pattern is made for each panel and gore so that when the fabric pieces are cemented and sewed together the envelope will have the required shape when filled with gas The outside of the envelope is coated with aluminized paint for protection and

2)
ing

e envelope

fabric This suspension system can be arranged in a number of ways, depending upon the particular airship configuration (Fig 3) Basically however they all consist of cable systems attached to the car which terminate in fabric curtains which in turn are cemented and sewed to the envelope proper The envelope also contains one or more air cells, fastened to the bottom or sides of the envelope which are used to maintain the required pressure in the envelope without adding or valving of gas as the ship ascends or descends These air cells are called ballonets and are usually made of a fabric much lighter in weight than that of the envelope, because they must merely retain gas tightness and do not have to withstand the normal envelope pressure

The fabric envelopes when not in use, can be folded and shipped or stored in a space which takes up less than 1% of the inflated volume This feature and the ability to erect the envelope by merely inflating it are two of the advantages of the fabric pressure type airship over the rigid one

Other components. The airship car is of conventional aircraft construction, earlier of a fabric covered tubing framework but now of a metal monocoque design Much like an airplane it contains the crew compartments the engines, the landing gear and all the related instruments controls and fuel A few additional accessories required for the airship car are the pressure controls airscoops behind the propellers valves and the fan system necessary for maintaining the pressure in the envelope by pumping air in and out of the ballonets

The airship tail surfaces have taken on three typical configurations named from the placement of the surfaces on the envelope They are the cruciform (+), the X(×), and the inverted

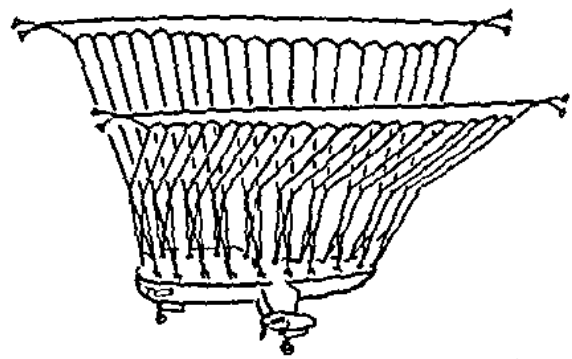


Fig 2 Typical internal rigging of nonrigid airships

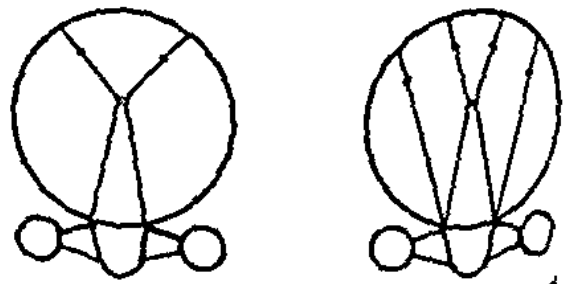


Fig 3 Two types of internal suspension for nonrigid airship cars

Y(1) These tails are made up of a fixed main surface and a controllable smaller surface on the aft end The construction consists primarily of lightweight metal structural beams covered with *doped fabric These are held to the envelope by* cables which distribute the load into fabric patches cemented to the envelope proper These surfaces are so efficiently designed that they weigh only about 0 9 lb/ft of tail area

The nose cone made up of metal wood or plastic battens is laced to the envelope to serve the dual purpose of providing a good point of attachment for mast mooring and of adding extra rigidity to the nose because it encounters the *greatest dynamic pressure loads in flight Some* times the nose battens are covered to provide streamlining

Erection for flight The erection of a fabric pressure type airship is a spectacular sight and takes place in a relatively short time The envelope is spread out on the floor of the airship hangar and a net is placed over it As gas is fed into the envelope from tank cars each containing about 200 000 ft^3 of 99 9% pure helium compressed to 2100 psi the net which is held down by sand bags is permitted to rise slowly care being taken that the envelope does not slip out from under the net Fins nose cone battens air valves and helium valves are attached and the envelope is then allowed to rise high enough from the floor to permit rolling the car underneath After attachment of the car the net is removed and the airship is rigged for flight

The strength of the material used in the fabric pressure type airship envelope is a function of the internal gas pressure the distribution of the gas in the envelope the location of the weights attached to it and the aerodynamic and ground handling loads imposed on the airship in flight and at the mast One of the most important properties of the fabric pressure type airship is its ability to accept an overload condition which in a nonpressurized airship would result in a structural failure In other words if the airship envelope should encounter for example a gust of greater velocity *than it* had been designed to withstand there would be a momentary buckle or wrinkle in the envelope with a complete structural recovery the moment the force was removed This forgiveness is a special feature of the pressure type structure utilizing a flexible material for the load carrying members *See* AEROSTAT [KAR RSR]

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Blindness

A

correction or whose vision no matter how good subtends an angle not greater than

VISION) The incidence of blindness in the United States has never been accurately determined but estimates made in 1958 place the number at approximately 320 000 persons In addition to advantitious causes blindness is chiefly due to cataract glaucoma and optic nerve atrophy *See* EYE DISORDERS

The ability of certain blind people to move about their environment with relative freedom to perceive and to judge accurately the presence and even the distance of obstacles in their paths and immediate surroundings has given rise to many speculations concerning special endowments of the blind Surveys and experimental investigations show that almost 80% of the blind possess this ability The sensory basis of obstacle perception has been found to be chiefly audition hearing Frequencies of approximately 10 000 cps and above usually produced by a cane or the shuffle of feet upon the ground give rise to changes in pitch as the blind person approaches an obstacle Deaf blind persons or blindfolded persons who are totally deaf are unable to acquire this ability despite any amount of training whereas every person who has normal hearing is able to acquire the ability with training Under certain conditions the blind may use other than auditory cues These are thermal cues warmths or colds radiated from or interrupted by the obstacle cutaneous pressures on face and forehead caused by the deflections of the wind or breath from the obstacle and olfactory cues (odors) given off by the obstacle

Great variability exists among the blind in their distant perception of obstacles Some are able to report the first perception of the obstacle at about 20 ft Others can give their first report only when within a few feet of it In their close perception of the obstacle almost all blind subjects are able to indicate its presence when within inches of it

On the basis of the research findings guidance devices to help the blind localize objects and avoid dangers in their environments have been constructed and are now being experimentally tested [P WO]

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Bloch theorem

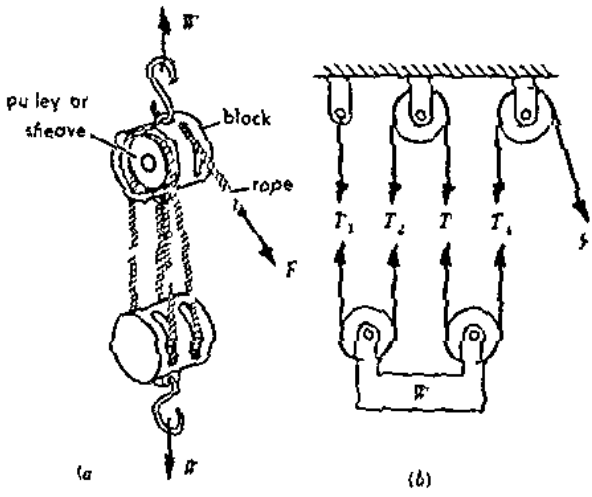
The theorem which states that the wave functions of an electron moving in a periodic potential (such as in a crystal lattice) take the form of plane waves which are modulated by a function which has the same periodicity as the potential That is the wave function ψ_k may be written

$$\psi_k = e^{k \cdot r} u_k(r)$$

where k is the wave vector and $u_k(r)$ is a function which has the periodicity of the potential *See* BAND THEORY OF SOLIDS

Block and tackle

The block and tackle is a combination of a other flexible material and i frictionless pulleys The pulleys are wheels used to change the direct



Block and tackle (a) Actual appearance (b) Schematic

application of force of the flexible member (rope or chain) that runs on the pulleys As in a lever the summation of torques about the axis of rotation of the pulley equals zero for static equilibrium Tension T in the rope is the same on both sides of the pulley

For example in the particular block and tackle illustrated here at static equilibrium the summation of forces in any direction equals zero Each vertical rope carries one fourth the weight algebraically $T = T_2 = T_3 = T_4 = W/4$ and therefore the applied force F also equals one fourth the weight W For this case mechanical advantage MA is

$$MA = \frac{W}{F} = \frac{W}{W/4} = 4$$

The block and tackle is used where a large multiplication of the applied forces is desirable Examples are lifting weights sliding heavy machinery into position and tightening fences *See* SIMPLE MACHINE [R M PH]

Blocking oscillator

A relaxation oscillator that generates a short time duration pulse using vacuum tube or transistor circuitry The input and output are coupled together by a transformer in a positive or regenerative feedback arrangement and the output current is periodically interrupted because of regenerative action which drives the input far into the reverse bias direction The duration of the period between pulses which coincides with the period during which the output current is blocked is dependent upon the value of the RC time constant in the input circuit The blocking oscillator may be made to operate in either an astable or monostable fashion When operated as a monostable device considerable control can be exercised over the shape of the output pulse This characteristic makes it useful as a pulse generator *See* PULSE GENERATOR

[illegible] Miller

transistors or vacuum tubes may be used If the input voltage is highly negative the output circuit will be nonconducting and the input will be rising as capacitor C charges toward the supply voltage along the exponential curve as shown As soon as it reaches the point at which output current starts to flow regenerative action occurs because of the transformer coupling and polarity causing a fast rise in input voltage and a corresponding drop in output current When the point at which the input becomes forward biased is reached the input impedance becomes low and current flows through C into the input of the device charging it in the direction indicated The rise in input voltage ceases when the output circuit cannot supply the required input current in addition to the circuit losses At this point current reversal takes place and regenerative action causes the output current to cease The input voltage is driven below cutoff by an amount equal to the voltage developed across C while the input was forward biased In the transistor circuit shown the diode in the collector circuit limits the positive peak voltage swing which might otherwise exceed the collector voltage rating

Synchronized blocking oscillator The blocking oscillator may be synchronized with external pulses occurring at a rate slightly faster than its own natural frequency in the same manner as with multivibrators *(see Fig 2)* They may be used in the

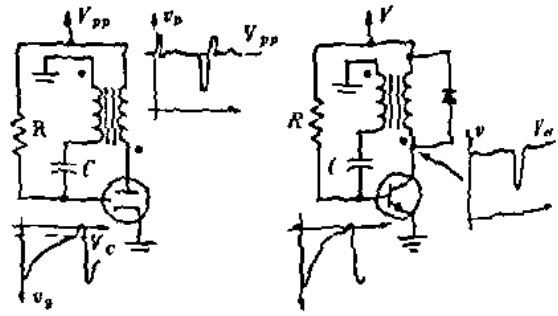


Fig 1 Free running blocking oscillator

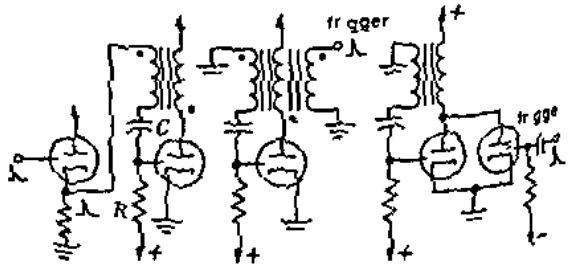


Fig 2 Synchronized blocking oscillators

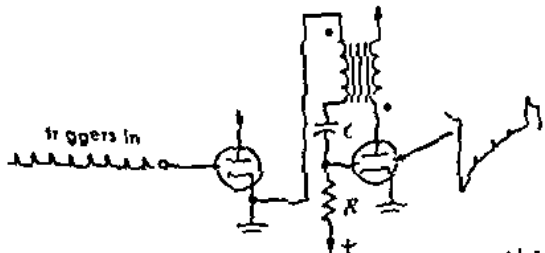


Fig 3 Blocking oscillator as a frequency divider

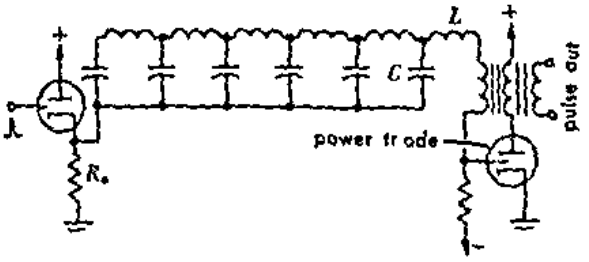


Fig 4 Line-controlled blocking oscillator

same manner as a frequency divider as shown in Fig 3 *See* MULTIVIBRATOR SCALING CIRCUIT

The blocking oscillator becomes a monostable device if the resistance R is returned to a voltage sufficiently far in the reverse bias direction so that an external trigger must be applied before an action can be initiated There is more freedom of control of the circuit elements for control of pulse duration in the monostable circuit if it is desired to use the blocking oscillator as a pulse generator

Line controlled blocking oscillator A pulse of specified width containing a considerable amount of power can be generated by combining a monostable blocking oscillator with an open circuit transmission line in the regenerative circuit A practical circuit is shown in Fig 4 The pulse width will be

$$T = 2n\sqrt{LC}$$

where L is the inductance and C the capacitance of each section of the simulated line and n is the number of sections For the use of simulated transmission lines in such applications *see* PULSE GENERATOR *see also* DELAY LINE [E M C]

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Blood

The fluid that circulates in the closed blood vessels of the body Blood consists of plasma in which the cells float The chief components of the plasma are proteins (albumin and globulins) anions (mainly chloride and bicarbonate) and cations (mainly sodium with smaller concentrations of potassium calcium and magnesium) The cells are derived from extravascular sites and then enter the circulatory system They frequently leave the blood vessels to enter the extravascular spaces where they may be transformed into connective tissue cells The fluid part of the blood is in equilibrium with the tissue fluids of the body The circulating blood carries nutrients and oxygen to the body cells and is thus an important means of maintaining the homeostasis of the body It transmits hormones from their sites of origin throughout the body and is thus the transmitter of the chemical integrators of the body Blood also circulates immune bodies and contains several of the components essential for the formation of blood clots Because of these functions blood can be regarded as a connective tissue

The cells of the blood include the red blood cells and the white blood cells In all vertebrates except most mammals the red blood cells or corpuscles contain a nucleus and cytoplasm rich in hemoglobin In mammals with very few exceptions the nucleus has been extruded during the developmental stages In normal adult men the blood contains about 5 000,000 red blood corpuscles or erythrocytes per cubic millimeter in normal adult women about 4 500 000 The erythrocytes in man are about 8 microns (μ) in diameter and about 2 μ at their thickest and have a biconcave shape They contain hemoglobin which imparts to them their color and possess an envelope which when viewed with the electron microscope appears highly structured It is the hemoglobin which is involved in the transport of oxygen and carbon dioxide and which plays a role in maintaining a constant pH in the blood When circulating in the blood vessels the red blood cells are not evenly dispersed In the narrowest vessels the capillaries they are often distorted In certain conditions they may be densely aggregated This is known as a sludge The erythrocytes respond to changes in osmotic pressure of the surrounding fluid by swelling in hypotonic fluids and by shrinking irregularly in hypertonic fluids Shrunken red blood cells are referred to as crenated cells The average life of the mature red blood cell is surprisingly long about 120 days *See* HEMOGLOBIN

In man the white blood cells (leukocytes) in the blood are fewer in number There are about 5000–9000/mm^3 In general there are two varieties agranular and granular The agranular cells include the small medium and large lymphocytes and the monocytes (Fig 1) The small lymphocytes are spherical and about the diameter of erythrocytes or a little larger They constitute about 20–25% of the white blood cells The medium and large lymphocytes are relatively scarce In all lymphocytes the nucleus occupies nearly the whole volume of the cell and the cytoplasm which surrounds it forms a thin shell The cytoplasm stains deeply with basic dyes as a result of its high content of ribonucleic acid The typical monocyte is commonly as large as a large lymphocyte (12 μ) and constitutes 3–8% of the white blood cells The nucleus is relatively small eccentric and oval or kidney shaped The cytoplasm is relatively larger in volume than that in lymphocytes and does not stain as deeply with basic dyes

The granular white blood cells or granular leukocytes are of three varieties neutrophil eosinophil and basophil Their structure varies somewhat in different species and the following description applies to those of humans

The neutrophils comprise 65–75% of the leukocytes They are about as large as monocytes The nucleus is highly variable consisting of 3–5 lobes joined together by threads of chromatin The cytoplasm contains numerous minute granules which stain with neutral dyes and eosin

The eosinophils (also called acidophils) are

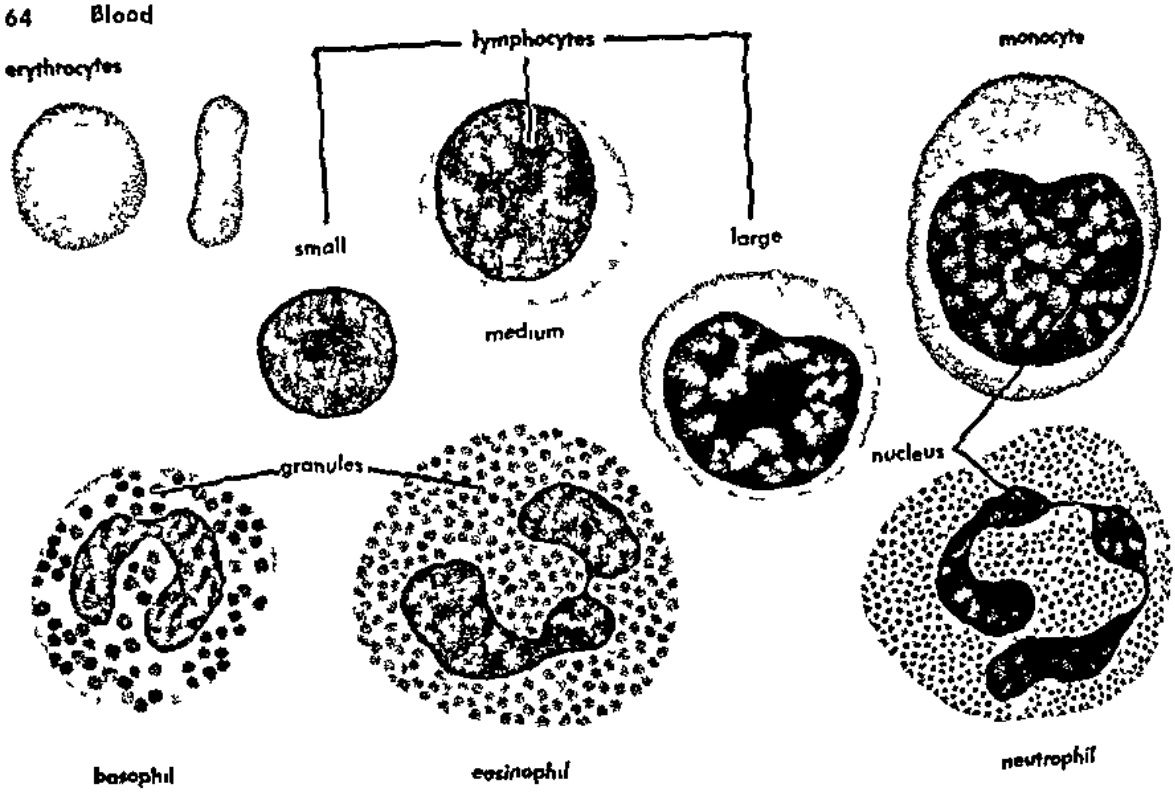


Fig 1 Diagrammatic representation of human blood cells

numerous constituting about 1% of the leukocytes The nucleus commonly contains but two lobes joined by a thin thread of chromatin The granules which fill the cytoplasm are larger than those of the neutrophils and stain with acid dyes

The basophils are about the same size as the other granular leukocytes Basophils constitute about 0 5% of the leukocytes The nucleus may appear elongated or with one or more constrictions The granules are moderately large, stain with basic dyes and are water soluble.

The blood platelets are small spindle shaped or rodlike bodies about 3 μ long which occur in large numbers in circulating blood In suitably stained specimens they consist of a granular central portion (chromomere) embedded in a homogeneous matrix (hyalomere) They change their shape rapidly on contact with injured vessels or foreign surfaces and take part in clot formation During this process numerous fibrils of fibrin radiate from the platelets The platelets are not to be regarded as cells and are thought to be cytoplasmic bits broken off from their cells of origin in bone marrow, the megakaryocytes

The functions of the leukocytes while they are circulating in the blood are not known However, when they leave the blood vessels and enter the connective tissue they constitute an important part of the defense mechanism and the mechanism of repair Many of the cells are actively phagocytic and engulf debris and bacte[illegible]

cy[illegible]
in[illegible]
su[illegible]
la[illegible] formation of new connective tissue in regions of injury

Some of the cells of the blood are terminal cells in the sense that they are fully differentiated and have little or no capacity for division These are the erythrocytes and the granulocytes The other cells the agranular leukocytes, as stated above may develop extravascularly into other cell types (macrophages, fibroblasts, plasma cells) All blood cells are formed in the hematopoietic organs (chiefly lymph nodes and spleen for agranular leukocytes, red bone marrow for erythrocytes and granular leukocytes in the adult) In these organs the blood cells develop from precursor cells which themselves are thought by many to be derived eventually from the least differentiated cells of this strain, the hemocytoblast or primitive mesenchymal cell *See* CONNECTIVE TISSUE, *see also* CIRCULATORY SYSTEM, HEMATOPOIESIS, HOMEOSTASIS, IMMUNOLOGY, OSMOREGULATORY MECHANISMS; PHAGOCYTOSIS, SPECIALIZED TISSUE [IG]

PLASMA

Plasma is the residual material left after removing the cellular elements from blood Serum differs very little from plasma except that fibrinogen and several minor protein constituents of plasma are in large part removed in the clotting process

Plasma proteins. By far the major constituents of plasma and serum are proteins The total protein of human serum is approximately 7 g/100 ml and most other mammals show similar levels Procedures of electrophoresis have demonstrated the extreme heterogeneity of these proteins although there are several constituents present in high concentration Free solution electrophoresis demonstrated six serum protein fractions However newly demonstrated methods such as starch gel electro-

phoresis and agar immuno electrophoresis show as many as 20 different components and there are undoubtedly many more Albumin makes up more than one half of the total It is the major contributor to the total colloid osmotic pressure of the serum not only because of its large amount but also because of its relatively low molecular weight approximately 45 000 The second major group of proteins in serum are the γ globulins which make up approximately one-sixth of the total These are of great importance because they contain most of the antibodies In Fig 2 the absence of the γ globulin peak in fractions 5–10 of the agammaglobulinemia serum is apparent *See* ALBUMIN ANTIBODY ELECTROPHORESIS GLOBULIN PROTEIN

The lipoproteins are another important class of serum proteins that have recently attracted considerable interest because of their possible relationship to arteriosclerosis They fall into two distinct classes the α and β lipoproteins which differ markedly in the lipid protein ratio The serum lipids are almost entirely in the form of lipoproteins particularly the cholesterol and phospholipids Marked disturbances in the lipids and lipoproteins are found in certain hyperlipemic and hypercholesterolemic states and in biliary cirrhosis An excess of serum lipids sometimes results in lipid deposits in the skin and elsewhere *See* CHOLESTEROL LIPID

Other serum proteins that are present at relatively high concentrations are the iron binding proteins the copper proteins and numerous glycoproteins Interest in the copper proteins has increased following the observation that they are deficient in the neurological disorder Wilson s disease Another recently described class of proteins are the haptoglobins Their primary significance lies in the variations encountered in normal individuals that have a genetic basis There is also a wide variety of enzymes clotting factors complement components enzyme inhibitors and many other proteins in small amounts *See* ENZYME

The site of production of many of these proteins is not clear However albumin fibrinogen prothrombin the lipoproteins serum esterase and some of the clotting factors appear to be produced by the liver Considerable evidence points to the plasma cells as the source of the γ globulins *See* FIBRINOGEN

Variation in disease Many of the proteins show wide change in disease states Of particular interest are certain inherited conditions in which one or another of the proteins are completely missing Agammaglobulinemia is one example individuals with this disease lack γ globulin They are unable to form antibodies and suffer from severe and recurrent infections Other patients suffer from an excess of certain of the γ globulins and these in turn may precipitate out under certain conditions with resultant harmful effects Multiple myeloma a malignant disease shows the most extreme abnormalities in plasma proteins The abnormal myeloma protein produced by the malignant cells may make up 80% of the total protein Another abnormal protein is the C reactive protein that appears in a variety of infections and is widely measured for diagnostic purposes In certain kidney diseases and disorders of the intestine serum or plasma proteins may be lost from the body in very large amounts Extreme hypoproteinemia may develop with resultant fluid accumulation in various parts of the body Disorders of the liver also cause fluid accumulation particularly in the abdomen which is due in part to defective synthesis of albumin by the damaged liver and resultant decreased colloid osmotic pressure

Other plasma constituents In addition to the proteins there are many other important classes of compounds that circulate in the blood plasma Most of these are smaller molecules which are freely diffusible through the capillaries and therefore are distributed similarly through all the fluids of the body and are not as selectively characteristic of *the plasma and serum as are the proteins* In terms of concentration the electrolytes are of most importance They are the primary factors in the effective osmotic pressure of the plasma and aid considerably in the control of the pH The chief cations are sodium potassium calcium and magnesium The chief anions are chloride bicarbonate phosphate sulfate and mixed organic acids Sodium and chloride are present in the highest concentrations Potassium although present in low concentrations is of considerable importance Symptoms of hypo and hyperpotassemia in various disorders chiefly involve the muscles and even the heart with changes in the electrocardiogram *See* CALCIUM METABOLISM ELECTROCARDIOGRAPHY PHOSPHATE METABOLISM

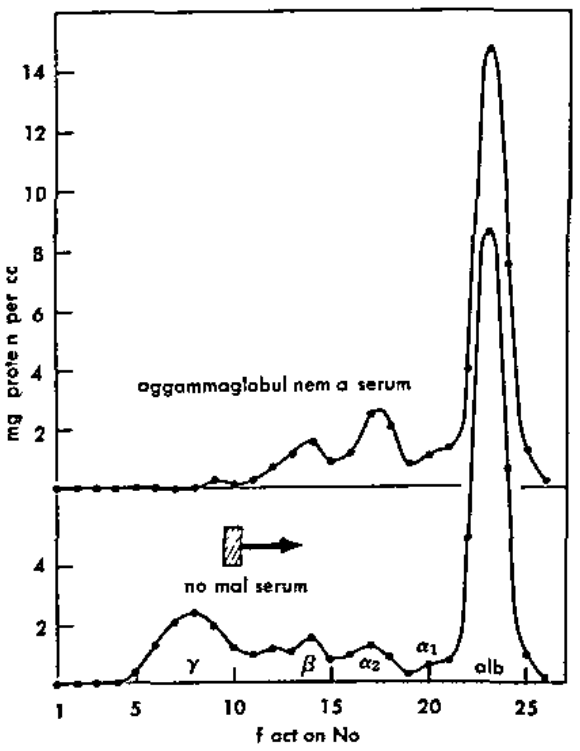


Fig 2 Curves of protein concentration in separated serum protein fractions following electrophoresis

Urea uric acid creatinine and pyruvic acid are other important organic constituents of the plasma Many of these substances rise significantly in kidney disease and bring on the symptoms of uremia Glucose is also an important constituent primarily because it is a major source of energy for cells throughout the body Recently evidence has been obtained that nonesterified fatty acids are also a primary source of energy Although present at a low concentration they have a very rapid turnover They circulate in plasma bound to albumin Marked changes in glucose and fatty acids occur in diabetes Free amino acids are also of considerable importance and these are utilized for protein synthesis throughout the body Bilirubin the carotenes vitamin A iodine steroid hormones and many other substances are found bound in large part to the serum proteins *See* BILIRUBIN BIOCHEMISTRY CREATINE CREATININE HORMONE UREA URIC ACID [HCK]

BLOOD COAGULATION

When mammalian blood is shed it congeals rapidly into a gelatinous clot of enmeshed fibrin threads which trap blood cells and serum Modern theories envision a succession of reactions leading to the formation of insoluble fibrin from a soluble precursor fibrinogen Blood clots on contact with injured tissues which provide tissue thromboplastin a protein phospholipid complex The interreactions of tissue thromboplastin calcium ions and several proteins of plasma including proaccelerin (labile factor) and proconvertin result in the conversion of prothrombin into a proteolytic enzyme thrombin Proconvertin is probably two substances the precursor of serum prothrombin conversion accelerator or pro-SPCA and the Stuart factor In turn thrombin partially digests fibrinogen forming soluble fibrin which polymerizes into insoluble fibrin the structure of the clot

Thromboplastic activity also occurs when shed blood touches glass In this reaction three or more plasma proteins react with calcium and phospholipids principally derived from blood platelets to form plasma thromboplastin These proteins include antihemophilic factor (lacking in hemophilia) Christmas factor or plasma thromboplastin component (lacking in Christmas disease a hemophilialike state) Hageman factor and possibly plasma thromboplastin antecedent (lacking in plasma thromboplastin antecedent deficiency) The liquid state of circulating blood is maintained by inhibitors of these reactions

Once formed the clot shrinks expelling liquid serum This clot retraction requires the presence of platelets its function is unknown

Acquired or inherited deficiencies of clotting factors other than calcium or Hageman factor result in hemorrhagic disorders Clinical tests of the coagulability of blood include (1) determinations of the clotting time which is the time elapsing until shed blood clots (2) prothrombin time which is the time elapsing until plasma clots in the presence of tissue thromboplastin (3) enumeration of platelets and (4) crude quantification of clot retraction and of the various protein clotting factors Tests of serum prothrombic activity and thromboplastin generation measure the initial stages of clotting

Prothrombin proconvertin and Christmas factor are probably synthesized in the liver in the presence of vitamin K, formed primarily by intestinal flora Deficiency of vitamin K or its inhibition by ingested coumarin compounds impairs the synthesis of these compounds and decreases the coagulability of blood Heparin a polysaccharide sulfuric acid complex found particularly in liver and lungs impairs coagulation by interfering with the actions of thromboplastin and thrombin, its presence in normal blood is disputed Both coumarin compounds and heparin are used clinically to impede coagulation in thrombotic states including thrombophlebitis and coronary heart disease *See* VITAMIN K [ODR]

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Blood groups

The blood of humans and higher animals has been classified according to the red blood cell antigens Three major systems have been discovered consisting of the ABO factors (or groups) the MNS factors and the Rh factors The study of these factors has contributed to immunology, ethnology and genetics made blood transfusion a safe practice identified the cause of erythroblastosis fetalis (hemolytic disease of the newborn), and provided a method for exclusion of parentage The last important in resolving cases of disputed parentage is possible because blood factors are inherited and with few exceptions according to a known mechanism of heredity Furthermore almost all the blood factors show more or less striking differences among racial groups These differences are currently expressed in terms of gene frequency The various systems are independent of each other so that a given blood is first classified by the ABO system then the MNS the Rh system and others described below

In 1900 when the principle underlying the ABO system was discovered human blood differences were thought to be a simple matter—an individual had either O A B or AB factor in his blood Subgroup A_1 of groups A and AB was added in 1911 As K Landsteiner predicted transfusion became a safe and routine procedure provided that patient and donor belonged to the same blood group

In 1927 the blood factors M N and P were discovered with the aid of antibodies produced in rabbits by injection of selected human red cells and rendered specific by suitable absorption of species-specific antibodies This method is known as heterоimmunization in contrast to isoimmunization in which the antibodies are produced in response to antigens within the same species In 1939 Hill isoimmunization in man was established as the

Table 1 Well known blood group systems

Blood group system	Discovery date
ABO	1900
A_1 A_2	1911
MN	1927
S_s	1947
P	1927
Tj^a	1951
Secretion or nonsecretion of ABO in saliva (Se-se)	1932
Lewis substance on red cells and saliva	1946
Rh and subtypes	1939–1945
Lutheran (Lu^a)	1945
Kell (k)	1946
Duffy (Fy^a)	1950
Kidd (Jk^a)	1951

cause of intragroup hemolytic transfusion reactions (for example group A to group A) Shortly after this it was shown that isoimmunization of an Rh negative mother by Rh positive fetal blood was the cause of hemolytic disease of the fetus and newborn Numerous additional blood factors were discovered in the study of sera of Rh positive mothers of erythroblastotic infants and also in the sera of recipients of blood transfusions The discovery of new blood factors was facilitated by new methods for detection of atypical antibodies particularly the antiglobulin reaction of R R Coombs (*see* IMMUNOLOGY)

At least nine well known blood group systems (Table 1) are now available for the study of individual differences their heredity and their role in population genetics By the permutations and combinations of the 9 known blood group systems more than 1 000 000 varieties of individual bloods can now be identified

The table does not include the additional sub varieties of the ABO system and genetically related factors such as M_1^a Vw Hunter Henshaw and U of the MNSs system

ABO system The scheme of the four bloods in its simplest form is given in Table 2

The diagnostic reagents that is anti A and anti B used to test the four blood groups are produced in human volunteers of group B and A by injection of A and B group specific substances prepared from cow and horse stomach extracts Group O sera can more readily detect weaker forms of A (A_3 A_4 A_o A_m) and the rarely found form of

Table 2 Four blood groups reaction of serum with red blood cells

Blood group	Serum contains antibodies	React on with red blood cells of group O	A	B	AB	Incidence in white population U S %
O	Anti B anti A	–	+	+	+	45
A	Anti B	–	–	+	+	41
B	Anti A	–	+	–	+	10
AB	None	–		–	–	4

+ = agglutination of red blood cells
– = no agglutination of red blood cells

B B_w Potent group O sera are prepared by injecting group O volunteers with A and B substances

The A and B substances are also present in body fluids such as saliva and seminal fluid in about 80% of the population who are then called secretors In the remaining 20% the water soluble substances are not present in the organs and tissues these people are known as nonsecretors Group O individuals are also classified as secretors or nonsecretors of a basic substance called H The secretor status is inherited as a dominant and nonsecretor as a recessive characteristic The ABH substances are polysaccharide amino acid complexes and each has a characteristic terminal grouping

The A and B blood factors are inherited as a series of 3 alleles A B and O the latter being recessive There are 6 genotypes and 4 phenotypes because neither AA and AO nor BB and BO can be differentiated from each other The heredity of the ABO groups is given in Table 3

Table 3 Heredity of the ABO groups

Matings (phenotypes)	Children possible
O × O	O
O × A	O A
O × B	O B
O × AB	A B
A × A	O A
A × B	O A B AB
B × B	O B
B × AB	A B AB
AB × AB	A B AB
AB × A	A B AB

An incompatibility of the ABO blood factors such as a mating of father A B or AB and mother O may result in hemolytic disease of the newborn This is due to the presence of anti A and anti B in the mother's serum The vast majority of the cases are mild An ABO incompatibility also reduces the incidence of Rh hemolytic disease to a considerable degree

As a rule the agglutinable factor in the red cell and the secretion factors are fully expressed This is known as complete penetrance (*see* PENETRANCE GENE) In rare instances however the B factor and secretion property are suppressed as in the Bombay type of blood where red cells behave like those of group O although their serum contains a potent anti H which reacts with all group O bloods

Of great theoretical interest is a type of blood occasionally found in nonidentical twins of different blood groups Because of presumed placental anastomosis (joining of the blood vessels) each twin shares some of the blood of the co twin (chimera) In one twin the blood was a mixture of O + A and in the co twin the blood was a mixture of A + O In both only anti B was This set of twins differed also in other blood factors Judging by analogy with chimeras

one may expect successful takes of transplants of skin and other organs

MNSs system The anti M and anti N are rarely present in human sera because the M and N antigens unlike the ABO antigens are not accom

anti N
inject
tests
corre

NN, are observed A rare allele at (Mg) has been described by F Allen

The Ss factors are closely associated with the MN system In the white population tests with anti S and anti s give three types of reactions corresponding to *SS*, *Ss*, and *ss* In Negroes there is a

negroids and the low incidence factors Mi^a and Vw

Rh system The Rh factor (Rh_0 or D) is clinically important because in more than 90% of all cases of hemolytic disease of the fetus or newborn the mother is Rh (D) negative and her serum contains anti Rh_0 (anti D) Some of these Rh negative mothers are immunized by Rh positive fetal red cells if the red cells are compatible with maternal anti A and anti B agglutinin in the serum The maternal antibodies exert their harmful effect on the fetus in the uterus resulting in stillbirths or in fetal hydrops a widespread edema of the fetus More frequently the newborn infant apparently normal at birth soon develops severe jaundice

Table 4 Three Rh Hr sera Incidence of reactions and antibodies produced

Terminology		Percentage		
Fisher Race	Wiener	Positive	Negative	Antibodies
Anti D	Anti Rh_0	85	15	Very frequent
Anti C	Anti rh	73	27	Very rare
Anti-c	Anti hr'	80	20	Occasional
Anti E	Anti rh''	30	70	Occasional
Anti-e	Anti hr''	97	3	Very rare

and staining of the brain cells with bile pigments may result Early exsanguination transfusion repeated if necessary, will save almost all affected infants

There are two main varieties of Rh antibodies saline or complete antibodies, and albumin or incomplete antibodies Only the latter antibodies pass the placental barrier into the fetal circulation The fetal red cells thus become coated with a layer of antibody globulin which can be detected by means of the direct antiglobulin reaction or direct Coombs test This is one of the important diagnostic criteria for hemolytic disease due to Rh or other antibodies of different specificities

In addition to the Rh factor, Rh_0 or D there are two others (C and E) and two corresponding genetically related Hr factors c and e The incidence of positive and negative reactions with the three anti Rh sera and two anti Hr sera and their current terminologies are presented in Table 4 An antibody corresponding in specificity to anti d has not yet been found

Eight types are observed when all bloods are tested with the three anti Rh sera These types are listed in Table 5

The eight types are further divided when tested with anti c and anti e According to one theory that of linkage at three closely spaced loci each of the sets of blood factors is inherited as a pair of

and E-e in
ed as men

tioned above According to another theory the heredity of the Rh factors is determined by a series of multiple alleles at one locus

The two contrasting theories of the inheritance of blood factors are illustrated below

Linkage
Fisher Race
D ↔ (d)
C ↔ c
E ↔ e

Multiple alleles
Wiener
R^0, R^1 R^2 ↔ r', r'', r

Table 5 Eight Rh subtypes

Terminology		Reactions with			Incidence	
Fisher Race	Wiener	Anti D	Anti C	Anti E	%	Classification
DCe	Rh_1	+	+	−	54	Rh positive (85%)
DCE	Rh_2Rh_2	+	+	+	15	
DcE	Rh_2	+	−	+	14	
Dce	Rh_0	+	−	−	2	
dce	rh	−	−	−	13	Rh negative (15%)
dCe	rh	−	+	−	1 5	
dcE	rh''	−	−	+	0 5	
dCF	rh rh''	−	+	+	very rare	

+ = positive reaction agglutination − = negative reaction

Table 6 Frequency of the Rh genes

Fisher Race	Wiener	%
DCe	R^1	40 76
dce	r	38 86
DcE	R^2	14 11
Dce	R^0	2 57
dcE	r'	1 19
dCe	r	0 98
DCE	R^z	0 24
dCE	r^y	Very low

The eight genes or chromosomes are listed in Table 6 not taking into account the additional variants

There is at present insufficient evidence to support either theory but most workers prefer to use the DCE terminology Clinically it is important to differentiate a homozygous from a heterozygous *Rh* positive father A heterozygous *Rh* positive father and an Rh negative mother may have Rh positive or Rh negative offspring while a homozygous Rh positive father and an Rh negative mother will have only Rh positive offspring For an Rh_1 individual this can be determined statistically by tests for C c factors If c negative the individual is homozygous for C and statistically is also homozygous for D the most frequent combinations of chromosomes being *DCe/DCe* if c positive he is more frequently heterozygous that is *DCe/dce*

In addition to the main blood factors listed above the situation is complicated by the existence of the following variants D^u D— C^w C^u C^x c^v E^u and E^w Two additional blood properties to which antibodies have been described are f and V With rare exceptions anti f reacts with all bloods containing factors c and e on the same chromosome *Anti V* reacts exclusively with selected f positive bloods—mainly negroids D^u may be of two varieties one of which is inherited and more frequent in negroids and the other due to gene interaction with genes D and C on opposite chromosomes

Other blood group systems Briefly the other blood group systems are as follows

P more frequent in negroids is related to the high *incidence factor* Tj^a *It was shown that* P soluble substance is present in echinococcus cyst fluid

The Lewis blood factors are primarily secretion properties According to R Ceppellini the heredity of the Lewis reactions on the red cells may be understood in terms of interaction of the genes for ABH secretion and Lewis secretions

The Lutheran system now includes the genetically related Lu^b *Anti* Lu^a *acts on* 7% of all bloods while anti Lu^b as expected agglutinates 99% of all bloods

The Kell factors (K k) were at first believed to be a 2 gene system with 3 genotypes corresponding to 3 phenotypes The Kell system is now complicated by the occurrence of two related blood properties Kp^a (2%) and Kp^b (99%)

The Duffy factors (Fy^a Fy^b) also a 2 gene system at least for a caucasoid population are now complicated by the discovery of a third allele *Fy* The *Fy* allele has a very high incidence and occurs only in negroids It is characterized by its failure to react with both anti Fy^a and anti Fy^b

The Kidd factors (Jk^a Jk^b) result from two genes with three phenotypes corresponding to three genotypes

In addition to the nine blood systems listed previously mention must be made of several low incidence blood factors such as Becker Ven Wr^a, Be^a Ca and Di^a The latter is important because it has an incidence ranging to 40% in some American Indians and about 10% in Chinese and Japanese but no incidence in caucasoids The factors Mi^a and Vw have been shown to belong to the MNSs system The Graydon factor is identical with Vw

When high incidence factors are considered one may mention Tj^a (part of the P system) Vel and Yt^a Antibodies for these blood factors react with almost all bloods tested *See* ANTIGEN BLOOD

[P L]

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Blood vessels

Tubular channels for blood transport there are three principal types arteries capillaries and veins

Arteries carry blood from the heart through a system of successively smaller vessels There are three major layers in the arterial wall the outer adventitia of connective tissue the middle elastic and muscular layer and the inner lining or endothelium *The proportionate thickness of these layers varies according to the size and location of the artery* In the largest arteries such as the aorta elastic tissue is prominent and expansion and recoil occur with each systolic contraction of the heart The medium sized arteries have a predominantly muscular wall although elastic elements are present In smaller arterioles the middle coat is entirely muscle and even this is gradually lost as *the caliber decreases to a few microns in diameter*

Capillaries are the smallest but most extensive blood vessels forming a network everywhere in the tissues which presents a huge total surface area of endothelium The wall of naked endothelium serves as a semipermeable membrane for passage of materials between the circulatory system and the body tissues Normally only a small portion of most capillary beds carries blood the remaining portion being temporarily bypassed Such alteration allows for the shift of blood as well as increases or decreases in volume to a particular region or organ This constitutes one of the vital homeostatic mechanisms of the body

The veins carry blood from the capillary beds to the heart through increasingly larger vessels The smallest are venules and the larger veins like the

arteries have been given specific names The walls of the veins superficially resemble those of the arteries but marked differences appear Veins are larger more distensible and thinner walled than the corresponding arteries they have much less muscular tissue in their walls In many locations there are valves which act to prevent reflux of blood The pattern of branching of veins is less regular and less constant than that of their arterial counterparts The larger veins and arteries have their own blood vessels (vasa vasorum) for nourishment of the walls and also are innervated by a complex system of nerves particularly to muscular tissue which are vasomotor in function

In certain locations the vessels are modified for particular functions as the sinusoids of the liver and the choroid plexuses of the brain ventricles *See* CIRCULATORY SYSTEM [F G ST]

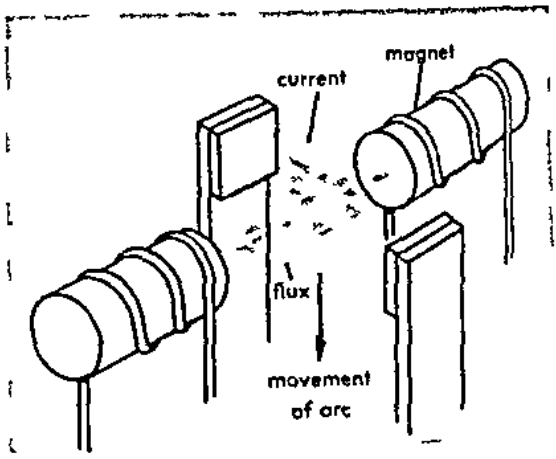
Blood plate hemolysis

The destruction of red blood cells in an agar medium such as beef heart infusion agar with rabbit's blood contained in a petri dish The cells are destroyed by hemolysin a toxin produced by such bacteria as streptococcus and staphylococcus The types of destruction or hemolysis are given Greek letters and usually apply to streptococcus and its classification Green discoloration (alpha) around a streptococcal colony or the halo of clearness (beta) contrast with the deep pink background of growth medium Absence of change in the red cells and consequent absence of discoloration around the colony represent the gamma type Many microorganisms produce hemolysins especially the pathogenic (disease producing) strains Cross appearance of the colony and microscopic form of its stained bacteria are needed for primary identification Hemolysis is a property widely used in microbiology *See* LANCEFIELD DIFFERENTIATION SCHEME STAPHYLOCOCCUS STREPTOCOCCUS [P L B]

Blowout coil

A coil of an electromagnet associated with the contacts of an electrical switching device to aid in the extinction of the arc formed as the contacts interrupt the current Breaking a metallic circuit carrying current always produces an arc which must be extinguished in order to open the circuit Special devices are often used to extinguish such arcs rapidly to prevent damage to the contacts

One means is to generate a strong magnetic field perpendicular to the axis of the arc The arc reacts to the field just like a current carrying conductor in a motor that is the arc moves perpendicular to the flux and the current in the arc as shown in the illustration If the contacts are shaped so that the arc [illegible] a is [illegible] flux generated by the electromagnet is proportional to the current and always in the proper direction to move the arc in the desired direction even though the current may be alternat



Relation of directions of current magnetic flux and movement of arc

ing Blowout coils are used in contactors circuit breakers switches and relays With their associated magnetic structures they are usually incorporated into assemblies which include refractory enclosures and baffles known as arc chutes to confine and cool the arc as it moves *See* CIRCUIT BREAKER [W N C]

Blowpipe

In glass blowing a long straight tube on which molten glass is gathered and worked partly by blowing into the tube The blowpipe is spun to shape the glass object further by centrifugal force or by a tool in which case the blowpipe acts as a spindle for turning

In analytical chemistry a blowpipe is a small tapered and frequently curved tube that directs a jet usually of air into a flame to concentrate the flame onto an unknown substance Coloration of the flame and other characteristic reactions in the reducing and in the oxidizing portions of the flame created by the blowpipe aid in identifying the substance Such a blowpipe may be blown directly by the analyst from a bellows or from a pressurized line *See* MINERALOGY [F H R]

Blueberry

Several species of the genus *Vaccinium* plant order Ericales ranging from low growing almost prostrate plants to vigorous shrubs reaching a height of 12 15 ft The fruit a berry is usually black and covered with bluish bloom generally occurring in clusters and has numerous small seeds a char[illegible] blueberry from the [illegible]tty seeds. [illegible]ther con[illegible]ed States [illegible]s all cultivated varieties [illegible] are American in origin

Types The highbush blueberry represented by *V australe* and *V corymbosum* provides most of the cultivated plants These are bushes reaching [illegible]ed by hard [illegible]berry [illegible]ks so [illegible]does

best in an acid soil preferably sand and peat and must have an ample water supply and good drainage It can be grown on ordinary mineral soils if the water is properly regulated and the soil acidity is kept in the range pH 4-6 Nitrogen is utilized as ammonium rather than nitrate The highbush blueberry has been under cultivation since 1910 when the first experiments on its culture were reported Production in the United States is greatest in New Jersey followed by Michigan North Carolina and Washington The fruit is sold fresh canned and frozen The blueberry is becoming increasingly popular in home gardens although its cultural requirements are rather exacting For garden culture mulching with sawdust or other organic matter is desirable because the roots are shallow



A cluster of blueberries

The dryland blueberry *V ashei* is adapted to relatively dry soils and has been brought under cultivation in Florida and Georgia

In the Northeast the lowbush blueberry *V lamarckii* grows wild over thousands of acres of dry hillsides where it is harvested commercially especially in Maine but also in other New England states Michigan Minnesota and a few others Some berries are sold fresh, but most are canned or frozen to be used for pies In some areas the plants are burned over every 3 years to kill certain weeds and to remove the old wood thus stimulating vigorous new growth Lowbush blueberries are harvested with a small scoop resembling a cranberry scoop which combs the berries from the plants whereas the highbush and dryland berries are picked by hand

In the Northwest fruit of the evergreen blueberry *V ovatum* is harvested in the wild and large tonnages of the leafy twigs are shipped for use as florists greens

Value of crop The annual crop value of cultivated blueberries is in excess of $10 000 000 and the value of blueberries harvested in the wild is almost $5 000 000 *See* ERICALES FRUIT GROWING (SMALL) [J H CE]

Bluebird

Any of three North American species of the genus *Sialia* family Turdidae They are related to the thrushes

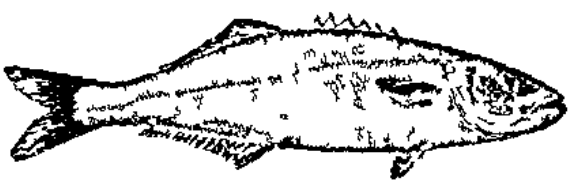


The bluebird *Sialia sialis* length to 7½ in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

The eastern bluebird *Sialia sialis* is the best known This blue-backed chestnut breasted song bird was common in the eastern United States before the spread of the European starling and English sparrow but has suffered severely in competition with these two birds for nesting sites It is now relatively uncommon The western bluebird *S mexicana* is similar but shows chestnut on the back The mountain bluebird *S currucoides* is pale blue beneath darker blue above *See* PASSERIFORMES [J D B]

Bluefish

The only species of the family Pomatomidae *Pomatomus saltatrix* is a moderately large voracious predatory fish of the Atlantic highly favored by fishermen as a food and sport fish It is also found in the Mediterranean Sea and the Indian Ocean but does not occur off European shores in the Atlantic Bluefish travel in large schools which are highly destructive to other fishes When they attack a school of fish they kill much more than they can eat Most bluefish weigh between 3 and 5 lb but the American record is 27 lb and larger ones up to 50 lb are known

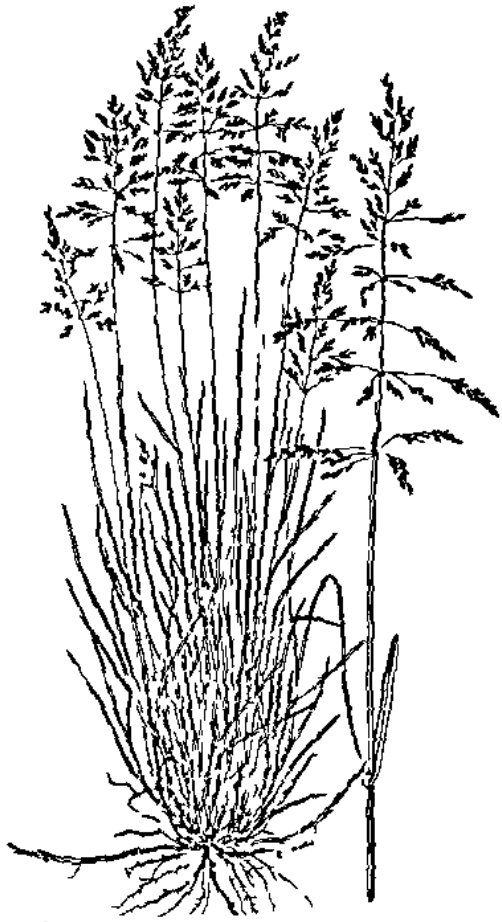


The bluefish *Pomatomus saltatrix* length to 45 in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

In California the name bluefish is applied to *Cynoscion parvipinnis* related to the California white sea bass and a member of the croaker family *See* PERCIFORMES

Bluegrass

A common name applied to several species but particularly to Kentucky bluegrass (*Poa pratensis*) and to Canada bluegrass (*Poa compressa*) Ken



Kentucky bluegrass Poa pratens s

tucky bluegrass is widely grown in temperate humid regions doing best on fertile soils that are loamy or heavy in texture Canada bluegrass is more abundant on less fertile soils in cooler regions Both species are perennial form sod by under ground creeping stems and have extensive root systems which are finely branched and compara tively shallow Top growth is 1 2 ft tall and leafy except for seed stalks These grasses are utilized primarily for pasture Bluegrasses respond to fertilizers especially those supplying nitrogen and the herbage generally is high in the mineral ele ments particularly phosphorus Growth occurs from early spring to late fall except for near dormancy during the hot, dry summer period *See* GRASS CROPS [H B S]

Bluestem grass

The most important forage grasses in those parts of the Great Plains which have 15–30 in annual rainfall from mid Canada to Mexico The two major species of the bluestem group are big blue stem (*Andropogon furcatus*) and little bluestem (*Andropogon scoparius*) Big bluestem is a large perennial, 3–5 ft tall with somewhat coarse stems. It thrives on the more fertile soils and produces nutritious forage Little bluestem is a tufted peren nial (bunchgrass), 1–2 ft tall with wiry stems It tolerates moderately poor soils and droughty sites but makes nutritious feed on the better soils Al though both species may be injured by heavy con tinuous grazing under controlled management they are important range grasses for summer graz ing and also for winter range where grasses are cured on the stem *See* GRASS CROPS [H B S]

Boa

Any of about 40 species of primitive snakes of the subfamily Boinae, family Boidae Most of the boas are tropical occurring mostly in South America and southeast Asia Two small species occur in the United States, one of which the rubber snake *Charina bottae*, is found northward into Idaho and Montana Many of the boas are large the anaconda *Eunectes murinus*, of South America being the largest of all snakes with a maximum length of 33 ft Several boas are small or moderate in size



The boa constrictor, *Constrictor constrictor* length to 15 ft (*From E L Palmer, Fieldbook of Natural H story McGraw Hill 1949*)

Boas have vestigial pelvic girdles and rudimentary femur bones Their scales are small sometimes granular and the abdominal plates are relatively narrow The pupil is vertical Most boas are ter restrial or arboreal, a few small species burrow *See* SQUAMATA [J D B]

Bobcat

An American cat *Lynx rufus*, of moderate size about 3 ft long and weighing up to 40 lb The bobcat also known as the wildcat formerly ranged from central Mexico through most of the United States and into southern Canada It is now rare in the more densely settled parts of the East but is still more common than suspected in many areas, particularly in the forests and brushy habitats of the South It is secretive and primarily nocturnal preying mainly upon rabbits rodents and birds, but eating whatever small animals it can catch



The bobcat Lynx rufus length 38 In (*From P M Duncan ed , Cassell's Natural History Cassell*)

The bobcat may be distinguished from the larger and more northerly distributed lynx by the virtual absence of ear tufts and by restriction of the black tip on the tail to the upper side only its feet are also somewhat smaller than those of the lynx *See* CARNIVORA [J D B]

Bobolink

A *short-billed American songbird Dolichonyx oryzivorus* of the oriole family The breeding male is a strikingly marked black bird with a golden yellow or whitish nape a broad white band across the top of the wing and a white rump The female is a streaked *brown bird with a dusky and buff* striped crown usually mistaken for a sparrow Fall males and young resemble the females in this plumage bobolinks are known as reedbirds in the South



The bobolink *Dolichonyx oryzivorus* length to 8 in (*From E L Palmer Fieldbook of Natural History McGraw-Hill* 1949)

Bobolinks migrate in large flocks which are sometimes *destructive to grain In* the summer their diet is mainly insects The bobolink s breed *ing range* extends across southern Canada and the northern United States it winters in South Amer *ica See* PASSERIFORMES [J D B]

Body rhythm

A generic term *that traditionally refers* to a restricted but varied class of bodily processes having in *common* some degree of regular periodicity However because the vast majority of all physiological processes exhibit some order of cyclic variation it is admittedly arbitrary to select a few examples and designate them as the body rhythms For example *physiological processes* as diverse as spontaneous discharge of resting nerve cells, osmotic pressure *of blood serum* resting blood pressure and growth rate of the total organism all show a periodicity if accurately measured *More* over if observed under suitably standardized conditions *the periodic* pattern of such processes is found to be sufficiently regular to qualify as a rhythm Since so many bodily functions at the cell tissue organ and system levels are cyclic in character it is not surprising that a number of total *bodily functions the traditional body rhythms*, also are characterized by rhythmicity The body rhythms which are commonly studied include hunger thirst sexual behavior the sleep wakefulness cycle body temperature and general activity level *See HUNGER REPRODUCTIVE BEHAVIOR SLEEP* THIRST

Some of these body rhythms seem to derive their rhythmicity for the most part from underlying physiological processes but in other cases the specific *time constant* appears to be imposed by environmental factors In cases of the latter type however it has *frequently* been shown that once it is established the rhythm can be maintained for a while by physiological mechanisms exclusively On the other hand none of the body rhythms is immune *to some influence from the external environment It seems that the necessity for rhythmicity of* functions is imposed physiologically but the precise rhythm adopted is within limits open to influence by environmental factors

Mechanism The details of the underlying mechanism *vary considerably among these various* rhythms Thus in the cases of hunger and thirst the time span between successive bouts of ingestion is dependent on the amount previously ingested and the rate at which available materials in the internal environment are either utilized or lost from the body Complex physiological mechanisms impose limits on *both parts of this* sequence and quantitatively regulate the many bodily reactions involved Superimposed on this physiological substratum however are such external influences as cultural eating customs availability of nutrient *materials* and *personal* eating habits That *the* rhythm of feeding and drinking cycles becomes internalized to some *degree is indicated* by the manner in which they will persist autonomously for a while even when the individual is fasting Exemplifying the manner in which one body rhythm can influence another is the relation that *exists between these ingestion cycles* and the excretory cycles Substantial variation in the rhythm of the ingestion cycles *soon leads* to comparable changes in the excretory cycles Conversely alterations in excretion must *soon be mirrored* by appropriate changes in ingestion A notable example of the latter case is the excessive fluid ingestion *(polydipsia) which results from* the pathological increase of fluid excretion (polyuria) seen in certain endocrine *disorders See* DEFECATION *URINATION*

Sexual behavior The rhythmicity of sexual behavior in the vast majority of animal species clearly demonstrates the general rule that the relative portance of external or experiential inf

body rhythms increases as one ascends the phylogenetic scale The fundamental hormonal shifts which are responsible for the estrous cycle in infraprimate species determine sexual receptivity in the female and thus rigidly account for the rhythm of sexual behavior in such lower animals In primate and human females, the analogous menstrual cycle is equally based on endocrine events but the associated mating behavior is more loosely related to this underlying hormonal process The infrahuman primate female such as the chimpanzee sometimes will accept the male although she is not hormonally in heat

Human sexual behavior bears little if any relation to the physiological factors governing ovulation and subsequent menstruation In fact in human beings there is no clear rhythm at all as far as sexual behavior is concerned There is simply an irregular periodicity that is physiologically influenced only by short term factors of fatigue and satiation

In contrast many species of lower animals are the so-called 'seasonal breeders' their sexual rhythm has a primary seasonal periodicity For some species these rhythms are at least in part determined by variations in the length of day at different times of the year This influence of light is thought to be mediated through the hypothalamus and the pituitary gland When such animals are experimentally deprived of the light cues however it appears that the pituitary is able to maintain the seasonal rhythm autonomously at least for a period of time With some exceptions these rhythms of sexual behavior are determined by the receptivity of the female of the species

Sleep wakefulness The pattern of the sleep wakefulness rhythm of an organism can be characterized as either polyphasic or monophasic In the former case the individual accumulates the required amount of sleep at two or more separate times during a 24-hour period In the monophasic cycle all of the day s sleep typically occurs in one *sequence* In general the monophasic pattern only *arises in the course* of the ontogenetic development of certain higher animals and man The *emergence of this* monophasic cycle such as that in the adult human is *thought to represent* the achievement of cerebral cortical control over a primitive subcortical neural *mechanism* that is directly responsible for maintaining wakefulness

[illegible] overall picture in the case of higher animals including *man is one of* the individual learning to adapt his sleep wakefulness cycle to the 24-hour dark light cycle This final adult sleep cycle seems largely *an acquired* one, but it still comes to have some physiological autonomy as d *some of the other rhythms* previously discussed Its rhythm persists for a time although day night cues are *absent or* when the individual is kept awake for prolonged periods *The diurnal* temperature cycle is an important physiological body rhythm that has a periodicity similar to the sleep-wakefulness cycle In the typical human the temperature cycle has one maximum and one minimum during each 24-hour period Considerable individual variation is seen, but the peak characteristically occurs in the late afternoon and the lowest body temperature is recorded sometime during the last half of the night's sleep It is not certain whether this temperature rhythm merely reflects the sleep-wakefulness cycle or is causally related to it

General activity level. There is one body rhythm the general activity level, that appears to be a kind of superordinate rhythm influenced by many cyclical body processes It has been studied almost exclusively in infrahuman animals and generally is measured in one of two ways The animal can be placed in a so called stabilimeter which is a cage balanced on pivots or suspended by springs in such a way that the slightest movement of any kind is quantitatively recorded An alternate method of measurement involves the use of a cage in which the floor or the total unit moves in a continuous manner when the animal is running in place The latter method records only the locomotor *activity* of the animal Although there are differences in detail between results obtained in these two ways there are some general conclusions that apply to both

There is a close relationship between the observed cycles of activity and other body rhythms. For example when an animal is hungry thirsty or known to be primed for sexual responsivity the activity level is increased, provided these underlying states have not persisted for too long *Similarly* there is a correlation of the activity rhythm with the sleep wakefulness cycle In this regard the diurnal light variation seems to be a particularly important factor in the control of the activity level

Effect of estrous cycle With one exception attempts to find a hormonal mechanism that might normally influence the activity level have not been successful It has been convincingly demonstrated that the estrous cycle, which is under ovarian control has an effect on general activity of female mammals However, experimental removal of endocrine glands not affecting the estrous cycle simply depresses the activity level in a way that might be expected in a debilitated animal

Control by the brain Studies concerned with the effects of brain lesions suggest that some portions of the frontal cortex may ordinarily have an overall inhibitory influence on the activity level in mammals There is some experimental support for the general expectation that subcortical mechanisms also influence the activity level but there is as yet no definitive information to indicate that these lower centers contribute any of the rhythmic aspects of the activity level *See* BRAIN (R A W)

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Boiler feed water

Water added to a steam generating unit at a rate commensurate with the removal of steam from the unit. Addition of water to an operating steam boiler requires the use of a feed water pump or other de vice that will develop a pressure higher than that of the generated steam It also requires means for control of the rate at which water is added

Reciprocating plunger type pumps driven by steam from the boiler itself acting upon pistons of larger area are used in many instances for the smaller sizes of units and have the advantage of simplicity and independence from other sources of power These pumps may have single or multiple cylinders with single or double acting plungers and can be operated at variable speed to deliver the water at a sufficiently steady and controlled rate to maintain water level in the drum

Pumps for the larger high pressure units are usu ally of the centrifugal type with multiple stages connected in series to develop the required feed water pressure They may be driven by electric motors or by auxiliary steam turbines When a pump is operated at constant speed flow is con trolled by regulating valves in the discharge piping to the economizer or boiler

Portable fire tube boilers are sometimes served by a feed water injector which utilizes the energy of a jet of steam supplied from the boiler itself that develops high velocity by expanding through a nozzle and imparts kinetic energy to entrained sup ply water that is converted to pressure in a dis charge tube connected to the boiler shell

For boilers having relatively large water storage capacity such as the shell type or multiple drum water tube units intermittent manual regulation of feed water flow is adequate for maintaining the wa ter level within acceptable high and low limits Automatic control gives closer regulation

Water level is made visible by an illuminated gage glass required by law for reasons of safety It is attached to a water column or vertical chamber that is connected without obstruction between up per and lower nozzle openings provided in the drum Audible alarm signals operated by float or other mechanism in the water column are some times used to give warning of extreme conditions

For water tube boilers having single drums of relatively small diameter more continuous and ex act regulation of feed water is required Automatic single element control devices can be used to oper ate the supply valve or to change pump speed in response to change in water level

A condition known as swell or surge is caused by the steam in the generating tubes below the water surface Changes in rate of generation affect the volume of submerged steam with consequent dis placement of water into or out of the drum

Swell can be compensated for by automatic three element control which regulates the rate of feed water flow primarily to equal the rate of steam output as determined by metering equipment but follows this with readjustment to restore water level to the normal range *See* FEED WATER STEAM GENERATING UNIT [F G E]

Boiler water

Water in the steam generating section of a unit (*see* STEAM GENERATING UNIT) A sufficient quan tity of water must be maintained in a boiler to as sure circulation along and cooling of the heat absorbing surfaces Because the steam withdrawn is of high purity contaminants that enter with the feed water even in small concentrations accumu late in the boiler water These substances can be rendered harmless by additions of chemicals for internal treatment proportions are determined by sampling and analysis of the boiler water The contaminants are ultimately removed by blowdown

Although most troublesome impurities are re moved from the water before it is pumped into a boiler (*see* BOILER FEED WATER) residual amounts are inevitably present and other less objectionable solutes may remain or actually be contributed by the treating process Contamination of condensate may occur from leakage of raw cooling water into the main condenser Other impurities such as iron or copper may be acquired from the piping and equipment of the preboiler system

Corrosion of steel is minimized by maintaining an alkaline condition of the boiler water This is normally produced by the internal chemical treat ment required for prevention of scale and should be held within the range of 10 5 11 5 pH

Residual calcium hardness is eliminated by in troducing sodium or potassium phosphate which causes precipitation of calcium as a phosphate sludge Under proper conditions of alkalinity mag nesium is precipitated as a nonadherent hydroxide The sludge and hydroxide are carried in suspension and eventually removed in the blowdown

For pressures up to 1800 psi dissolved oxygen in the feed water can be scavenged as it enters the drum by maintaining a small concentration of so dium sulfite or hydrazine in the boiler water Above this pressure complete removal of oxygen from the feed water is essential

Silica which may form adherent scale especially in combination with unreacted calcium or magne sium is held below a safe concentration that de pends on the operating pressure by control of blowdown Silica has the singular property of be ing vaporized at significant and increasing rates as temperatures of the boiler water exceed 500°F corresponding to operating pressures of 650 psi and higher In vapor solution with the output steam silica is not arrested by mechanical means (*see* STEAM SEPARATOR) and may cause trouble some deposits on turbine blades resulting in low ered capacity and costly outage for removal This difficulty can be eliminated by the use of steam washers in the steam separator drum The washers remove the silica by contact with pure condensate or feed water in which it dissolves and is retained in the boiler *See* FEED WATER [F G E]

Boiling point

The temperature at which a liquid changes to a gas For pure substances at a fixed pressure the boiling or vaporization process occurs at a single temperature as heat is added the temperature remains constant until all the liquid has boiled

The normal boiling point is defined as the boiling point at a total applied pressure of 1 atm that is the temperature at which the vapor pressure of the liquid equals 1 atm (760 mm Hg)

The pressure dependence of the boiling point (expressed as absolute temperature T_b) is given by the Clapeyron equation

$$\frac{dT_b}{dP} = \frac{T_b \Delta V_v}{\Delta H_v}$$

where ΔV_v and ΔH_v are the volume change and the heat absorbed during the vaporization process and P is the pressure exerted on the liquid Both are necessarily positive so the boiling point increases with applied pressure For substances boiling in the region of room temperature the rate of change of boiling point with temperature is approximately 0 04°/mm Hg (where the pressure is approximately 1 atm) For example for water at 100°C and 1 atm pressure $dT_b/dP = 0.0369$°/mm Hg

The boiling point cannot be raised indefinitely however As the pressure is increased the density of the gas phase increases until it finally becomes ind

it

tur

He

ormal boiling point (4 2°K) of any substance and tungsten carbide has one of the highest (6300°K)

The boiling point is a rough measure of the intermolecular potential energy of the system although the heat of vaporization is a better measure A liquid whose molecules are held together only weakly boils at a low temperature substances with stronger intermolecular forces boil at higher temperatures

For solutions of two or more compounds the melting process normally occurs over a range of temperatures and a distinction is made between the boiling point (or bubble point) the temperature at which the first bubbles of vapor appear and the condensation point (or dew point) the temperature at which the last trace of liquid disappears or alternatively at which the first droplets of liquid appear (see EQUILIBRIUM PHASE) Measurement of the boiling point of a solution and the difference between it and the boiling point of the pure solvent provides a convenient method of determining the molecular weight of a dissolved nonvolatile solute

Precision measurement of boiling points is known as ebullliometry The principal experimental difficulty is to be sure that true equilibrium is reached and that the liquid is not superheated into a metastable state See CRITICAL CONSTANT DISTILLATION, LIQUID, SOLUTION, VAPOR PRESSURE [R.L.S]

Bolometer

An instrument for measuring the energy of electromagnetic radiation in certain wavelength regions It depends for its operation on the change in resistance of a thin conductor caused by the heating effect of the radiation Bolometers are utilized in detecting the heat of radiation from stars and are especially useful in the microwave and infrared regions of the spectrum

Invented by S P Langley in 1880 a typical form of the bolometer consists of two nearly identical strips of thin (about 0 002 mm) platinum foil These strips are blackened and form two arms of a Wheatstone bridge They are mounted close together and are relatively unaffected by small changes in the ambient temperature Only one strip is exposed to the radiation to be measured The change in temperature detectable by this instrument may be less than 0 0001°C

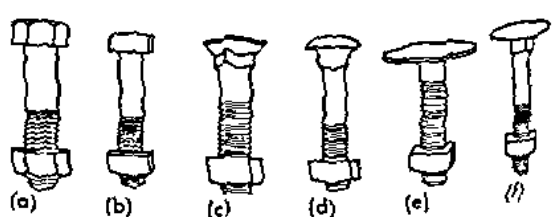
The sensitive bolometer element should be able to receive narrow beams of radiation and should be thin so it will be heated rapidly Such a bolometer in a periodically interrupted beam of radiation will produce an alternating current whose magnitude is independent of slow changes in the resistance of other components in the circuit The alternating current can be amplified and measured with instruments attached to the output of the bolometer

Large changes in resistance have been obtained by using semiconductor devices such as the thermistor or materials such as niobium nitride which become superconducting at temperatures near absolute zero See BARRETTER, RADIOMETRY, THERMISTOR [E.W.R]

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Bolt

A rod usually of metal with a head at one end and a screw thread on the other A bolt is used to fasten objects together A bolt is passed through



Examples of bolts (a) Heavy weight standard bolt (b) Regular weight standard bolt (c) Countersunk carriage bolt (d) Round head carriage bolt (e) Elevator bolt (f) Step bolt

clearance holes in two or more parts a nut is engaged on the threaded end and the parts are drawn together Bolts can be obtained in a variety of forms as illustrated each suited for a specific application American standard hexagon wrench head bolts and nuts are available in three degrees of finish unfinished bolts are finished only on the thread semifinished bolts are machined under the head and finished bolts are fully machined on all surfaces The two standard weights for bolts are regular and heavy Regular bolts are for general use Heavy bolts are for applications where a greater bearing surface is needed For the same nominal size a heavy bolt or nut has larger head and nut dimensions than one belonging to the regular series Wrench head bolts are specified by giving the diameter number of threads per inch series class of thread length finish and type of head for example

½-13 UNC-2A × 1¾ SEMIFIN HEX HD BOLT

Machine bolts are used in the automotive aircraft and machinery fields where a snug full bodied fit is needed They are available with such heads as square hexagon and flat and with either square or hexagon nuts

Stove bolts are used on electrical equipment and household appliances either in tapped holes or with nuts They are available with round oval truss or flat heads Normally they come with square nuts

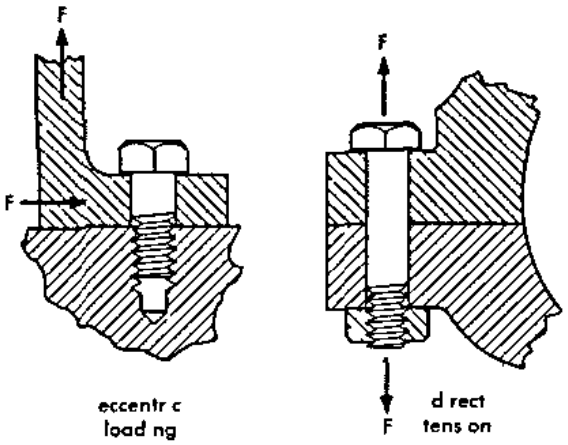
The carriage bolt is a round head type with nut it is used as a through bolt In general castings and forgings are fastened by carriage bolts with either square or hexagon nuts The head is essentially of the truss type For normal application the square neck style is used although carriage bolts can be obtained with other neck forms such as oval or ribbed

Special bolts are elevator bolts plow bolts step bolts strut bolts tire bolts T head bolts and track bolts Plow bolts are employed on agricultural equipment *See* NUT SCREW FASTENER [W J L]

Bolted joint

The assembly of two or more parts by either a threaded bolt and nut or a screw which passes through one member and threads into the other (see [illegible] assem nts

t of a riveted joint and hole spacings and bolt sizes can be calculated by the same rules and equations (*see* RIVETED JOINT) The bolt may be in single or double shear or it may be in tension The surface of the cylindrical section of a bolt is also in compression on one side when the bolt is in shear Bolts or screws may be so loaded that they are in axial tension only The bolt holding the cap on a connecting rod is an excellent example of a bolt substantially in pure tension



Two common forms of bolted joint

FASTENER) Many devices are used to determine tension as a function of the torque applied to the bolt as the tightening torque is applied Using Young's modulus of elasticity for the bolt material it is easy to calculate the tensile stress Bolt and nut assemblies often include special lock washers to prevent accidental loosening of the fastening by vibration Where critical loads are to be carried and safety is paramount bolts or screws smaller than ½ in in diameter are dangerous to use because it is easy to overload the bolt or screw in assembly and actually twist it off with standard wrench sizes *See* JOINT (MECHANICAL) STRUCTURAL CONNECTIONS WELDED JOINT [L S L]

Boltzmann constant

A constant occurring in practically all statistical [illegible] of 1 380 × letter k If rees Kelvin an energy and is usually called the [illegible] gy At 300°K (room temperature) $kT = 0.0259$ electron volt

The value of the Boltzmann constant may be determined from the ideal gas law For 1 mole of an ideal gas

$$PV = RT \qquad (1)$$

where P is the pressure V is the volume and R is the universal gas constant The value of R 8.31×10^7 ergs/°C/mole may be obtained from equation of state data Statistical mechanics yields for the gas law

$$PV = NkT \qquad (1a)$$

Here N the number of molecules in 1 mole is

called Avogadro's number and is equal to 6.02×10^{3} molecules/mole (*see* AVOGADRO NUMBER) Hence comparing Eqs (1) and (1*a*)

$$k = R/N = 1.380 \times 10^{-16} \text{ erg/°K} \qquad (2)$$

Since k occurs explicitly in the distribution formula any entity calculated using the Boltzmann distribution depends explicitly on k Examples are specific heat viscosity conductivity and the velocity of sound Perhaps the most unusual relation involving k is the one between the probability of a state W and the entropy S,

$$S = k \ln W \qquad (3)$$

which is obtained by a process of identification similar to the one just described

Any relation derived on the basis of either the partition function or the Bose Einstein Fermi Dirac or Boltzmann distribution contains the Boltzmann constant *See* BOLTZMANN STATISTICS BOSE EINSTEIN STATISTICS FERMI DIRAC STATISTICS KINETIC THEORY OF MATTER STATISTICAL MECHANICS [M DR]

Boltzmann statistics

To describe a system consisting of a large number of particles in a physically useful manner recourse must be had to so called statistical procedures If the mechanical laws operating in the system are those of classical mechanics and if the system is sufficiently dilute the resulting statistical treatment is referred to as Boltzmann or classical statistics (Dilute in this instance means that the total volume available is much larger than the proper volume of the particles) A gas is a typical example the molecules interacting according to the laws of classical mechanics are the constituents of the system and the pressure temperature and other parameters are the over all entities which determine the ma

[illegible]

n and velocity of every molecule at any time The purpose of the statistical description is to extract from the mechanical description just those features which are relevant for the determination of the mascroscopic properties and to omit the others

Distribution function The basic notion in the statistical description is that of a distribution function Suppose a system of N molecules is contained in a volume V The molecules are moving around colliding with the walls and with each other Construct the following geometrical representation of the mechanical system Introduce a 6-dimensional space (usually called the μ space) three of its coordinate axes being the spatial coordinates of the vessel x y z and the other three indicating cartesian velocity components v_x v_y, v_z A molecule at a given time having a specified position and velocity may be represented by a point in this 6-dimensional space The state of the gas a system of N molecules, may be represented by a cloud of N points in this space In the course of time this cloud of N points moves through the μ space

Note that the μ space is actually finite the coordinates x, y, z of the molecules' position are bounded by the finite size of the container and the velocities are bounded by the total energy of the system Imagine now that the space is divided into a large number of small cells of sizes w_1 w_i A certain specification of the state of the gas is obtained if at a given time t the numbers $n_1(t)$, , $n_i(t)$, of molecules in the cells 1 2 i are given The change in the state of the system in the course of time is now determined by the behavior of the functions $n_i(t)$ as functions of time Strictly speaking these functions may change discontinuously in the course of time But how detailed the description so obtained is depends of course, on the sizes chosen for the cells w_i One gets the crudest possible description by having just one cell of size V in the coordinate subspace with N particles in it all the time A very detailed description is obtained if cells the size of a molecule are chosen In that case even a small change in the state of the molecules will cause a profound alteration in the numbers n_i To apply statistical methods one must choose the cells such that on the one hand a cell size w_i is small compared to the macroscopic dimensions of the system while on the other hand w_i must be large enough to allow a large number of molecules in one cell That this is possible stems from the fact that the molecular dimensions (linear dimension about 10^{-8} cm) are small compared to macroscopic dimensions (typical linear dimension 10^{+7} cm) In this case it is possible to have about 10^{15} cells each of linear dimension 10^{-3}, where in each cell there is "room" for 10^{15} molecules If the cells are chosen in this manner, the numbers $n_i(t)$ the occupation numbers will be slowly changing functions of time The distribution functions $f_i(t)$ are defined by

$$n_i(t) = f_i(t) w_i \qquad (1)$$

The distribution function f_i describes the state of the gas and f_i of course varies from cell to cell Since a cell i is characterized by a given velocity range and position range and since for appropriately chosen cells f_i should vary smoothly from cell to cell f_i is often considered as a continuous function of the variables x y, z v_x v_y v_z The cell size w_i then can be written as $dx dy dz dv_x dv_y dv_z$

In applications the continuous notation is often used this should not obscure the fact that the cells are finite L. Boltzmann called them physically infinitesimal

Since a cell i determines both a position and a velocity range one may associate an energy ϵ_i with a cell This is the energy a single molecule possesses when it has a representative point in cell i This assumes that apart from instantaneous collisions molecules exert no forces on each other If this were not the case the energy of a molecule

would be determined by the positions of all other molecules

Boltzmann equation; H theorem Most of the physically interesting quantities follow from a knowledge of the distribution function, the main problem in Boltzmann statistics is to find out what this function is It is clear that $n(t)$ changes in the course of time for three reasons (1) molecules located at the position of cell i change their positions and hence move out of cell i, (2) molecules under the influence of outside forces change their velocities and again leave the cell i, (3) collisions between the molecules will generally cause a (discontinuous) change of the occupation numbers of the cells Whereas the effect of (1) and (2) on the distribution function follows directly from the mechanics of the system a separate assumption is needed to obtain the effect of collisions on the distribution function This assumption the collision number assumption asserts that the number of collisions per unit time of type $(i\,j) \rightarrow (k\,l)$ (molecules from cells i and j collide to produce molecules of different velocities which belong to cells k and l), called $A_{ij}{}^{kl}$, is given by

$$A_{ij}{}^{kl} = n\, n_j a_{ij}{}^{kl} \tag{2}$$

Here $a_{ij}{}^{kl}$ depends on the collision configuration and on the size and kind of the molecules but not on the occupation numbers Furthermore, for a collision to be possible, the conservation laws of energy and momentum must be satisfied, so if $\epsilon = \frac{1}{2}mv_i^2$ and $\mathbf{p} = m\mathbf{v}_i$ then

$$\epsilon_i + \epsilon_j = \epsilon_k + \epsilon_l \tag{3a}$$

$$\mathbf{p} + \mathbf{p}_j = \mathbf{p}_k + \mathbf{p}_l \tag{3b}$$

It is possible to show that the geometrical factor $a_{ij}{}^{kl}$ has the property

$$u_i w_j a_{ij}{}^{kl} = w_k w_l a_{kl}{}^{ij} \tag{4}$$

Here $a_{kl}{}^{ij}$ is the geometrical factor belonging to the collision which starting from the final velocities (k and l), reproduces the initial ones (i and j) The gains and losses of the molecules in say cell i can now be observed If the three factors causing gains and losses are combined the Boltzmann equation is obtained

$$\frac{\partial f_i}{\partial t} + (\mathbf{v}_i \nabla_x f_i) + (\mathbf{X}_i \nabla_v f_i) = \sum_{j\,k\,l} a_{ij}{}^{kl} u_i (f_k f_l - f_i f_j) \tag{5}$$

Here $\nabla_x f_i$ is the gradient of f with respect to the positions $\nabla_v f_i$ refers similarly to the velocities and $\mathbf{X}$ is the outside force per unit mass at cell i This nonlinear equation determines the temporal evolution of the distribution function Exact solutions are difficult to obtain Yet Eq (5) forms the basis for the kinetic discussion of most transport processes There is one remarkable general consequence which follows from Eq (5) If one defines

$$H(t) = \sum n_i \ln f_i \tag{6}$$

one finds by straight manipulation from Eqs (5) and (6) that

$$\frac{dH}{dt} \leqq 0 \qquad \frac{dH}{dt} = 0 \quad \text{if } f_i f_j = f_k f_l \tag{7}$$

Hence H is a function which in the course of time always decreases This result is known as the H theorem The special distribution which is characterized by the relation

$$f_i f_j = f_k f_l \tag{8}$$

has the property that collisions do not change the distribution in the course of time it is an equilibrium or stationary distribution

Maxwell Boltzmann distribution *It should be* stressed that the form of the equilibrium distribution may be determined from Eq (8) with the help of the relations given as Eq (3) For a gas which as a whole is at rest it may be shown that the only solution to the functional equation (8) is given by

$$f_i = Ae^{\beta \epsilon_i} \tag{9a}$$

or

$$f(\mathbf{x},\mathbf{v}) = Ae^{(-1/2)\beta m v^2 - \beta U}\, d^3x\, d^3v \tag{9b}$$

Here A and β are parameters not determined by Eq (8) and U is the potential energy at the point x y z Equation (9) is the Maxwell Boltzmann distribution Actually A and β can be determined from the fact that the number of particles and the energy of the system are specified namely

$$\Sigma n_i = N \tag{10a}$$

$$\Sigma n_i \epsilon_i = E \tag{10b}$$

From (9) and (10) it can be shown immediately that

$$\frac{E}{N} = \frac{3}{2\beta} \tag{11a}$$

$$A = \frac{N}{V}\left(\frac{\beta m}{2\pi}\right)^{3/2} \tag{11b}$$

Therefore β is related directly to the energy per particle while A is related to β and to the number density Other physical quantities such as pressure must now be calculated in terms of A and β Comparing such calculated entities with those observed at a certain point one identifies an entity like β (a parameter in the distribution function) with a measured quantity such as temperature More precisely $\beta = 1/kT$ where k is the Boltzmann constant This is the result of an identification It is not a deduction It is possible by specialization of Eq (9b) to obtain various familiar forms of the distribution law If $U = 0$ one finds immediately that the number of molecules whose absolute value of velocities lies between c and $c + dc$ is given approximately by

$$Ae^{-1/\beta mc}\, c^2\, dc \tag{12}$$

Equation (12) is useful in many applications

If on the other hand a gas is in a uniform gravitational field so that $U = -mgz$ one finds again from Eq (9) that the number of molecules at the height z (irrespective of their velocities) is given by

$$\text{Constant} \times e^{-\beta mgz} \tag{13}$$

If one uses the fact that $\beta = 1/kT$ then Eq (13) expresses the famous barometric density formula the density distribution of an ideal gas in a constant gravitational field

Statistical method, fluctuations The indiscriminate use of the collision number assumption leads via the H theorem to paradoxical results The basic conflict stems from the irreversible results that appear to emerge as a consequence of a large number of reversible fundamental processes Although a complete detailed reconciliation between the irreversible aspects of thermodynamics as a consequence of reversible dynamics remains to be given it is now well understood that a careful treatment of the explicit and hidden probability assumptions is the key to the understanding of the apparent conflict *See* THERMODYNAMICS (CHEMICAL) It is clear for instance that Eq (2) is to be understood either in an average sense (the average number of collisions is given by $\overline{n_i n_j} a_{ij} k l$ where $\overline{n_i n_j}$ is average of the product) or as a probability but not as a definite causal law The treatment usually given actually presupposes that $\overline{n_i n_j} = \overline{n_i}\,\overline{n_j}$ that is it neglects fluctuations

To introduce probability ideas in a more explicit manner consider a distribution of N molecules over the cells w in μ space

$$\begin{array}{ccc} w_1 & w_2 & w_i \\ n_1 & n_2 & n_i \\ \epsilon_1 & \epsilon_2 & \epsilon_i \end{array} \tag{14}$$

Let the total volume of the μ space be Ω Suppose that N points are thrown into the μ space What is the probability that just n_1 points will *end up* in cell 1 n_2 in cell 2 n_i in cell i and so on? If all points in the space are equally likely (*equal a priori probabilities*) the probability of such an occurrence is

$$W(n_1 \quad n \quad) = \frac{N!}{n_1! n_2! \quad n_i!} \left(\frac{w_1}{\Omega}\right)^{n_1} \quad \left(\frac{w_i}{\Omega}\right)^{n_i} \tag{15}$$

One now really defines the probability of a physical state characterized by Eq (14) as given by the essentially geometric probability shown in Eq (15) The probability of a state so defined is intimately connected with the H function If one takes the ln of Eq (15) and applies Stirling's approximation for $\ln n!$ one obtains

$$\ln W = -H \tag{16}$$

(*see* PROBABILITY) The H theorem which states that H decreases in the course of time therefore may be rephrased to state that in the course of time the system evolves towards a more probable state Actually the H function may be related (for equilibrium states only) to the thermodynamic entropy S by

$$S = -kH \tag{17}$$

Here k is again the Boltzmann constant

Equations (16) and (17) together yield an important result,

$$S = k \ln W \tag{18}$$

which relates the entropy of a state to the probability of that state sometimes called Boltzmann *relation*

The state of maximum probability, that is the set of occupation numbers $n_1, \quad n$ which maximizes Eq (15), subject to the auxiliary conditions given in Eq (10), turns out to be given by the special distribution

$$n_i = Ae^{-\beta\epsilon_i} \tag{19a}$$

$$\Sigma n_i = N \tag{19b}$$

$$\Sigma n_i \epsilon_i = E \tag{19c}$$

This again is the Maxwell Boltzmann distribution Hence the equilibrium distribution may be thought of as the most probable state of a system If a system is not in equilibrium it will most likely (but not certainly) go there, if it is in equilibrium it will most likely (but not certainly) stay there By using such probability statements it may be shown that the paradoxes and conflicts mentioned before *may indeed be removed* The general situation is still not clear in all details although much progress has been made especially for simple models A consequence of the probabilistic character of statistics is that the entities computed also possess this characteristic For example, one cannot really speak definitively of the number of molecules hitting a section of the wall per second but only *about* the probability that a given number will hit the wall or about the average number hitting In the same vein the amount of momentum transferred to a unit area of the wall by the molecules per second (this in fact is precisely the pressure) is also to be understood as an average This in particular means that the pressure is a fluctuating entity In general it may be shown that the fluctuations in a quantity Q are defined by

$$\frac{\overline{Q^2} - (\overline{Q})^2}{(\overline{Q})^2} \cong \frac{1}{N} \tag{20}$$

where $\overline{Q}$ = the average of Q and N = number of particles in the systems When the fluctuations are small the statistical description as well as the thermodynamic concept is useful The fluctuations in pressure may be demonstrated by observing the motion of a mirror suspended by a fiber in a gas On the average as many gas molecules will hit the back as the front of the mirror so that the average displacement will indeed be zero However it is easy to imagine a situation where more momentum is transferred in one direction than in another

resulting in a deflection of the mirror From the knowledge of the distribution function the probabilities for such occurrences may indeed be computed the calculated and observed behavior agree very well (*see* BROWNIAN MOVEMENT) This clearly demonstrates the essentially statistical character of the pressure

For some important applications of Boltzmann statistics *see* KINETIC THEORY OF MATTER for fundamental theory, *see* STATISTICAL MECHANICS *see also* BOLTZMANN TRANSPORT EQUATION QUANTUM STATISTICS [M DR]

Bibliography See STATISTICAL MECHANICS

Boltzmann transport equation

An equation which describes in mathematical terms the behavior of a collection of particles under the influence of driving forces An assembly of particles is described statistically by specifying the distribution function $f(\mathbf{p}\,\mathbf{r})$ which gives the probability that a particle of momentum $\mathbf{p}$ will be found in the six dimensional volume element $dp_x dp_y dp_z dx dy dz$ centered about $\mathbf{p}$ and the coordinate point $\mathbf{r}$ When no external force fields act on the particles they will attain an equilibrium distribution by virtue of their mutual interactions such as collisions This equilibrium distribution depends on the statistics obeyed by the particles—Fermi Dirac statistics for particles of half integral spin and Bose Einstein statistics for particles of integral spin *See* BOSE EINSTEIN STATISTICS FERMI DIRAC STATISTICS *see also* BOLTZMANN STATISTICS KINETIC THEORY OF MATTER STATISTICAL MECHANICS

This article is concerned with electrical conductivity of metals However the problem encountered in finding $f(\mathbf{p}\,\mathbf{r})$ is not unique to the theory of electrical conductivity Also in the theory of gas discharges the theory of diffusion and viscosity and the treatment of diffusion of neutrons the transport equation which is presented here is valid

Usual form of equation The function $f(\mathbf{p}\,\mathbf{r})$ is obtained by solving a continuity equation The requirement that $f(\mathbf{p}\,\mathbf{r})$ represent a steady state solution is equivalent to the equation

$$-\left(\frac{\partial f(\mathbf{p}\,\mathbf{r})}{\partial t}\right)_{force} = \left(\frac{\partial f(\mathbf{p}\,\mathbf{r})}{\partial t}\right)_{collisions} \qquad (1)$$

where the left hand side represents the time rate of change of the distribution function due to driving forces If the driving forces are of electromagnetic origin one obtains the usual form of the Boltzmann transport equation

$$q\left[\mathbf{E} + \frac{1}{c}(\mathbf{v}\times\mathbf{H})\right]\cdot\nabla_p f(\mathbf{p}\,\mathbf{r}) + \mathbf{v}\cdot\nabla_r f(\mathbf{p}\,\mathbf{r}) = \left(\frac{\partial f}{\partial t}\right)_{coll} \qquad (2)$$

where q is the charge of the particle $\mathbf{E}$ is the electric field intensity c is the velocity of light $\mathbf{v}$ is the velocity of the particle and $\mathbf{H}$ is the magnetic field intensity

Equation (2) is merely a formal statement that in the steady state the number of particles in any given element $dpdr$ is constant in time The first term of the left hand side of Eq (2) gives the number of particles which leave that element of phase space per unit time because of a change in their momentum This change comes about by virtue of the accelerating force in this case the electromagnetic force acting on a moving charged particle The second term of the left hand side gives the number of particles which leave the same element $dpdr$ per unit time because of their finite velocities that is because of motion which takes them from a region dr to a region dr' in a given time interval The right hand side of Eq (2) corresponds to the net number of particles which enter this same volume element per unit time because of collisions The left hand side of Eq (2) is called the drift term the right hand side the collision term of the Boltzmann equation

Quantum mechanical analog The Boltzmann equation as presented by Eq (2) does not provide a completely satisfactory description of the physical system This equation was obtained by arguments of classical physics only It is known however that in calculations of properties of particles such as electrons nuclei and atoms a quantum mechanical procedure should be used A quantum mechanical description of the physical system can be given in terms of the density matrix $\rho(\mathbf{p}\,\mathbf{p}')$ The analog of the classical Boltzmann equation is then

$$i\left(\frac{\partial \rho}{\partial t}\right) = [H\,\rho] \qquad (3)$$

Here H is the complete Hamiltonian for the assembly of particles and $[H\,\rho]$ is the commutator of H and ρ The solution of Eq (3) will specify how ρ evolves in time in the presence of force fields and other perturbations that may be present provided these force fields and perturbations are included in the Hamiltonian The problem of finding a solution to Eq (3) has been considered and it appears that the classical Boltzmann equation is valid in the limit of weak fields *See* HAMILTON'S EQUATIONS OF MOTION QUANTUM THEORY NONRELATIVISTIC

Solution for electrons The remaining portion of this article is restricted to electrons which obey Fermi Dirac statistics The collision term for electrons may be written

$$\left(\frac{\partial f}{\partial t}\right)_{coll} = \int [S(\mathbf{p}\;\mathbf{p}')f(\mathbf{p}')[1 - f(\mathbf{p})] - S(\mathbf{p}\;\mathbf{p}')f(\mathbf{p})[1 - f(\mathbf{p}')]]\,d\mathbf{p}' \qquad (4)$$

Here $f(\mathbf{p})$ now represents the probability of occupation of a quantum state of this momentum and $S(\mathbf{p}\,\mathbf{p}')$ is the probability per unit time for a transition from an initial state $\mathbf{p}$ to a final state $\mathbf{p}'$ because of collisions The first term in the integrand represents scattering events from a state of mo

mentum p to the state of momentum p the second term scattering from the state p to the state p′ In the first term the factor $f(\mathbf{p})[1-f(\mathbf{p}')]$ appears because the event in question can occur only if the initial state is occupied [probability $f(\mathbf{p})$] and the final state p is unoccupied (probability $[1-f(\mathbf{p}')]$)

When Eq (4) is substituted into Eq (2) one obtains an integrodifferential equation It has not proved feasible to obtain a solution of this equation in closed form in the general case

The Boltzmann equation can be solved without difficulty provided two assumptions are made First one assumes that the electric and magnetic fields are sufficiently weak to permit a perturbation approach Second one assumes that the collision term may be expressed by means of a relaxation time $\tau(\mathbf{p})$ for the electrons which though it may be a function of p does not depend on the deviation of $f(\mathbf{p}\,\mathbf{r})$ from the equilibrium distribution These conditions are not always satisfied however *See* RELAXATION TIME (ELECTRONS)

According to the first assumption one writes

$$f(\mathbf{p}\,\mathbf{r}) = f_0(\epsilon) + f_1(\mathbf{p}\,\mathbf{r}) \tag{5}$$

where $f_0(\epsilon)$ is the Fermi Dirac distribution The existence of a meaningful relaxation time is equivalent to the statement that the approach to equilibrium as a result of collisions is exponential in time with a single characteristic time constant τ that is

$$\left(\frac{\partial f}{\partial t}\right)_{coll} = -\frac{f-f_0}{\tau} \tag{6}$$

One can now show that the solution to Boltzmann's equation is given by

$$f_1 = -\mathbf{v}\cdot\psi(p\,r)\frac{\partial f_0}{\partial \epsilon}$$

$$\psi(p\,r) = \frac{\tau[\mathbf{P} - \alpha\tau\mathbf{H}\times\mathbf{P} + (2\tau)^2\mathbf{H}(\mathbf{H}\cdot\mathbf{P})]}{1+(\alpha\tau H)^2}$$

$$\text{where } \mathbf{P} = e\mathbf{F} - T\nabla\left(\frac{\eta}{T}\right) - \frac{\epsilon}{T}\nabla T \qquad \alpha = e/mc \tag{7}$$

Here e is the electronic charge η is the Fermi energy ϵ is the energy of the electron and m is its mass

It is now possible to obtain all of the transport properties of the collection of electrons described by the distribution function which is obtained when Eq (7) is substituted into Eq (5) For example the electric and thermal current densities J and Q are given by the integral over the distribution of ev and of ϵv respectively In the case of vanishing magnetic field one finds that

$$\mathbf{J} = \lambda_1\left[e^2\mathbf{F} - eT\nabla\left(\frac{\eta}{T}\right)\right] - K_2\left(\frac{e}{T}\right)\nabla T \tag{8}$$

$$\mathbf{Q} = \lambda_2\left[e\mathbf{F} - T\nabla\left(\frac{\eta}{T}\right)\right] - \lambda_3\left(\frac{1}{T}\right)\nabla T \tag{9}$$

$$\text{where} \qquad \lambda_n = -\frac{4}{3m}\int N(\epsilon)\tau\epsilon^n\frac{\partial f_0}{\partial \epsilon}\,d\epsilon$$

provided the energy is a quadratic function of the magnitude of the momentum The relationship between the energy and the momentum of electrons in metals is frequently more complicated In that event the expression for λ_n has to be modified somewhat *See* FREE ELECTRON THEORY OF METALS [F J B]

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Bonding

The act of connecting the various structural metal parts of a metal enclosure or vehicle (aircraft automobile) so that these parts form a continuous electrical unit Bonding serves to minimize or eliminate interference such as that caused by ignition systems It also prevents buildup of static electricity on one part of the structure, which can by subsequent discharge to other parts cause static interference Bonding is achieved by bolting the parts together in such a way as to achieve good electrical contact or by connecting them with heavy copper cables or straps *See* NOISE, ELECTRICAL

Bonding also refers to the fastening together of two pieces by means of adhesives as in anchoring the copper foil of printed wiring to an insulating baseboard *See* ADHESIVE [J MR]

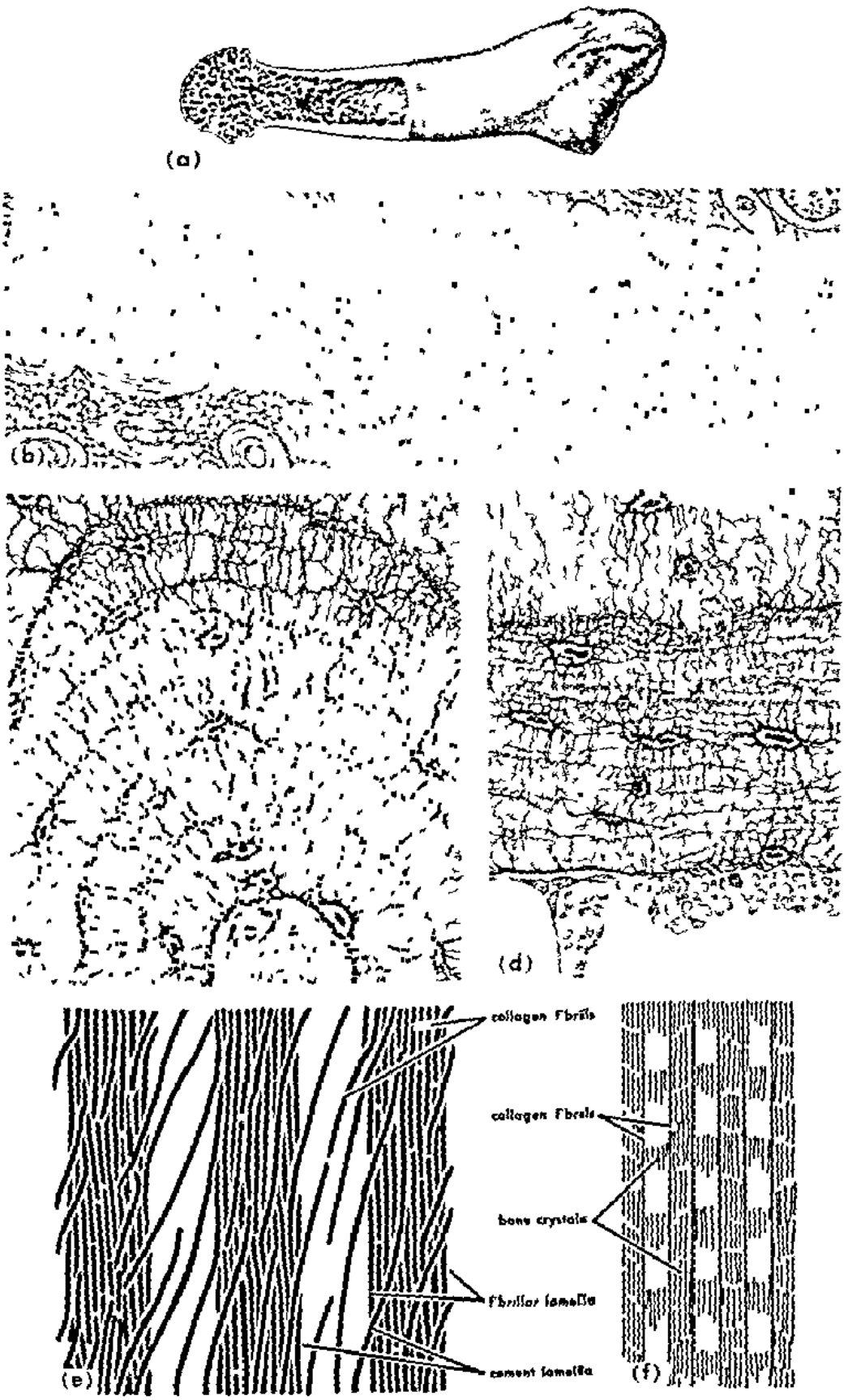
Bone

The hard connective tissue which forms the skeleton of vertebrates For a detailed discussion of histology of bone *see* SKELETAL SYSTEM, for a detailed discussion of biochemistry of bone *see* SPECIALIZED TISSUE

Bone consists of collagen fibrils which have become organized in layers and upon which there is an impregnation of mineral salts especially calcium phosphate and carbonates Organic material consisting of blood bone cells (osteocytes) and cartilaginous material, are also present *See* CONNECTIVE TISSUE

The outer portion of most bones is compacted into a hard shell like cortex, the inner portions are porous or spongy In the typical long bones of the adults the compact outer bone is present as a hollow long shaft with a medullary cavity containing either bone marrow or fatty tissue depending on hematopoietic activity The spongy portions of these long bones are found in the end regions or epiphyses, where new growth occurs in undeveloped bones

While most bone is formed by transformation of a cartilaginous precursor some bone develops directly from the deposit of minerals in fibrous tissue The time of ossification of different bones follows a definite pattern providing there is no abnormality of formation The primary centers of ossification of the larger human bones appear about the end of the second month of fetal life At birth many bones have not yet begun to ossify, for example some of



General view of structure of bone from the gross to the submicroscopic (a) Fifth metatarsal human (b) Low power microscopic view of dense bone showing Haversian system (osteon) (c) High power microscopic view of transverse section of osteon (d) High power microscopic view of longitudinal section of osteon (e) Diagram of submicroscopic relations of adjacent fibrillar and cement lamellae (f) Diagram of submicroscopic relations of bone crystals and collagen fibrils

those of the wrist Completion of ossification does not occur in some bones until after puberty or even later *See* CALCIUM METABOLISM PARATHYROID GLAND

Aside from furnishing the principal means of support for the body the bones also act as levers for motion the type being dictated by the nature of the articulation concerned

In most older persons there are additional small bones found in various areas particularly around joints or imbedded in tendons These sesamoid bones are of inconstant appearance and are usually noted only incidentally

The importance of the closely adherent fibrous covering of bones the periosteum cannot be over estimated This thick layer of connective tissue carries nutrient blood vessels in its deeper parts and the nutrition of the underlying bone depends almost entirely on this supply The periosteum itself is osteogenic that is bone-producing especially in the younger individual when full growth has not been attained The osteogenic properties of periosteum are of vital importance in formation of new bone after injury as in the repair of fractures

Bone is not the inert substance it was formerly believed to be but acts as a dynamic and powerful factor in general body metabolism particularly with regard to calcium and other inorganic ions The influences of vitamin D pituitary growth hormone estrogens and the thyroid and parathyroid hormones can readily be seen in many disease states in which these important regulating substances are altered *See* BONE (BIOPHYSICS)

[E G ST]

Bone (biophysics)

Bone represents the supporting tissue of the body As such it shows a truly amazing example of the relationship of structure and function Bone is an outstanding example of he

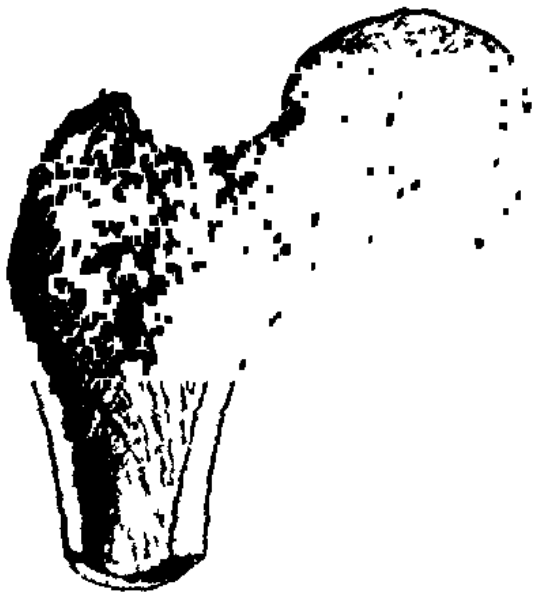
[illegible] unit of bone is the osteon or Haversian system This consists of a thin wall of blood vessels with its surrounding concentric layers of bone through which are spaced the living bone cells the osteocytes The metabolism of bone is quite rapid and the Haversian systems apparently are constantly replaced throughout life In bone from older persons this process apparently slows down since there is a considerable amount of dead bone in wh[illegible] blood [illegible] placec[illegible] not a[illegible] [illegible]ough understood however it seems to explain the increasing brittleness of bone with age

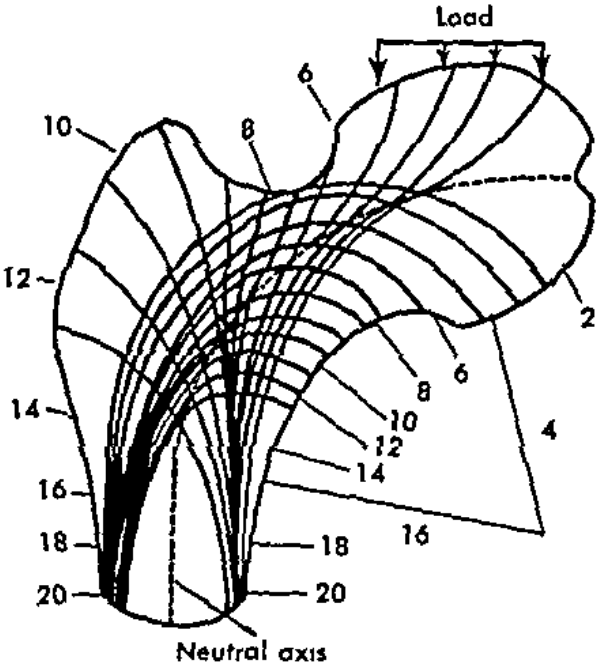
Components The actual bone substance itself consists of both organic and inorganic components The organic represents approximately one half by weight and two-thirds by volume with considerable variations apparently largely due to age and the amount of use The main organic component is collagen This collagen apparently differs only very slightly from the collagen existing in connective tissue In addition to this there is a ground substance which appears to be very similar to the interstitial fluid of connective tissue The organic component is similar to a naturally occurring mineral called calcium hydroxy apatite The crystalline structure of this mineral is well known however in living bone there seems to be a number of additional ions which may either be replacements for some of the usual elements in the crystalline structure or may find their way into the interstices of the crystal lattice When the organic and inorganic components are constituted into normal bone the strengthening effect is apparently similar to the Biblical bricks made with straw or to a modern fiberglass plastic laminate

Strength The structure of bone is stronger in compression than in tension in the ratio of about 4 3 thus, most fractures occurring in bone are tension or shear failures Because bone is alive and constantly being repaired it has one very unusual quality it almost never fails due to fatigue The only examples of a fatigue fracture in bone are those seen usually in military training and hence called *march fractures* in which a soldier not previously used to repetitive exercise is forced to march 30 or 40 miles in a single day This may result in a fatigue fracture of one of the foot metatarsal bones

A number of records have been made of the breaking strength of bone and these have varied considerably depending upon the preparation of the tissue the species and the age of the bone Other studies have shown that in the human fibula there is a considerable difference in the breaking strength from one portion of the bone to another All of this seems to indicate that bone is not a standard structure but varies significantly depending upon its function

The Haversian systems or osteons of bone are usually oriented parallel to the long axis of the bone and this apparently is reflected in Benninghoff s lines which can be demonstrated after the bone is decalcified and a needle is inserted into the surface Longitudinal splits occur in the shaft of most long bones However in areas of tendon attachments no such splits can be demonstrated apparently because of the different orientation of the bone in these areas The gross structure of bone as well as the fine structure apparently reflects the distribution of stress bone has been said to represent a nearly perfect engineering design considering the materials which are available biologically The joint cartilage consists of a rubbery substance with very great durability which represents the actual bearing surface This joint cartilage however has no structural strength It is supported by a plate of bone the subchondral plate which forms the end of the bone proper This subchondral plate is supported by a framework of bone called trabec



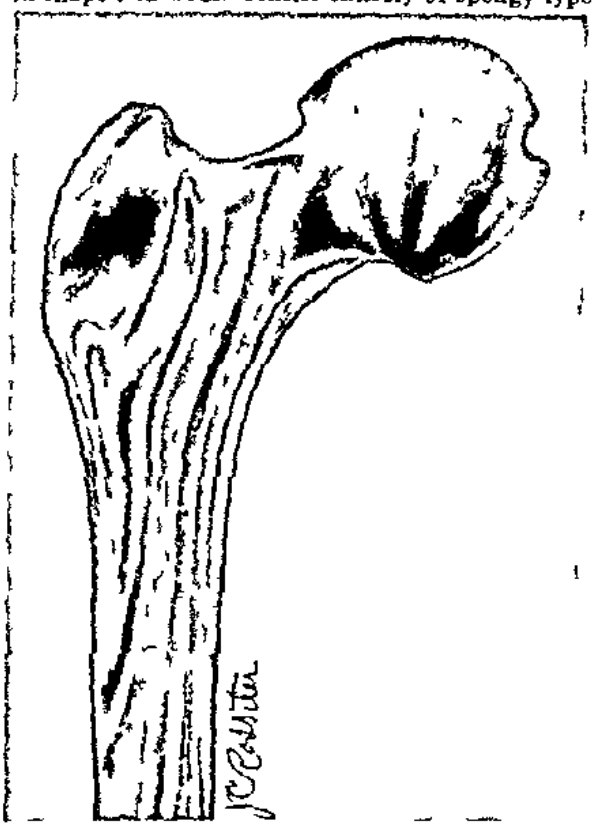


Frontal longitudinal section of left femur shown with calculated trajectories of principal stresses in right femur Numbers mark positions of transverse sections for analysis (J C Koch, Laws of bone architecture Am J Anat 21 177–298 1917)

ulae The elements of this trabecular framework are oriented according to known engineering laws of stress distribution and are supported by other trabeculae which meet them at right angles This is considered to be the best method for supporting a long thin structural column The trabecular systems exist only near the ends of the bone where the pattern of stress transmitted to the bone through the joint is relatively simple In the central portion of the bone the structure becomes tubular, and such a structure is recognized as being the most efficient method of transmitting forces encountered here, tension compression, torsion and bending or any combination of these

Testing The testing of bone using the Stresscoat technique has indicated that the bone is so nicely designed that there are no areas of sharp concentration of stress The Stresscoat method uses a brittle lacquer and therefore must be applied to dried and properly prepared bones It is not possible to stress these bones exactly as forces are applied in the body The use of the photoelastic method gives similar results, although this method is open to rather serious questions since it must be carried out with plastic models of the bone and it is certain that the very complex microscopic and macroscopic structure of bone cannot be duplicated by a single piece of plastic Results of photoelastic analysis however, are quite similar to those carried out by the Stresscoat method and indicate once again that there are no areas of very great concentration of forces in the bone

Developmental aspects From the developmental standpoint the growing bone represents truly amazing adaptations and a response to function The length of the bone is controlled by the rate of growth of the epiphyseal line which is a small cartilage plate at the end of the bone If this epiphyseal line were the only factor controlling the growth of the bone the bone would be hourglass in shape and would consist entirely of spongy type



Photoelastic stress pattern of upper end of femur (H M Ich Photo-elastic studies of bone forms J Bone and Joint Surg 22(3) 621–626 1940)

of bone The thickness of the bone however is supplied by growth of bone from the periosteum where the bone develops directly in connective tissue If the only factor of the periosteum were that of bone growth the bone would be very much thicker than it actually is The third factor then is that of bone absorption The bone follows the engineering laws of stress applied so that immediately below the growing epiphyseal line the excess bone both on the outside of the shaft and in the narrow cavity is removed thus ending up with a hollow narrow cavity and a shaft which expands to a graceful trumpet shape in approaching the epiphyseal line at the end During the active period of bone growth in children this process of remodeling is so active that a healed fracture may be impossible to identify after a period of a year or two because of the marked remodeling that has taken place with bone growth

Summary Bone represents a remarkable adaptation of structure to function from its microscopic to macroscopic characteristics The important factor in modeling the bone is strain imposed by stress of use and this apparently leads to differences in the consistency of bone from one part of the bone to another The strength of bone is not only variable from one portion of the bone to another but from one species to another and particularly it varies markedly with the age of the individual Chemically bone represents a plastic laminate with organic materials consisting of collagen and interstitial substance impregnated with inorganic materials of a mineral hydroxy apatite

See BIOPHYSICS BONE [C O BF]

Book manufacture

The production of books in their physical form as distinguished from their literary creation Although it is an essential part of book publishing book manufacturing is mostly carried on by outside plants few publishers maintain their own production facilities The process is similar in most respects to the production of other forms of printing but differs in that a number of specialized operations centered chiefly in the bindery are involved Manufacturing expenses constitute the largest percentage about 40% of the book publisher s sales dollar

Orders for book manufacturing emanate from book publishers in the form of specifications for the purchase of the typography or type composition of the book its printing and finally its binding Most book manufacturers provide a complete service covering all the above together with storage and shipping service for their publisher customers They may also include plate making services or offset lithography printing or sometimes both Others may provide only binding or other combinations

Type and plates The cycle of book manufacturing commences with the setting of the type This is usually done on line-casting composing machines less frequently on single-letter typecasting units and sometimes by composition on film by a photocomposing machine Proofs (or in the latter case positives) are supplied to the publisher usually in the form of galleys—long sheets each carrying about 20 in of type Corrections and any changes by the author (author s alterations) are entered on these and the type corrected accord

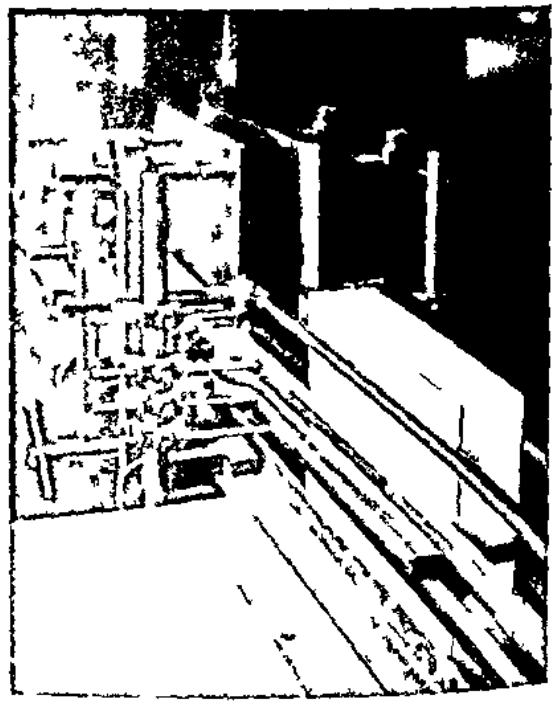


Fig 1 Gathered signatures being jogged into position prior to gluing of backs (*Rand McNally*)

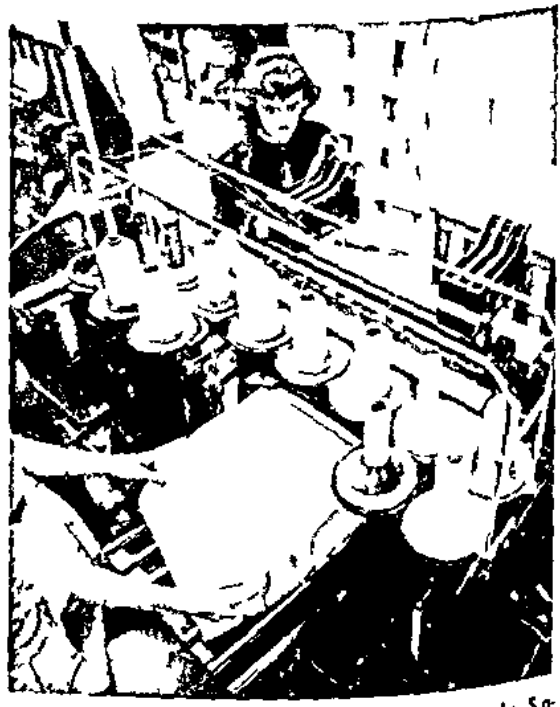


Fig 2 Smythe-sewing of the signatures of books Signatures come from machine in continuous sewed section and are cut apart as they come from machines Collating marks are shown (*Rand McNally*)

ingly Following a predetermined type page format usually derived from the setting and making up of sample pages in advance the galleys of type are broken into pages mostly of straight text matter but including display typography for title pages contents chapter openings and part titles Indexes and other material are added page proofs are pulled and the pages are proofread for elimination of any final errors

If the book is to contain illustrations these may be supplied by the publisher as photoengravings either line or halftone If the former they are inserted in their designated places in the pages of type to be printed with the text matter If they are halftones (reproductions of photographs wash drawings or other tonal copy) they will usually be printed on a separate sheet or sheets of coated or smooth finish paper and bound into the book separately

If the book is to be printed by offset lithography photographic negatives of the artwork and of the type (the latter made from press or repro proofs of the type) are assembled or stripped together into pages and the pages stripped together into flats which are the equivalent of type forms in letterpress These flats which may include 4 8 16 or more pages are really large composite negatives with the smaller negatives mounted into correct position within a frame of heavy opaque paper and from them offset plates are made

In most instances the book will be printed from electrotypes or plastic plate reproductions of the type matter and engravings These are duplicate plates made from molds of the type pages In the case of electros plates are shaved trimmed and beveled for attachment to the bed of the press With plastic plates much the same procedure is followed *See* COMPOSITION (TYPE) PRINTING PLATE

Printing presses If the book is a comparatively short run of a few thousand it will probably be printed on flat bed cylinder letterpresses The plates are mounted by means of catches on a special base carried on the bed of the press and are so arranged or imposed as to enable the printed sheet to be folded down into a signature in which the pages will be in consecutive order Signatures are in various multiples of four pages generally 32 128 depending upon the caliber of the paper For longer runs the sheets may be printed from electros or plastic plates which have been curved to fit the plate cylinder of a rotary press which operates at much higher speeds An extremely long run may be printed on a similar type of press but one which is fed from a continuous web of paper from a roll When books are printed by offset the plates in the form of large flexible sheets of metal are wrapped around the plate cylinder of the press and the book is printed by the rotary principle Some web offset equipment in multicolor is likewise used *See* PRINTING

Binding operations At this stage end sheets made of stronger and heavier paper and sometimes printed or tinted are pasted to the first and last signatures of the book to form the bond between book and cover At the same time any illustrations on different stock are pasted to the required position on or in the signature Those which are to be wrapped around a signature are so positioned in the gathering operation

The printed sheets now go to the bindery for folding on large high speed folders and depending upon the number of pages in the book are folded

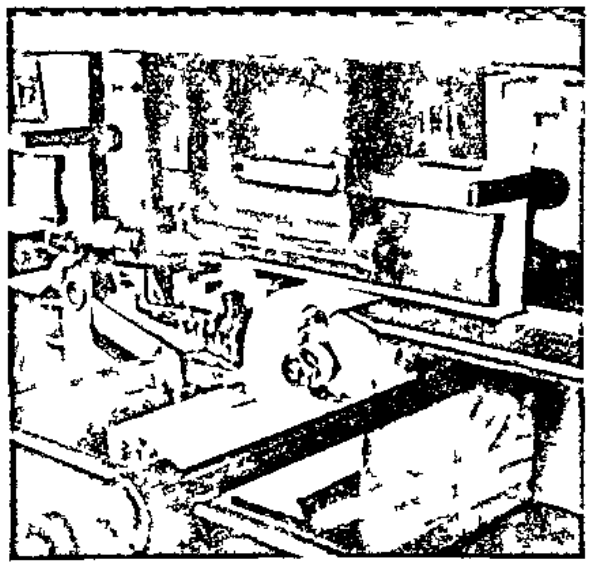


Fig 3 Gluing of the gathered folded pages of a book Glue applied to the back of the signatures holds them in position until they can be McCain sewed together (*Rand McNally*)

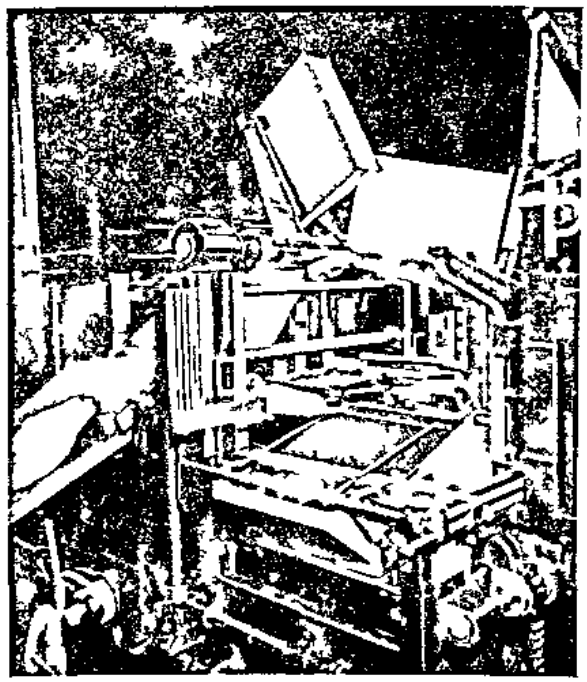


Fig 4 Casing in machine Here the cover or case is applied to the sewed pages of the book (*Rand McNally*)

into the various combinations referred to most commonly in 32 and 64-page signatures These are then loaded into the hoppers of the long gathering machines each signature being in its own hopper station and in the proper numerical sequence When the machine is in operation the grippers of each hopper station pull down and deposit on a traveling chain the correct signature for that station the successive signatures being placed one on top of the other so that a complete book composed of all the signatures with signatures arranged in order is delivered at the end of the machine

Most books are sewed through the middle of each signature and signature to signature until the entire book is sewed Books are then given a light coat of glue along the sewed back edge enough to hold the book in shape for trimming to prearranged size Many school books and other reference books are side sewed—that is sewed at the edge of the signatures near the back of the book

Books are also bound by so called perfect binding a process which relies on the fibrous nature of the paper and the quality of the adhesive instead of the sewing to hold the book together After such books have been gathered the backs of the folds are trimmed off the edges usually roughened and a coat of highly flexible glue is applied to form the bond between the pages On some machines a strip of stretchable cloth or paper is applied for further reinforcement

The glued book either sewed or perfect bound is then trimmed on two or three sides depending on the publisher s preference for smooth or rough trim and is then fed to the hopper of the rounding and backing machines Here the back is formed into a flat arc the crease in the edge formed another coat of glue applied over the back and one or two strips of crash or paper applied The last crash unit is about 1 in wider than the thickness of the book These flaps will in the next stage afford the hinge between book and cover Some books will have the bits of multicolored woven cloth called head and tail bands glued on in the same operation

fed or a web fed casemaker Any one of these machines may also combine cloth and paper or two kinds of cloth into cases on which a strip of one material runs down the back of the book or across its front cover in combination with other different or similar materials

Decoration of the cover including the lettering of the title author's name and publisher may be achieved by hot stamping the finished case from the impress on a brass d
the pigmer
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ing may al
of letter quality and in various colors of special stamping inks for less expensive books Designs and illustrations for the cover usually originate with the publisher

The majority of schoolbook covers are printed in full color offset on the cloth before casemaking and then sheeted for that operation In some instances the title data may be stamped on in ink in a separate impression

Final unification of the book and its cover is made in the casing in and building in operations As the former implies an adhesive is applied to the endsheets of each book fed into the machine the cover drawn from a hopper and fitted to the book and the book discharged for the next stage

Some books are built in or pressed until dry in the time-honored way of stacking them between edged boards which fit into the hinge of the book after which screw clamps are applied and the books kept in press for a few hours until dry Newer methods however are rapidly replacing this system These include the use of building in or the various kinds of pressing machines which apply heat and pressure to the cover and the joint of the freshly cased book so that it is dry and ready for jacketing and shipment

Books intended for general bookstore and other consumer sales are generally jacketed by hand or machine and then packed in cartons or strapped on skids for shipment or for storage [B WO]

Boolean algebra

A branch of mathematics that was first developed systematically because of its applications to logic by the English mathematician George Boole around 1850 Closely related are its applications to sets and probability It also underlies the theory of relations A modern engineering application is to electrical relays *See* SWITCHING THEORY

Set theoretic interpretation Most basic is the use of Boolean algebra to describe combinations of the subsets of a given set I of elements its basic operations are those of taking the intersection or common part $S \cap T$ of two such subsets S and T their union or sum $S \cup T$ and the complement S' of any one such subset S These operations satisfy many laws including

$$S \cap S = S \qquad S \cap T = T \cap S \qquad (1)$$
$$S \cap (T \cap U) = (S \cap T) \cap U$$

$$S \cup S = S \qquad S \cup T = T \cup S \qquad (2)$$
$$S \cup (T \cup U) = (S \cup T) \cup U$$

$$S \cap (T \cup U) = (S \cap T) \cup (S \cap U) \qquad (3)$$
$$S \cup (T \cap U) = (S \cup T) \cap (S \cup U)$$

If O denotes the empty set and I is the set of all elements being considered then the following laws are also fundamental

$$O \cap S = O \qquad O \cup S = S \qquad I \cap S = S \qquad (4)$$
$$I \cup S = 1 \qquad S \cap S' = O \qquad S \cup S = I$$

The above laws are fundamental all other algebraic laws of subset combination can be deduced from them

In applying Boolean algebra to logic Boole observed that combinations of properties under the common logical connectives and or, and not also satisfy the laws specified above These laws also hold for

propositions or assertions when combined by the same logical connectives

Boole stressed the analogies between Boolean algebra and ordinary algebra If $S \cap T$ is regarded as playing the role of st in ordinary algebra $S \cup T$ that of $s+t$ O of 0 I of 1 and S as corresponding to $1-s$ the laws listed above illustrate many such

$S \cup T$ is $s+t-st$ Using Stone's analogy Boolean algebra refers to Boolean rings in which $s^2 = s$ a condition implying $s+s=0$ *See* RING THEORY SET THEORY

Boolean algebra arises in other connections as in the algebra of (binary) relations Such relations ρ σ refer to appropriate sets of elements I J

Any such ρ can be defined by describing the set of pairs $(x\ t)$ with x in I and y in J that stand in the given relation—a fact symbolized $x\ \rho\ y$ just as its negation is written $x\ \rho\ y$ Because of this set theoretic interpretation Boolean algebra obviously applies with $x(\rho \cap \sigma)y$ meaning $x\ \rho\ y$ and $x\ \sigma\ y$ and $x(\rho \cup \sigma)y$ meaning $x\ \rho\ y$ or $x\ \sigma\ y$

Abstract relationships Before 1930 work on Boolean algebra dealt mainly with its postulate theory and with the generalizations obtained by abandoning one or more postulates such as $(p) = p$ (Brouwerian logic) Since $a \cup b = (a \cap b)$ clearly one need consider $a \cap b$ and a as undefined operations In 1913 H M Sheffer showed one operation only $(a \mid b = a \cap b)$ need be taken as undefined In 1941 M H A Newman developed a remarkable generalization which included Boolean algebras and Boolean rings This generalization is based on the following laws

$$a(b+c) = ab + ac \quad \text{and} \quad (a+b)c = ac + bc \tag{5}$$

$$a1 = 1 \qquad a + 0 = 0 + a = a \qquad aa = 0 \qquad \text{and} \qquad a + a = 1 \tag{6}$$

From these assumptions the idempotent commutative and associative laws (1) and (2) can be deduced

Such studies lead naturally to the concept of an abstract Boolean algebra defined as a collection of symbols combined by operations satisfying the identities listed above in formulas (1) to (4) Ordinarily the phrase Boolean algebra refers to such an abstract Boolean algebra and this convention is adopted here

The class of finite (abstract) Boolean algebras is easily described Each such algebra has for some nonnegative integer n exactly 2^n elements and is algebraically equivalent (isomorphic) to the algebra of all subsets of the set of numbers 1 n under the operations of intersection union and complement Further if m symbols a_1 a_m are combined symbolically through abstract operations $\cap$ $\cup$ and assumed to satisfy the identities of (1) to (4) one gets a finite Boolean algebra with 2^{2^m} elements —the free Boolean algebra with m generators

Infinite relationships The theory of infinite Boolean algebras is much deeper it indirectly involves the whole theory of sets One important result is Stone's representation theorem Let a field be defined as any family of subsets of a given set I which contains with any two sets S and T their intersection $S \cap T$ union $S \cup T$ and complements S T Considered abstractly any such field of sets obviously defines a Boolean algebra Stone's theorem asserts that conversely any finite or infinite abstract Boolean algebra is isomorphic to a suitable field of sets His proof is based on the concepts of ideal and prime ideal concepts which have been intensively studied for their own sake Because ideal theory in Boolean algebra may be subsumed under the ideal theory of

(algebras) is the fact that in this case any prime ideal is maximal

The study of infinite Boolean algebras leads naturally to the consideration of such infinite distributive laws as

$$x \cap (\bigcup_B y_\beta) = \bigcup_B (x \cap y_\beta) \qquad x \cup (\bigcap_B y_\beta) = \bigcap_B (x \cup y_\beta) \tag{7}$$

$$\bigcap_C [\bigcup_{A_\gamma} u_{\gamma\alpha}] = \bigcup_F [\bigcap_C u_{\gamma\,\phi(\gamma)}] \qquad \bigcup_C [\bigcap_{A_\gamma} u_{\gamma\alpha}] = \bigcap_F [\bigcup_C u_{\gamma\,\phi(\gamma)}] \tag{7'}$$

For finite sets B of indices $\beta = 1$ n if $\bigcup_B y_\beta$ means $y_1 \cup$ $\cup y_n$ and so on the laws (7) and (7') follow by induction from (1) to (3) Also if the symbols x y_β and so on in (7) and (7') refer to subsets of a given space I and if $\bigcup_B y_\beta$ and $\bigcap_B y_\beta$ refer to the union and intersection of all y_β in B respectively then (7) and (7') are statements of general laws of formal logic However they fail in most infinite Boolean algebras This is shown by the following result of Alfred Tarski if a Boolean algebra A satisfies the generalized distributive laws (7) and (7') then it is isomorphic with the algebra of all subsets of a suitable space I A related result is the theorem of Loomis (1947) which states that every σ complete Boolean algebra is isomorphic with a σ field of sets under countable intersection countable union and complement

In general such completely distributive Boolean algebras of subsets may be characterized by the properties of being complete and atomic These properties may be defined roughly as the properties that (i) there exists a smallest element $\bigcup_B y_\beta$ containing any given set B of elements y_β and (ii) any element $y > 0$ contains an atom (or point) $p > 0$ such that $p > x > 0$ has no solution (from Euclid a point is that which has no parts) Condition (ii) is also implied by the descending chain condition of ideal theory

Other forms

complete The field of Borel sets of a topological space is complete as regards countable families B of subsets S_β but not for uncountable B In a zero dimensional compact space the sets which are both open and closed (which disconnect the space) form a

shows that the most general Boolean algebra can be obtained in this way

Many other interesting facts about Boolean algebra are known For instance there is an obvious duality between the properties of n and u in the preceding discussion However so many such facts have natural generalizations to the wider context of lattice theory that the modern tendency is to consider Boolean algebra as it relates to such generalizations For instance the algebras of *n* valued logic intuitionist (Brouwerian) logic and quantum logic are not Boolean algebras but lattices of other types The same is true of the closed sets in most topological spaces For further information about Boolean algebra *see* LATTICE (MATHEMATICS) *See also* TOPOLOGY [G BI]

Bibliography G Birkhoff *Lattice Theory* rev ed Am Math Soc Colloq Publs vol 25 1948 G Birkhoff and S MacLane *Survey of Modern Algebra* rev ed 1956 G Boole *An Investigation of the Laws of Thought*, 1854 M H Stone Theory of representations for Boolean algebras *Trans Am Math Soc* 40 37–111 1936

Bootes

The Bear Driver in astronomy a northern and summer constellation Bootes is one of the earliest recorded constellations Arcturus an orange first magnitude navigational star dominates the constellation It has been kno n and ad

ventionally pictured as a driver of the Bear (Ursa Major) nearby In a more recent version he is seen seated smoking a pipe his feet dangling and with one hand holding the leash of the Hunting Dogs (Canes Venatici) *See* CONSTELLATION [C S Y]

Bootstrap circuit

A single stage amplifier circuit in which the output load is connected between the negative terminal of the anode voltage supply and the cathode and the signal voltage is applied between grid and cathode A change in grid voltage changes the input signal voltage with respect to ground by an amount equal to the output signal voltage This circuit action is obtained by charging a capacitor through a special circuit in such a way that as the capacitor charges the grid and cathode voltages of the output tube rise simultaneously with respect to ground, in effect these voltages are "raised by their own bootstraps hence the name A bootstrap circuit is used to generate saw tooth waveforms *See* SAW TOOTH WAVE [J MR]

Boracite

A borate mineral with chemical composition $Mg_3B_7O_{13}Cl$ It occurs in Germany England and the United States usually in bedded sedimentary deposits of anhydrite ($CaSO_4$) gypsum ($CaSO_4 \cdot 2H_2O$) and halite (NaCl) and in potash deposits of oceanic type The chemical composition of natural boracites varies, with Fe^{++} or Mn^{++} replacing part of the Mg^{++} to yield ferroan boracite or manganoan boracite *See* BORATE MINERALS

Boracite occurs in crystals which appear to be isometric in external form, despite the fact that the arrangement of the atoms in the crystal structure has only orthorhombic symmetry When this natural low temperature form is heated to 265°C a slight readjustment of the atoms takes place internally without change in external form The atomic symmetry of this resulting high temperature form is then consistent with the external habit The high temperature form does not occur naturally

The hardness is 7–7½ on Mohs scale specific gravity 2 91–2 97 for colorless crystals and 2 97 3 10 for green and ferroan types Luster is vitreous inclining toward adamantine Boracite is colorless to white inclining to gray, yellow, and green, and rarely pink (manganoan), its streak is white, and it is transparent to translucent It is strongly piezoelectric and pyroelectric and does not cleave [CLC]

Borane

One of a class of binary compounds of boron and hydrogen often referred to as boron hydrides The term borane is sometimes used to denote substances which may be considered to be derivatives of the boron hydrogen compounds such as BCl_3 and $B_{10}H_{12}I_2$

The simplest borane is B_2H_6, other boranes of increasingly higher molecular weight are known one of the least volatile of which is an apparently polymeric solid of composition $(BH)_x$ Certain boranes such as BH_3 and B_4H_7 are not known as such but can be prepared in the form of adducts with electron donor molecules The formulas names melting points, and boiling points of some of the more common boranes are listed in the table

The most spectacular projected large scale use of the boranes and their derivatives is in the field of high energy fuels for jet planes and rockets The heats of combustion of the boranes per unit weight are such as to permit specific impulses approaching 300 seconds a distinct improvement over hydrocarbon fuels The thermal decomposition of B_2H_6 has been used to produce coatings of pure elemen

Properties of boranes

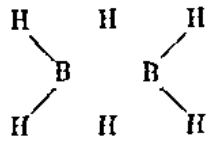
Formula	Name*	Melting point (°C)	Boiling point (°C)
B_2H_6	Diborane (6)	−165	−9°
B_4H_{10}	Tetraborane (10)	−120	58 4
B_5H_9	Pentaborane (9)	−47	6 †
B_5H_{11}	Pentaborane (11)	−123	213
$B_{10}H_{14}$	Decaborane (14)	99 5	

* The nomenclature used is that of G W Schaeffer and T Wartik as presented at the March 1954 meetings of the American Chemical Society in Kansas City The prefix designates the number of boron atoms in the molecul and the numeral suffix indicates the number of hydrogen atoms

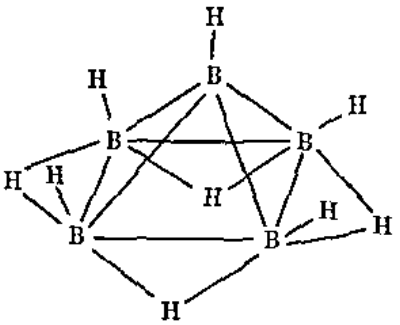
† Extrapolated boiling point

tary boron for neutron detecting devices and for applications requiring hard corrosion resistant surfaces
for natur
cially effe
bers

Structure The molecular structures possessed by the boranes are exhibited by no other class of substances Because of the lack of sufficient electrons for the formation of the requisite number of covalent bonds normal covalently bonded structures of the hydrocarbon type are not possible The boranes are sometimes referred to as electron deficient substances The hydrogen bridge bonding in B_2H_6



in which only four electrons are utilized to link the two central hydrogen atoms to the two boron atoms is illustrative of the type of bonding which prevails in the boranes In no case are the simple chain and ring configurations of carbon chemistry encountered in the more complex boranes Instead the boron atoms are situated at the corners of polyhedrons An example of such a structure is that of pentaborane (9)



Preparation The first important work on the boranes was that of Alfred Stock and coworkers whose investigations in this field began about 1912 Their method of preparation which utilized the decomposition of metallic borides (mainly magnesium boride) by mineral acids as a first step yielded exceedingly small amounts of the boranes The discouragingly small yields reported by Stock were significantly improved upon by H I Schlesinger and A Burg who developed an electrical discharge method based on the over all reaction

$$6H_2 + 2BBr_3 \rightarrow B_2H_6 + 6HBr$$

Later a number of chemical methods involving the metathetical exchange of hydride ion for halide or alkoxy groups were evolved by H I Schlesinger H C Brown and coworkers One example of the latter is

$$6LiH + 2BF_3 \xrightarrow{Et_2O} 6LiF + B_2H_6$$

Reactions of this type have been utilized to prepare B_2H_6 on a commercial scale

No practical direct routes to the higher molecular weight boranes are known Instead substances such as B_4H_{10} B_5H_9 and $B_{10}H_{14}$ are generally prepared by the thermal decomposition of B_2H_6, a process in some ways analogous to the cracking of hydrocarbons

Reactions As a class the boranes are quite reactive substances and are generally decomposed at times explosively on contact with air Their reactivities with air and water decrease with increasing molecular weight B_2H_6 reacts instantaneously whereas $B_{10}H_{14}$ must be heated with air or water to obtain an appreciable reaction rate Because boranes react readily with air laboratory investigations are almost invariably carried out in all glass vacuum apparatus or in inert atmosphere dry boxes Prolonged exposure to hydrocarbon greases in which the boranes dissolve and with which they slowly react must be avoided Animal tests have indicated that the boranes are quite toxic and severe physical discomfort can result from the inhalation of their vapors However their characteristic odor which has been compared with that of chocolate but which is distinctly more disagreeable is so intense as to provide adequate warning before a dangerous level of exposure is reached

With the possible exception of $B_{20}H_4$ the known boranes are not indefinitely stable at room temperature They decompose more or less rapidly to yield elementary hydrogen and boranes richer in boron When stored as a gas at approximately one atmosphere pressure a sample of B_2H_6 at room temperature will normally decompose to the extent of several per cent per month The order of stability for the well characterized boranes is $B_{20}H_{14} > B_5H_9 > B_2H_6 > B_5H_{11} > B_4H_{10}$ B_2H_6 can be completely decomposed to its elements at 500–600°C whereas temperatures several hundred degrees higher are required for the quantitative conversion of $B_{10}H_{14}$ to its elements

Because of its ready availability the chemistry of B_2H_6 has been studied much more extensively than that of the other boranes The previously mentioned reaction of B_2H_6 with oxygen proceeds according to the equation

$$B_2H_6 + 3O_2 \rightarrow B_2O_3 + 3H_2O \rightleftharpoons 3B(OH)_3$$

and that with water yields hydrogen and boric acid

$$B_2H_6 + 6H_2O \rightarrow 6H_2 + 2B(OH)_3$$

Both of these reactions particularly the former are highly exothermic Stable partial hydrolysis or partial oxidation products have not been isolated

ften

$$B_2H_6 + 2NMe_3 \rightarrow 2Me_3NBH_3$$

More complex boranes can sometimes be split into more complex component boranes

$$B_4H_{10} + OR_2 \rightarrow \tfrac{1}{2}B_2H_6 + B_3H_7\,OR_2$$

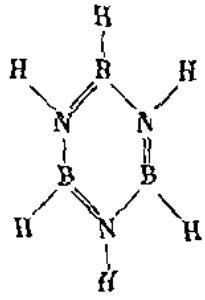
With ammonia at low temperatures B_2H_6 forms a solid product commonly called the diammoniate of diborane

$$B_2H_6 + 2NH_3 \rightarrow B_2H_6\,2NH_3$$

The structure of this solid has been extensively investigated and the evidence is strongly in favor of the formulation $[BH_2(NH_3)_2]\,[BH_4]$ When the diammoniate of diborane is heated at elevated temperatures hydrogen elimination occurs

$$3B_2H_6 + 6NH_3 \rightarrow 2B_3N_3H_6 + 12H_2$$

The product of this reaction borazine has physical (but not chemical) properties closely resembling those of benzene and its molecular structure



is formally similar to that of the carbon compound

An important class of compounds the borohydrides results from the reaction of B_2H_6 with metal hydrides With lithium hydride for instance lithium borohydride is formed

$$2LiH + B_2H_6 \xrightarrow{Et_2O} 2LiBH_4$$

A similar reaction which gives rise to a triborohydride is indicated by the equation

$$NaH + B_4H_{10} \xrightarrow{Et_2O} \tfrac{1}{2}B_2H_6 + NaB_3H_8$$

Treatment of B_2H_6 with ethylenic compounds produces alkyl boranes

$$B_2H_6 + C_2H_4 \rightarrow B_2H_5C_2H_5$$

A large excess of ethylene leads to the formation of triethylborane

The known derivatives of the boranes (other than BH_3) are relatively few in number Several halo alkyl and amino boranes have been reported but in general these have not been extensively characterized *See* BORON BORON FUEL HYDRIDE METAL [r w]

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Borate

A generic term referring to salts related to boric oxide B_2O_3 or commonly to only the salts of orthoboric acid H_3BO_3

Boron acids and salts

Acid	Common name	Typical salt	Common name
H_3BO_3	Boric acid orthoboric acid	Na_3BO_3	Sodium orthoborate
HBO_2	Metaboric acid	$NaBO_2\,4H_2O$	Sodium metaborate
$H_2B_4O_7$	Pyroboric acid	$Na_2B_4O_7\,10H_2O$	Borax, sodium tetraborate
		$KB_5O_8\,4H_2O$	Potassium pentaborate

The acids from which these salts are produced are listed in the table Only orthoboric acid is important in its free state Some of the others are known only in the form of salts

The naming of these compounds is additionally complicated by the fact that other polyborates are known and several systems for naming the salts are used For example borax is also known as pyroborate diborate or sodium (1 2) borate this latter name based on the formula $Na_2O\,2B_2O$

A dilute solution of any sodium borate contains mainly H_2BO_3 and BO_2 ions The borates are used in manufacture of borosilicate glasses ceramic glazes vitreous enamels detergents and water softening agents flameproofing materials preservatives and fluxes

Minerals related to borax are the main source of borates The largest deposits are found in California Recent work has produced boron nitride an abrasive harder than diamond and boron hydrides which are used as rocket fuels *See* BORATE MINERALS BORON [E E WR]

Borate minerals

A large and complex group of naturally occurring crystalline solids in which boron occurs in chemical combination with oxygen hence the term borate With the exception of avogadrite $(K\,Cs)BF_4$ and ferrucite $NaBF_4$ all known boron minerals are borates Boron having an oxidation number (valence) of +3 does not act as a cation for example compounds of the type $B(NO_3)_3$ are not known to exist Rather boron combines with oxygen to form anions of varying degrees of complexity Borate minerals may contain silicon phosphorus or arsenic These specifically are the borosilicates the borophosphates and the boroarsenates Of these three groups the first is by far the largest

Occurrence The average amount of boron in the earth s crust is estimated as 3 parts per million Fortunately large quantities are concentrated in deposits of hydrated borate minerals that are easily worked and boron is not like some minor elements so completely dispersed that it is hard to find and use Deposits are found in the United States (Mojave Desert) Turkey USSR (Inder district) Tibet Italy Germany Argentina Bolivia Canada China India Iran New Zealand New Guinea and Syria The minerals of chief commercial importance are borax $Na_2B_4O_7\,10H_2O$ and kernite $Na_2B_4O_7\,4H_2O$ Large quantities of these minerals are mined at the Kramer deposit Boron California Borax is also extracted in large

Borate minerals

Mineral name	Empirical formula	Structural formula
Anhydrous borates		
Suanite	$Mg_2B_2O_5$	$Mg_2(B_2O_5)$
Kotoite	$Mg_3B_2O_6$	$Mg_3(BO_3)_2$
Jeremejevite	$AlBO_3$	Cristobalite-like structure
Nordenskioldine	$CaSnB_2O_6$	$CaSn(BO_3)_2$
Ludwigite	$(Mg\ Fe^{2+})_2Fe^{3+}BO_5$	$(Mg\ Fe^{2+})_2Fe^{3+}BO_3O_2$
Boracite	$Mg_3B_7O_{13}Cl$	Complex 3-dimensional network
Hydrated borates		
Sassolite	H_3BO_3	$B(OH)_3$
Pinnoite	$Mg(BO_2)_2\ 3H_2O$	$Mg[B_2O(OH)_6]$
Teepleite	$Na_2BO_2Cl\ 2H_2O$	$Na_2[B(OH)_4]Cl$
Fluoborite	$Mg_3(BO_3)(OH\ F)_3$	
Colemanite	$Ca_2B_6O_{11}\ 5H_2O$	$Ca[B_2O_4(OH)_2]\ H_2O$
Meyerhofferite	$Ca_2B_6O_{11}\ 7H_2O$	$Ca[B_3O_3(OH)_5]\ H_2O$
Inyoite	$Ca_2B_6O_{11}\ 13H_2O$	$Ca[B_3O_3(OH)_5]\ 4H_2O$
Inderite	$Mg_2B_6O_{11}\ 15H_2O$	$Mg[B_3O_3(OH)_5]\ 5H_2O$
Borax	$Na_2B_4O_7\ 10H_2O$	$Na_2[B_4O_5(OH)_4]\ 8H_2O$
Tincalconite	$Na_2B_4O_7\ 5H_2O$	$Na_2[B_4O_5(OH)_4]\ 3H_2O$
Kernite	$Na_2B_4O_7\ 4H_2O$	$Na_2[B_4O_5(OH)_2]\ 3H_2O$
Veatchite	$SrB_6O_9\ 2H_2O$	$Sr[B_3O_4(OH)_2]_2$
Probertite	$NaCaB_5O_9\ 5H_2O$	$NaCa[B_5O_6(OH)_6]\ 2H_2O$ or $NaCa[B_5O_7(OH)_4]\ 3H_2O$
Ulexite	$NaCaB_5O_9\ 8H_2O$	$NaCa[B_5O_6(OH)_6]\ 5H_2O$
Borosilicates		
Datolite	$CaBSiO_4\ H_2O$	$Ca_4[BSi_4O_4(OH)]_4$
Reedmergnerite	$NaBSi_3O_8$	Feldspar structure
Danburite	$CaB_2Si_2O_8$	Feldspar structure
Tourmaline	$(Na\ Ca)(Li\ Al)_3Al_6(OH)_4(BO_3)_3Si_6O_{18}$	
Borophosphates and boroarsenates		
Lunebergite	$Mg_3B_2(OH)_6(PO_4)_2\ 6H_2O$	
Seamanite	$Mn_3(PO_4)(BO_3)\ 3H_2O$	
Cahnite	$Ca_2B(OH)_4(AsO_4)$	

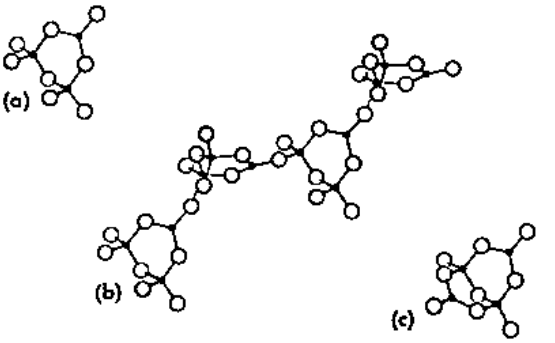
amounts from the brine at Searles Lake California

Structural classification Any rational classification of the borate minerals must rest directly on a knowledge of their crystal structures Not all of the structures are known but a sufficient number have been worked out so that at least a partial classification can be made The crystal chemistry of the borates is similar to that of the silicates with the additional complication that boron can occur in either triangular or tetrahedral coordination Boron will combine with three oxygen atoms to form a planar triangular group BO_3 or with four oxygen atoms to form a tetrahedral group BO_4 These groups of threefold and fourfold coordination result in isolated ions such as BO_3^{3-} or $B(OH)_4^{1-}$ or the molecule $B(OH)_3$ contained in sassolite Alternatively the groups may share corners in various ways to form polyanions of varying complexity These polyanions may be relatively simple as in the pyro ion $O_2B—O—BO_2$ or more complicated For example the mineral meyerhofferite $Ca_2B_6O_{11}\ 7H_2O$ contains insular polyions of composition $[B_3O_3(OH)_5]^{-2}$ formed by corner sharing of a $BO_2(OH)_2$ tetrahedron with two $BO_2(OH)$ triangles as shown in the illustration Other examples shown are the insular polyion $[B_4O_5(OH)_4]^{-2}$ found in borax $Na_2B_4O_7\ 10H_2O$ and the infinite chains of composition $[B_3O_4(OH)_3]_n^{n-}$ found in colemanite $Ca_2B_6O_{11}\ 5H_2O$ Three rules have emerged for predicting the nature of the polyanions in borates (in the absence of Si P or As) (1) polyanions are formed by the corner sharing only of triangles and tetrahedra in such manner that a compact insular group of low negative charge results (2) these insular groups may polymerize to form infinite chains as for example

$$n[B_3O_3(OH)_6]^{-2} - [B_3O_4(OH)_3]_n^{-2n} + nH_2O$$

Meyerhofferite Colemanite

(3) in hydrated borates those oxygens not shared



• boron

○ oxygen

Structural elements (a) Meyerhofferite (b) Colemanite (c) Borax

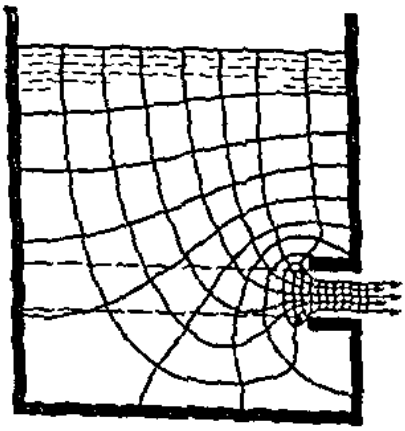
between two borons always attach a hydrogen atom and become hydroxyl groups

In the borosilicates there is much evidence for the linking of boron oxygen polyanions with silicon oxygen tetrahedra but the details for most minerals are unknown In borophosphates and boroarsenates there does not appear to be sharing between phosphate or arsenate tetrahedra and borate polyanions In the table is a list of some of the more common borate minerals Structural formulas are given where it is possible to do so The table also includes several minerals that serve as examples of structural types even though they may be actually comparatively rare in occurrence [C L C]

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Borda mouthpiece

A reentrant tube in a hydraulic reservoir as illustrated The contraction coefficient of a Borda mouthpiece can be calculated more simply than for other discharge openings



Streamlines around a Borda mouthpiece

As a liquid accelerates toward a discharge opening the streamlines converge This convergence may cause the issuing jet to contract to a smaller cross section than that of the opening the region of the jet of least cross section being called the vena contracta The ratio of vena contracta area to opening area is the contraction coefficient The frictional forces in the vicinity of a simple opening alter the accelerations in the liquid but with a Borda mouthpiece friction is so reduced near the opening that the contraction coefficient can be calculated from hydrostatic considerations alone with close agreement to measurements The coefficient thus calculated is 0 5 *See* ORIFICE, VENTURI TUBE [F H R]

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Borer

A name frequently applied to the snail *Fupleura caudata* of the family Muricidae class Gastropoda phylum Mollusca This snail is closely related to the rock shells of the genus *Murex* but differs from them in having only two growth ridges to a whorl instead of three It varies in color from bluish white to reddish brown and is usually less than 1 in long The shell is solid with about five whorls, distinctly flattened at the shoulders



The borer *Eupleura caudata* length to 1¼ in (from E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

The borer is a very active and common animal among rocks at low tide from Cape Cod to Florida It is a shallow water species seldom found at depths over 50 ft Frequently it is confused with the oyster drill to which it is closely related but from which it may be readily distinguished by its thickened lip bordered within by raised granules Because of the latter structure the borer is also called the thick lipped drill Similar to other carnivorous snails, this animal drills holes through the shells of mollusks and feeds on the soft parts of its victim *See* GASTROPODA, OYSTER DRILL ROCK SHELL SNAIL [J D B]

Boride

A binary compound of boron and a metal formed by heating a mixture of the two elements Boron does not conform to the usual rules of valence in forming these compounds The borides along with the carbides and the nitrides are called interstitial compounds These compounds have crystal structures and properties very similar to those of the original metal hence it is suggested that the boron is located in the cavities of the metallic lattice

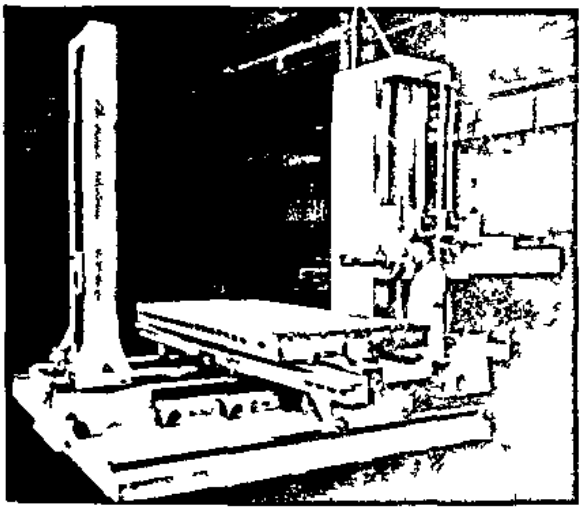
The borides are very hard and refractory and show high electrical conductivity Typical borides are Ni_2B NiB_4 MnB MnB_2 and Cu_3B

A compound of boron and nitrogen boron nitride is an abrasive harder than diamond *See* ABRASIVE BORON, SOLID STATE CHEMISTRY [E E W R]

Boring

A machining operation that increases the size of an existing hole in a workpiece The usual purpose of boring is to machine a hole to a desired diameter while obtaining required accuracy and finish In metal working boring is performed after making a circular hole in the piece by some method such as coring drilling burning punching or trepanning *See* DRILLING MACHINE

Boring machines may be listed in two categories horizontal and vertical The former type holds the workpiece stationary on a movable table A rotating



Horizontal boring machine (Giddings and Lewis Machine Tool Co)

spindle holding the cutting tool can be fed into the work from a vertically adjustable head as illustrated On vertical machines the work is revolved on a circular table while tools may be fed in for boring as well as facing operations *See* MACHINING OPERATIONS [A T]

Boring and drilling, mineral

The drilling of holes for exploration extractive development and extraction of mineral deposits Exploration holes are drilled to locate mineral deposits define their extent determine their ore dressing characteristics determine mining or quarrying conditions to be met in their development or extraction and otherwise to establish the commercial value of the deposit Holes for extractive development are drilled for blasting mine dewatering access for utility lines grouting for water control pilot holes for shaft sinking and as small shafts for back filling ventilation portals and escape ways

Elements of drilling The two essentials are a process to detach particles of soil or rock from the floor of the hole and a way to remove the loosened particles from the hole The principles that can be applied to these processes are limited by the confines of the drill hole but they can be combined into an innumerable variety of drilling methods applicable to mineral work

Drills and equipment Energy and action required for the two processes of drilling are furnished in various ways Drills are designed to create *motion rotary* linear or combined rotary *and* linear motion Auxiliary drill rig equipment (pumps compressors generators) may introduce additional energy into the hole in the form of hydraulic pneumatic or electric power Another source of energy may be created at the bit by conversion of gases into heat

The energy of motion created by the drill may be transmitted to the drill bit by a shaft (drill rods drill pipe drill stem drill steel) or by a flexible cable (wire line rope) Drill rods drill pipe and drill steel are tubular so that they may be used for the injection of fluids compressed air or gases

Types of drilling Five general categories may be classified rotary drilling penetration by the abrasive action of a drill bit in rotary motion core drilling rotary drilling an annular groove leaving a central core percussion drilling penetration by the chopping or crushing action produced by a drill bit in linear motion rotary percussion drilling combination of rotary and linear motions to produce penetration fusion piercing penetration by flaking or melting caused by the application of heat

Principal drilling methods Many drills may be adapted to a variety of drilling methods particularly those drills designed to produce penetration by rotary motion and which also incorporate dual linear motion mechanisms one for control and one for hoisting Some drills are specifically designed for a combination of drilling methods

Drilling methods have terminology generally indicative of the outstanding feature of the method but the same term may be used for a method that is also used for a type of drilling as in the use of the term rotary drilling

Rotary drilling This is vertical drilling through a rotary table and the typical drill is that used for drilling exploratory and producing wells for the petroleum minerals (oil and gas) The rotary table turns a square kelly with mud swivel at the top and connection to drill pipe below Penetration is by rotation of drill bits of two types (1) roller bits which have rolling cutters with projecting hard teeth and (2) drag bits with fixed chisel type hard cutting edges Cuttings removal is by circulation of drilling mud which is also used to protect the wall of the hole and eliminate the need for casing Controlled vertical motion of the tools

tial support of the weight of drill pipe and heavy drill collars

Smaller rotary drills with a thrust mechanism added to react against the weight of the drill and increase *bit pressure are used for seismograph* prospecting core drilling water wells and blast holes

Auger drilling Rotary type auger methods penetrate by the cutting or gouging action of chisel type cutting edges forced into the formation by rotation of the bit Cuttings are removed by mechani*cal action* Auger rods are made with a *continuous*

draw the tools The method is used for drilling blast holes and for reconnaissance prospecting A special type is used as a mining tool

Diamond drilling Another rotary type this drilling utilizes the extreme hardness of the diamond

on abrasive bits Core drilling rotates an annular bit to cut a narrow kerf around a central core and thus obtain unaltered samples of the formation drilled Diamond drills are the principal tools for exploration of mineral deposits

The diamond drill furnishes rotary motion for penetration and generally also has dual linear motion mechanisms a hydraulic cylinder or screw mechanism to control the feed of the bit against the rock and a wire line hoist or pneumatic cyl inder for tool withdrawal The drill head usually swivels for drilling at any angle Tubular drill rods transmit rotary motion to the core barrel which has a core retaining device just above the diamond bit The ring shaped diamond bit is set with indus trial grade diamonds those with imperfections that prohibit their use as gems Water or mud circula tion cools the bit and removes the cuttings Double tube core barrels may be used to keep water circu lation from washing the core

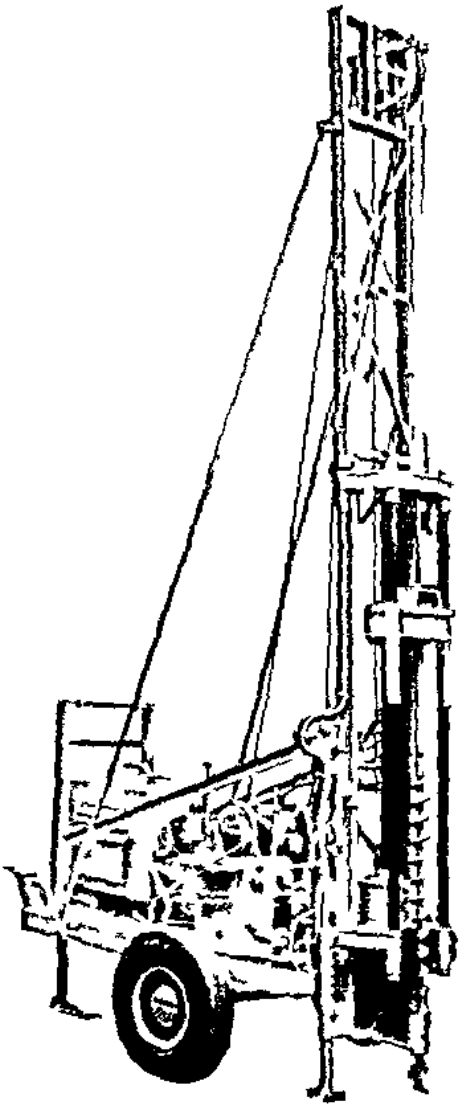


Fig 1 Combination auger churn and core drill

Standard core drill sizes*

Size	Diameter in	
	Hole	Core
EX	1½	1⅛
AX	1 13/16	1⅝
BX	2⅜	1⅝
NX	3	2⅛
2¾ × 3⅞	3⅞	2 11/16
4 × 5½	5½	3 13/16
6 × 7¾	7¾	5 13/16

* Diamond Core Drill Manufacturers Association

A few variations are developed Surface set b ts contain a single laver of diamonds Impregnated bits have diamond fragments distributed thro igh the crown so that fresh cutting points are exposed as the bit wears *Noncoring diamond* bits may be used where a core is not desired as in diamond blast hole drilling

Shot (abrasive) drilling This method of rotary core drilling uses hard chilled steel shot or other loose abrasive as a cutting medium Penetration is accomplished by the grinding action of the abra sive when dragged over the rock by a rotating core barrel with a blank steel bit much as any grinding process utilizing a loose abrasive

The method is employed (1) to obtain cores in large diameter holes where abrasive bit cost is suf ficiently lower than diamond bit cost to offset the increased operating costs of slower progress, and (2) to drill shafts and other large-diameter holes where it is more economical to drill a groove and remove the unneeded core than to drill the ent re cross sectional area

Cuttings are removed from under the bit by wa ter circulation but without sufficient velocity to carry them to the surface Shot core barrels are therefore built with a chip box (calyx) on top so that the cuttings are retained when they settle out under the velocity drop at the top of the core barrel

Air percussion drilling Penetration of this drill ing is by crushing action under pneumatically pow ered impact The drill bit is chisel type commonly with four cutting edges in the form of a cross The drill produces linear impact motion by means of a reciprocating pneumatically powered piston to strike a rapid series of blows against a tubular dr ll steel which transmits the energy to the bit The drills also provide pneumatically powered rotary motion constantly to change the position of the b t against the floor of the hole Cuttings are usually blown out of the hole by compressed air injec ed through the hollow drill steel and bit although wa ter may be substituted with drills designed for haz ardous dust conditions Dust collectors may be used

samples

r bla

gs for

both surface and underground work The method is limited in hole size and depth by two considera tions—constant loss of bit gage and absorption of dynamic energy by the drill steel Tungsten carb de

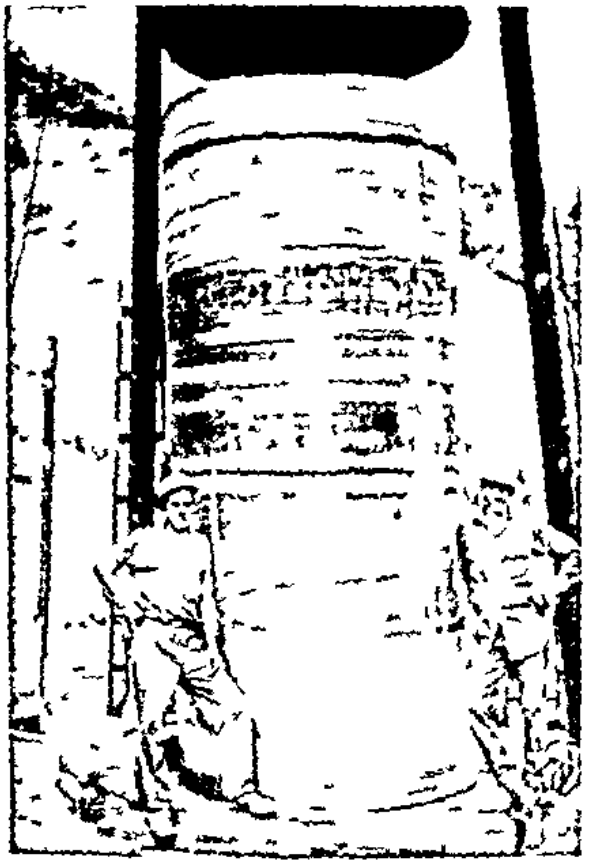


Fig 2 Shot drill core from drilled shaft

cutting inserts help retain gage and special down the hole drills are of aid in the latter problem

Cable tool (churn) drilling A different percussion type method this penetrates by crushing impact of a falling heavy chisel bit The drill creates an oscillating vertical linear motion which is transmitted to the drilling tools by wire line cable so that they are alternately lifted and dropped The cuttings are suspended in water by the churning action of the tools and then periodically removed by bailing Churn drills are sometimes used for prospecting where analysis of the cuttings gives sufficient information In mineral exploitation work they are used for drilling blast holes in quarrying for drilling water wells and for drilling access holes for utility lines into mines

Fusion piercing methods For these an oxygen acetylene blow pipe applies intense heat to the floor of the hole and penetrates by flaking or melting Drills must produce both linear and rotary motion to handle the blow pipe and break up slag formed in the process The cuttings and slag are blown from the hole Fusion piercing methods have been used successfully for drilling blast holes in hard taconite formations

Other important drilling methods A considerable number of these indicate the wide range of drilling methods available by innumerable combinations of basic drilling principles

Air rotary or gas drilling Air or natural gas is employed as the circulating medium in rotary type drilling Faster rates of penetration ha

tained with these methods but ground water conditions may prohibit their use

Variations of auger techniques Auger mining utilizes the conveyor action of continuous flight augers for actual mining operations in large-diameter horizontal holes such as for mining coal in the high wall beyond the economical limits of strip mining The science of electronics has been applied to guide such an auger and keep it within the bed *See* MINING EXCAVATION

Auger stem drilling uses a short helix run on a solid square stem as a bit for gouging out and collecting cuttings With a derrick higher than the hole is deep the auger can be withdrawn quickly and spun rapidly to throw off the cuttings by centrifugal force The method is suitable for holes from 12 72 in or larger diameter By substituting a bit incorporating a steel cylinder to confine the cuttings the terminology is changed to bucket drilling

Variations of rotary drilling Among a large possible number of rotary drilling techniques several are of considerable current use

Reverse circulation drilling usually refers to a variation of the rotary drilling method in which the cuttings are pumped up and out of the drill pipe This is advantageous in certain large diameter holes The term is also applied to diamond core drilling when the water is injected through a stuffing box into the annular space around the drill rods and thus forced up special large drill rods Here the water forces the core up through the drill rods as a piston through a cylinder

Rotary blast hole drilling is a term commonly applied to two types of drilling In quarrying and open pit mining it implies rotary drilling with roller type bits using compressed air for cuttings removal either conventional rotary table drive or hydraulic motor to produce rotation and with hydraulic or wire line mechanisms to add part of the weight of the drill to the weight of the tools and thereby increase bit pressure In underground mining and sometimes above ground it implies the drilling of small diameter blast holes with a diamond drill using either coring or noncoring diamond bits

Rotary percussion drilling methods are combinations of the use of both rotary motion and linear motion to produce penetration

Shaft drilling is shaft sinking by drilling a hole the size of the shaft as contrasted with conventional shaft sinking methods of drilling small holes and blasting The perfect arch action of the smooth cut circular wall of a drilled shaft makes shaft lining unnecessary in hard massive rocks, and much safer and more economical in others because a blasted wall is shattered and requires more concrete for lining due to overbreak Both shot core drilling and rotary drilling methods are used in shaft drilling with variations such as the use carbide or rolling cutters on the core ba tary reaming a pilot hole in st

hole type rotary drills A core barrel has been developed for shaft drilling that brings the core to the surface in the core barrel

Miscellaneous drilling and coring Four other drilling methods and one additional coring technique are considerably developed and applied

Down-the-hole drilling is air percussion type (for large-diameter blast holes) with the reciprocating pneumatic piston placed in the drill tools close to the bit for minimizing energy losses

Sonic drilling methods are percussion or rotary percussion type utilizing for impact the energy of a drill stem vibrating at sonic frequency One method of producing sonic vibration is by use of eccentric weights driven by mud turbine

Turbodrilling is rotary drilling with rotary motion created in the hole close to the bit by a turbine

rods to chop through soils and wash the cuttings to the surface It is percussion type drilling for which churn drills are ideally suited but is often used on other drills because of the need for rotary coring methods in another part of the same hole When a combination churn and diamond drill is not available the method may be used with a diamond drill with a cathead by snubbing a manila rope to create the churning action By introducing a check valve at the bit the churning action may also be used to pump the cuttings up the drill rods using natural ground water or water added to the hole a prospecting method called hollow rod drilling

Wire line coring is a method of removing core by pulling the inner tube of the core barrel with the bit core barrel and drill rods remaining in the hole The inner tube is dropped or pumped down through the drill rods and recovered by running a retriever on a wire line so the periodic removal of core can be done in deep drill holes in less time than required by screwing and unscrewing the drill pipe or drill rods In rotary drilling the inner tube was designed to pass through the drill pipe and seat above a ring type roller cutter core bit In

[illegible] See CORE DRILLING WELL LOGGING (MINERAL) *see also* OIL AND GAS WELL DRILLING [F C S T]

Boring sponges

Clionidae a family of marine sponges of the class Demospongiae order Clavarinellida which contains species which excavate galleries in mollusk shells corals limestone and other calcareous matter Water currents are maintained through the tissues of clionids exactly as in other Demospongiae and the boring sponges do not obtain food from their hosts when the calcareous matter [illegible] through holes in the calcareous substrate continuous with the extensive galleries within. Boring sponges feed on phytoplankton and other organic matter drawn in from the surrounding sea water through the ostia The most important genus, Cliona, has a skeleton of monactinal megascleres provided with terminal knobs Microscleres may be present in the form of spiny diactinal spicules or spirasters or both

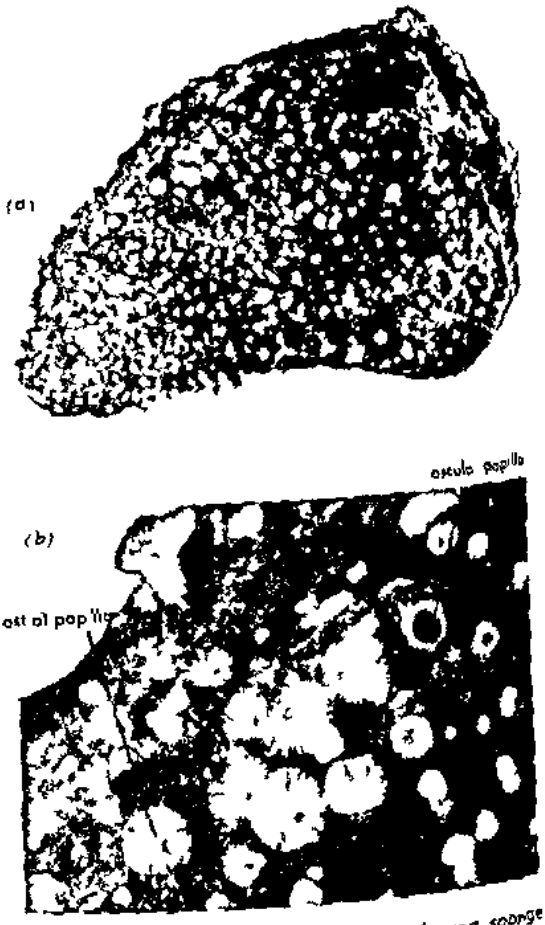


Fig 1 (a) *Cliona celata* a common boring sponge living in an oyster shell (b) Enlarged portion of a showing expanded ostial and oscular papillae (After *Hartman, 1958*)

The boring process involves the excavation by the sponge of numerous minute particles of calcium carbonate which pass out of the sponge by way of the exhalant canals and oscula Piles of such calcareous chips often accumulate around the oscular tubules Pseudopodia and cytoplasmic films put out by cells in contact with the calcareous substrate apparently insinuate themselves into the calcium carbonate possibly by localized secretion of an acid to excavate particles of relatively uniform size The cells are able to penetrate conchiolin a proteinaceous substance which separates successive layers of calcium carbonate in mollusk shells, but they do this less readily than they excavate the calcareous layers

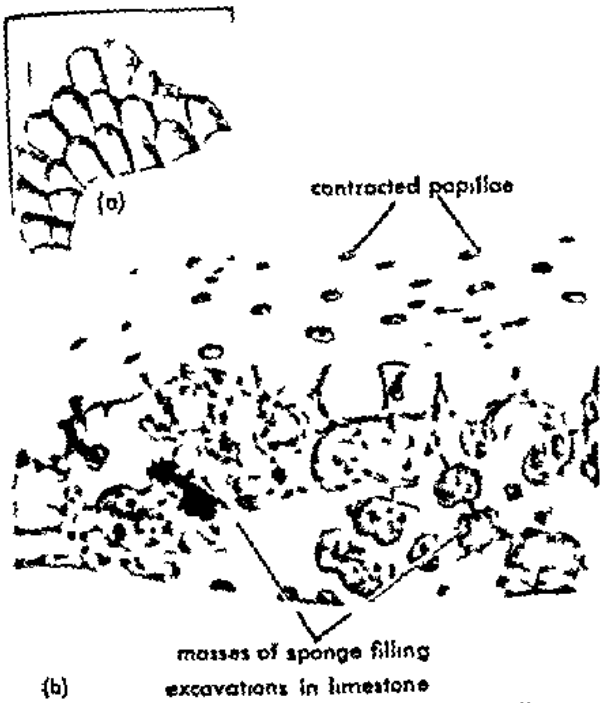


Fig 2 Destructive action of clionids (a) Small piece of calcite showing how a clionid has excavated uniform chips from it (after Nasonov 1883) (b) Section through a piece of limestone (enlarged) to show the excavations made by a clionid Contracted papillae can be seen on the upper surface (after Vosmaer 1935)

Clionids are regarded as a nuisance in oyster beds because their excavations weaken the shells of these mollusks and thus hinder processing in canning factories Boring sponges are also of economic importance because they attack limestone breakwaters

Clionids are found in all seas chiefly in tidal and shallow waters A few species reach a depth of at least 1000 meters Their excavations are known in fossil mollusk shells at least as far back as the Devonian period *See* DEMOSPONGIAE Oyster [W D H]

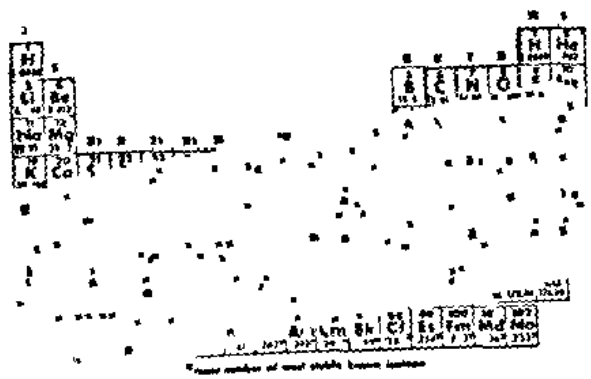
Bornite

A mineral having composition Cu_5FeS_4 and crystallizing in the isometric system *Bornite* crystals are rare and are usually massive with metallic luster The brownish bronze color on the fresh fracture quickly tarnishes to a variegated purple and blue hence the name peacock ore The hardness is 3 (Mohs scale) and specific gravity is 5 07 Bornite is a widely occurring mineral but as a copper ore is of lesser importance than chalcopyrite and chalcocite It is usually found associated with other copper minerals in hypogene deposits Fine crystals have been found at Bristol Connecticut and at Cornwall England Large masses have been mined in Chile Peru Bolivia and Mexico, and in the United States at the Magma Mine Arizona and Butte Montana *See* CHALCOCITE CHALCOPYRITE, COPPER [C S HU]

Boron

Chemical element number 5, boron, B, belongs to group III of the periodic table of elements It has three valence electrons and is nonmetallic in behavior It is classified as a metalloid and is the only nonmetallic element which has fewer than four electrons in its outer shell The free element is prepared in crystalline or amorphous form The crystalline form is an extremely hard brittle solid It is of jet black to silvery gray color with a metallic luster One form of crystalline boron is bright red in appearance The amorphous form is less dense and is a dark brown to black powder

In the naturally occurring compounds boron exists as a mixture of two stable isotopes with atomic weights of 10 and 11 The B^{10} isotope which normally makes up 18 8% of the total boron, is an effective absorber for thermal neutrons The large relative difference between the atomic masses of the isotopes B^{10} and B^{11} permits their separation and concentration by fractional distillation and diffusion processes Such processes have been operated on a large scale using boron trifluoride etherate as the reaction medium Sir Humphry Davy and Joseph Gay Lussac with Louis Jacque Thenard obtained the element from boric acid almost concurrently in 1807 and 1808 respectively Davy used electrolysis whereas Gay Lussac and Thenard used potassium to reduce boric acid



Very little in the way of analyses accompanied the work of these original investigators The first serious investigation pertaining to boron was carried out at the end of the nineteenth century by Henri Moissan who in 1892 first obtained boron of better than 98% purity He also repeated the work of earlier investigators and reported for the first time analyses which showed large amounts of impurities usually consisting of oxygen and the reducing metal

Uses Elemental boron is used chiefly in the metal industry Because it is extremely reactive at high temperatures, particularly with oxygen and nitrogen boron is used as a deoxidizer and degasifier in metallurgical processes It is used to refine the grain of aluminum castings and to facilitate the heat treatment of malleable iron Recent developments in alloy steels have shown that the presence

of boron considerably increases the high temperature strength characteristics Elemental boron is finding increasing use in the atomic reactor and in high temperature technologies

In combination with plastics or aluminum boron provides an effective lightweight neutron shielding material Boron containing shields are valuable because of their satisfactory mechanical properties and because boron absorbs neutrons without producing high energy γ rays Rods and strips of boron steel have been used extensively as control rods in existing atomic reactors

Boron can be produced in various shapes by conventional hot pressing methods Temperatures of the order of 2000°C are required and the operation must be carried out in an inert atmosphere The use of boron has been patented for such diversified applications as in motor starting devices phonograph needles lightning arresters thermal cutouts for transformers ignitors in rectifier and control tubes alloys resistant to high temperature abrasion and scaling constant potential controllers thermoelectric couples and resistance thermometers

Certain compounds of boron such as borax and boric acid have been known and used for a long time in glass enamel ceramic and mining industries Refined borax ($Na_2B_4O_7\ 10H_2O$) is an important ingredient of a variety of detergents soaps water softening compounds laundry starches adhesives toilet preparations cosmetics talcum powder and glazed paper It is also used in fireproofing disinfecting of fruit and lumber weed control and insecticides as well as in the manufacture of leather paper and plastics

Preparation The literature describes a variety of methods for the preparation of elemental boron from boron oxide halides hydrides and other boron containing compounds These methods involve electrothermic electrochemical and direct pyrolysis procedures and may be classified as follows

Thermoreduction of boron oxygen compounds with an active metal

$$B_2O_3 + 3Mg \rightarrow 2B + 3MgO \qquad (1)$$

alkali metal reduction of boron halides

$$BCl_3 + 3Na \rightarrow B + 3NaCl \qquad (2)$$

hydrogen reduction of the halides

$$2BCl_3 + 3H_2 \rightarrow 2B + 6HCl \qquad (3)$$

carbothermic reduction of borates

$$Na_2B_4O_7 + {}^{\sim}C \rightarrow 2Na + 7CO + 4B \qquad (4)$$

electrolysis of fused borates or other boron-containing compounds

$$2KBF_4 + 6KCl \rightarrow 2B + 8KF + 3Cl_2 \qquad (5)$$

and thermal decomposition of boron hydrides

$$B_2H_4 \rightarrow 2B + 3H_2 \qquad (6)$$

Of these methods reactions (1) (3) and (5) are used on a commercial scale for the production of boron

A schematic diagram of a crystalline boron reactor is shown in Fig 1 A photograph of a high purity crystalline boron deposit is shown in Fig 2

In general production of high purity (above 99%) boron involves secondary treatment (such as vacuum degassing or controlled halogenation) of the crude products as obtained by any of the above listed methods

Properties Many properties of boron have not been sufficiently established experimentally The literature shows considerable inconsistency in physical properties this is the result of the questionable purity of some sources of boron as well as of the variations in the methods and temperatures of preparation A summary of the most recent information pertaining to the physical properties of boron is shown in the table Samples of boron having the highest purity whether crystalline or amorphous are black in color The samples of so-called Moissan (amorphous) boron exhibit various shades of brown which are associated with the presence of various amounts of boron suboxide impurities Crystalline boron although relatively brittle compared to diamond is second only to diamond in hardness Facets on the minute single crystals are clearly visible when viewed through a microscope of at least 30 power

The crystal structure of crystalline boron is not simple A recent study shows that the tetragonal unit cell contains fifty atoms

A new crystalline modification of boron was reported recently It is somewhat more dense than the normal crystalline boron (2 46 g/cm³ as opposed to 2 33 g/cm³) It is a red sandy red glass or red microcrystalline material Its crystalline structure is rhombohedral

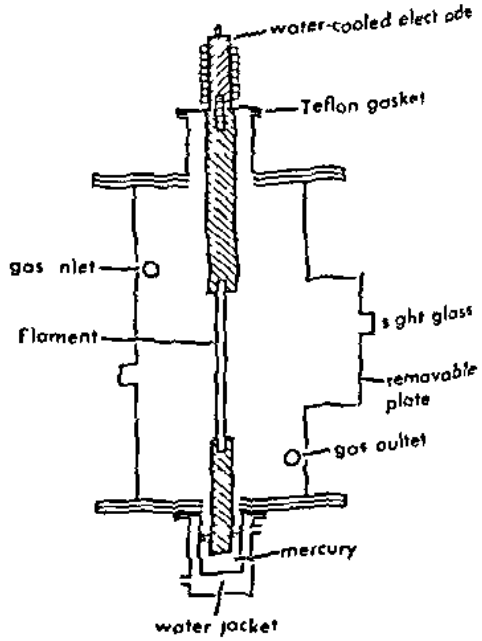


Fig 1 Diagram of crystalline boron reactor



Fig 2 Typical boron mineral deposit

Boron possesses a negative temperature coeffi cient of resistivity which means that its electrical conductivity rises rapidly with increase in tem perature E Weintraub's data show an increase of almost 2×10^6 in the 100–1000°C temperature range W C. Shaw found that the resistivity of boron decreased by a factor of almost 10^{10} between the temperatures of —70 and 700°C

The chemical properties of boron depend largely on the physical form as well as on the purity of samples Amorphous boron oxidizes slowly in the air even at room temperature and is spontaneously flammable at about 800°C A special reactive form of amorphous boron may be prepared by the mag nesiothermic reduction of anhydrous alkali borates This form may catch fire in air at temperatures below 100°C and is generally characterized by an extremely small particle size (smaller than 1 mi cron) and high alkali metal impurity (5–10%) content

Boron is not affected by either hydrochloric or hydrofluoric acids even on prolonged boiling Crys talline boron is quite stable to heat and oxidation even at relatively high temperatures It is slowly attacked and oxidized by hot concentrated nitric acid and by mixtures of sodium dichromate and sulfuric acid Hydrogen peroxide and ammonium persulfate also slowly oxidize crystalline boron These reagents are found to act violently on sam

Physical properties of boron

Property	Temper ature °C	Value	Units
Density			
crystalline	25–27	2 31	g/cm³
amorphous	25–27	2 34	g/cm³
Moh hardness			
crystalline		9 5	
Melting point		2300	°C
Boil ng point		2550	°C
Res stivity	25	$1\ 7 \times 10^6$	ohm cm
Coeff cient of ther mal expansion	20–750	$8\ 3 \times 10^{-6}$	cm/°C
Heat of com bustion	25	302 0 ± 3 4	kcal/mole
Entropy			
crystalline	25	1 403	cal/(mole)(deg)
amorphous	25	1 564	cal/(mole)(deg)
Heat capacity			
gas	25	4 97	cal/(mole)(deg)
crystalline	25	2 65	cal/(mole)(deg)
amorphous	25	2 86	cal/(mole)(deg)

ples of amorphous boron All varieties of boron are completely oxidized by molten mixtures of alkali carbonates and hydroxides Chlorine bro mine and fluorine act easily on boron with forma tion of the corresponding boron halides (bromine acts at 700°C chlorine at 410°C, and fluorine at room temperature) Boron reacts vigorously with sulfur at about 600°C to form a mixture of boron sulfides Boron nitride is formed when boron is heated in a nitrogen or ammonia atmosphere above 1000°C Boron is reported to react at high tem peratures with phosphorus and arsenic It is not re active with hydrogen until temperatures of 1800–2000°C are reached It reacts with silicon to form silicon borides above 2000°C Boron reacts with a majority of metals and metallic oxides at high temperatures to form metallic borides

Natural occurrence Boron makes up 0 01% of the earth s crust It is never found in the uncom bined or elementary state in nature Besides being present to the extent of a few parts per million in sea water it occurs as a trace element in most soils and is an essential constituent of several rock forming silicate minerals such as tourmaline and datolite The presence of boron in extremely small amounts seems to be necessary in nearly all forms of plant life but in larger concentrations it be comes quite toxic to vegetation Only in a very limited number of localities are high concentra tions of boron or large deposits of boron minerals to be found in nature the more important of these seem to be primarily of volcanic origin

As a result the world s important deposits of borates are to be found only in such localities as the barren wastes of south central and south west Asia portions of Asia Minor the pampas of South America and the desert areas of California and Nevada all of which are immediately adjacent to regions of former intensive volcanic activity

The United States accounts for about 95% of the world s reported output of borax Argentina Italy and Turkey are also producers of borates It is believed that there are considerable deposits of borate ores in the Soviet Union but the extent of present exploitation is unknown *See* BORATE MINERALS

Extraction and refining Borax is produced from bedded deposits and from natural brines found in the United States The entire output comes from California

The deposit of kernite (rasorite) and borax (tincal) in the Kramer district of California is the world s principal source of boron compounds The deposit consists of two beds of borate minerals approximately 200–250 ft thick interspersed with shale and covered by 150 750 ft of overburden Until the late 1950s the ore was mined by shrink age stoping and room and pillar metho ls The overburden has now been stripped off so that open pit mining operations can be carried out The crude ore is crushed and concentrated by magnetic separators calciners and various air classifying units to yield a borate concentrate of the desired

composition and density The ore concentrates are then further refined at the mine site by specially adapted crystallization techniques

A variety of refined borate products (such as sodium metaborate potassium pentaborate and ammonium borate) and several grades of boric acid obtained from acidification of borax with sulfuric acid are routinely produced

Another important source of borate minerals is a dry lake containing an alkaline brine permeating the mineral bed that carries in addition to borax various other alkaline and miscellaneous mineral salts This dry lake known as Searles Lake is located in northwestern San Bernardino County California

In the Trona process brine is obtained from wells drilled in the salt body approximately 60–70 ft below the surface of the lake This brine is transported to the plant where it is stirred and blended with various end liquors resulting from previous operations of the process It is then evaporated to a desired concentration During this evaporation carbonate sulfate and chloride of sodium are removed by means of salt traps and filters At the end of the evaporation process the brine is essentially saturated with potassium chloride It is then cooled rapidly under conditions that cause potassium chloride to crystallize whereas borax and other salts remain in solution The crude borax of the supersaturated solution is crystallized upon further cooling and is further refined by recrystallization techniques Various grades of sodium tetraborate and of boric acid are manufactured by this process

Another process for the recovery of borax consists of carbonating the alkaline brine with CO_2 gas Sodium bicarbonate is precipitated and this procedure serves to recover sodium carbonate The resulting reduction in alkalinity increases the borax solubility by permitting the formation of the more soluble acid borates After filtering off the bicarbonate crop a portion of fresh raw brine is added to adjust the alkalinity back to that of the tetraborate The mixture is then cooled to bring about the crystallization of a substantial crop of borax

In the Tuscan region of Italy boric acid together with ammonium salts and carbon dioxide is recovered from hot springs and fumeroles Besides recovering considerable amounts of borates sufficient to supply most of Italy's domestic needs considerable electric power has also been obtained from the hot springs

Inorganic compounds Refined boric acid (H_3BO_3) is used extensively as a raw material for the production of other boron compounds It is used in leather manufacturing electroplating antiseptics cosmetics electrolytic condensers and in hydrogen ion control

Sodium perborate ($NaBO_3 \cdot 4H_2O$) usually prepared electrolytically from borax and caustic is used as a bleach as a disinfectant as an ingredient in tooth pastes and mouth washes and in electroplating

Anhydrous sodium tetraborate ($Na_2B_4O_7$) prepared by high temperature dehydration of borax is used extensively as a replacement for the parent material

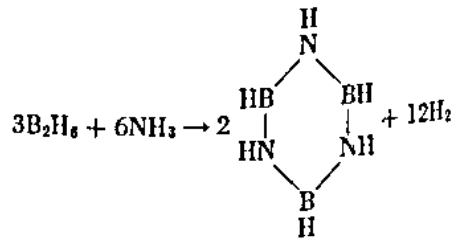
Boric oxide or boric anhydride (B_2O_3) is produced by the dehydration of boric acid In addition to its wide use as an intermediate in the production of boron halides and of metallic borides it is also used in the atomic energy industry as a thermal neutron absorber (boraxal) It is used in glass manufacturing in welding fluxes and in ore processing

Boron carbide B_4C is produced by the high temperature (about 2500°C) interaction of boric oxide (B_2O_3) and carbon in an electrical resistance type furnace It is a black, lustrous solid It is used extensively as an abrasive because its hardness approaches that of the diamond It is also used as an alloying agent particularly in molybdenum steels

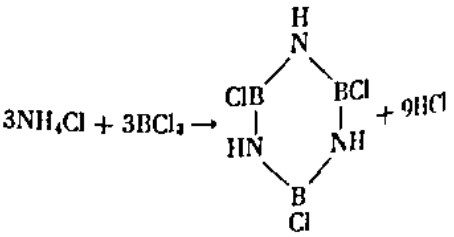
The use of boron carbide in nuclear engineering both as a construction material and as a neutron absorber is potentially of considerable magnitude

Metallic borides are usually prepared by hot sintering of the elements They may also be prepared by carbothermic or aluminothermic reduction of metal oxide boron oxide mixtures Borides have much in common with true metals They have a high electrical conductivity high melting points and extreme hardness Many metal borides are now used as components of cermet compositions in the ever growing high temperature refractory materials technology *See* BORIDE, CERMET

Nitrogen compounds Boron forms a large number of compounds with nitrogen At low temperatures diborane reacts with ammonia or amines to form ammoniates or the amine boranes When diborane and ammonia are heated above 200°C. hydrogen is eliminated and a six membered boron nitrogen ring compound borazene is formed



By analogous methods substituted borazenes may be obtained from amines and diborane The reaction of boron trichloride with ammonium chloride at elevated temperatures produces a substituted borazene in which a chlorine atom is attached to each boron atom



Borazenes are of interest because of their similarity in physical properties to aromatic organic compounds Borazene itself is structurally very similar to benzene and in fact has been referred to as inorganic benzene

In addition to the ring compounds of borazene type boron halides boron hydrides and borate esters form a number of addition compounds with ammonia and amines in which boron acts as a Lewis acid Some of these compounds particularly the amine boranes are useful as reducing agents in organic synthesis and have been suggested as polymerization catalysts and petroleum additives *See* Acid and base

Because of the unusual stability of the boron nitrogen chemical bond the compounds containing this bond are converted to boron nitride on heating to high temperatures These and similar compounds that boron forms with phosphorus and arsenic have been extensively investigated as possible building blocks in the field of polymer chemistry

Boron nitride (BN) is an interesting compound which has many potential commercial applications It is a white fluffy powder with a greasy feel It has an x ray diffraction pattern almost identical with that of graphite indicating a close similarity in structure but it does not conduct electricity Boron nitride may be prepared in a variety of ways as for example by the reaction of boric oxide with ammonia alkali cyanides and ammonium chloride or of boron halides with ammonia The unusually high chemical and thermal stability combined with the high electrical resistance of boron nitride suggest numerous uses for this compound in the field of high temperature technology Boron nitride can be hot pressed into molds and worked into desired shapes A cubic form of boron nitride called borazon has been prepared at pressures near 65 000 atm and temperatures near 1500°C It is comparable to the diamond in hardness and apparently has properties superior to those of diamond with regard to oxidation electrical resistance and thermal stability This material will probably take its place with diamond for industrial grinding

Halides Boron trihalides are colorless volatile compounds that are extremely susceptible to moisture Boron trifluoride is a gas (bp −101°C) and has been an article of commerce for a considerable period Boron trichloride (bp 12 4°C) and boron tribromide (bp 90 4°C) have become available on a commercial scale only recently Boron triiodide is a white crystalline solid (mp 49 6°C) Boron halides with the exception of the iodide can be made by heating elemental boron or borides with halogens The iodide can be prepared only indirectly as for example from boron trichloride and hydriodic acid or from iodine and sodium borohydride Boron trifluoride is most readily obtained from the reaction of boric acid hydrogen (or a metallic) fluoride and sulfuric acid

Boron halides and in particular the trifluoride and trichloride are valuable catalysts and are used extensively in the chemical industry They are valuable intermediates in the production of metal borohydrides and various boron hydrogen compounds Boron trichloride is used in the refining of aluminum magnesium zinc and copper and as a fire extinguisher for magnesium and other metal fires

Boron trifluoride combines with fluoride ions to form fluoborate (borofluoride) ions (BF_4^-) Several of the metallic fluoborates and fluoboric acid have important uses in the electroplating industry

Organic compounds Organic compounds of boron are numerous and varied They may be broadly subdivided into two classes alkyl and aryl derivatives of boron in which boron is directly bonded to carbon and the boron oxygen carbon compounds such as borate esters and boroxines These latter substances may be regarded as derivatives of boric acid or boric oxide

Boron alkyls such as trimethyl boron (a gas bp −21 8°C) and triethyl boron (liquid bp 95°C) are extremely reactive materials Most of the boron alkyls are spontaneously inflammable in air Controlled oxidation yields alkyl boron oxides (R BO) which dissolve in water to form alkyl boric acids R $B(OH)_2$ Boron alkyls are usually prepared from boron halides and metal alkyls (such as zinc) or Grignard reagents (RMgX) or by the reaction of diborane with unsaturated hydrocarbons

Boron aryls such as triphenyl boron (mp 142°C) are usually solids The aryl compounds are also prepared by the Grignard method from boron halides The boron aryls are somewhat less sensitive to oxygen than their alkyl analogs

The aryl and the alkyl compounds of boron are potentially useful intermediates for the synthesis of other boron compounds Sodium tetraphenyl borohydride a valuable analytical reagent is used for the estimation of potassium rubidium and cesium

Borate esters are derivatives of boric acid (or oxide) and alcohols or phenols They may be prepared either directly from parent materials or indirectly from the reaction of boron halides with alcohols or phenols or by ester interchange reactions In general borate esters are extremely sensitive to hydrolysis but if the alcohol is sufficiently hindered sterically this hydrolytic tendency can be appreciably reduced The simplest borate ester trimethyl borate is a valuable intermediate for the preparation of metal borohydrides In addition to synthetic possibilities for borate esters a number of miscellaneous uses have been described principally in the patent literature Some of these include the use of borate esters in cosmetic preparations as antioxidants for rubber and alcohols as curing agents for epoxy resins as petroleum additives in pharmaceutical preparations in plasticizers and as surface active agents

Boric oxide dissolves readily in borate esters to form materials known as boroxines Although most of these boroxines will burn in the air their combustion product is glassy boric oxide and for these reasons they have been proposed and used as extinguishing agents in metal

Analysis The detection of boron is generally based upon the green coloration which is imparted by its volatile compounds to an alcohol flame or a nonluminous gas flame Minerals are tested for boric acid by mixing them with calcium fluoride and sulfuric acid and introducing them close to the lower margin of a flame If boric acid is present volatile boron trifluoride is formed this gives a green coloration to the flame

With yellow turmeric paper free boric acid or acidified solutions of borates give a red brown coloration which appears only after the paper is dried If the paper is then moistened with ammonia it is temporarily colored blue black

Boric acid can be determined quantitatively by conversion to methyl borate and subsequent saponification with calcium hydroxide If a weighed amount of calcium oxide is used the increase in weight after ignition represents directly the amount of boric oxide taken up

Boric acid (or soluble borates) are conveniently determined volumetrically For this purpose the weak boric acid is converted into a stronger monobasic acid this can then be titrated directly with standard sodium hydroxide using *phenol* phthalein as indicator

For the estimation of boron in metallic borides boron carbide boron nitride and elemental boron the sample is first digested to a soluble sodium borate by fusion in a mixture of sodium carbonate and sodium nitrate The boron in the resultant melt is converted to boric acid by treatment with hydrochloric acid and the resulting solution titrated with standard sodium hydroxide in the presence of mannitol *See* Borane Boron fuel

[F H M V V L]

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Boron fuel

A chemical fuel chiefly for space vehicles in which the metal boron is the principal combustible element To obtain a high *heat of combustion per unit mass* an element of low atomic weight is necessary Hydrogen (H) atomic *number* 1 *either* as a constituent of gasoline or other liquid fuel or alone as a gas is commonly used *Boron* (B) atomic number 5 is another possible fuel *element* The heats of formation for hydrogen with *fluorine* (F) or oxygen (O) as HF and as H_2O are 3 21 kcal/g in both cases for boron they are 3 91 kcal/g for BF_3 and 4 33 kcal/g for B O The extent to *which* these higher heats of formation can *be converted* into useful thrust depends on the properties of the combustion products and engine operating conditions Thus if the operating temperature is high B_2O_3 will be vaporized giving a net release of heat of only 3 16 kcal/g *See* Metal base fuel

[D A]

Bose Einstein statistics

The statistical description of quantum mechanical systems in which there is no restriction on the way in which particles can be distributed over the individual energy levels This description applies when the system has a symmetric wave function This in turn has to be the case when the particles described are of integer spin

Distribution probability Suppose one describes a system by giving the number of particles n_i in an energy state ϵ_i where the n are called occupation numbers and the index i labels the various states The energy level ϵ_i is of finite width being really a range of energies comprising say g_i individual (nondegenerate) quantum levels If any arrangement of particles over individual energy levels is allowed one obtains for the probability of a specific distribution

$$W = \prod_i \frac{(n_i + g_i - 1)!}{n_i!(g_i - 1)!} \tag{1}$$

In Boltzmann statistics this same *probability* would be

$$W = \prod_i \frac{g_i^{n_i}}{n_i!} \tag{1a}$$

See Boltzmann statistics

The equilibrium state is defined as the most probable state of the system To obtain it one *must* maximize Eq (1) under the conditions that

$$\Sigma n_i = N \tag{2a}$$

$$\Sigma \epsilon_i n_i = E \tag{2b}$$

which express the fact that the total number of particles N and the total energy of the system E is fixed One finds for the most probable distribution

$$n_i = \frac{g_i}{\frac{1}{A} e^{\beta \epsilon_i} - 1} \tag{3}$$

Here A and β are parameters to be *determined* from Eqs (2a) and (2b) actually $\beta = 1/kT$ where k is the Boltzmann constant and T is the absolute temperature

In the classical case that is when Boltzmann statistics are employed the equilibrium *distribution* may be obtained from a specific assumption about the number of collisions of a certain kind *One assumes* that the number of collisions per second in which molecules with velocities in cells i and j in phase space produce molecules with *velocities* in cells k and l is given by

$$A_{ij}^{kl} = n_i n_j a_{ij}^{kl} \tag{4}$$

where a_{ij}^{kl} is a geometrical factor In the Bose

case Eq (3) may be obtained in a similar way from a collision number assumption which reads

$$A_{ij}^{kl} = a_{ij}^{kl} n_i n_j \left(\frac{g_k + n_k}{g_k}\right)\left(\frac{g_l + n_l}{g_l}\right) \tag{5}$$

One observes the interesting fact that the number of collisions depends on the number of particles in the state to which the colliding particles are going The more heavily populated these states are the more likely a collision is Quite often one defines f the distribution function by

$$n_i = f_i g_i \tag{6}$$

Applications An interesting and important result emerges when one applies Eq (3) to a gas of photons that is a large number of photons in an enclosure (Since photons have integer spin this is legitimate) For photons one has

$$\epsilon = h\nu \tag{6a}$$

$$p = \frac{h\nu}{c} \tag{6b}$$

where h is the Planck constant, ν the frequency of the photon c the velocity of light ϵ the energy of the photon and p the momentum of the photon The number of photons in a given energy or frequency range is

$$g = \frac{8\pi}{c^3} V\nu^2\, d\nu \tag{7}$$

where V is the volume of the enclosure containing the photons Actually for a gas of photons condition (2a) is not necessary (the number of photons is not fixed) and thus the distribution function depends on just one parameter β A can be shown to be unity If one also uses the fact that $\beta = 1/kT$ one obtains from Eq (3) for the number of photons in the frequency range $d\nu$

$$n(\nu)\, d\nu = \frac{8\pi}{c^3} V \frac{\nu^2\, d\nu}{e^{h\nu/kT} - 1} \tag{8}$$

The energy density (energy per unit volume) in the frequency range $d\nu$ is by Eqs (8) and (6a)

$$\rho(\nu)\, d\nu = \frac{8\pi h}{c^3} \frac{\nu^2\, d\nu}{e^{h\nu/kT} - 1} \tag{9}$$

One recognizes Eq (9) as the celebrated Planck radiation formula for black body radiation (*see* HEAT RADIATION) Thus black body radiation must be considered as a photon gas with the photons satisfying Bose Einstein statistics

For material particles of mass m contained in a volume V one may write Eq (3) as

$$f(v_x v_y v_z)\, dv_x\, dv_y\, dv_z = \left(\frac{m}{h}\right)^3 V \frac{dv_x\, dv_y\, dv_z}{\frac{1}{A} e^{mv^2/2kT} - 1} \tag{10}$$

where $v = \sqrt{v_x^2 + v_y^2 + v_z^2}$ is the total velocity The expressions (2) may now be written as integrals If the so-called virial theorem is used

$$PV = \tfrac{2}{3}E \tag{11}$$

where P is the pressure V is the volume and E the energy Eq (2) yields a pair of implicit equations which give the equation of state of an ideal Bose gas

$$\frac{N}{V}\lambda^3 = B_{1/2}(A) \tag{12a}$$

$$\lambda^3 \frac{P}{kT} = B_{3/2}(A) \tag{12b}$$

In Eqs (12)

$$\lambda^2 = \frac{h^2}{2\pi mkT}$$

while $$B_\rho(A) = \frac{1}{\Gamma(\rho + 1)} \int_0^\infty \frac{u^\rho\, du}{\frac{1}{A} e^u - 1} \tag{13}$$

Here Γ is the usual Γ function and $u = mv^2/2kT$ From Eq (12) one obtains the relation between P V and T by eliminating A

Now if one develops the numerator of the integral in Eq (13) in an infinite series one obtains the so called Einstein equations

$$\frac{N}{V} = \frac{1}{\lambda^3} \sum_{l=1}^{\infty} \frac{A^l}{l^{3/2}} \tag{14a}$$

$$P = \frac{kT}{\lambda^3} \sum_{l=1}^{\infty} \frac{A^l}{l^{5/2}} \tag{14b}$$

It is easy to verify that the sums (14) diverge for $A > 1$ however they still converge for $A = 1$ For $A = 1$ $N/V = 2.61/\lambda^3$ and $P = 1.34kT/\lambda^3$ Einstein interpreted N/V $2.61/\lambda^3$ as a maximum possible density If the gas is compressed beyond this point the superfluous particles will condense in a zero state where they do not contribute to the density or the pressure If the volume is decreased this curious condensation phenomena results yielding the zero state which has the paradoxical properties of not contributing to the pressure volume or density There is now considerable evidence that many of the superfluid properties exhibited by liquid helium are in fact manifestations of an Einstein condensation Particularly convincing is the observation that liquid He^3 which has half integer spin and thus must satisfy Fermi Dirac statistics shows no superfluid properties The discussion so far was for ideal Bose systems For non ideal Bose systems the situation is currently under intensive study It appears that a fairly complete description of the experimental facts of He^4 is possible thus providing direct evidence for the reality of the condensation phenomenon *See* FERMI DIRAC STATISTICS QUANTUM STATISTICS QUANTUM THEORY NONRELATIVISTIC STATISTICAL MECHANICS

[M DR]

Bibliography See STATISTICAL MECHANICS

Botanical gardens

A garden for the culture of plants collected chiefly for scientific and educational purposes Such a garden is more properly called a botanical insti

tution in which the outdoor garden is but one portion of an organization including the greenhouse the herbarium the library and the research laboratory (*see* HERBARIUM) For example at the Missouri Botanical Garden in a typical year 16 scientists were employed on research projects (in addition to educational activities) doing research on such subjects as lawn grass fossil plants culture of succulents culinary herbs plants of Panama *Rauwolfia* and local flora

Famous botanical gardens It was only in modern Europe after the foundation of the great medieval universities that botanical gardens for educational purposes began to be established in connection with the schools The oldest gardens are those at Padua (established 1533) and at Pisa (1543) The botanical garden of the University of Leiden was begun in 1587 and the first greenhouse is said to have been constructed there in 1599 Louis XIII authorized the establishment of a royal garden in Paris for the instruction of students it was opened to the public in 1640 under the name Jardin du Roy Later the name was changed to the Musee National d Histoire Naturelle The Oxford University Botanic Garden the first in Great Britain was established in 1621 In Berlin the Botanischer Garten was established in 1646 In 1655 a garden was founded at Uppsala Sweden of which Carolus Linnaeus the father of modern plant taxonomy was director from 1742 to 1777 In Russia Peter the Great s Druggist s Garden was founded at St Peters burg in 1713 In 1817 the Conservatoire et Jardin Botaniques were established at Geneva and became one of the leading botanical centers of the world The Royal Botanical Gardens at Kew England were officially opened in 1841 This institution came to be known as the botanical capital of the world

The first of the great tropical gardens was founded at Calcutta in 1787 The original name, Royal Botanic Garden, was changed in 1947 to Indian Botanic Garden Another great tropical garden the Jardin Botanico of Rio de Janeiro was founded in 1808 The great tropical botanical garden of Buitenzorg (Bogor) Java which originated in 1817 has an area of 205 acres with an additional 150 acres in the Mountain Garden

Gardens in North America The first great garden of the United States was founded by Henry Shaw at St Louis in 1859 and is now known as the Missouri Botanical Garden The New York Botanical Garden was chartered in 1891 and the Brooklyn Botanic Garden in 1910 The Jardin Botanique of Montreal the leading garden of Canada was opened in 1936 *See* ARBORETUM

[ELC]

Bibliography *See* PLANT TAXONOMY

Botany

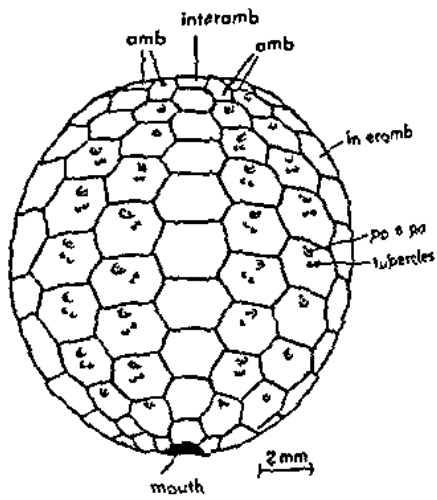
That branch of biological science which embraces the study of plants and plant life According to the specific objectives of the investigators botanical studies may range from microscopic observations of the smallest and most obscure plants to the study of the trees of the forest One botanist may be interested mainly in the relationships among plants and in their geographic distribution whereas another may be primarily concerned with structure or with the study of the life processes taking place in plants

The principal divisions of botanical science are as follows plant anatomy (including morphology) plant disease (pathology) plant physiology plant taxonomy cytology, ecology embryology genetics and paleobotany (see separate articles for the sciences listed above) Other subjects are concerned with the study of specific groups of plants such as bacteriology mycology (fungi) agrostology (grasses) algology (algae), and bryology (liverworts and mosses) A number of agricultural subjects also have botany as their foundation such as horticulture forestry, landscape architecture floriculture agronomy and plant breeding

[PDS]

Bothriocidaroida

An order of Perischoechinoidea in which the ambulacra comprise two columns of plates the interambulacra one column, and the madreporite is



Bothriocidaris reconstruction of test

placed radially *Bothriocidaris* (see illustration) the only known genus occurs in the upper Ordovician of Estonia and is the oldest recognized echinoid *See* PERISCHOECHINOIDEA

[DBT]

Botulism

A type of food poisoning due to intoxication by the extremely potent exotoxin produced by the anaerobic bacteria *Clostridium botulinum* and *C parabotulinum* These species differentiated on the basis of the ability to hydrolyze protein, both produce an exotoxin of similar pharmacologic and immunologic properties Five antigenic types of the toxin exist, most of which have been chemically purified and toxoid or antitoxin immunization is type specific Immunization against botulism is

generally not considered necessary since the dis ea e is comparatively rare The disease in humans most commonly follows ingestion of unheated im properly processed food with pH above 4 5 in which growth and toxin production has occurred It is characterized by respiratory failure The dis ea e may occur spontaneously in a variety of ani mals including chickens ducks mink cattle and horses

The causal organism is isolated from suspected food and the toxin type is determined by neutrali zation tests with antitoxin of known types Cell free filtrates of incriminated food may also be used for toxin typing In humans an acute gas troenteritis may or may not precede the principal symptoms of extreme weakness dry mucosa loss of accommodation ocular muscle paralysis and difficulty in swallowing These symptoms commonly occur within 48 hours after the ingestion of the toxic food Prevention of botulism is best ac complished by safe procedures of food preserva tion In e tablished cases serum therapy is useful only in massive doses and is effective only if toxin is not bound to motor nerve terminals *See* BACTERI OLOGY MEDICAL IMMUNOLOGY SEROLOGY TOXIN BACTERIAL [L S M]

Boundary layer flow

The flow of that portion of a viscous fluid which is in the neighborhood of a body in contact with the fluid and in motion relative to the fluid Wherever a vi cous fluid flows past a boundary the layers of the fluid nearest the boundary are s ibjected to shearing forces which cause the velocity of these layers to be reduced (*see* VISCOUS FLOW) As the boundary is approached the velocity continuously decreases until immediately at the boundary the fluid particles are at rest relative to the body This region of retarded velocity is called the boundary layer and a graph of the variation of velocity with distance from the wall or boundary describes a boundary layer profile (Fig 1) The primary effects of the viscosity of the fluid are concentrated in this boundary layer whereas in the outer or free stream flow the viscous forces are negligible (*see* FLOW OF FLUIDS) L Prandtl founded modern boundary layer research in 1904 when he recog nized that the flow in the boundary layer could be treated separately from the free stream flow and simplified the Navier Stokes equations for use in the boundary layer (*see* NAVIER STOKES EQUA TIONS) Because the friction forces due to the vis cosity of the fluid are restricted to the boundary layer this region is also often called the friction layer

The velocity of the fluid within the boundary layer approaches the local free stream velocity asymptotically as the distance from the wall is increased thus the actual thickness of the bound ary layer is difficult to determine An arbitrary boundary layer thickness δ is usually defined as that distance from the wall or boundary where the velocity of the flow in the boundary layer reaches 99% of the local free stream velocity (Fig 1) The thickness of a boundary layer depends upon the viscosity of the flowing fluid the free-stream flow conditions the roughness of the immersed surface or boundary and the extent of the surface over which the fluid has passed Each body moving through a viscous fluid is sheathed in a mantle of boundary layer flow The thicknesses of boundary layers surrounding vehicles moving through the air range from less than 0 1 in near the front of a high speed aircraft to more than 10 ft at the rear of a dirigible or an airship

The viscous shearing force created within the boundary layer constitutes a major portion of the resistance or drag experienced by an airplane in flight or by fluids passing through pipes and chan nels this shearing force opposes the relative mo tion of any viscous fluid past a bounding or im mersed surface The boundary layer thickness generally increases with the extent of the surface over which the fluid has passed In the flow of fluid through pipes the boundary layer formed at the walls thickens until the pipe is entirely filled with boundary layer flow (Fig 2) When such a condi tion is reached fully developed pipe flow is said to exist In cases of unbounded flows such as a thin flat plate placed parallel to the flow direction the boundary layer continues to increase in thickness as the fluid passes downstream (Fig 3) This growth of the boundary layer results in a deflection or displacement of the free stream flow away from the surface thus apparently increasing the thick ness of the plate

Boundary layer separation In flowing over a surface of changing contour the velocity and pres sure of a fluid vary (*see* BERNOULLI S THEOREM)

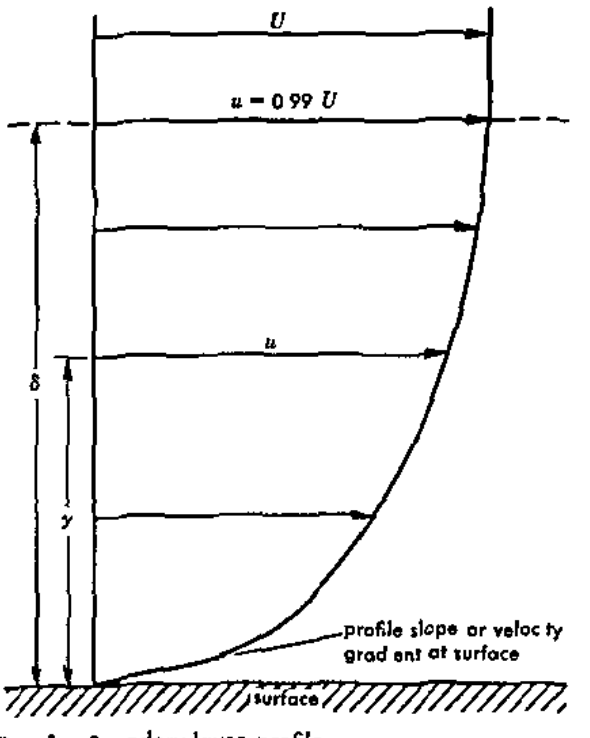


Fig 1 Boundary layer profile

As the flow velocity increases the pressure must decrease In the free stream where there are negligible losses to viscosity the flow is always able to proceed into regions of increasing pressure at the expense of its velocity the opposing pressure forces being balanced by the forces that result from the change in momentum of the flow However within the boundary layer where the momentum of the fluid has been reduced in overcoming viscous forces the remaining momentum may be insufficient to allow the flow to proceed into regions of increasing pressure At the position on the body where this condition exists the boundary layer no longer continues to follow the contour of the boundary but instead leaves or separates from the surface This phenomenon is known as boundary layer separation (Fig 4) Beyond the point of separation between the surface and the separated boundary layer a region of reversed or upstream flow exists This reversed flow and the separated boundary layer subsequently coalesce to form a wake of low velocity fluid behind the body The separation of the flow in the boundary layer limits the lifting capabilities of wings and causes the stalling of airplanes (*see* AIRPLANE) The efficiencies of fluid machines and mechanisms such as turbines compressors pumps and propellers are decreased by flow separation originating in the boundary layer

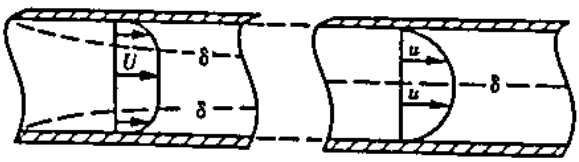


Fig 2 Boundary layer development in a pipe

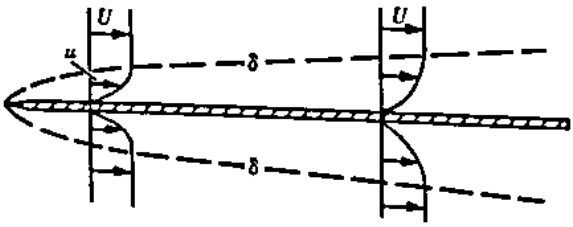


Fig 3 Boundary layer development on flat plate

Laminar and turbulent layer The flow in the boundary layer formed on a body exists in one of two characteristic states laminar or turbulent (*see* FLUID-FLOW PROPERTIES) If the flow is laminar strata or laminae of fluid pass smoothly across the surface whereas if it is turbulent the flow is characterized by a rapid churning or mixing between layers of flow having different velocities These two flow states are familiarly illustrated by the smoke rising from a cigarette in a still room At first the smoke rises in smooth continuous filaments which after some distance begin to oscillate and finally erupt into boiling turbulent flow This same phenomenon of transition from laminar to turbulent flow may occur within the boundary layer after the flow has passed over a surface for some distance The flow on the forward or upstream portion of a body is generally laminar However as the boundary layer develops on the after or downstream part of the body the flow may become turbulent The flow in the boundary layer at first smooth or laminar eventually begins to fluctuate and finally bursts into random turbulence (Fig 5) Turbulent flow may occur within the boundary layer even when as is generally the case,

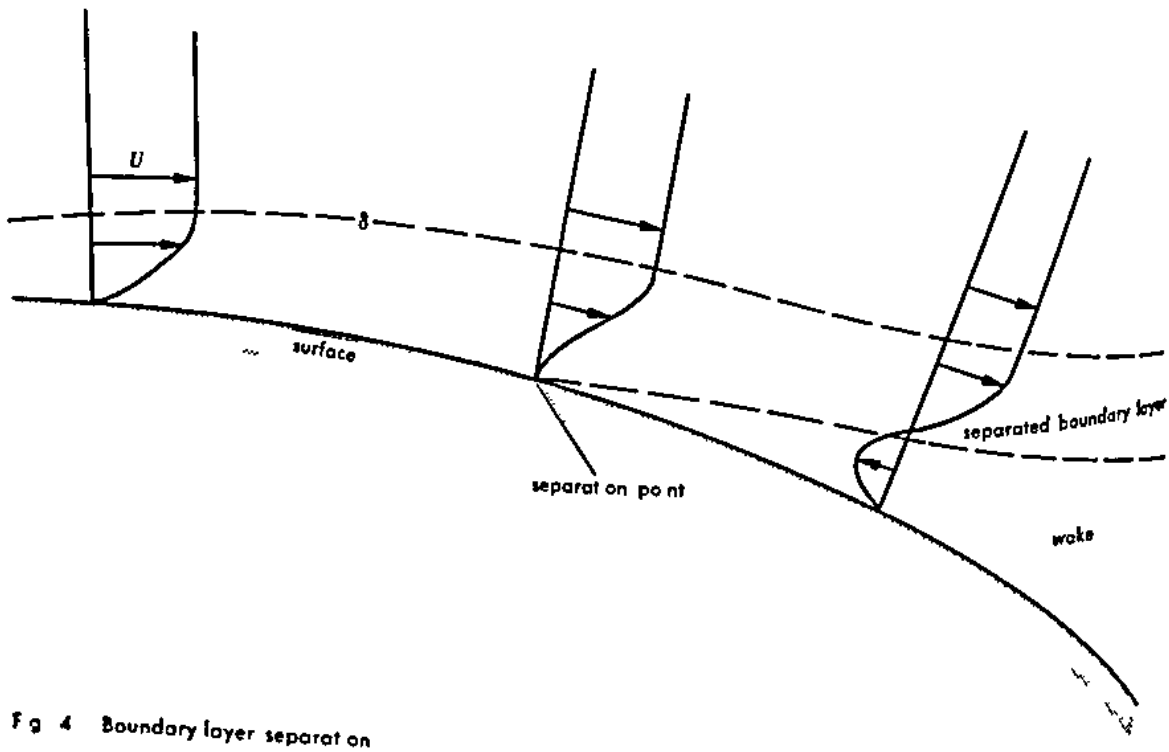


Fig 4 Boundary layer separation

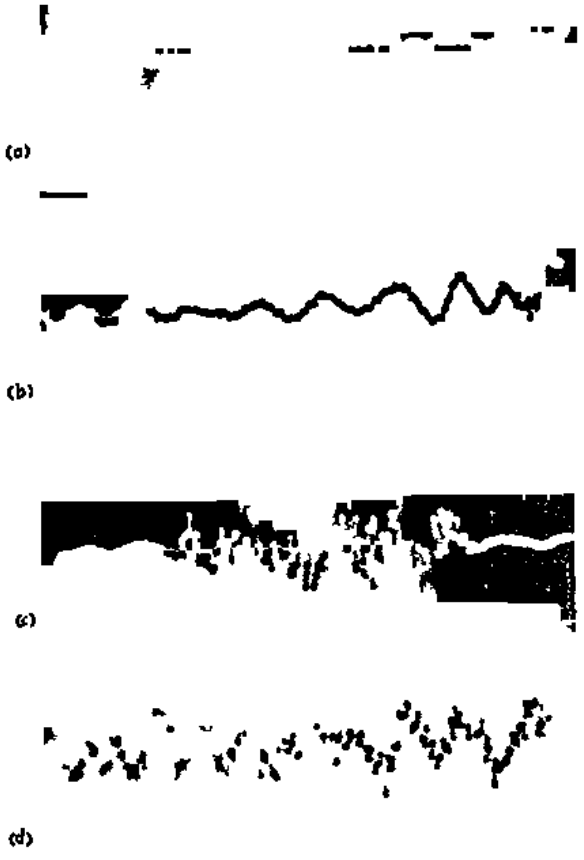


Fig 5 Photographs of oscilloscope traces showing velocity fluctuations in the boundary layer (a) Laminar flow with small oscillations (b) Oscillations amplified to form Tollmien Schlichting waves (c) Turbulent bursts indicating onset of transition (d) Fully developed turbulent fluctuations

the free stream flow outside the boundary layer is laminar Turbulent flow is readily distinguished from laminar by experiment however a complete and precise theoretical explanation of the processes which cause a laminar boundary layer to become turbulent has not yet been formulated

Critical Reynolds number Among the first to investigate the transition from laminar to turbulent flow O Reynolds suggested a dimensionless ratio the Reynolds number as a flow parameter useful in determining the extent of laminar boundary layer flow over a surface (*see* REYNOLDS NUMBER) It has since been determined that for many specific shapes there exists a Reynolds number above which the flow in the boundary layer no longer remains laminar but becomes turbulent This Reynolds number is known as the critical Reynolds number of the boundary layer

In dealing with boundary layer flows the Reynolds number is usually written as

$$R = U\delta^*/\nu$$

where U is the local free stream velocity ν is the kinematic viscosity of the fluid and δ^* is the displacement thickness of the boundary layer a characteristic parameter defined as

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{U}\right) dy$$

u being the velocity at any distance y away from the surface Transition generally will not occur below a Reynolds number $R = 575$

The term critical Reynolds number is often used in a slightly different sense when bluff or blunt bodies such as spheres or circular cylinders placed perpendicular to the flow are being considered In these cases the critical Reynolds number is that value at which there occurs a sudden drop or decrease in the drag coefficient of the body Here the Reynolds number is defined using the diameter D of the sphere or cylinder in place of the displacement thickness δ^* of the boundary layer The critical Reynolds number of a sphere is about 325 000 and that for a circular cylinder about 450 000

Stability of laminar layer To predict the theoretical value of the critical Reynolds number of an arbitrary boundary layer it has been found convenient to assume that the laminar boundary layer flow is not absolutely smooth and laminar but that it contains velocity fluctuations of infinitesimal amplitude It is further assumed that these fluctuations cover a wide range of frequency of oscillation Based upon these assumptions the Tollmien Schlichting stability theory has been developed This theory shows that under certain conditions in the boundary layer velocity fluctuations of particular frequencies are amplified whereas fluctuations of all other frequencies are damped The amplified fluctuations increase in magnitude and cause the flow within the boundary layer to oscillate at their particular frequency These large oscillations within the boundary layer are known as Tollmien Schlichting waves (Fig 5*b*) The oscillations increase in amplitude and eventually cause turbulent flow When the flow conditions are such that no fluctuations regardless of frequency are amplified the boundary layer is said to be stable If however the Reynolds number of the boundary layer is large enough fluctuations of some frequency are amplified the boundary layer is unstable and the flow eventually becomes turbulent

Transition to turbulent flow may also be caused by a finite disturbance to the boundary layer such as surface roughness A roughness element on the surface may result in localized separation of the boundary layer causing turbulence to be shed from the element frequently the wake of the roughness element may cause a wedge of turbulent flow to be formed downstream just as turbulent flow may be formed behind an object dipped into a smooth stream of water It has been further postulated that such a transition can be excited even on a smooth surface by large velocity fluctuations within the boundary layer Thus amplified Tollmien Schlichting waves can have the same effect in causing transition as disturbance or roughness elements on the surface Both the Tollmien Schlichting

stability theory and Taylor's finite disturbance theory have been confirmed conclusively by experiment

Skin friction The viscous shearing forces which retard the flow within the boundary layer stem from the friction developed between the moving fluid and the surface or skin of the immersed body The accurate calculation and prediction of the surface shear or skin friction which will exist on a given body is the primary goal of boundary layer theory Because skin friction produces a direct shearing resistance or drag and also may result in separation of the boundary layer a knowledge of its distribution and magnitude is useful in determining the performance of bodies moving through viscous fluids

The shearing stresses existing within a fluid are proportional to the viscosity of the fluid and to the rate of change of strain within the fluid Thus for laminar flows a relatively simple relation for the shearing stress may be written as

$$\tau = \mu \frac{du}{dy}$$

where τ is the shearing or frictional stress μ is the viscosity of the fluid and du/dy is the gradient or rate of change of velocity normal to the surface The skin friction or shearing stress at the surface is found by evaluating this relation at the surface where $y = 0$ so that

$$\tau_0 = \mu \left.\frac{du}{dy}\right|_0$$

Thus the skin friction of a laminar boundary layer can be determined directly from its boundary layer profile

For turbulent flows however the shearing stress is further increased by turbulent mixing which results in exchange of mass and momentum within the boundary layer Laminar shear is caused only by molecular interaction within the fluid whereas turbulent shear is determined mainly by the interaction of macroscopic portions or particles of fluid In a turbulent flow finite particles of fluid having different velocities are churned or mixed together by the turbulent fluctuations In this manner, the exchange of momentum among the particles produces an increased resultant shearing stress A particle moving from a low velocity region into a region of higher velocity must be accelerated to the velocity of its new environment and the force required to produce this acceleration reduces the momentum of the surrounding particles The turbulent mixing and consequent momentum exchange within the boundary layer tend to produce a profile in which there is a more uniform distribution of velocity than in the case of laminar flow (Fig 6) Prandtl's mixing length theory treats the additional shearing stresses caused by turbulence as an apparent increase in the viscosity of the fluid and gives the friction in the boundary layer as

$$\tau = \rho\epsilon \frac{du}{dy}$$

where ρ is the density of the fluid and ϵ is the apparent kinematic viscosity or eddy viscosity of the fluid The determination of ϵ is dependent on the scale of the turbulence and is indicated by the size of the turbulent eddies

In the part of a turbulent boundary layer which is in the immediate proximity of the surface the turbulent fluctuations are almost completely damped by the wall This region is called the laminar sublayer and the shear within this region including the skin friction follows the laws of laminar flow This sublayer is however extremely thin and the velocity gradients are much larger hence, the skin friction is much greater than for completely laminar boundary layers

Layers in compressible flow As the free stream flow approaches sonic velocity additional considerations complicate the behavior of the boundary layer For example the energy lost to skin friction produces sufficient heat to invalidate the assumptions of constant fluid density and viscosity Thus the heat produced by skin friction results in a thermal boundary layer of varying temperature near the surface At a Mach number $M = 3$ the surface temperature is raised about 50°C above the temperature of the ambient fluid The interaction of this variation of temperature with the variation of velocity in the boundary layer makes a rigorous theoretical analysis of the flow almost intractable However several parameters have been shown to influence the behavior of boundary layers in compressible flows Among these is the Mach number $M = U/c$ where U is the velocity of the fluid and c is the sonic velocity Also of importance is the Prandtl number $P = \nu/a$ where ν is the kinematic viscosity of the fluid and a is the thermal diffusivity

The shock waves which may develop on a body also have a considerable and generally adverse effect upon the boundary layer (see COMPRESSIBLE FLOW) A shock wave almost inevitably results in premature transition from laminar to turbulent flow in the boundary layer and if strong enough will cause an early separation of the flow Although

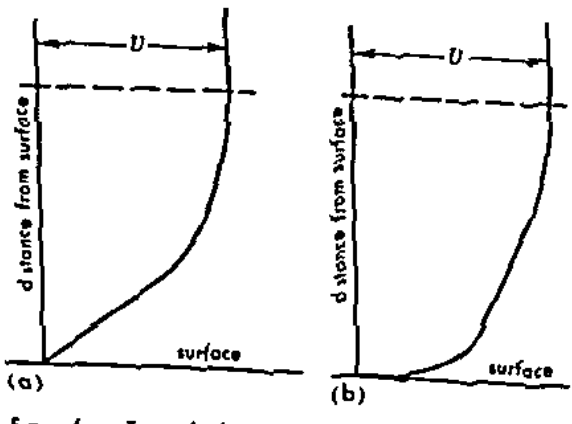
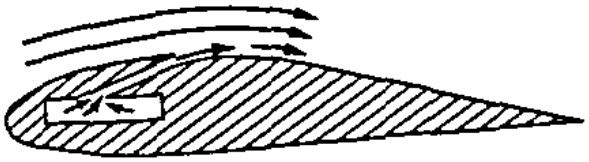


Fig 6 Typical boundary layer velocity profile (a) Laminar (b) Turbulent



Fg 7 Airfoil with blowing boundary layer control

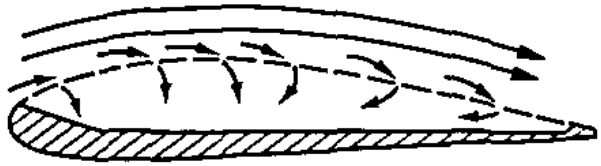


Fig 8 Airfoil with suct on boundary layer control

theoretical treatments have been developed the greater part of compressible boundary layer tech nology is based upon empirical relations obtained from experimental results

Boundary layer control The natural develop ment of a boundary layer is affected by the contour and surface roughness of the body on which it is formed Therefore by the reduction of surface roughness and the choice of surface contours some amount of control may be exerted upon the devel opment of the boundary layer Attention to surface roughness waviness and continuity is particularly important in the preservation of laminar boundary layers Even the protuberance on a surface which is apparently most insignificant may produce local ized transition to turbulent flow Transition on air craft wings is often produced by the remains of insects which have impinged upon the wings at high speeds Rivet heads skin laps and joints and other surface discontinuities readily produce tur bulent flow on airplanes

The over all contour of the body is also an im portant consideration if laminar boundary layer flow is to be maintained Recently many laminar airfoil sections have been developed for high speed aircraft In fact the term streamlining has come to describe the technique of designing shapes upon which the boundary layer growth is minimized (*see* STREAMLINING) The body shape also has a large influence upon the separation of the flow and to give low resistance or drag shapes must be designed which prevent or delay boundary layer separation These techniques of influencing the development of the boundary layer by prescribing the geometry of bodies may be called geometric boundary layer control

Because the amount of control available by purely geometric means is limited additional meth ods for influencing the development of the bound ary layer have evolved These methods in general are intended either to remove the low momentum flow from the boundary layer or to restore the lost momentum In the latter method the retarded flow in the boundary layer is reenergized by supplying high velocity *flow through slots or jets in the sur* face of the body (Fig 7) This blowing boundary layer control requires suitable pumps and ducts within the body to provide the necessary quantities of blown or ejected fluid This technique has as yet not proven to be an economical method of control although several aircraft utilizing varia tions of the principle have been flown Blowing boundary layer control is intended to suppress or delay the separation of the boundary layer rather than to preserve laminar flow and as a result is limited in its applications

The method of controlling the boundary layer by the removal of the retarded flow called suction boundary layer control may be applied both to maintain laminar flow and to prevent boundary layer separation By sucking away the flow in the lower regions of the boundary layer through slots or perforations in the surface the development of the boundary layer can be readily influenced (Fig 8) The proper distribution of this suction as determined by the requirements of the boundary layer equations allows a designer to tailor the development of the boundary layer to his particular demands By maintaining the boundary layer Reyn olds number below its critical value the flow can be kept in a stable condition and thus remain laminar By thinning the boundary layer properly it can be made to resist separation Practical suc tion systems for maintaining laminar flow and for delaying flow separation have been demonstrated in *flight* [J J CO]

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Bourdon spring pressure gage

A mechanical pressure measuring instrument em ploying as its sensing element a curved or twisted metallic tube flattened in cross section One end of the tube is closed and the fluid pressure to be measured is applied through the other end As the pressure is increased the tube becomes more nearly circular in cross section and tends to straighten The motion of the free (closed) end of the tube is a measure of the internal pressure

The fundamental principle that motion of a bour don tube is proportional to applied pressure is credited to Eugene Bourdon nineteenth century French inventor

Pressure-measuring instruments using bourdon tubes are used for pressure ranges from 0–10 pounds per square inch gage (psig) to 0–100 000 psig as well as for vacuum The accuracy may be from 0 1 to 2 0% of full scale reading depending on the materials design and precision of compo nents

The bourdon pressure element may be made in any one of a number of shapes The commonest forms are the C tube the spiral and the helical element

The C tube is simple and rugged and is widely used in concentric dial indicating pressure gages The C tube is also used in some electrical pressure

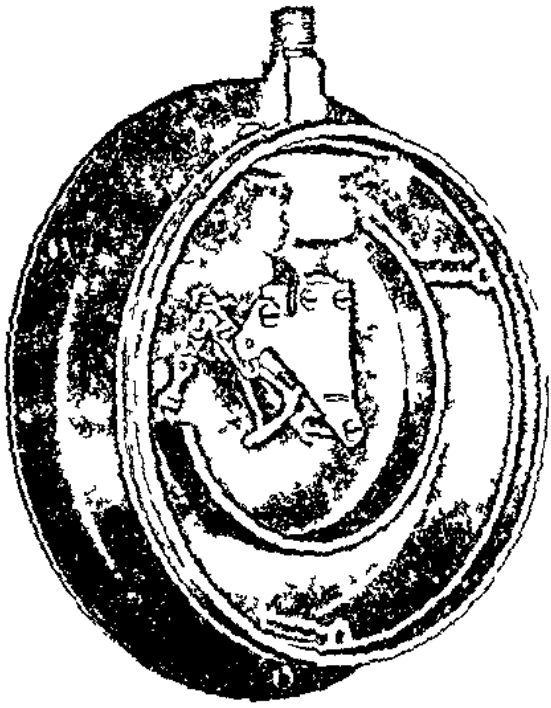


Fig 1 C tube bourdon element with mechanism for industrial pressure gage (The Foxboro Co)

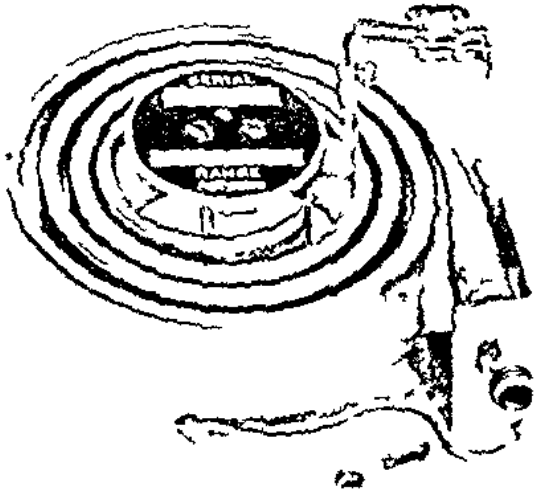


Fig 2 Spiral bourdon element (The Foxboro Co)

transducers where small *tip motion* is permissible or desirable Ranges are to 20 000 psi *See* PRESSURE TRANSDUCER

The spiral and helical forms are used in recording and controlling instruments for greater tip motion or lower wall *stress* Spiral bourdon elements are available for ranges as high as 0–4000 psi and *helical* elements for pressures as high as 100 000 psi

The twisted tube rugged and compact is often preferred especially for use with electrical pressure transducers

Bourdon tubes are available in a variety of copper alloys and AISI 300 ser ss st ...
some i
format
resi in
have a nearly constant modulus are also availabl

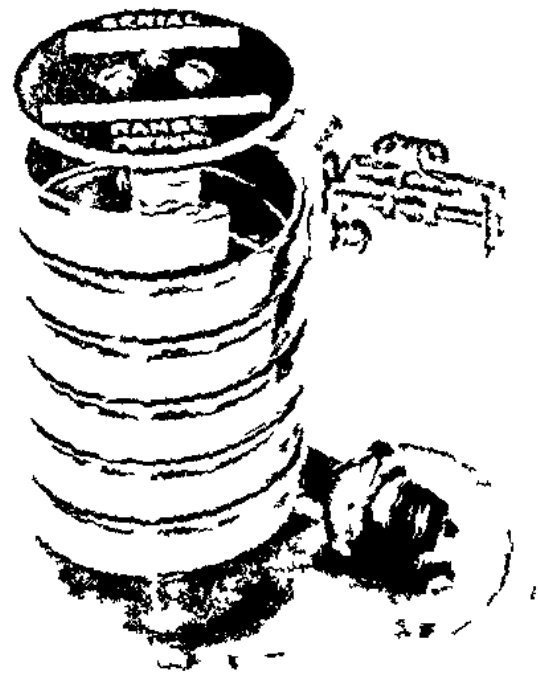


Fig 3 Helical bourdon element (The Foxboro Co)



Fig 4 Twisted bourdon element (Norwood Controls)

so that the pressure reading is not affected by the temperature of the instrument

Mechanical and pneumatic instruments with bourdon elements allow measurement accuracies to within 0 5% of full scale pressure Electrical transducers are available if greater accuracy is needed Bourdon gages measure the difference between internal and external pressure on the tube Since the external pressure is almost always atmospheric pressure the gage reads the difference between the measured pressure and atmospheric pressure hence the term gage pressure

The bourdon gage is the most popular industrial pressure measuring instrument because of its relatively low cost reasonably high accuracy and durability *See* PRESSURE MEASUREMENT

[B D H H G P]

Bournonite

A mineral having composition $PbCuSbS_3$ and crystallizing in the orthorhombic system Tabular crystals of bournonite are frequently twinned with reentrant angles hence the name cogwheel ore It also occurs in short prismatic crystals as well as in massive and granular aggregates The hardness is 2 5–3 (Mohs scale) and the specific gravity is 5 8 5 9 The luster is metallic and the color steel gray to black Bournonite is found in veins associated with tetrahedrite galena sphalerite and chalcopyrite and is mined as an ore of copper lead and antimony Notable localities are in Cornwall England Australia Mexico and Bolivia *See* ANTIMONY COPPER LEAD METALLURGY [C S HU]

Boyle's law

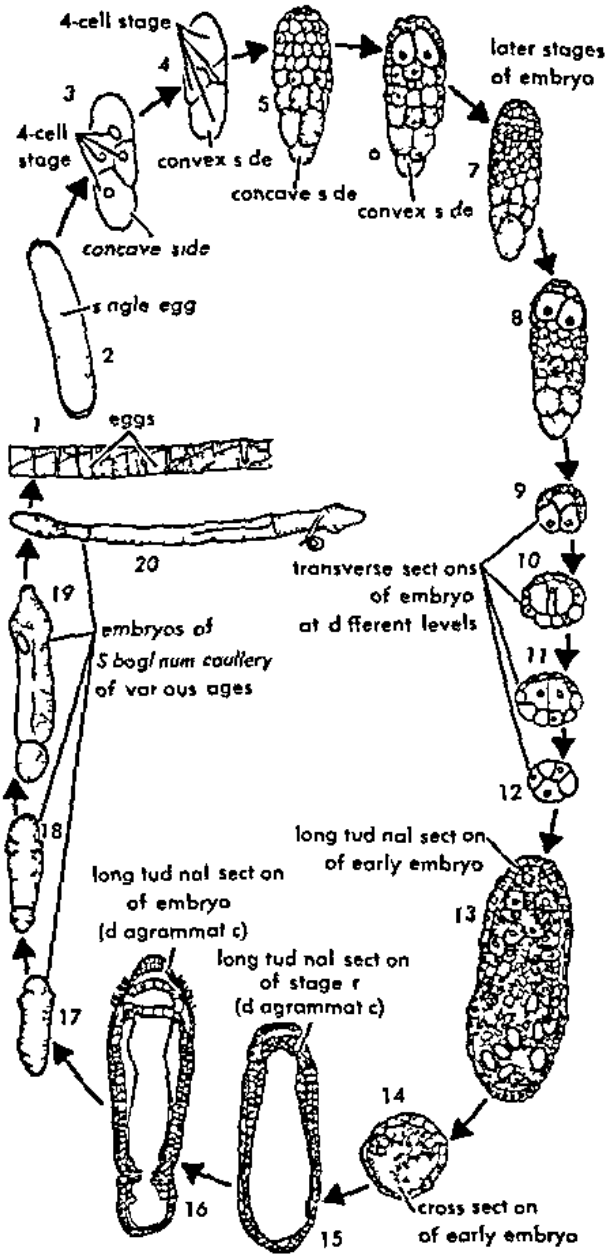
A law of gases which states that at constant temperature the volume of a gas varies inversely with its pressure This law formulated by Robert Boyle (1627 1691) can also be stated thus the product of the volume of a gas times the pressure exerted on it is a constant at a fixed temperature The relation is approximately true for most gases but is not followed at high pressures The phenomenon was discovered independently by Edme Mariotte about 1650 and is known in Europe as Mariotte's law *See* GAS [F H R]

Brachiata

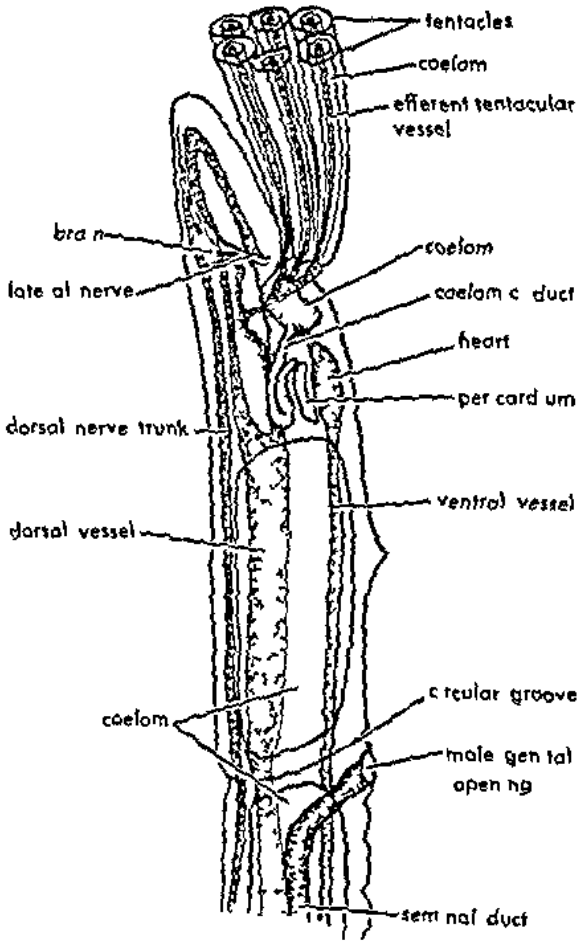
A phylum of marine animals which are found at great depths They are of no known economic importance but are of great theoretical interest They are sedentary organisms found in the bottom ooze encased in a tube which they secrete about their body This phylum contains at the present time one class two orders and four families as follows

Phylum Brachiata
  Class Pogonophora
    Order Athecanephria
      Family Siboglinidae
    Order Thecanephria
      Family Polybrachiidae
      Family Lamellisabellidae
      Family Spirobrachiidae

The members of this phylum are deuterostomous invertebrates in which the body consists of three segments surrounded by a cuticle The body of these animals bears a tentacular apparatus on the short anterior section The first two segments are not sharply delimited from each other and appear as one segment The elongated posterior or trunk segment is set off from the anterior by a circular groove The sexes are separate with the gonads being located in the last or trunk segment Very little is known about larval stages and embryonic development in these animals The coelomoducts of the posterior segment function as gonoducts The nervous system consists of an anterior dorsally located mass of ganglia the brain This is located in the first segment and extends to the posterior as the dorsal nerve trunk A pair of



Embryology of *S bogl num coullery*



Lateral v ew of anter or end of a pogonophore

lateral nerves arises from the brain and gives off branches to the tentacles the tentacular nerves *There is a closed circulatory system with a ventral* muscular heart associated *with two main vessels* the ventral and dorsal vessels. A sac*like pericar*dium is present *in* some species *See* POGONOPHORA

[C B C]

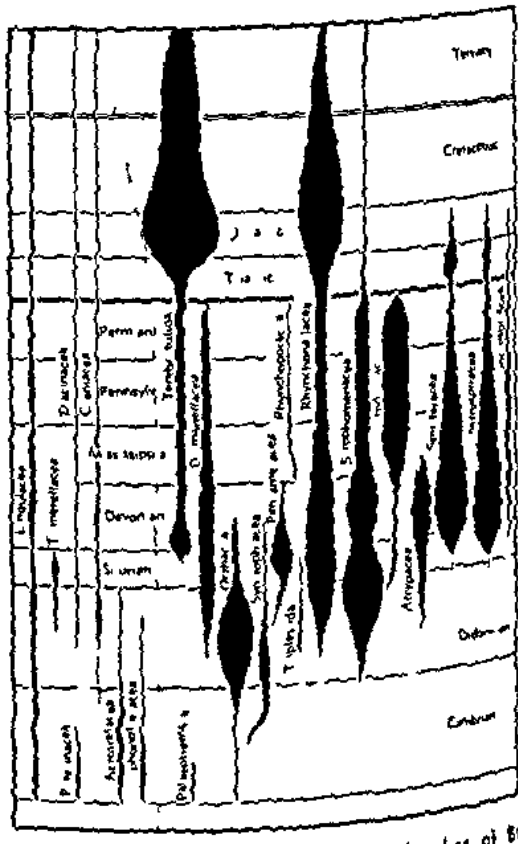
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Brachiopoda

A phylum of the *animal kingdom* comprising bivalved organisms which are exclusively marine and commonly called lamp *shells They range* from the strand line where *Lingula* is common to abyssal depths the habitat *of Pegalodiscus* They were abundant during the *Paleozoic* gradually declined toward the end of the *Mesozoic* decreased abruptly in the Cenozoic and at the *present* time are considered to be rare They are now relatively common in the seas around *Japan and* extend to the Philippine Islands They have been included with the Bryozoa in the phylum Molluscoidea *but are* now recognized as a distinct phylum They differ fundamentally from the Bryozoa in skeletal structure development after settling of the larva position of a bivalve shell sexual reproduction and non colonial habit The phylum is subdivided into two classes the Articulata which have articulating structures and the Inarticulata which lack such structures Classification is based on the nature of the valve union development of the shell the character of the pedicle opening development and morphology of the internal structures and external features A classification scheme follows See separate articles on each class and order

Phylum Brachiopoda
Class Inarticulata
Order Atremata
Order Neotremata
Class Articulata
Order Palaeotremata
Order Protremata
Order Telotremata

Morphology The bivalve shell is generally unequal The lower or ventral part is usually larger than the upper or dorsal The ventral valve usually has a small hole apically situated the foramen through which emerges a fleshy stalk the pedicle for attachment to some substratum The foramen is restricted below by the presence of delt d al plates The pedicle extends from an opening between both valves in *Lingula* from the ventral valve in *La-*



Geolog cal range chart of the superfam lies of Brachiopoda (From R C Moore C G Lalicker and A G Fischer *Invertebrate Fossils McGraw-Hill* 1952

queus and is absent in *Craniscus* The external shell may be smooth plicate (folded) costate (ribbed) or spiny The shell substance consists of chitin calcium carbonate calcium phosphate prismatic fibers or some combination of these materials The shell structure may be punctate or impunctate and is composed of three layers The outermost or periostracum is of chitin the middle laminated layer consists of parallel laminae of calcite and the thick inner layer is composed of prismatic fibers Both valves may be convex or one may be flat and the other convex At maturity the shells may range from several millimeters in width in *Rhynchonella* to as much as 300 mm in *Productus giganteus* Shell coloration is variable in living forms and is rarely retained in fossils *Pictothyris* and *Frenulina* are brilliant red with white streaks splashes or dots *Terebratalia* is dull red *Hemithyris* is chestnut brown *Lingula* is an emerald green *Terebratulina* is white and *Gryphus* is greyish The various internal structures of the shells are of taxonomic importance These may be either the muscle scars of *Lingula* the simple articulating structures of *Hemithyris* or the complex brachidia of *Spirifer* which are characteristic of advanced genera and the complex pallial markings in *Strophomena* External characters of importance are the nature of the delthyrium mode of growth convexity of the valves structure of the hinge line and surface sculpture

Ecology Most brachiopods both fossil and living occur in a well oxygenated marine environment of normal salinity Certain genera such as *Lingula* can survive conditions that would be fatal to other genera Living species extend from tidal flats to abyssal depths of 2737 fathoms but are most abundant in the neritic seas They are nektonic during only a brief period of their larval stage and therefore migration is slow After settling they may form clusters either by attaching to older shells or to one another by means of their pedicles Except for *Lingula* and *Glottidia* which bury into muddy or sandy bottoms most genera are cemented by their lower valve or are attached by their pedicle to a firm substratum which may be a shell stone or rocky bottom They prefer places not under the direct influence of drainage from the land

Distribution The distribution of living brachiopods is universal Shallow water forms particularly the genera *Terebratalia Frenulina* and *Bouchardia* are restricted in distribution Certain genera like *Laqueus* and *Pictothyris* are confined to the northern hemisphere while *Pirothyris* and *Magadina* are restricted to the southern hemisphere and some s[illegible]
both ar
bution (
range is usually less Brachiopods are more common in temperate and tropical seas than elsewhere The seas around Japan are known for the abundant yield of brachiopods

As fossils brachiopods first appear in the Cambrian where they are represented by 9 superfamilies Since Cambrian forms show good development of internal characters it is considered that Brachiopods originated in the Precambrian age Of the 19 superfamilies recorded from the Ordovician 7 date back to the Cambrian By the close of the Ordovician 2 became extinct 5 extend into the Silurian where they became extinct 6 range to the present day 3 extend to the Devonian where they became extinct 1 became extinct by the close of the Paleozoic and 2 range to the Jurassic Genera and species are most numerous in the Paleozoic when brachiopods attained their acme during the Ordovician and Silurian After the close of the Paleozoic they showed a steady decline through the Mesozoic and only few lived in the Tertiary They are relatively abundant in the Tertiary rocks of Australia New Zealand Belgium Italy and Japan [K H]

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Brachythoraci

An order of joint necked fishes also known as Aspinothoracida In contrast with the arctolepiform arthrodires the members of this group possessed reduced or obsolescent pectoral spines and all fixed connections between the dorsal and ventral portions of the thoracic armor were lost Thus unrestricted by barriers of bone the pectoral fins and their supporting structures were among the largest and longest based of any developed by the placoderms Whether this situation was ancestral or the later product of evolutionary development is a matter of debate The brachythoracines were well established by the end of the Early Devonian and were most widespread in the seas of Late Devonian times at which time the gigantic *Dunkleosteus* and *Titanichthys* of North America and a large and varied European fauna lived *See* ARCTOLEPIFORMES ARTHRODIRA [D H D]

Bradyodonti

An order perhaps composite in nature of Paleozoic cartilaginous fishes (Chondrichthyes) presumably derived from primitive sharks They are mainly represented by dentitions which appear to have been adapted to the eating of mollusks and other shelled invertebrates the body (seldom preserved) appears to have been broad and flattened with large pectoral fins as in the later skates and rays of similar habits The first bradyodonts appear at the end of the Devonian they flourished during the Carboniferous but declined and vanished by the end of the Permian concomitantly with a reduction in the invertebrate fauna at that time There are four families In the Cochliodontidae the main tooth structures consist of a large spirally twisted tooth plate in each jaw half each plate formed by

the fusion of a row of successional teeth In the Petalodontidae teeth with deep roots and flattened diamond shaped crowns were numerous and formed crushing pavements In the Psammodontidae upper and lower dentitions consisted of a few large quad rilateral plates arranged in two rows meeting in the midline In the obscurely known Copodontidae there was but a single subquadrate tooth medially placed at the front end of the upper and lower jaws *See* CHONDRICHTHYES *see also* CHIMAERAE ELASMOBRANCHII FOSSILS [A S R]

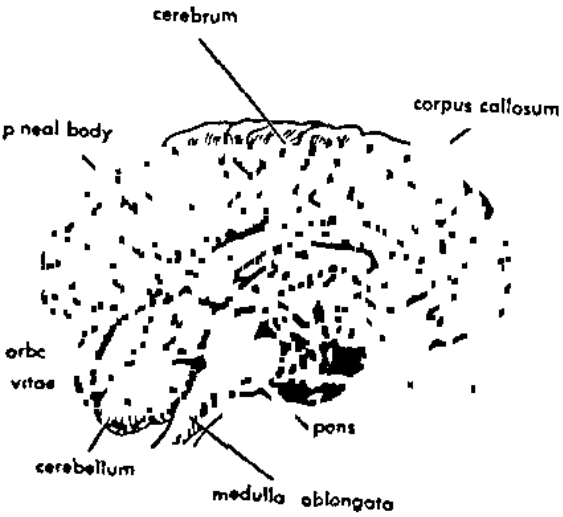
Brain

That portion of the central nervous system en closed in the skull and consisting of cerebral hem ispheres cerebellum midbrain pons and medulla oblongata *See* CENTRAL NERVOUS SYSTEM

In vertebrates the central nervous system and related structures arise from the neural plate of the embryo This is an ectodermal area on the pos terior surface of the embryo which extends along the developing body The neural plate folds from each side to form the neural tube which then de taches from the overlying ectoderm to lie beneath it The anterior portion of the neural tube develops increasingly specialized structures as growth con tinues Three expansions are first seen which are the primary brain vesicles—the forebrain midbrain and hindbrain For details of embryology *see* NERV OUS SYSTEM

The forebrain develops into the massive telen cephalon composed mostly of the cerebral hemi spheres but also containing the olfactory struc tures (rhinencephalon) and the corpus striatum a ganglionic mass of connections to lower structures

The diencephalon arises from the forebrain to form the thalamus a major sensory relay site and other structures including the hypothalamic area which is concerned with autonomic or vegetative functions



Sag ttal section through human brain (*From H E Walter and L P Sayles* B ology of the Vertebrates 3d ed *Macm llan* 1949)

The midbrain or mesencephalon remains rela tively small but serves as a vital connecting link between higher and lower centers by virtue of the nerve fibers which pass through it as well as by the presence of important relay nuclei

The hindbrain differentiates into the cerebellum the major center for muscular coordination and the pons or bridge which is characterized by com municating fibers between the lower and higher centers and the cerebellum

The medulla oblongata also develops from the hindbrain It serves chiefly as the great pathway for all nerve fibers which pass to and from the spinal cord In addition, it contains important nu clei or cell centers, for some of the specialized cranial nerves as well as less well defined vital cen ters that control, for example respiration heart rate and vasomotor activity *See* NEUROPHYSIOL OGY

The nuclei of the anterior cranial nerves are found in the pons and midbrain which also conta n many associative and correlative mechanisms for the mediation of sensation and motor activity *See* CRANIAL NERVE

Within the brain the original lumen of the neu ral tube has altered with the development of spe cialized structures so that a system of ventricles is present A large lateral ventricle shaped somewhat like a wishbone lies in each cerebral hemisphere Each communicates with the third ventricle a nar row slit lying between the halves of the diencepha lon From this a narrow tube or aqueduct passes backward through the midbrain to connect with the rhomboid shaped fourth ventricle This lies in the upper portion of the medulla, with the cerebellum projected over it The ventricular system contains cerebrospinal fluid which passes out of the fourth ventricle to form a layer around the brain in the subarachnoid spaces of the meninges The latter are the membranous coverings of the brain and spi nal cord which also act as supportive structures and as a means for the supply and drainage of blood to the central nervous system

The previous description applies chiefly to man and higher vertebrates Lower forms show less spe cialization of derived structures and the retention of important areas which are decreased in man, such as optic olfactory and auditory centers

In the lowest vertebrates the brain is little more than a few nodules on a central cord of nerve t is sue As progression occurs along the developmental scale more and more features are added or sub merged in favor of specialized mechanisms, until the cerebral cortex of man is reached This repre sents the highest development of the nervous sys tem and contains many intricate structures and mechanisms about which there is still little infor mation Memory, thought imagination logic and other abstractions are functions of cortical activ ity In addition there are specific areas for the control or regulation of highly developed motor activities and the recognition of sensory stimuli of almost infinite variety and pattern [E C S]

Brake

A machine element for applying friction to a mov ing surface to slow it down or bring it to rest Because most equipment rolls on wheels or may have wheels or drums controlled by the rotation of shafts brakes usually apply torsional friction forces to the shafts through the wheels or drums These forces dissipate the kinetic energy of rota tion or translation of the machine by converting it into heat energy The brake differs from the cou pling and the clutch in that instead of connecting shafts together the shaft is connected to the sta tionary parts of the machine

The drum or rim of the brake rotates with the shaft, remaining parts of the assembly are static and establish means of applying friction to the ro tating element The principal parts are the rotating drums the friction shoes and the means of anchor

The limitations on the applications of brakes are similar to those of clutches, except that the serv ice conditions are more severe because the entire energy is absorbed by slippage and provisions must be made for the dissipation of greater quantities of heat

Types of brakes Friction brakes are classified according to the kind of friction element employed and the means of applying the friction forces

Single block The simplest form of brake consists of a short block fitted to the contour of a wheel or drum and pressed up against the surface by

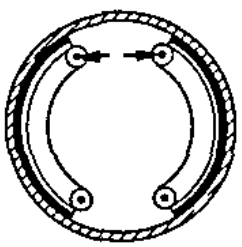


Fig 1 Single block brake with block fixed to operat ing lever Force in direction of arrow applies brake

means of a lever on a fulcrum as widely used on railroad cars The block may have the contour lined with friction brake material which gives long wear and a high coefficient of friction The fulcrum may be located with respect to the lever in a manner to aid or retard *the braking torque of the block* The lever may be operated manually or by a re motely controlled force (Fig 1)

Double block Two single block brakes in sym metrical opposition where the operating force on

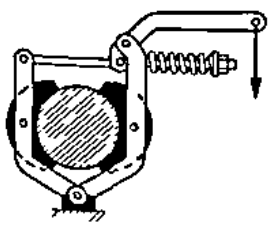


Fig 2 Double block brake with blocks pivoted on the r levers Force in d rection of arrow releases brake

the end of one lever is the reaction of the other is a double block brake (Fig 2) External thrust loads are balanced on the rim of the rotating wheel

External shoe An external shoe brake operates in the same manner as the block brake and the designation indicates the application of externally contracting elements In this brake the shoes are appreciably longer extending over a greater por tion of the drum (Fig 3) This construction allows

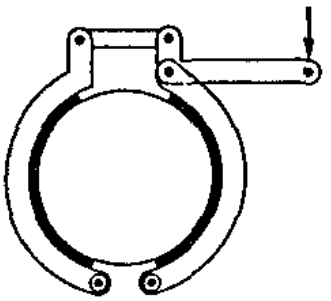


Fig 3 External shoe brake nearly surrounds the brake drum shoes are lined with friction material

more combinations for special applications than the simple shoe although assumptions of uniform pressure and concentrated forces are no longer pos sible In particular it is used on elevator installa tions for locking the hoisting sheave by means of a heavy spring when the electric current is off and the elevator is at rest Self energization is possible as with block brakes depending upon the arrange ment of the supporting mechanism

Internal shoe An internal shoe has several ad vantages over an external shoe Because it works on the inner surface of the drum it is protected from water and grit (Fig 4) It may be designed in a

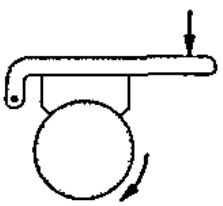


Fig 4 Internal shoe brake with brake lining

more compact package is easily activated and is effective for drives with rotations in both direc tions It meets the requirement of the automobile Early mechanical brakes had an elliptical cam modern brakes have hydraulic piston actuated shoes

Band Hoists excavating machinery and hy draulic clutch controlled transmissions have band brakes They operate on the same principle as flat belts on pulleys In the simplest band brake one end of the belt or band is fastened near the drum surface and the other end is then pulled over the drum in the direction of rotation so that a lever on a fulcrum may apply a tension to the belt

The belt may be a thin metallic strip with a friction lining The method of applying the lever on the fulcrum and attaching the belt determines the *structural* operation of the brake These variations make possible a sensitive differential brake self energizing brakes and brakes operating with equal effectiveness in both directions (Fig 5) The radial

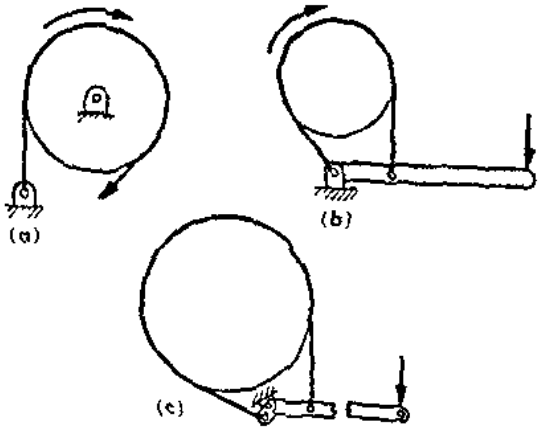


Fig 5 Band brakes (a) Basic structure (b) With direct action lever (c) Differential self assisting feature

pressure of the brake is [illegible] in the band
tion The
are comp[illegible] circular and are loaded by springs which are cam operated to lock and unlock

Disk Structurally similar to disk clutches disk brakes have long been used on hoisting and similar apparatus (Fig 6) Because more energy is absorbed in prolonged braking than in a clutch startup additional heat dissipation must be provided in equivalent disk brakes A significant new application of disk brakes is on the wheels of aircraft where segmented rotary elements are pressed against stationary plates by hydraulic pistons

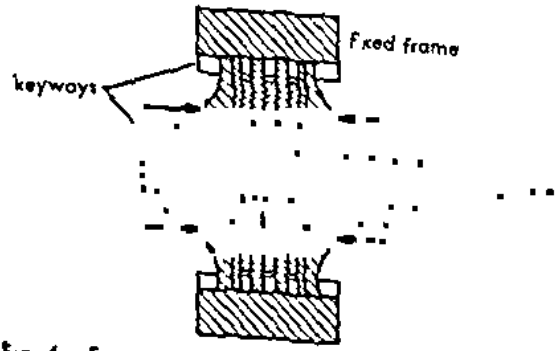


Fig 6 Forces in direction of arrows presses disks keyed to axle against disks keyed to frame

Flexibility self alignment and rapid cooling are inherent in this design A familiar application is the bicycle coaster brake [J J R]

Brake actuators A brake can be arranged so that it is normally released or applied a spring usually forcing it into the normal condition A controllable external force then applies or releases the brake This force can be, for example, mechanical through a linkage or cable to a lever, pneumatic or hydraulic through a cylinder to a piston or electric through a solenoid to a plunger

Air brake Railway brakes are normally applied air brakes, if the air coupling to a car is broken the brakes are applied automatically The brakeman to apply the brakes, releases the compressed air that is restraining the brakes by means of a diaphragm and linkage Over the road trucks and buses use air brakes Another form of air brake consists of an annular air tube surrounding a jointed brake lining that extends completely around the outside of a brake drum Air pressure expands the tube pressing the lining against the drum

Electromagnetic brake In commonly encountered electromagnetic brakes the actuating force is applied by an electric current through a solenoid (Fig 7) Direct current gives greater braking force than ac and is, therefore, used almost exclusively ac is rectified if used Usually the electromagnetic force releases the brake against a compression spring, thus providing braking action if the power fails and overspeed protection when used with dc series motors

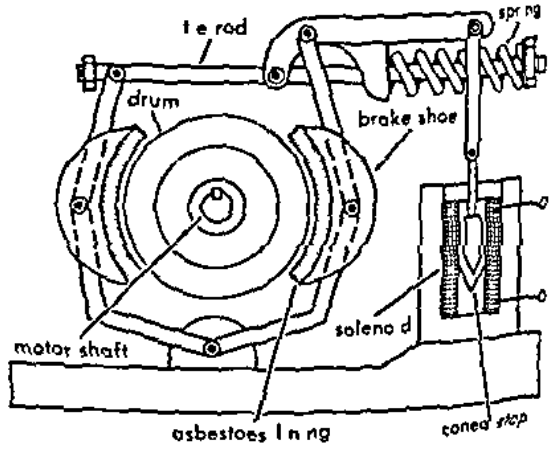


Fig 7 Electromagnetic actuator applied to double block brake

The plunger and its stop are cone-shaped to provide a higher force than without a stop but without an abrupt increase in force as the gap closes Because the solenoid force decreases somewhat when the brake is applied and the gap is thereby increased the retraction current is slightly higher than the current at which the spring overcomes the solenoid and applies the brake This operation is stable

The solenoid is wound with high impedance for shunt operation across a power line Shunt operation is common where loads and motor speeds vary widely or where a compound motor is used Where a series motor is used for high starting torque the solenoid is wound with low impedance for series operation in the circuit of the motor it protects In this way the brake will be applied if the motor starts to run away under light load [J E C]

Branch circuit

The portion of an electric wiring system following the final circuit overcurrent protective device and terminating at the utilization device (as a lighting fixture motor or heater) or a plug receptacle for the connection of portable lamps and appliances

Motor branch circuits must have conductors with current carrying capacity at least 125% of the motor full load current rating Overcurrent protection must be capable of carrying the starting current of the motor Maximum values are tabulated for various currents in the National Electrical Code *See* ELECTRICAL CODES

Branch circuits other than motor branch circuits are classified by the maximum rating of the overcurrent device Individual branch circuits may be of any size but may not exceed 150% of the rating of the appliance (10 amp and over) The

three types

1 15 and 20-ampere circuits may serve lights and appliances the rating of one portable appliance may not exceed 80% of the circuit capacity the total rating of fixed appliances may not exceed 50% of circuit capacity if lights or portable appliances are also supplied

2 30 ampere circuits may serve fixed lighting units in other than dwellings or appliances in any occupancy

3 50-ampere circuits may serve fixed lighting units in other than dwellings fixed cooking appliances or infrared lamp industrial heating appliances

Multiwire branch circuits consist of two or more ungrounded conductors having a potential difference (voltage) between them and a (neutral) grounded conductor having equal potential difference between it and each ungrounded conductor

Conventionally the current carrying capacity of conductors may be the same as the branch circuit rating (for example No 12 conductors in a 20-ampere branch circuit) however larger conductors may be required to avoid excessive voltage drop *See* WIRING (ELECTRIC) [W T S]

Branchiopoda

A subclass of crustaceans which are of small or moderate size A classification of the branchiopods follows

Subclass Branchiopoda
- Superorder Eubranchiopoda
  - Order Anostraca
  - Order Lipostraca
  - Order Notostraca
  - Order Conchostraca
- Superorder Oligobranchiopoda
  - Order Cladocera
    - Suborder Calyptomera
    - Suborder Gymnomera

The trunk region consists of 5–44 body rings or segments The number is usually constant but sometimes varies within a genus or even a species The posterior part of the body is usually without legs A carapace is present in most species in the form of a bivalved shell or a dorsal shield The paired eyes may be pedunculate (stalked) or sessile The antennae are powerful swimming structures which in some species may be reduced The trunk appendages are mostly foliaceous of almost uniform structure and their number varies greatly Most species are detritus and plankton feeders Almost all of them live in fresh water The group which shows some primitive features is quite heterogeneous See specific orders *see also* CRUSTACEA [F L.]

Branchiura

A subclass of the Crustacea known as the fish lice They are ectoparasites on such areas as the base of fins and the gill chamber walls of fresh water and marine fish *Argulus* (see illustration) is a common genus They are a small homogeneous group less than 100 species with world wide distribution and very much alike in appearance The disklike head and thorax (cephalothorax) is strongly flattened and bears a small unsegmented abdomen bilobed at its distal end Larger species may exceed 25 mm in length

Taxonomy The Branchiura have often been included within the Copepoda either as the subclass Branchiura opposed to the remainder grouped under Eucopepoda or as the order Arguloida equivalent in rank to the Calanoida Cyclopoida and Harpacticoida Though widespread acknowledgment is not yet apparent critical appraisal of branchiuran morphology ontogeny and ethology has revealed several basic characteristics which have no homologs in the eucopepods On the basis of these fundamental differences linkage to the Copepoda is no more justified than placement within the Branchiopoda Ostracoda or even Cirripedia

Some of the morphological characteristics distinguishing Branchiura from Copepoda include the presence of compound eyes totally different segmentation of the swimming legs location of the genital orifice on the thorax absence of a spermatophore and use of legs 2–4 in copulation The absence of larval stages either suppressed in the embryonic period or as a free swimming nauplius followed by metamorphosis into the immature adult form is noteworthy Behavioral differences occur in the method of spawning branchiurans attach small masses of eggs enveloped in gelatinous sheaths to stones and other firm objects on the bottom

Morphology The appendages all on the cephalothorax consist of two pairs of antennae the mouthparts which are one pair of mandibles and two pairs of maxillae and four pairs of swimming legs They originate on the underside of the near the midline and extend laterally

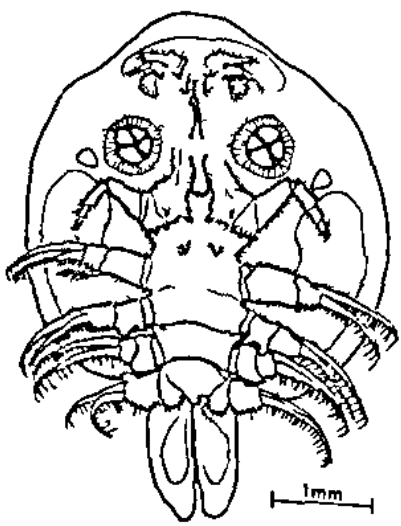
lar to the longitudinal axis The wafer thin cephalothorax with its appendages appressed to the underside permits fish lice to flatten themselves against a fish s skin The resulting highly streamlined contour serves to minimize the considerable force of frictional drag found in a dense medium like water

Other adaptations for holding fast to a mucus covered swimming fish include numerous spinules and strategically placed hooks on the underside of the body and utilization of specialized portions of the body as suction cups Despite these elaborate specializations fish lice never lose the ability to abandon a host and swim At least some of this activity is associated with mating and spawning

Reproduction Breeding males seek the female which remains passively on the host Use is made of the second to fourth pairs of swimming legs in copulation these appendages bearing pegs and corresponding sockets arranged in a manner unique to each species Spawning females swim from the host to find firm objects such as stones on which to fix the mass of eggs encased in a gelatinous sheath Following direct embryonic development the hatching juvenile resembles the parent although the appendages do not assume an adult form until later Sexual maturity occurring about a month after hatching requires at least seven molt stages and when attained does not seem to stop growth

Nutrition Branchiurans feed on tissue fluids especially blood The mouth located at the end of a movable proboscis is applied to the host s skin and the rasping mandibles make the necessary wound Fish lice usually are no threat to fish populations In restricted areas such as hatchery ponds however an infestation can increase to levels that bring about high fish mortality Treatment may require such drastic measures as drainage and cleaning before restocking can be successful [A F]

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Branchiura *Argulus japonicus* Thiele male fish louse (After O L Meehean 1940)

Brass

An alloy of copper and zinc The term brass was once applied to copper tin alloys but these are now called bronze Brass was known to the Romans but modern brass is made by a process patented in 1 81 by James Emerson Brasses containing 75–85% copper are red gold and malleable those containing 60–70% are yellow and also malleable and those containing 50% or less copper are white brittle and not malleable Alpha brass contains up to 37% zinc β brass contains 46% zinc or more Specific brasses are designated as follows gilding (95% copper 5% zinc) commercial bronze (90 10) red (85 15) low (80 20) cartridge (70 30) yellow (66 34) and Muntz metal (60 40) When small amounts of other metals are added other names are used with a little tin it is called admiralty or naval brass, with lead leaded brass with nickel nickel silver (which contains no silver) and with manganese manganese bronze (which contains no tin) In manufacture lump zinc is added to molten copper and the mixture is poured into either castings ready for use or billets which after annealing are further worked by rolling extruding or forging Brass is widely used in cartridge cases plumbing fixtures valves and pipes electrical equipment screws clocks, and musical instruments *See* ALLOY BRONZE COPPER ZINC [C CO]

Brayton cycle

A thermodynamic cycle consisting of two reversible constant pressure processes interspersed with two constant entropy processes A reciprocating engine operating on this cycle patented in 1872 by G B Brayton was the first successful gas engine built in the United States The Brayton cycle requires a large volume of gas at low pressure whereas the Otto cycle requires less cylinder displacement but subjects the working substance to higher peak pressure and temperature The Brayton cycle is consequently adaptable to rotating turbine engines whereas the Otto cycle fits reciprocating piston engine principles (*see* OTTO CYCLE)

In steady flow machinery such as gas turbine the heat transfer and combustion processes proceed at more nearly constant pressure than at constant volume The constant pressure portions of the Brayton cycle correspond to these heat transfer and combustion processes Air is drawn into the compressor portion of a gas turbine device and is compressed (Fig 1) This compression at constant entropy corresponds to path $a\,b$ on the air standard cycle (Fig 2) Fuel and air mix and burn in the combustion chamber adding heat at con-

stant pressure corresponding to path *b c* The hot gas expands in the turbine proper along path *c d* In an actual engine such as an aircraft turboprop the spent gas exhausts at state *d* and is replaced by fresh air at state *a*

The three basic processes of a power cycle compression heat addition and expansion are done successively each by a separate piece of machinery operating on a steadily flowing stream This action is in marked contrast to that of a reciprocating engine where each process is carried out sequentially in a cylinder on an isolated batch of working substance

The compression ratio $r = v_a/v_b$ of the compressor is the principal factor that determines the efficiency η of the ideal Brayton cycle Thus

$$\eta = 1 - \frac{1}{r^{k-1}}$$

where $k = c_p/c_v$ the ratio of specific heats of the working substance at constant pressure and constant volume

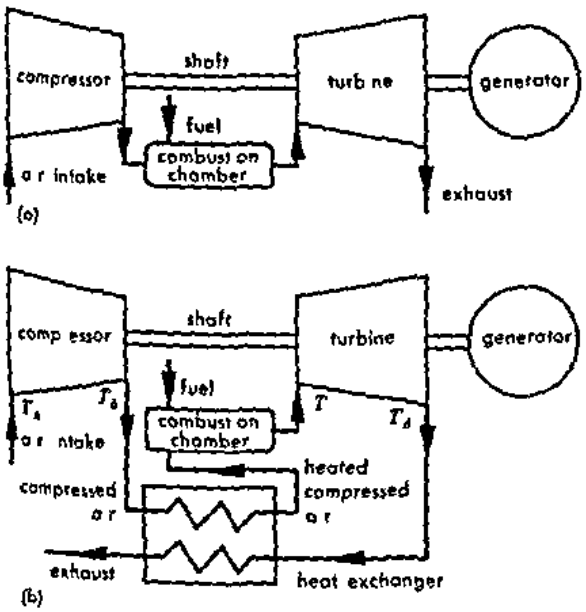


Fig 1 Gas turbine (a) Simple open-cycle (b) With regeneration

In an actual Brayton cycle over all efficiency is considerably altered by inefficiency of the components For given turbine inlet temperature and specified component efficiencies there is a peak efficiency corresponding to a particular compression ratio This is in marked contrast with the ideal Brayton cycle wherein the efficiency increases continuously with increasing compression ratio

Efficiency of both the ideal and the actual Brayton cycle is improved by regeneration The exhaust gas passes through a heat exchanger where it transfers a portion of its heat to the gas that leaves the compressor (Fig 1) The gas leaving the turbine at state *d* has a higher temperature than the

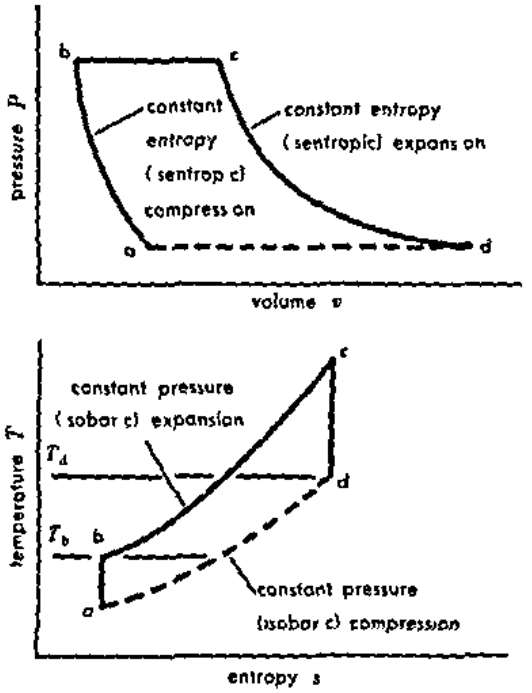


Fig 2 Air-standard Brayton cycle

gas leaving the compressor at state *b* (Fig 2) This temperature difference causes some of the heat in the exhaust gas to flow into the compressed gas The exhaust gas then leaves the machine part way along path *d a* at a lower energy state than without regeneration In addition the working substance is carried part way along path *b c* in the heat exchanger so that less of the increase in energy need be supplied by the fuel Less energy is rejected to the surroundings and less energy is required from the fuel but the work developed by the cycle remains the same Overall efficiency is increased *See* THERMODYNAMIC CYCLE TURBINE

[J B]

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Brazil nut

A large evergreen tree (*Bertholletia excelsa*) native to the Amazon Valley of South America and its fruit known also as para nuts. The seeds (nuts) are triangular in cross section 20–30 being closely fitted into a thick walled woody spherical container (fruit) which is 5–6 in in diameter and which falls to the ground when mature

Brazil nuts require a tropical climate and commercial production is limited almost entirely to wild trees of the Amazon Valley Native workers collect the fallen fruits and extract the nuts which are then shipped to markets downstream Most of the nuts are exported to Europe and the United States where they are in great demand as dessert nuts and for use in candy and bakery goods *See* NUT CROP CULTURE

[E F S]

Brazing

A group of welding processes for joining metals by use of nonferrous filler metals which have lower melting points than the metals joined Molten filler metal is distributed by capillary attraction between the closely fitted surfaces of the metals to be joined (base metals) which are heated but not melted The filler metal selected must wet the base metals that is adhere to them by alloying and diffusion and have a melting point above 800°F The high melting point and greater strength of brazing filler metals differentiate brazing from soldering

Brazing processes are widely used in industry for the fabrication of parts from a variety of metals and alloys Recent interest has focused on the braz ing of metals to ceramic materials by use of special coatings on the nonmetals Vacuum furnace brazing particularly for use in brazing heat resistant alloys is also a field which is progressing rapidly

Processes Brazing processes are identified by the method of heating employed Eight classifica tions are recognized

Torch brazing Heating is accomplished by use of one or more gas torches usually fueled by acety lene propane or city gas burned with air com pressed air or oxygen depending upon the tem perature and amount of heat required A flux is used and the brazing filler metal may be preplaced in the joint or it may be face-fed manually into the joint when the parts have reached a suitable tem perature

Twin carbon arc brazing Heat is furnished by an ac or dc arc drawn between two graphite or carbon electrodes held at an angle to each other in a spe cial holder The intense heat produced must be carefully controlled and directed to prevent over heating of parts during the brazing operation A flux is used and the brazing filler metal is usually face-fed

Furnace brazing Furnaces with automatic time and temperature controls and heated by gas oil or electricity are used to heat the assemblies to be brazed individually in batches or on a con tinuous conveyor passing through the furnace The brazing filler metal is preplaced in or adjacent to the joint A flux may be used or an atmosphere maintained in the furnace to perform a similar function

Induction brazing Heating is accomplished by an electric current induced in the parts to be brazed by placing them in or near a coil carrying alternating high frequency electric current ob tained from a motor generator resonant spark gap or vacuum tube oscillator source The brazing filler metal is usually preplaced and a chemical flux or atmosphere used

Resistance brazing Heat is developed by the resistance of the parts to the flow of an electric current Ac or dc current is brought to the parts by electrodes arranged so that the joint forms part of the circuit The brazing filler metal may be pre placed or face fed Flux must be carefully placed usually wet as most fluxes are insulating when dry An atmosphere instead of a chemical flux is oc casionally employed

Dip brazing In chemical bath dip brazing the brazing filler metal is preplaced in the joint and

metal will melt and flow the parts are covered cle ned in a ba suitable pot When the assembly is sufficiently heated and the filler metal has flowed into the joint it is removed and the filler metal allowed to sol d ify This method is usually employed only with small parts

Block brazing Heat is furnished by separately heated large metal blocks which are applied to an assembly in which the brazing filler metal has been preplaced and fluxed The blocks impart suf ficient heat to the assembly to cause flow of the brazing filler metal This process is seldom used

Flow brazing Molten brazing filler metal is poured over a joint to furnish the heat and filler metal required This method is little used since it is uneconomical and not as efficient as other avail able methods

Variations and refinements exist within the process groups Considerations in the selection of a brazing process include the properties of the base and filler metals the joint design the number of parts to be brazed and the size of the parts

The steps in obtaining a good brazed joint in clude selection of compatible base and filler met als precleaning of both to remove contaminants use of a flux or cleansing atmosphere to reduce oxides formed and to protect against oxidation dur ing the brazing operation, maintenance of the rela tionship of the parts by use of jigs if necessary and postcleaning particularly when a corrosive flux is used

Brazing alloys Brazing filler metals range in composition from pure metals such as copper nickel or silver to complex alloys Among the mo t useful for the brazing of steels copper all y nickel alloys and precious metal contacts are al loys of silver and copper with additions of zinc cadmium nickel tin or phosphorus in various amounts and combinations Alloys of copper phosphorus copper zinc and copper gold are al o common

Filler metals for brazing aluminum and alumi num alloys usually contain 4 13% silicon with copper 0 3–4% balance aluminum The lower s con percentages are generally used in filler metals for furnace and dip brazing Magnesium brazing filler metals consisting of magnesium alloyed with up to 12% aluminum and 5% zinc may be used f r brazing selected magnesium alloys Stabilized stainless steels of the 18–8 type may be brazed using the copper silver base type of filler metals used for steel. However, the unstabilized types are

quently the brazing of stainless steel with filler metals useful in this range of temperature must be done very rapidly or avoided altogether Both stainless steels and heat resistant alloys particularly for high temperature service applications are often brazed at temperatures of about 2000°F with filler brazing metals of nickel containing various combinations of chromium boron silicon iron phosphorus or carbon as alloying elements A typical analysis would be nickel 65–75% chromium 13–20% boron 2 75–4 75% Special brazing filler metals for jewelry have been used for centuries

Fluxes Brazing fluxes function to protect the joint from oxidation and to remove any oxides which may form during the heating brazing and cooling periods of the brazing procedure Fluxes may be chemical formulations or cleansing and protective atmospheres Chemical fluxes are mixtures of many compounds prepared for use in brazing specific groups of metals and alloys Commonly used in fluxes are borates, fluoroborates fluorides chlorides of sodium potassium and lithium borax boric acid and alkalies, together with wetting agents and water Fluxes are applied to the brazing area and filler metal in liquid paste or powder form (Table 1)

Atmospheres usually used in furnace brazing may be combusted fuel gas dissociated ammonia hydrogen inorganic vapors or inert gases such as helium or argon (Table 2) The dew point of the furnace atmospheres must be kept at a low level for successful brazing of many metals and alloys

Close fitted parts are required for brazing For brazing steel with copper a press fit to 0 002 in clearance may be used For most other filler metals a 0 002 to 0 005-in clearance is desirable Larger clearances 0 004-in to 0 010 in or more, are needed *when brazing aluminum or magnesium alloys* *See* SOLDERING WELDING AND CUTTING OF METALS

[L E A]

Table 1 Typical chemical fluxes used in brazing

A W S type no	Base metal	Useful temp range, °F	Flux ingredients
1	Aluminum alloys	700–1190	Chlorides fluorides
2	Magnesium alloys	900–1200	Chlorides, fluorides
3	Steel stainless steel, copper alloys nickel alloys	700–2000	Boric acid borates fluorides fluoroborates wetting agent (must contain a fluorine compound)
4	Aluminum bronze and aluminum brass (containing over 0 5% aluminum)	1050–1800	Chlorides, fluorides borates wetting agent
5	Steel stainless steel copper alloys, nickel alloys	1000–2200	Borax boric acid borates, wetting agent (no fluorine in any form)
6	Titanium and zirconium base alloys	700–1600	Chlorides fluorides wetting agent

Table 2 Typical brazing atmospheres*

A W S type no	Base metals	Atmosphere	Maximum dew point of incoming gas °F
1	Copper brass	Combusted fuel gas (about 1% hydrogen)	Room temperature
2	Copper brass, low carbon steel nickel, Monel medium carbon steel	Combusted fuel gas (about 15% hydrogen)	Room temperature
3	Same as type 2 plus high carbon steel preferable for medium carbon steel	Combusted fuel gas–dried (about 15% hydrogen)	−40
4	Same as 3	Combusted fuel gas–dried (about 40% hydrogen)	−40
5	Same as type 3 plus alloys containing chromium (no appreciable aluminum titanium silicon or beryllium present)	Dissociated ammonia (about 75% hydrogen)	−65
6	Same as type 2	Cylinder hydrogen	Room temperature
7	Same as type 5 plus cobalt chromium tungsten alloys and carbides	Deoxygenated and dried hydrogen	−75

* Chemical flux may be required in addition to atmosphere for alloys with volatile constituents Other atmospheres used for special purposes are inorganic vapors such as zinc or cadmium and purified inert helium or argon gas Vacuum furnace techniques are also used for brazing

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Breadboarding

Assembling an electronic circuit in the most convenient manner on a board or other flat surface without regard for final locations of components to prove the feasibility of the circuit and to facilitate changes when necessary Standard breadboards for experimental work are made with mounting holes and terminals closely spaced at regular intervals so that parts can be mounted and connected without drilling additional holes

Printed circuit boards having similar patterns of punched holes with various combinations of holes connected together by printed wiring on each side, are often used for breadboarding when the final version is to be a printed circuit *See* CIRCUIT ELECTRONIC, PRINTED CIRCUIT

[J MR]

Breadfruit

The multiple fruit of an Indomalaysian tree *Artocarpus altilis* of the mulberry family (Moraceae) The perianth pericarp and receptacle are all joined in a multiple fruit having a high carbohydrate content The fruits vary considerably in size



Breadfruit (*Artocarpus altilis*) (a) End of branch with multiple fruit (b) Longitudinal section of multiple fruit (c) Staminate flower cluster (*From O Degener Ferns and Flowering Plants of Hawaii National Park 1930*)

and are often borne in small clusters Breadfruit is a wholesome food for both man and beast It is eaten fresh or baked boiled roasted fried or ground up and made into bread There are many varieties some having seeds and some seedless *See* URTICALES [P D S]

Breakdown

A disruptive discharge of electric current through the insulation in a component due to weakening of the insulation at one point The damage is usually permanent and causes failure of the component, an exception however is the metallized paper capacitor which heals itself after a breakdown by burning away the metallic coating and thereby isolating the flaw in the insulation

The term breakdown is also applied to a desired discharge of electricity between two electrodes in a gas as in gas discharge electron tubes neon tubes and fluorescent lamps Here the breakdown occurs at a voltage that is dependent on gas density, electrode shape electrode spacing and polarity The same action can be undesirable and may cause failure of a tube not designed to handle gas discharges *See* BREAKDOWN POTENTIAL, GAS TUBE INSULATION ELECTRIC [J MM]

Breakdown potential

That potential difference in a gaseous discharge at which a sudden change in the conduction state takes place An alternative term is sparking potential *See* SPARK ELECTRIC

In general the breakdown potential is a complicated function which depends on such factors as electrode material both macroscopic and microscopic electrode shape chemical surface states of the electrodes constitution and pressure of the gas temperature electrode separation distance and time dependence of applied potential difference It is also dependent at least to some extent on the current in the initial conduction state Because each of these factors plays a part in determining the breakdown potential it is exceedingly difficult to obtain precise information about this potential Invariably several factors will change during the course of an experiment perhaps masking changes in the effect presumably under investigation

In certain cases the nature of the influence of one of the above factors may be readily determined The presence of sharp points at the electrodes and particularly at the cathode produces a marked lowering of the breakdown potential This is because the strong electric field around such a point results in intense ionization once an initial electron enters the region In the mechanism proposed for the propagation of the spark through the gap such intense ionization will result in a copious supply of photons which then produce ionization by the photoelectric effect in other parts of the gap As an example of how conditions may change however the evaporation and sputtering of such a point will smooth it off Thus the next spark will have a greater breakdown potential

Because the easy production of electrons is an important condition reduction of the surface work [illegible] ...ction of the ...be small ...tandpoint of electron production the ionization potential of the gas is important Other effects may obscure this however For example the addition of a small impurity to either helium or neon will result in a decrease in the sparking potential This is due to collisions of the second kind in which an excited atom of the main gas may ionize an impurity atom with which it collides In other cases the addition of a gas with a high density of molecular states may increase the breakdown potential Here the excitation energy of an atom may be transferred to molecular excitation in a collision thus reducing photon production

For a discussion of the effects of pressure and electrode separation *see* BREAKDOWN ELECTRICAL CONDUCTION IN GASES, SPARK GAP [G R M]

Breakwater

A protective barrier of a harbor to break or deflect the force of the seas thereby providing a safe and comparatively calm anchorage behind it Break waters are necessary where adjacent land projec tions and nearby islands are inadequate to give the harbor full protection from the seas More than one breakwater may be required for adequate protec tion and entrances must be left at the ends or be tween breakwaters for the passage of ships in and out of the harbor

Breakwaters may be of any type of construction *that will withstand the force of the seas during the* heaviest storms The most usual breakwater is a mound of stone rubble dumped on the ocean or harbor bed and rising to a height above mean sea level Sometimes it is capped on the top and sea face with variously shaped concrete blocks regu larly or irregularly placed

Sometimes the mound does not rise above the wa ter but is surmounted by a vertical face superstruc ture of masonry or concrete A vertical face break water *of masonry or concrete may be built without* the rubble mound provided the sea bed is firm Ver tical face breakwaters are built in the Great Lakes by driving down two rows of piling and filling the space between with stone rubble *See* COASTAL EN GINEERING *see also* HARBOR [E J Q]

Breast

The human mammary gland usually well developed in the adult female but rudimentary in the male Each adult female breast contains 15 20 separate branching glands that radiate from the nipple During lactation their secretions are discharged through separate openings at base of the nipple

In both sexes the paired ridges (milk lines) de velop in the 6 week old fetus and extend from the axilla downward converging toward the anterior abdomen Most portions of these milk lines regress leaving only slight prominences in the regions des tined to become the nipples or breasts During the middle part of fetal life clusters of epidermal cells grow down into these areas to form cords which will later become hollow ducts After birth slow progression is made in the size and branching of each primary duct Development in the male usu ally ends at this stage

In the female the hormonal changes of adoles cence cause enlargement of the breast tissue but much of this is connective tissue although some glandular buds form With the advent of full men struation the breasts develop under the influence of the *ovarian estrogenic hormones If pregnancy* ensues the glandular tissue reaches full develop ment and lactation begins shortly after delivery After the cessation of lactation the breasts regress considerably and once again reflect cyclic regula tion

Occasionally the male breasts will be stimulated by estrogens possibly of adrenal origin Liver dis ease may prevent the normal destruction of estro gens so that gynecomastia (enlargement of the breasts in the male) results

The breasts of infants may respond to maternal hormone influence during the first few days or weeks of life but regression ordinarily occurs spontaneously

Supernumerary nipples or breasts are not rare They are of minor clinical significance because they are usually rudimentary but may constitute a severe cosmetic or pyschic problem which is readily amenable to surgery *See* LACTATION [E G ST]

Breast disorders

Any pathology of the mammary gland Breast dis orders may result from congenital or developmental abnormalities inflammations hormonal imbalances and most important from tumor formation

Congenital defects are usually unimportant ex cept for their psychic or cosmetic implications Supernumerary nipples and breasts or accessory breast tissue are common examples

Inflammations are not encountered frequently and usually result from a staphylococcal or strepto *coccal invasion incurred during lactation* Such mastitis may be of a diffuse or local nature and abscesses may be present particularly if staphylo coccal strains are present Occasionally the breast becomes involved as part of a more generalized invasion by the organisms of syphilis tuberculosis and others A special form of inflammation may re sult from fat necrosis Although any age is sus ceptible older women show a slightly higher incidence for several reasons The most common cause of fat necrosis is injury from trauma

Hormonal imbalances are believed to be responsi ble for the variants of the most common nontumor ous breast disorder of women cystic hyperplasia This term is used to describe the changes seen but many synonyms exist The changes are thought to result from exaggeration or distortion of the nor mal cyclic alterations induced during the menstrual interval Although a wide range of clinical and pathologic variation is commonplace three major types or tendencies prevail The first called fibrosis or mastodynia is marked by an increase of connec tive tissue in the breast without a proportionate increase in glandular epithelium The second cystic disease is characterized by an increase in the glandular and connective tissues in local areas with a tendency toward formation of variably sized cysts The third major type is adenosis in which glandular hyperplasia is predominant

Each major form of cystic hyperplasia has its own clinical characteristics ages of highest inci

portions of both glandular and connective tissues It occurs most often in younger women but may be encountered at any age between puberty and meno pause

Breast cancer is the most significant lesion of the female breast accounting for 20 000–25 000 deaths in the United States each year It rarely occurs before the age of 25 but its incidence increases each year thereafter with a sharper climb noted about the time of menopause Several gross and microscopic varieties exist but the clinical features are similar Early breast cancer may appear as a small firm mass which is nontender and freely movable Diagnosis at this time carries a more favorable prognosis than later when immobility nipple retraction lymph node involvement and other signs of extension or spread are noted Paget s disease of the nipple is a special form of breast cancer in which there are early skin changes about the nipple *See* HORMONE STAPHYLOCOCCUS STREPTOCOCCUS [E C ST]

Breccia

A rock composed of fragments similar to a conglomerate in distribution of sizes of the materials (coarser than 2 mm diameter) Breccias differ from conglomerates in the sharp angular nature of the fragments The sedimentary breccias are to be distinguished from volcanic breccias formed by the agglomeration of volcanic materials and tectonic breccias formed by fracturing and disruption *due to faulting*

Breccias derived from erosion of cliffs or scarps with little or no transportation are called talus *breccia* or scree Intraformational conglomerates *are often called* breccias if the pebbles are angular Some intraformational breccias may be called *desiccation breccias* for they apparently resulted from the mud cracking and desiccation shrinking of a mud bottom after withdrawal of water Later *invasion of* water disturbed the cracked pieces and *arranged them in a* thin layer of relatively flat pebbles

A similar origin is *inferred* for flat limestone pebble *conglomerates* Reef flank breccias are formed from the talus of coral and algal limestone reefs Such breccias *include* fragments of reef materials *eroded by wave action* and mixed with calcareous *fossil remains*

A type of breccia that *received* increased attention *in the* 1950s was a soft rock *deformation* product Such breccias are *similar both* to flat shale pebble conglomerates *and* to fault breccias They develop as a result of *gravitational* slumping *or sliding* down a slope where a *soft* shale bed is interbedded with *more competent beds* such as sandstone or siltstone Very large pieces of the shale bed may become *detached* and deformed and even squeezed up through *overlying layers* giving a picture of badly distorted *and in* some cases almost unrecognizable *bedding* A characteristic of these breccias is that *they are* intraformational that is higher beds carry *across the* deformed zone without disturbance *See* CONGLOMERATE GRAVEL SEDIMENTARY ROCKS

[R S]

Breeding (animal)

The activities concerned with improving the inborn or hereditary characteristics of farm animals The first step in animal breeding is to define the ideal This is often difficult as several things must be considered and the net practical merit of the animal is not always proportional to the simple sum of its merit in each of these The ideal is often an intermediate or a balance or ratio of two or more characteristics or involves improving a character only up to a certain threshold

Selection for animal improvement Breeders rely mainly on selection for animal improvement This means merely that the more favored animals are allowed or caused to have more offspring than the less preferred ones This practice tends to increase the frequency of those genes which improve the animals in the breeder's viewpoint and to decrease the frequency of those genes which make the animals inferior Selection is only partly under man s control Accidents and disease often frustrate his intentions of getting many offspring from his better animals Natural selection may either oppose or reinforce the breeder s selection but except for obvious defects, opposition is more *usual* because natural selection in the past will have tended to make the existing animals already somewhere near *optimum for* survival unless the environment has recently changed markedly

Selection made wholly on the qualities of the animal itself is called individual or mass selection Selection based on ancestors and collateral relatives is family or pedigree selection Selection based on the *merit* of the offspring is a progeny test Actually the selection will usually be made on some combination of these and will be more or *less* sequential in time with additional cullings *being* made as new information about the animal *appears* and as economic circumstances permit

Genetic importance Genetic experiments in the 1920s *demonstrated* that breeding animals for disease resistance was biologically possible However economic reasons make this unlikely to be important with animals except where no effective serum medicine or treatment has been found for a specific disease and where the value of the *individual* animal is small

Selection indexes which take account of the differences between phenotypic and genetic *correlations* were first devised in 1936 Developing refining testing and using selection *indexes* will probably be a prominent part of future animal breeding

The rate of genetic improvement *but not its ultimate* limits can be predicted if the heritability and the intensity of selection for a *character* are known The amount of genetic improvement in a generation is the product of the accuracy the intensity of the selection and the amount *of add*itively genetic variation in the population Accuracy can be low because of deceptive appearances of

environmental effects and gene interactions such as dominance and epistasis which is the masking effect between two different pairs of genes (*see* DOMINANCE RECESSIVENESS BLENDING) Intensity may be slight because few animals can be culled or because carelessness or procrastination may allow many good animals to be sold thus causing poorer ones to be retained The amount of variation caused by average gene effects may be small for several reasons chiefly these are that (1) only a few genes may affect the character and the effects of these may be small (2) the population may be nearly homozygous for such genes (3) each gene may have favorable effects in some combinations and unfavorable effects in others such as over dominance and many kinds of epistasis so that its average effect is small

Mating system Decisions on how to mate the chosen individuals that is the mating system can be based either on consanguinity or on phenotypic resemblance of the mates Mating relatives leads to some form of inbreeding Avoiding consanguinity is outbreeding Close inbreeding is generally avoided except by the few who are making partially inbred lines for crossing or some similar purposes Most breeders of seedstock practice extremely mild inbreeding to the extent of staying within a pure breed or even within some family of a pure breed in order not to dilute its merit by outcrossing with animals considered inferior

Mating of phenotypic like to like is practiced widely when starting a new breed or when first starting to select in a new direction It produces more animals at both extremes and fewer intermediates This is helpful in the first 1–3 generations of breeding in a new direction After that a breeder must erect some kind of pedigree fence or barrier around his stock if he is to make much further progress

Mating phenotypic unlikes is practiced widely for the purpose of correcting defects This makes the next generation more uniform and is especially useful when breeding for an intermediate type

Heterosis Heterosis or hybrid vigor resulting from crossbreeding or some other type of outbreeding has long been used especially in breeding commercial animals In chickens outbreeding can follow to some extent, the same pattern used in producing hybrid corn For pigs and less prolific species regular plans for using heterosis usually take the form of rotational crossing of breeds or lines The producer raises his own replacement females but buys males of some other line which crosses well with the lines from which came the sire and the maternal grandsire of his females If only two breeds are used in the rotation (criss crossing) the two genes at a locus will both come from the same breed in about one third of all the gene loci In a regular three breed rotation the fraction is 1/7 In a regular four breed rotation it is 1/15 Most animal producers who try to follow a rotational crossbreeding system will try to use at least 3 breeds in their rotation in order to get somewhere near maximum heterosis without complicating their plans unduly *See* HETEROSIS

Artificial insemination Artificial insemination has long been used in horse breeding It was not a widespread practice until the late 1920s when it began to be used widely in those situations where maximum use of a limited number of imported and expensive sires must be made quickly For example it was used when Russian animal husbandry was reconstructed after World War I Since 1935 its use in dairy breeding has become widespread The major genetic consequence of artificial breeding is that the sires can be selected more intensively since fewer are needed

The practice of making new breeds for special purposes or environments by starting with a cross or a mixture of crosses of several breeds has been more widely followed since about 1920 Some examples are the Santa Gertrudis and Brangus breeds of cattle the Palomino and Quarter Horses the Corriedale and Columbia sheep and the Minnesota No 1 and Lacombe breeds of swine

Economic situations can sometimes change the animal breeder's ideal rapidly For example the worsening competitive position of lard since about 1919 has made the ideal pig have much less lard and more muscle than formerly Rapid gain is still desired but part of that gain is lard For selecting only those rapidly gaining pigs which have little lard probing techniques have been devised for measuring the thickness of fat on the living animal This permits mass selection on all in addition to the sib test or progeny test on a small sample *See* GENETICS [J L L]

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Breeding (plant)

Scientific plant breeding involves the application of genetic principles to the improvement of plants and relies heavily upon the related sciences of statistics pathology physiology and biochemistry Initially progress in plant breeding was dependent upon selection of chance variants With the rapid development of genetics in the twentieth century plant breeders rapidly accepted and applied the pertinent aspects of this new science It has been estimated conservatively that the production of corn in the United States has been increased by approximately 750 000 000 bu/year through the use of hybrid corn Wheat production has been increased by approximately 250 000 000 bu/year through the development of disease and insect resistant variants *See* GENETICS

Plants may be divided into two groups on the basis of type of pollination those that reproduce primarily by self pollination and those that reproduce by cross pollination In the latter pollen transfer may be effected by either air currents or

insects Because of the ease of controlling pollination somewhat different breeding procedures are used for these two classes of plants

Self pollinating species Plants reproducing typically by self pollination include such crop plants as wheat oats barley and most of the edible legumes In such cases the commercial crop of a given variety is equivalent to a true breeding inbred line Because the desired combination of traits may not be available in any single strain the breeding procedure would be to cross selected parents which in combination possess all or a majority of the desired traits The offspring of the original cross are known as F_1 The F_1 hybrid material is then advanced to the F_2 the generation in which the first segregation or break up occurs Plants possessing the desired combination of traits are selected in the F_2 and later generations This procedure is known as pedigree selection An alternative procedure is to maintain a population from a given cross in bulk for several generations At this stage the population contains a wide diversity of types and each of the types is essentially true breeding Selection is then practiced as before The choice of procedures may be determined by the particular traits of interest and the facilities available When a particular strain possesses many of the desired traits and lacks the dominant form of a few traits that are simply inherited the backcrossing technique may be appropriate In this case the more desirable parent known as the recurrent parent is crossed to a strain carrying the desired dominants. The F_1 hybrid is then crossed back to the recurrent parent Backcrossing is repeated through several generations and selection is practiced in each generation for the desired dominant traits This procedure known as introgressive hybridization permits retention of the assemblage of desirable traits of the recurrent parent and the introduction of the desired traits from the nonrecurrent parent Under many conditions this backcross technique is more efficient than straight pedigree selection following hybridization The backcross technique has been used extensively in adding resistance to diseases (rust smut mildew, and so on) to established acceptable varieties of wheat oats and barley

Cross pollinating species Mass selection or individual plant selection is less efficient in cross-pollinating species because only the seed parent is under control However the open pollinated varieties of corn rye and forage plants were developed by such procedures In animal breeding more complete genetic control has been achieved by procedures such as family selection and full sib selection These procedures are used to a limited extent in plant breeding Instead plant breeders have made use of the more extreme forms of inbreeding such as self pollination In some species this is not possible and the most extreme inbreeding possible would correspond to the full sib selection of the animal breeder The choice of methods in plant

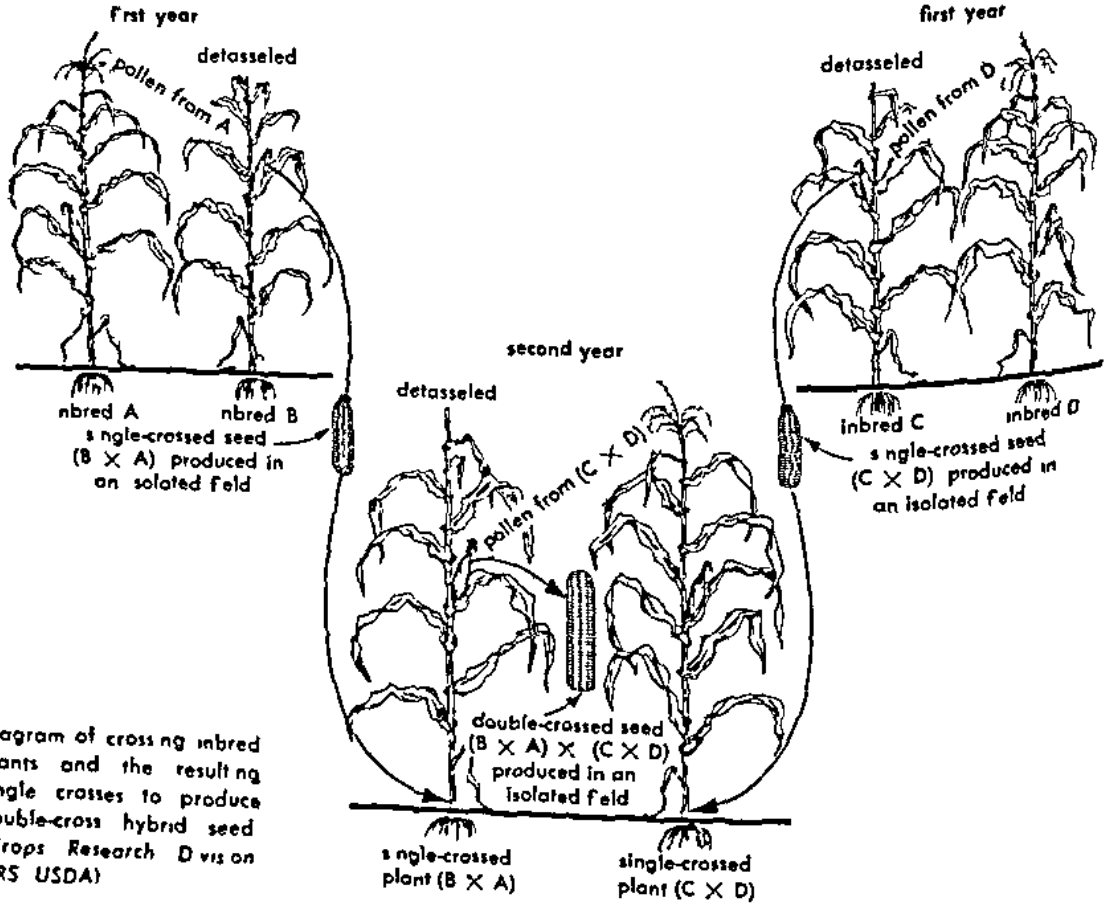


Diagram of crossing inbred plants and the resulting single crosses to produce double-cross hybrid seed (Crops Research Division ARS USDA)

and animal breeding is based on economic instead of genetic considerations In animals the long life history the relatively large cost per animal and the percentage of the population needed for replacement are important considerations In plants the cost per plant is relatively low and the number of progeny per mating high both of which considerations permit a much greater intensity of selection Because of these reasons inbreeding followed by hybridization has been used extensively in plant breeding

In cross pollinating species the individual plants comprising a variety are hybrids of unknown parentage Some possess desirable traits and others are inferior The objective therefore is to produce inbred lines with fixed genetic characteristics that in hybrid combination will equal or surpass the more desirable plants of the open pollinated variety

Inbred lines Inbred lines are usually developed by continued self fertilization Selection is practiced at the time of self pollination and again at harvest time The material surviving this selection is grown on a progeny row basis in which the seed from a single ear is planted in a single row In breeding and selection are continued until the lines reach the desired degree of uniformity Rigorous selection is practiced for general vigor yield resistance to disease and other important traits Because of the intensity of selection practiced relatively few of the initial plants will be represented by inbred progeny after two or three generations of self pollination The selection practiced ensures that the inbred lines retained will possess some of the traits deemed desirable or essential Inbred lines of cross-pollinating crops are relatively low in yield and their potential value lies in the performance of their hybrid progeny Unfortunately the appearance or performance of an inbred line has little predictive value relative to hybrid performance Thus all inbred lines must eventually be evaluated by some type of test cross or hybrid combination The type of test cross used depends somewhat upon the crop and the ease with which controlled pollinations can be effected The types of test crosses commonly used are top crosses (inbred × variety) single crosses (inbred × inbred) and 3 way crosses (inbred × single cross) The test crosses are then evaluated in replicated yield trials under the range of environments that would be encountered in commercial usage The extent of the testing program may be influenced by the eventual use to be made of the material

Economic considerations In certain of the forage crops the cost of producing F_1 seed for commercial use would be prohibitive When this is true the superior inbreds may be recombined into a synthetic strain which can be propagated under conditions of open pollination Such a synthetic line would possess much the same degree of variability characteristic of open pollinated varieties However if the selection and testing have been adequate the synthetic should produce the greater yield

When the seed cost of a crop is not a major item in production and when a high degree of uniformity is commercially desirable F_1 single cross seed may be used This is true for such crops as sweet corn and cucumbers In field corn the per acre cost for seed is of greater importance and the requirements for uniformity of crop less rigid Under these conditions the commercial hybrid is commonly a double cross (single cross A × single cross B) Formulas have been devised to predict the production performance of double crosses from data obtained in the preliminary trials of inbred lines In this way only a small sample of the predicted combinations needs to be subjected to replicated yield trials to determine those having commercial merit

Recurrent selection Breeding procedures designated as recurrent selection are coming into limited use In theory this method visualizes a controlled approach to homozygosity with selection and evaluation in each cycle to permit the desired stepwise changes in gene frequency Experimental evaluation of the procedure indicates that it has real possibilities Four types of recurrent selection have been suggested recurrent selection on the basis of phenotype recurrent selection for general combining ability recurrent selection for specific combining ability and reciprocal recurrent selection The methods are similar in the procedures involved and vary in the type of tester parent chosen and therefore in the efficiency with which different types of gene action (additive and nonadditive) are measured A brief description is given for the reciprocal recurrent selection

Two open pollinated varieties or synthetics are chosen as source material for example A and B Individual selected plants in source A are self pollinated and at the same time outcrossed to a sample of B plants The same procedure is repeated in source B using A as the tester parent The two series of test crosses are evaluated in yield trials The following year inbred seed of those A plants demonstrated to be superior on the basis of test cross performance are intercrossed to form a new composite which might be designated A_1 Then B_1 population would be formed in a similar manner The intercrossing of selected strains to produce A_1 approximately restores the original level of variability or heterozygosity but permits the fixation of certain desirable gene combinations The process in theory may be continued as long as genetic variability exists In practice the hybrid $A_n \times B_n$ may be used commercially at any stage of the process if it is equal to or superior to existing commercial hybrids

Cytoplasmic male sterility This has been found in several crop plants and is now being used to facilitate the production of hybrid seed Cytoplasmic male sterility occurring in normally self pollinating crop plants permits the use of breeding procedures appropriate to the cross pollinating types and the production of F_1 hybrid seed on a commercial scale Cytoplasmic male steri

used in the commercial production of hybrid seed for such crops as corn sorghum sugar beets tomatoes onions and petunias

Polyploids Polyploid series have been demonstrated in many plant genera Stable tetraploids may be induced artificially in a number of ways by genetic techniques colchicine treatment vegetative buds from callus tissue and others Within a given species tetraploids ($4n$) are normally characterized by a more sturdy growth habit larger leaves and larger flowers Artificially produced tetraploids of petunia and snapdragon are in common use Tetraploids of some forage legumes appear to have promise *See* POLYPLOIDY [G F S]

Bremsstrahlung

The electromagnetic radiation emitted by electrons when they pass through matter Charged particles radiate when accelerated and in this case the electric fields of the atomic nuclei provide the force which accelerates the electrons The continuous spectrum of x rays from an x ray tube is that of the bremsstrahlung in addition there is a characteristic x ray spectrum due to excitation of the target atoms by the incident electron beam The major energy loss of high energy (relativistic) electrons (energy $\gtrsim 10$ Mev depending somewhat upon material) occurs from the emission of bremsstrahlung and this is the source of the γ rays in a high energy cosmic ray shower *See* COSMIC RAYS

The spectrum of bremsstrahlung resulting from the collision of an electron with an atom is continuous and is roughly constant between $\nu = 0$ and $\nu = \nu_{max}$ ν_{max} is the maximum frequency of a photon which can be emitted that is $h\nu_{max} = T$ where T is the initial kinetic energy of the electron and h is Planck's constant The angular distribution of bremsstrahlung is roughly isotropic at low (nonrelativistic) electron energies but is largely restricted to the forward direction at high energies Very little bremsstrahlung is emitted at an angle much larger than $\theta \approx m_e c^2/T$ radians where m_e is the electron mass and c the velocity of light Bremsstrahlung emitted at the angle θ is polarized with the electric vector perpendicular to the plane con

[illegible] except near the angle θ A longitudinally polarized electron (that is one with its spin parallel to its velo[illegible]

[illegible] to all μ decay *See* PLASMA PHYSICS [C J C]

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Brevibacteriaceae

A family of bacteria in the order Eubacteriales class Schizomycetes division Protophyta It is represented by two genera *Brevibacterium* Breed 1953 and *Kurthia* Trevisan 1885 The family was proposed by R S Breed in 1953 to give taxonomic status to several species of gram positive rod shaped bacteria These were previously placed with other bacteria in the family Bacteriaceae in the sixth edition of *Bergey's Manual of Determinative Bacteriology* *Brevibacterium* Breed the type genus *See* EUBACTERIALES PROTOPHYTA

Brevibacterium Breed 1953 These are unattached unicellular nonphotosynthetic nonspore forming unbranched rod shaped organisms arranged singly in pairs or in short chains The microorganisms are nonmotile or motile with flagella gram positive and nonacid fast They require oxygen and grow best at high oxygen tension of 20% or more and are heterotrophic growing at the expense of organic compounds used as a carbon source They either produce acid without gas when carbohydrates are attacked or have no action on glucose Acid is not produced from lactose The type species is *Brevibacterium linens* (Weigmann) Breed

The seventh edition of Bergey's *Manual* describes 23 species in this genus The cells average 0.5–1.0 μ wide by 2–5 μ long They grow well on a meat extract medium the four marine species requiring a sea water base Colonies on agar are pigmented either in various shades of red and yellow or they are white Species have been isolated from dairy products rumen contents insects fish plants and soil

Kurthia Trevisan, 1885 This genus consists of unattached unicellular colorless nonspore forming unbranched rod shaped bacteria approximately 0.8 μ in length They are arranged in chains in liquid media and are motile with peritrichous flagella The microorganisms are gram positive and nonacid fast They are aerobic and heterotrophic No acid is produced from carbohydrates The species are not pathogenic to plants or animals The type species is *Kurthia zopfii* (Kurth) Trevisan

In the seventh edition of Bergey's *Manual of Determinative Bacteriology* the genus is represented by three species which have been isolated from hen manure feces and putrefying organic matter *See* BACTERIA TAXONOMY OF [I B D S]

Brick

A building material made usually from clay molded as a rectangular block and baked or burned in a kiln An American building brick measures about $2\frac{1}{4} \times 3\frac{3}{4} \times 8$ in an English brick about $2\frac{5}{8} \times 4\frac{1}{8} \times 9$ in The red color is due to iron oxides in the finished brick Unselected brick as it comes from the kiln is common brick brick selected for uniformity is face brick

Bricks may also be made of other materials The clay may be mixed with sand or lime the brick being pressed and steamed Bricks are commonly fashioned as insulating material as refractory material termed fire brick or for structural use *See* CLAY PRODUCTS ARCHITECTURAL, REFRACTORY [F R]

Bridge

A structure erected to span natural or artificial obstacles such as rivers highways or railroads and supporting a footpath or roadway for pedestrian highway or railway traffic Bridges may be classified in several ways A major distinction exists between fixed and movable bridges It is also possible to distinguish between the deck bridge whose roadway rests on top of the supporting structure and the through bridge where it is in or near the plane of the lower chord or flanges so that traffic passes through the supporting structure

Fixed bridges Fixed bridges are subdivided into short span and long span types The former type includes beam simple plate-girder and simple truss bridges The latter type includes continuous cantilever suspension and arch bridges For the discussion of arch bridges, however *see* ARCH

Beam bridges Beam bridges consist of a series of beams usually of rolled steel supporting the roadway directly on their top flanges The beams are placed parallel to traffic and extend from abutment to abutment When foundation conditions permit the economical construction of piers or intermediate bents a low cost multiple-span structure can be built Spans of 50 ft for railway beam bridges and 100 ft for highway beam bridges may be economical

Composite I beam bridges are beam bridges in which the concrete roadway is mechanically bonded to the I beams by means of shear connectors which develop horizontal shear between the concrete slab and the beam Such a connection forces a portion of the slab to act with the beam resulting in a composite T beam This construction yields a saving in weight of beams Rolled shapes such as the channel angle and I bars in serpentine form or in the form of a longitudinal helix and steel studs are used as shear connectors These connectors are usually welded to the flange of the steel beam and should extend at least half way into the slab *See* COMPOSITE BEAM

Plate girder bridges These bridges are used for longer spans than are practical with a beam bridge In its simplest form the plate girder consists of two flange plates welded to a web plate the whole having the shape of an I The railway deck plate girder consists of two girders which support the floor system for a single track directly on their top flanges A double track bridge consists of two single-track bridges placed side by side on common abutments or piers Through plate-girder bridges are used when clearance below the structure is limited For railway traffic the floor system consists of two stringers, one under each rail framing into floor beams which are supported by the girders just above their lower flanges

Truss bridges Truss bridges are used when the crossing is too long to be spanned economically by plate girders Where there is sufficient clearance underneath the bridge the deck bridge is more economical than the through bridge because the trusses can be placed closer together reducing the span of the floor beams For multiple spans, a saving is also effected in the height of piers

A through bridge is illustrated in Fig 1 The top and bottom series of truss members parallel to the roadway are called top chords and bottom chords respectively The diagonals and verticals form the web system and connect the top and bottom chords The point at which web members and a chord intersect is called a panel point Gusset plates connect the members intersecting at a panel point

Lateral bracing of a bridge ties the two trusses together and assures a stable and rigid structure The top lateral bracing consists of cross struts connecting the top chords at opposite panel points and the diagonals joining the ends of adjacent cross struts It decreases the unsupported length of the top chord members reducing the cross sectional area they require The floor beams and the diagonals connecting the ends of adjacent floor beams constitute the bottom lateral system Although the floor system of a highway bridge can take over the function of a lateral truss the lateral bracing must be provided to stiffen the structure during erection and to furnish wind resistance until the steel or concrete floor slab is in place

The stringers of an open floor railroad bridge should be braced to relieve them of bending due to lateral forces from the train In addition the floor beams should be provided with bracing to relieve the bending due to tractional forces

Portal and sway bracing are systems of bracing in transverse vertical planes of a bridge A sway frame is formed in the transverse planes at each end of the deck truss bridge by two diagonals the verticals the floor beam and the bottom strut This frame transmits the end reaction of the top lateral system to the abutment Intermediate sway frames in the plane of opposite verticals give added rigidity

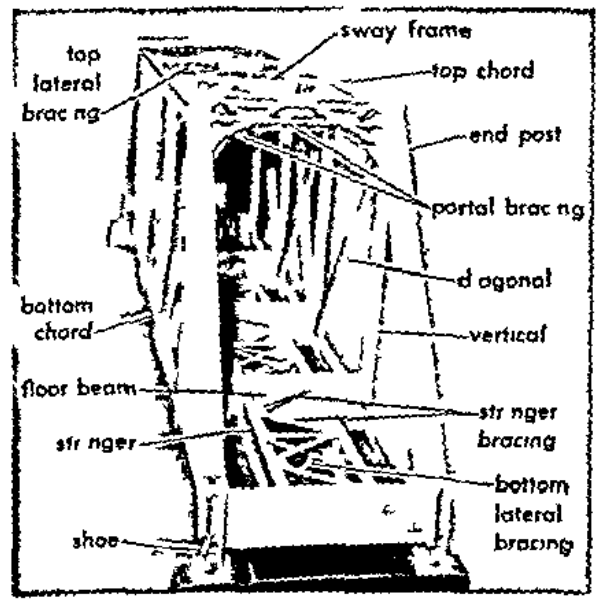


Fig 1 Scale model of a through truss railroad bridge

The end posts of the through truss bridge are tied together to form a rigid frame capable of transferring the end reaction of the top lateral system to the abutments To keep the bending stresses in the end posts as small as possible and to provide a rigid portal portal bracing should be as deep as head room allows and the end post should be braced by brackets or diagonal members

The common types of simple span bridge trusses are shown in Fig 2 The Pratt truss with its various modifications (Fig 2*a–c*) has tension diagonals and compression verticals The diagonal in every other panel of a Warren truss (Fig 2*d* and *e*) is in compression The depth of short span trusses is usually determined by the depth necessary for clearance at the portal For long spans it is usually economical to make the depth of the truss greater at the center than at the ends If the depth is increased in proportion to the increase in moment the force in the chord members can be more nearly equalized Figure 2*b* shows a curved chord Pratt truss

Trusses of economical proportions usually result if the ratio of depth of truss to length of span is approximately 1/5 to 1/8 and if the diagonals make angles of 45–60° with the horizontal The panel length produced in long span trusses when both of these factors are considered results in an uneconomical floor system To obtain panels of reasonable length subdivided trusses are often used (Fig 2*f–h*)

Continuous bridge A continuous bridge is a structure supported at three or more points and capable of resisting bending moments and shear at all sections throughout its length The positive bending moments are reduced by the negative mo- [illegible] of a continuous

omy of material, convenience of erection (that is, without need for falsework), and increased rigidity under traffic Its relative economy increases with the length of span No increase in rigidity is obtained by making more than three spans continuous The disadvantages are its sensitivity to relative change in the levels of supporting piers and the difficulty of weighing the reactions to predetermined values after construction

Cantilever bridge The cantilever bridge consists of two spans projecting toward each other and joined at their ends by a suspended simple span The projecting spans are known as the cantilever arms and these plus the suspended span constitute the main span The cantilever arms also extend back to shore, and the section from shore to the piers offshore is called the anchor span (Fig 3*a*)

Fig 3 (Facing) Some major United States bridges (*a*) The Greater New Orleans cantilever bridge across the Mississippi River (*Bethlehem Steel Company*) (*b*) Looking north from the south tower of the Mackinac Bridge during construction (*Mackinac Bridge Authority*) (*c*) Another view of the Mackinac Bridge (*Mackinac Bridge Authority*) (*d*) A vertical lift span and a swing bridge across the Arthur Kill, between Staten Island and New Jersey The vertical lift bridge will replace the swing bridge, which has been in use since 1888 (*Baltimore and Ohio Railroad Co*)

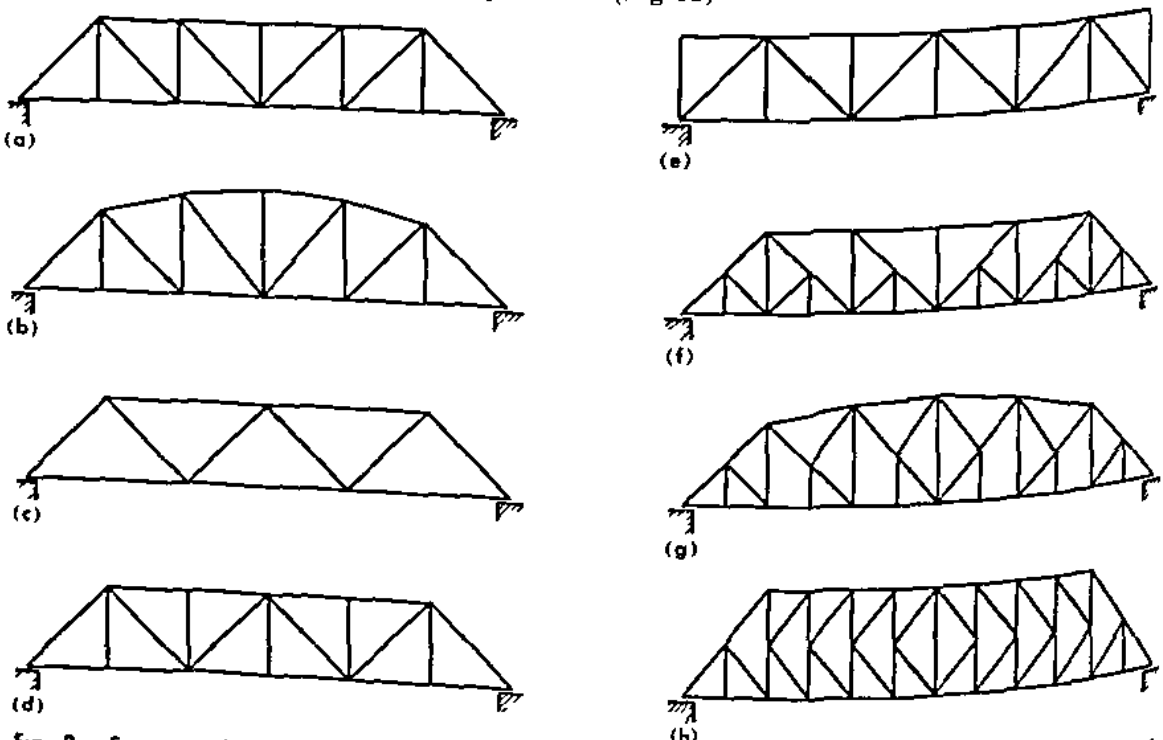
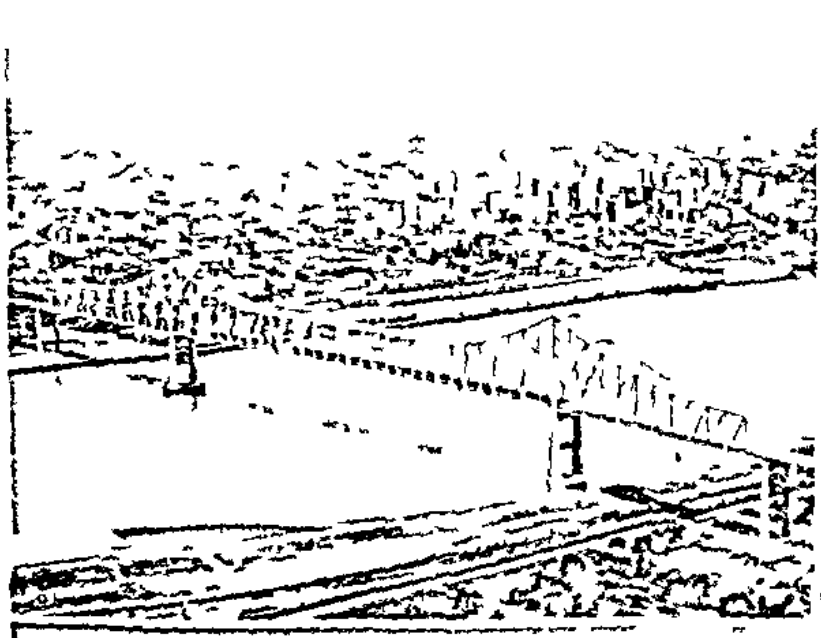
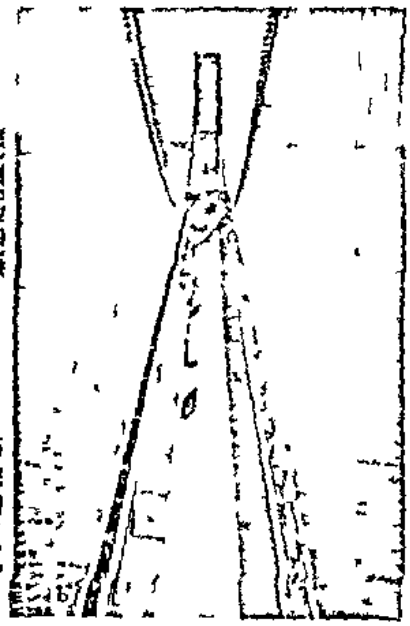
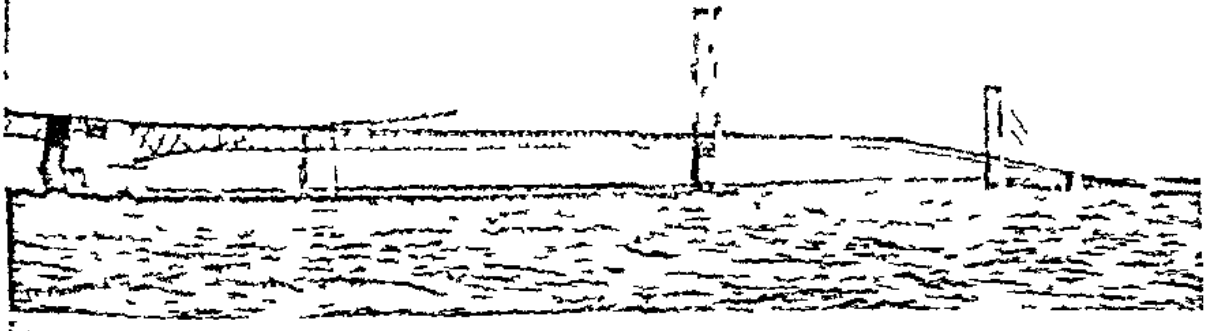
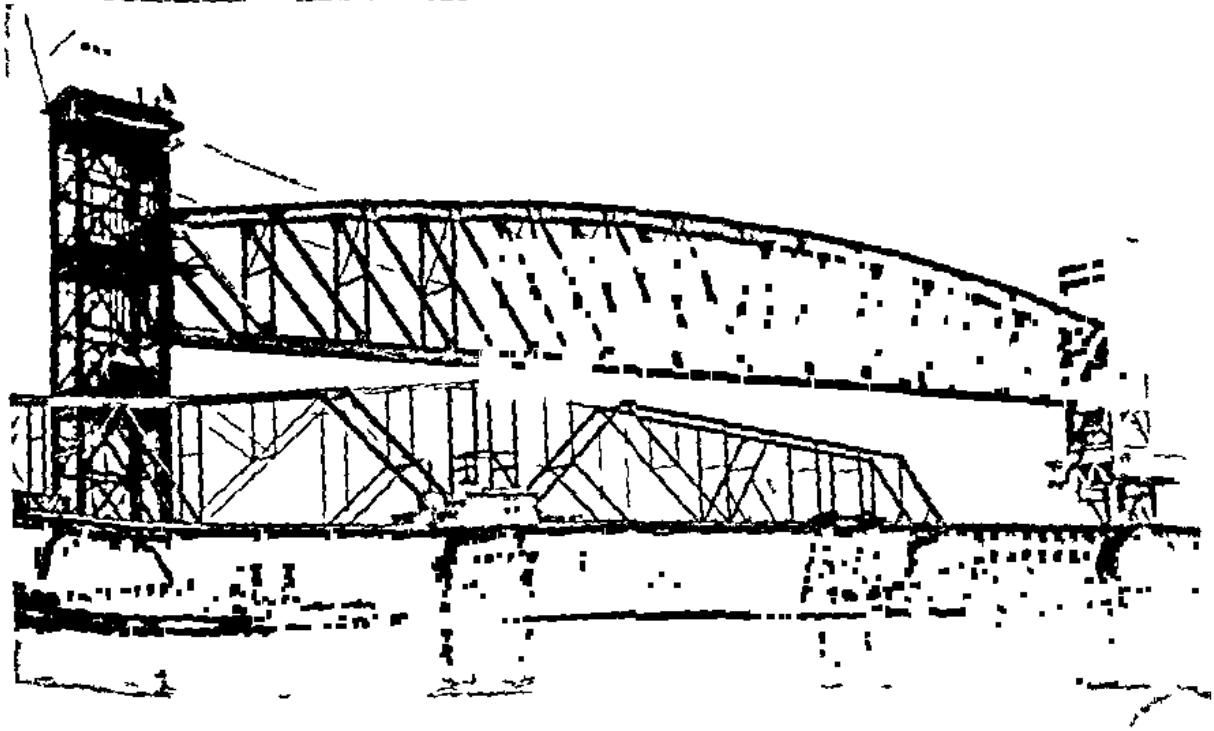


Fig 2 Some simple span bridge trusses (*a-c*) Pratt trusses (*d, e*) Warren trusses (*f h*) Subdivided trusses









The chief advantages of the cantilever design are the saving in material and ease of erection of the main span both due to the fact that no falsework is needed By adding continuity members after erection the cantilever bridge is made to act as a continuous structure under live load *See* CANTILEVER

Suspension bridge A suspension bridge is a structure consisting of either a roadway or a truss suspended from two cables which pass over two towers and are anchored by backstays to a firm foundation (Fig 3*b* and *c*) If the roadway is attached directly to the cables by suspenders the structure lacks rigidity with the result that wind loads and moving live loads distort the cables and produce a wave motion of the roadway When the roadway is supported by a truss which is hung from the cable the structure is called a stiffened suspension bridge The stiffening truss distributes the concentrated live loads over a considerable length of the cable The seven longest bridge spans in the world are all of the suspension type and all are in the United States The longest main span 4200 ft is possessed by San Francisco s Golden Gate bridge The Mackinac Bridge (connecting Michigan's upper and lower peninsulas) is second with a center span length of 3800 ft

Movable bridges A movable bridge facilitates navigation by raising the height of the usable channel or clearing the channel altogether The principal types are the draw bascule vertical lift swing, and pontoon bridges Drawbridges are of only historical interest today because they are no longer erected

Drawbridge A drawbridge can be raised lowered or drawn aside to provide a clear passage The drawbridge of ancient and medieval periods was built for military purposes It was constructed to bridge the moat around the castle or fortified town and to be raised in case of attack The open leaf also constituted an additional barricade across the entrance to the fortification Many of these early structures were operated by a lever system One end of the lever was connected to the free end of the span by chains and the other end was usually counterweighted An arrangement of counter weights attached to chains running over pulleys and connected to the free end of the span was also much in use The modern drawbridge is the bascule bridge

Bascule bridge The bascule bridge consists primarily of a cantilever span which may be either a truss or a plate girder extending across the channel The span is supported on a pinion at one end and balanced by a counterweight behind the pinion Bascule bridges may consist of one leaf which acts as a single simple span under live load or of two leaves which when the bridge is closed are locked together by a device that transmits shear but not moment Although the double leaf bascule is more attractive because of the symmetry of both piers and leaves the single leaf structure is generally more economical for spans of less than 100 ft The bascule bridge is advantageous when navigation requirements necessitate a high lift and the channel width is small

Vertical lift bridge This bridge is raised and lowered vertically by cables running over sheaves in towers at both ends A counterweight in each tower balances the weight of the movable span reducing the power required to move it Friction developed between the cables and the sheaves is utilized to raise or lower the span when the sheaves are rotated The 558 ft span of the lift bridge over the Arthur Kill an arm of New York harbor is the longest in the world of this type (Fig. 3*d*) Of unique design is the Houghton Hancock lift bridge across the Portage ship canal on Michigan s upper peninsula, it has an upper level for vehicular and pedestrian traffic and a lower level for railway traffic

Swing bridge The swing bridge is a movable bridge that pivots in a horizontal plane about a center pier (Fig 3*d*) The swing bridge provides unlimited vertical clearance but because of its wide central pier it requires a large horizontal area for its operation In general swing bridges are either center bearing or rim bearing In the center bearing type lateral support is provided by balance wheels, which roll on a circular track Support for the rim bearing type is provided by a large circular girder which rotates with the span In the open position the dead load is supported by the center support When the bridge is closed wedges are inserted at the ends of the span to provide a positive dead load reaction somewhat greater than the negative reaction due to live load and impact Wedges are also inserted between the span and the pier top of the center bearing swing bridge so that the live load is supported directly by the pier

Pontoon bridge This is a floating bridge supported by pontoons The structure may be a temporary one as for military usage or a permanent one if the level of the water can be carefully controlled A pontoon bridge may be advantageous where deep water and adverse bottom conditions make piers expensive Seattle s Lake Washington bridge consists of 25 reinforced concrete pontoons each 350 ft long by 59 ft wide and 14 5 ft deep

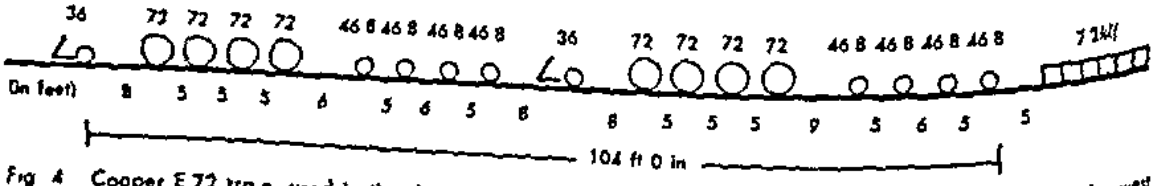


Fig 4 Cooper E 72 train used in the design of main line bridges The drawing represents the axle loads in kips (k) and spacing for two units of one of the heaviest diesel locomotives

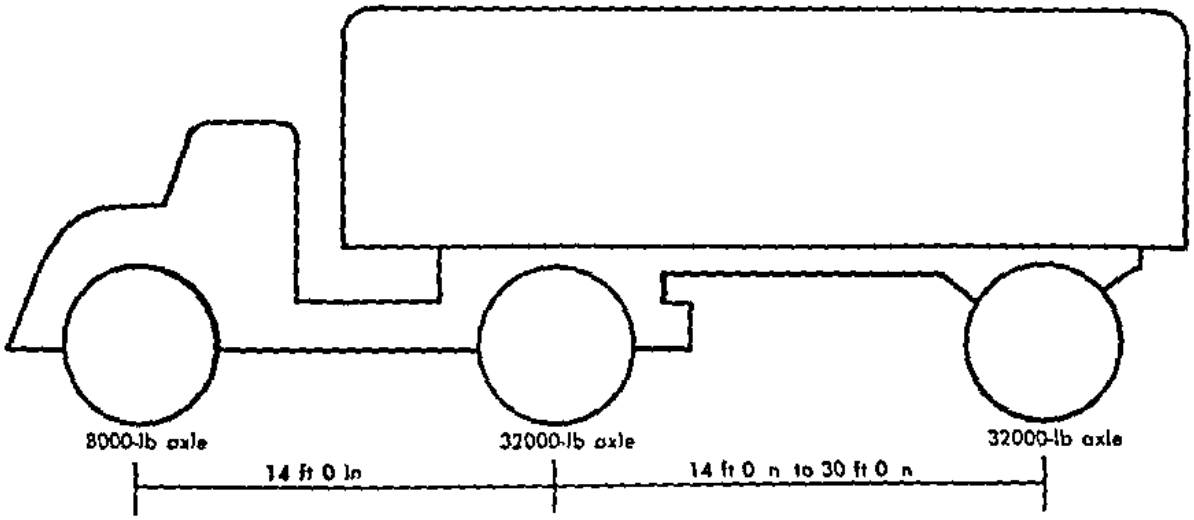


Fig 5 The H20-S16 loading for highway bridges represents a 20-ton tractor truck followed by a 16-ton single-axle semitrailer

A 378 ft pontoon is used as a floating draw span to give a clear channel opening 200 ft wide Adjacent pontoons are bolted together and each is secured by a pair of anchors one on each side

Reinforced concrete bridges The bridges that have been discussed are usually made of steel although they may carry a concrete roadway Increasingly however bridges are being constructed of reinforced concrete Such bridges are usually one of two types (1) the slab bridge which is simply a reinforced concrete slab extending from abutment to abutment and is economical for very short spans and (2) the deck girder bridge consisting of a concrete slab built integrally with a series of concrete girders placed parallel to traffic The advantages of concrete are durability and the ease with which a pleasing appearance can be obtained

Loading and floor systems The Cooper load used in the design of most railroad bridges is intended to represent two locomotives followed by a uniformly loaded train The number following the letter E in these loadings is the load in kips on the driving axle The intensity per lineal foot of the uniform load is one tenth the driving axle load The Cooper E-72 train shown in Fig 4 is recommended by the American Railway Engineering Association for the design of mainline bridges Figure 4 shows the axle loads and spacing for two units of one of the heaviest diesel locomotives

The railroad bridge usually has an open floor consisting of timber crossties resting directly on stringers which frame into floor beams Over city streets and main highways an open floor is prohibited and a ballasted roadway on a solid floor is necessary

The American Association of State Highway Officials loading used for highway bridges consists of a system of concentrated loads to represent a truck or of a load distributed uniformly along the traffic lane together with a concentrated load to represent a long line of medium weight vehicles with a heavy truck somewhere in the line The loading may consist of a two-axle truck or a tractor truck with semitrailer these are designated as H loadings and H S loadings respectively The H20-S16 loading (Fig 5) represents a 20 ton tractor truck followed by a 16 ton single axle semitrailer

The floor system for the highway bridge usually consists of a reinforced concrete slab supported on steel stringers placed parallel to the direction of traffic The stringers of the beam bridge rest on abutments or piers but the stringers of truss and plate girder bridges are supported on floor beams Lightweight floor construction consisting of either a steel plate (battledeck) or a steel open grid welded to the top flanges of the stringers decreases the dead load and may prove economical for long span bridges [C N C]

BRIDGE FOUNDATIONS

The foundation of a bridge comprises its piers and abutments In planning a bridge foundation one of the first tasks is choice of its location and

for design and economy

A general step taken in locating foundations is the study of maps and topographical data as well as of records showing water levels current direction and speed ice conditions wave action bulk head lines and water traffic Soil borings and depth soundings are also taken

Bridge piers Bridge piers are the intermediate foundations upon which the bridge superstructure rests They must carry dead and live loads without appreciable settlement under the action of wind water wave and ice and sometimes of shifting bottoms

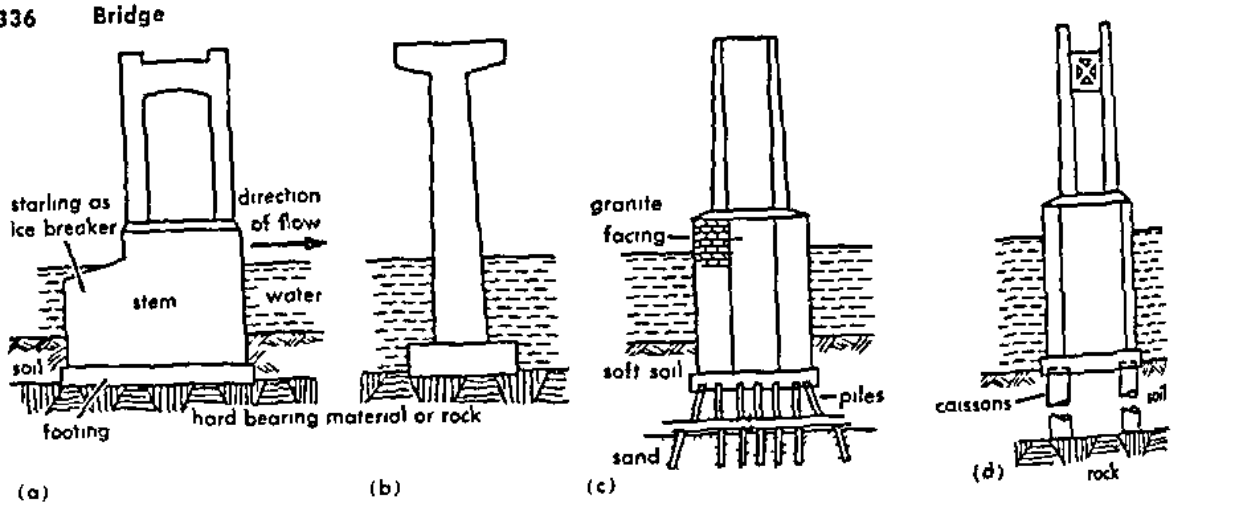


Fig 6 Some pier designs for large bridges (*a* to *d*) and small bridges (*e* to *h*) (*a*) Vertical shafts with heavy portal and base (*b*) Single battered shaft with cantilevered deck supports (*c*) Solid shaft, piles carry load to sand (*d*) Braced and battered shafts Caissons carry load to rock (*e*) Solid shaft with rounded ends (*f*) Portal and cantilevers (*g*) Solid shaft with triangular end (*h*) Braced tower on solid base

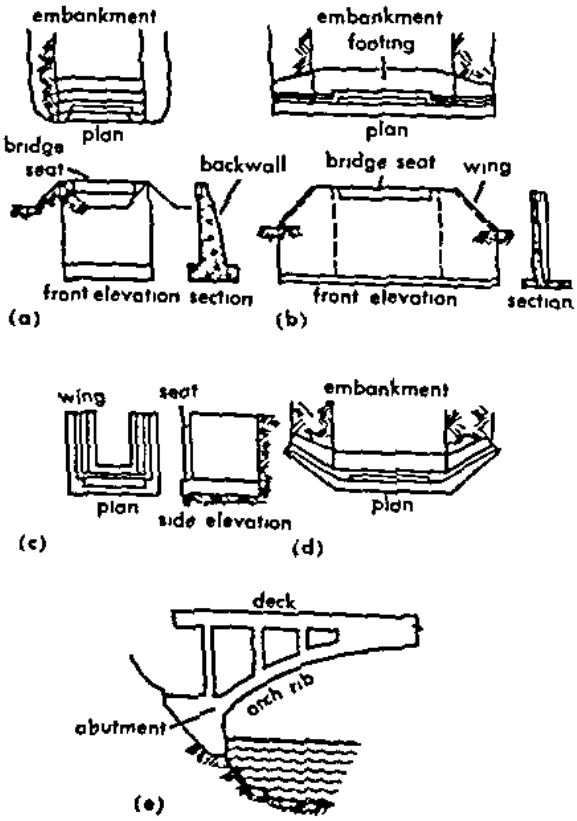


Fig 7 Abutment designs for bridges (*a*) Wingless (*b*) Straight wing (*c*) U-shaped (*d*) Beveled wing (*e*) Abutment for arch bridge

Location of piers may depend upon factors besides the presence of suitable foundation conditions A few of these are the need to use or to avoid certain property, the need to space the piers and abutments symmetrically; and the desirability of avoiding locations exposed to collision by traffic to scouring by flowing water, and to pressure from ice or log jams

The selection of pier design and location and the choice of bridge type are interdependent When shipping traffic requires large horizontal and vertical clearances, and road traffic must be uninterrupted high, long span structures are preferable Examples are suspension bridges, cantilever or continuous trusses, or arches If long, high approaches are dictated by terrain or other considerations a low bridge with movable span is desirable If vertical clearances are not important and foundation and river conditions permit, low piers and short spans may be the most economical design Nearness to bedrock may permit short span structures or heavy, long spans Rocky ravines require long arches or suspension bridges

Piers usually are sufficiently massive to present no problem in carrying vertical loads The soil or piles under a pier must be able to resist the applied loads, and this is the most difficult part of pier design (Fig 6). Scour, wave action and ice action are three important causes of instability

Scour by flowing water may undermine the pier especially if the waterway is narrowed by ice or log jams against the pier During a flood the river

bottom may be removed for a considerable depth and eddies around a pier can cause further excavation Selection of the proper bearing stratum and depth to avoid scour determines the pier height

Wave action is seldom serious against large piers although it is troublesome against cofferdams and caissons used during construction It may be dangerous to low light bridges or trestles

Ice action against piers may be large and if the point of application is high above the pier base there is a serious tendency to overturn The impact from floating ice floes or the effect of the wedging of ice among piers may be great Ice pressure may amount to several thousand pounds per linear foot It is preferable not to construct piers in icy rivers

Other loads to be considered in pier design are those caused by wind on the superstructure and pier the river current braking or starting traction from trains log jams and friction from deck bearings when spans expand or contract longitudinally Designers may also need to consider the effects of earthquakes and collision by ships Not all forces act at the same time and the factors of safety built into the design may be less for some infrequent combinations Loads of short duration are commonly omitted in computing settlement

Additional protection is often given piers by facing them with dense durable stone Using stone rather than concrete saves the time and expense of forms provides an attractive appearance and avoids the tendency of concrete to crack and deteriorate at the surface

Abutments Abutments are the end foundations on which the bridge superstructure rests They have features in common with piers but must resist earth pressure from the rear face as well as forces that act on piers Abutments also protect banks against erosion *See* RETAINING WALL

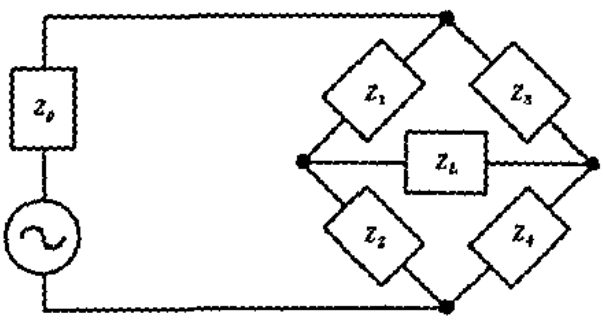
Modern bridge abutments are usually made of reinforced concrete A stone facing may be added for appearance The most common types of abutment are wingless straight wing beveled wing and U shaped (Fig 7) Wingless abutments are simply piers that have been designed to resist earth pressure in back and to provide a bridge seat Straight wing abutments provide wings to prevent fill from spilling around the ends this type is used with embankments of moderate height Beveled wing abutments also prevent or reduce the embankment spillage around the ends of the wing the wings may also be useful in deflecting a stream toward the opening U shaped abutments have wings perpendicular to the face which act as counterforts this type is very stable and is often used for architectural effect

Proper drainage of the fill behind abutments is essential to avoid increasing the lateral thrust gravel backfill open jointed drains and weep holes are used

Abutments for arch bridges must resist a large horizontal component of reaction as well as vertical load Because good foundation material is needed rocky gorges are ideal locations [R D C]

Bridge circuit

An electric network composed of four impedances forming a diamond shaped network These impedances shown in the illustration as Z_1 Z_2 Z_3 and Z_4 may be combinations of resistors capacitors, and inductors Bridge circuits perform numerous functions depending upon the type of circuit elements used in the arms of the bridge For example the bridge circuit can be used to determine the value of an unknown resistance This is done by making the arm impedances resistances with one of them the unknown The load impedance Z_L can be that of a measuring instrument such as a galvanometer The current through Z_L and therefore the voltage across it will be zero when $Z_1Z_4 = Z_2Z_3$ (*see* WHEATSTONE BRIDGE) With the proper combination of resistors and capacitors in the bridge arms the voltage across Z_L will be zero for some frequency Thus the bridge acts as a frequency measuring device *See* FREQUENCY MEASUREMENT



Bridge circuit

The property of the bridge circuit that the voltage across Z_L will be zero for the proper arm impedances and the proper frequency makes the circuit useful in an oscillator known as the Wien bridge oscillator It also has been used in the feedback path of some special amplifiers where its properties give the amplifier unusual characteristics *See* OSCILLATOR [H F K]

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Bridge vibration

A bridge is essentially a static structure loaded primarily by its own weight by the weight of passing traffic, and occasionally by wind The chief vibratory excitation of bridges resulted in the past from steam locomotives because their piston motion could not be entirely balanced by counterweights on the wheels It was necessary to avoid resonance between the wheel revolutions and the natural frequency of the bridge structure Similarly infantry broke cadence while crossing a bridge to avoid rhythmically exciting it into vibration These difficulties with vibration are now rare One important exception did occur with a large suspension bridge in Tacoma, Washington which was destroyed by vibration in 1941 This vibration

the torsional type involving the entire bridge deck was caused by a steady wind of some 40 mph forming alternating large eddies known as Karman vortices The mechanism of this failure has been studied exhaustively theoretically and experimentally Suspension bridges since then have been built with open trusses instead of solid steel side plates and with boxlike rather than open I type cross sections so that no recurrence of the phenomenon is expected *See* AEROELASTICITY KARMAN VORTEX STREET MECHANICAL VIBRATION

[J P D H]

Brillouin zone

In the propagation of any type of wave motion through a crystal lattice the frequency is a periodic function of the wave vector k that is it is a multivalued function of k moreover there are generally discontinuities in the function In order to simplify the treatment of wave motion in crystals zones are defined such that in each zone there exists but a single frequency for a given k and such that discontinuities occur only at the zone boundaries Such zones are called Brillouin zones In the study of complex metals and alloys where there may be several overlapping energy bands the geometry of the zones plays an important role

The central Brillouin zone for a particular solid type is a solid which has the same volume as the *primitive unit cell* in reciprocal space that is the space of the reciprocal lattice vectors and is of such a shape as to be invariant under as many as possible of the symmetry operations of the crystal *See* CRYSTALLOGRAPHY CRYSTAL STRUCTURE

Zone construction Let $\mathbf{a}_1$ $\mathbf{a}_2$ $\mathbf{a}_3$ be the primitive translation vectors for some crystal lattice New vectors $\mathbf{b}_i$ with $i = 1\ 2\ 3$ are defined as follows

$$\mathbf{a}_i \cdot \mathbf{b}_j = 2\pi\delta_{ij} \tag{1}$$

where δ_{ij} is unity when $i = j$ and zero for other values of i The vectors $\mathbf{b}_i$ are then given by

$$\mathbf{b}_1 = \frac{2\pi \mathbf{a}_2 \times \mathbf{a}_3}{\mathbf{a}_1 \cdot \mathbf{a}_2 \times \mathbf{a}_3} \qquad \mathbf{b}_2 = \frac{2\pi \mathbf{a}_3 \times \mathbf{a}_1}{\mathbf{a}_1 \cdot \mathbf{a}_2 \times \mathbf{a}_3}$$

$$\mathbf{b}_3 = \frac{2\pi \mathbf{a}_1 \times \mathbf{a}_2}{\mathbf{a}_1 \cdot \mathbf{a}_2 \times \mathbf{a}_3} \tag{2}$$

Now define vectors $\mathbf{K}_i$ by

$$\mathbf{K}_i = h_1\mathbf{b}_1 + h_2\mathbf{b}_2 + h_3\mathbf{b}_3 \tag{3}$$

where the h s are arbitrary integers The subscript i stands for some particular combination of the h The end points of the vectors $\mathbf{K}_i$ form a lattice of points in reciprocal space The vectors K have the property that plane waves of the form $e^{i\mathbf{K}\cdot\mathbf{r}}$ are periodic in the crystal lattice since if some $\mathbf{r}' = \mathbf{r} + \mathbf{R}_n$ is considered where $\mathbf{R}_n$ is a translation vector of the crystal

$$e^{i\mathbf{K}_i\cdot\mathbf{r}'} = e^{i\mathbf{K}_i\cdot\mathbf{r}} e^{i\mathbf{K}_i\cdot\mathbf{R}_n} = e^{i\mathbf{K}_i\cdot\mathbf{r}} \tag{4}$$

The last step follows since $\mathbf{K}_i \cdot \mathbf{R}_n$ is an integer times 2π Consequently the plane waves $e^{i\mathbf{K}_i\cdot\mathbf{r}}$ are suitable functions for the expansion of any function which is periodic in the lattice

Unit cells can be constructed in the reciprocal space of the lattice of the ends of the vectors K just as is done in the real crystal space The lines connecting one point with the other lattice sites are drawn and the planes which are the perpendicular bisectors of these lines are constructed The smallest enclosed solid figure is the first Brillouin zone It is the smallest unit cell in the reciprocal lattice which has the symmetry of the entire lattice Higher Brillouin zones are also formed

Brillouin zones for the body centered cubic face centered cubic and hexagonal closed packed lattices are shown in Figs 1–3

Application to band theory Each electron wave function in the crystal can be classified according to some k inside the first Brillouin zone For if $\mathbf{k}'$ is a vector in reciprocal space whose end point lies outside the zone then it can be written as

$$\mathbf{k}' = \mathbf{k} + \mathbf{K}_n \tag{5}$$

where k lies inside the zone and $\mathbf{K}_n$ is a reciprocal lattice vector According to the Bloch theorem

$$\psi_{\mathbf{k}}(\mathbf{r} + \mathbf{R}_j) = e^{i\mathbf{k}\cdot\mathbf{R}_j}\psi_{\mathbf{k}}(\mathbf{r}) \tag{6}$$

but $$e^{i\mathbf{k}'\cdot\mathbf{R}_j} = e^{i\mathbf{k}\cdot\mathbf{R}_j} e^{i\mathbf{K}_n\cdot\mathbf{R}_j} = e^{i\mathbf{k}\cdot\mathbf{R}_j}$$

since $\mathbf{K}_n \cdot \mathbf{R}_j$ is an integer times 2π Thus $\mathbf{k}'$ and k are equivalent in a certain sense For this reason it is possible to consider only the first zone in discussing the properties of solids

A fundamental point in the application of Brillouin zone theory to the study of the properties of metals and alloys is that the energy $E(\mathbf{k})$ of the states $\psi_{\mathbf{k}}$ must be a continuous function of k (although it will be multivalued if the *reduced zone* scheme is employed) inside the zone Discontinuities can occur only across the faces of the zone The number of allowed states inside each Brillouin zone can be determined as follows The number of allowed states per unit volume in the space of the vector k is $1/(2\pi)^3$ for each spin per unit volume of the crystal or $2/(2\pi)^3$ altogether Thus the number of states in the zone for each atom in the crystal is $2V/(2\pi)^3N$ where N is the number of atoms of the crystal and V is the volume A substance which has just enough electrons per atom to fill some zone may be an insulator or semiconductor If there are not enough electrons to fill a zone it must be a metallic conductor

Alkali metals These metals are body-centered cubic The volume of the zone is $2(2\pi/a)^3$ where a is the lattice constant The number of atoms per unit volume is $2/a^3$ so that the *first zone* can contain two electrons per atom However the atoms possess only one valence electron so that these metals should be good conductors which is the case

Noble metals Copper silver and gold are face-centered cubic and again the zone can hold two electrons per atom Thus these also are good conductors If the noble metals were adequately described by a free electron model the *Fermi surface* (the surface bounding the occupied volume of reciprocal space) would be a sphere which would

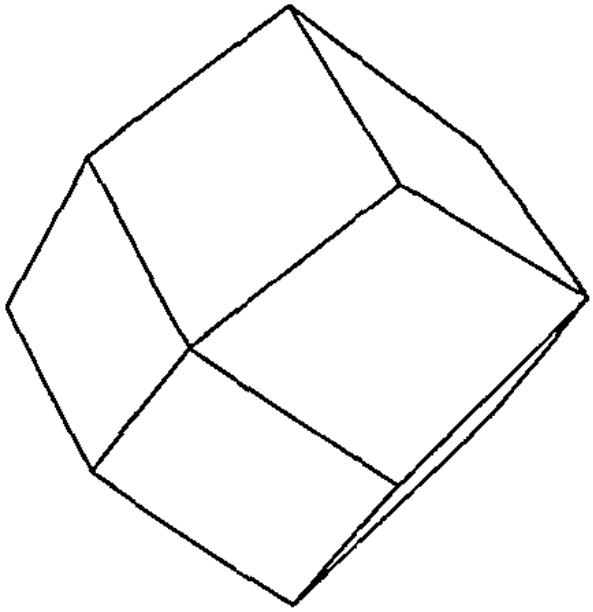


Fig 1 Brillouin zone for the body-centered cubic lattice

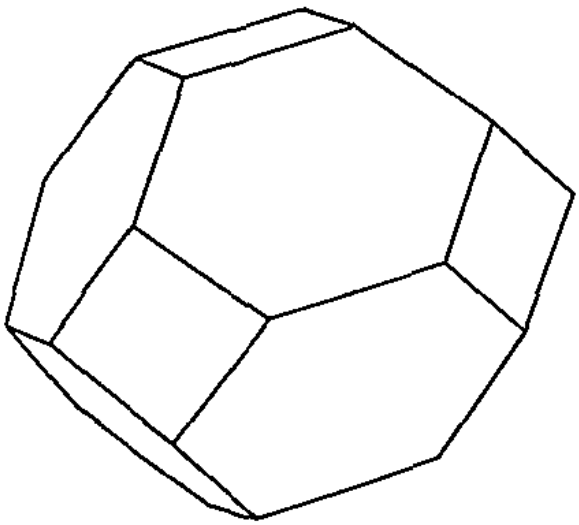


Fig 2 Brillouin zone for the face-centered cubic lattice

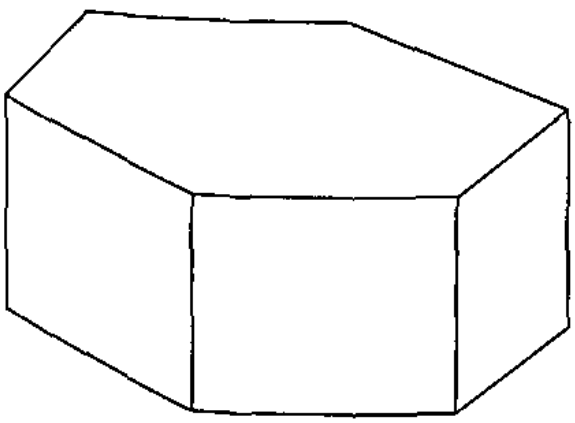


Fig 3 Brillouin zone for the hexagonal close packed lattice

approach closest to the surface of the zone It is likely, however, that the free electron model is not adequate for electrons near the Fermi surface, and that the Fermi surface either approaches the Brillouin zone very closely at certain points or ac tually touches it there

Divalent metals Except for barium and mercury, the divalent metals have either hexagonal close packed or face centered cubic structures The zones hold two valence electrons per atom, and on the basis of simple arguments, it would be expected that these materials should be insulators How ever, it is likely that some of the electrons go over into the next Brillouin zone leaving pockets of holes behind in the first zone

Semiconductors and insulators In diamond silicon germanium and gray tin all of which have the diamond structure of two interpenetrating face centered cubic (fcc) lattices, the Brillouin zone has the same form as for the fcc It can hold four electrons per atom This zone is separated from the next by an energy gap, since these materials are semiconductors or insulators Graphite, which has a hexagonal layer structure can be regarded as a semiconductor with a vanishing energy gap The Brillouin zone, in a simple model, is full at a temperature of 0°K, but there is no gap along the edges of the zone In bismuth, there is a zone which holds five electrons per atom There is a very small overlap of electrons across the faces of the zone, leading to the presence of a small number (about 10^{-5} per atom) of both electrons and holes at 0°K

Binary alloys Many of the properties of binary alloys which form substitutional solid solutions can be explained on the hypothesis that the solute contributes its valence electrons to form a com posite system whose fundamental parameter is the electron per atom ratio The electronic structure is assumed to be essentially unaltered Many changes of the properties, such as the lattice parameter, the concentration at which the various phases appear, and the Hall coefficient, can be explained in terms of overlap or contact of the Fermi surface with the Brillouin zone *See* ALLOY STRUCTURES, BAND THEORY OF SOLIDS [J C]

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Brine, microbiology of

The study of microorganisms that possess the abil ity to live in strong salt solutions These are found, often in large numbers inhabiting salines (salt marshes) of marine origin as well as inland salt ponds and lakes Such halophilic (that is salt loving) microorganisms are found as autochthons of, for example the Dead Sea, Great Salt Lake, the limans of the Black Sea, and sea water evaporation ponds used in salt manufacture Especially appar ent is their presence in sea water evaporation

ponds where they often color the brine a rich red or sometimes color it green The salt freshly produced from such brines usually contains a large number of halophilic bacteria These occasionally cause spoilage of fish meat vegetables and hides when salt has been used in the preservation process The spoilage condition is known as pink or pinkeye in salted fish and red heat or heating in salted hides

The microorganisms living in brine comprise a variety of different types bacteria yeasts molds algae protozoa and amebas A distinction is made between halo tolerant (facultative halophilic) microorganisms which thrive in fresh water as well as in saline environments and halo obligatory (obligate halophilic) microorganisms which require saline environments for their growth and reproduction Some of these organisms (the extreme halophiles) thrive best in salines containing 25–30% salt and do not develop when the concentration is below 10–15%

Halo obligatory bacteria Although many of these have been extensively studied their classification is still in a state of confusion In part this is due to (1) the extreme pleomorphism (morphological variability) of some of the bacteria and (2) their obligate halophilic nature which offers obstacles in their examination with the ordinary microbiological techniques The more important members of the group those causing spoilage of salted products are red (sometimes orange) in color because of the presence in the cells of carotenoid pigments of as yet unknown chemical composition They are ubiquitously distributed in strong brines and also have been isolated from other sources

Among the red halo obligatory bacteria at least three different types can be distinguished

1 *Gram-negative* nonsporeforming aerobic motile rods (0 5–0 9 $\mu \times 2$ 10 μ) often containing a number of refractive bodies within the cells The exact nature of these bodies is not known they are possibly gas filled vacuoles Optimum salt concentration for growth is 25 30% no development takes place at concentrations below 15% When the concentration of salt is lowered the cells become bulbous or even spherical and at a low enough concentration the cells will lyse (disintegrate) In saturated salt solutions the cells may appear flat as ribbons The type species is *Halobacterium halobium* (= *Pseudomonas salinaria*) See PSEUDOMONADACEAE

2 Gram negative aerobic cocci (0 9 2 7 μ) which occur singly in pairs or in packets Optimum salt concentration for growth is 20–25% no growth or poor growth takes place at concentrations below 10% The type species is *Sarcina morrhuae*

3 Gram negative aerobic cocci (0 9–1 5 μ) occurring singly in pairs and occasionally in chains No growth occurs in salt concentrations below 6–9% The type species is *Micrococcus morrhua* See MICROCOCCACEAE

In addition to the red halophilic bacteria a number of nonchromogenic halo obligatory bacteria have been isolated from brines In general the nonchromogenic species seem to have a lower optimum salt requirement (4 15%) than the red halophiles

Bottom sediments of the Dead Sea have been shown to contain a rich population of microorganisms including glucose fermenting denitrifying sulfur oxidizing and aerobic cellulose decomposing bacteria These grow in media containing 25% salt

Halo tolerant bacteria A number of bacterial types of common occurrence in fresh water mud and soil have been shown to tolerate but not require high salt concentrations (15–30%) in their growth medium These include lactic acid and butyric acid bacteria, sulfate reducing sulfur oxidizing nitrifying and denitrifying bacteria and bacteria that decompose protein urea pectin cellulose and fat Apparently these organisms can adapt themselves to live at high salt concentrations and therefore may be found as cohabitants of strong brines

Halophilic yeasts and molds These are found in curing brines and on salted food products Of special importance is the mold *Sporendonema epizoum* which causes the dun or discoloration of salt fish

Halophilic algae These in particular species of the flagellate *Dunaliella* are commonly found in brines *D viridis* is green in color and serves as food for the brine shrimp *Artemia salina* (see CRUSTACEA) *D salina* is red in color In the solar evaporation ponds of the salt industry the alga *Stichococcus* often predominates in brines of relatively low salinity See ALGAE

Much experimental work and speculation have been devoted to the problem of interpreting the physiological basis for the microorganisms halophilic ability If the internal environment of the cells has a chemical composition similar to that of ordinary soil and fresh water microorganisms the halophiles will in extreme cases have to withstand a high external osmotic pressure (100–200 atmospheres) The results of experiments indicate however that the internal solute concentration of cells of various halophiles is much higher than in those of nonhalophiles thus counterbalancing the external pressure See FOOD ENGINEERING FOOD PRESERVATION [M L]

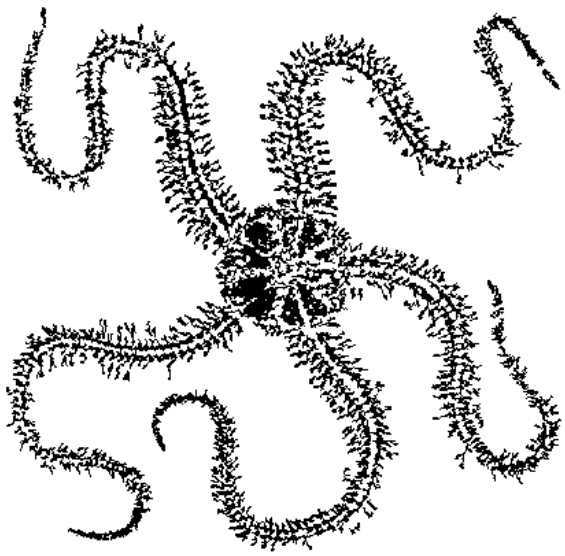
British thermal unit (Btu)

A unit quantity of energy Usually the expression is used in connection with energy as heat but it may be used when referring to energy as work or energy in any other form Before 1929 the 60 degree Btu was defined as that quantity of energy as heat required to increase the temperature of 1 lb of water from 59 5°F to 60 5°F the water being held under a constant pressure of 1 atmosphere (see CALORIE, CALORIMETRY) Because of the difficulty of experimentally determining the exact value of the Btu and especially its relation

to the foot pound (*see* HEAT) the Btu is now defined in terms of electrical units At the International Steam Table Conference in London in 1929 1 Btu was defined as 251 996 IT International Steam Table calories or 778.26 ft lb By definition 1 IT cal = 1/860 watthour hence a Btu is equivalent to approximately 1/3 watthour *See* ELECTRICAL MEASUREMENTS [H C W]

Brittle star

Numerous species of the class Ophiuroidea of the phylum Echinodermata These marine animals have five rays or arms which are sharply demarcated from the small rounded central disk The arms are long and slender and are used in locomotion The arms can be cast off readily when injured and regeneration occurs rapidly Brittle stars are bottom dwellers of shallow to deep water where they feed on a variety of minute organisms mainly crustaceans *Ophioderma brevispina* (see illustration) *Ophiura sarsi* and *Ophiothrix angulata* are common examples Brittle stars conceal themselves among seaweeds and under shells stones or other objects They are nocturnal in habit In most species the sexes are separate with fertilization occurring in the sea water A few brittle stars brood their young in the genital bursae where the eggs are retained



The brittle star *Ophioderma brevispinum* diameter to 5 in (*From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd London*)

and not liberated into the water Metamorphosis of the larvae occurs in the bursae and the brittle stars are liberated when the adult form is assumed *See* OPHIUROIDEA REGENERATION (BIOLOGY) [J D B]

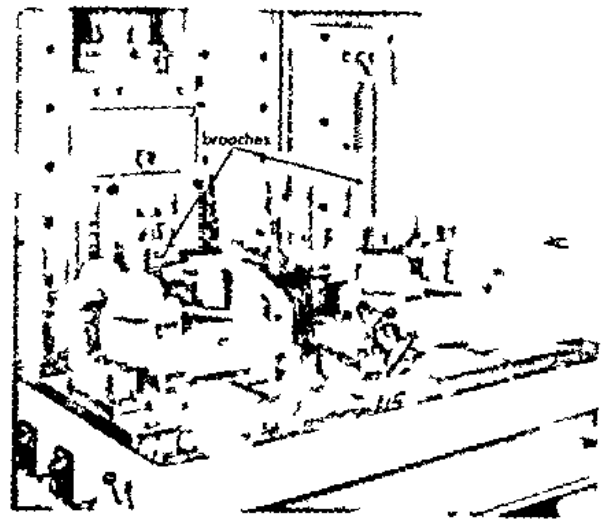
Brittleness

That property of a material manifested by fracture without appreciable prior plastic deformation A brittle fracture occurs on cleavage planes within the grains of a crystalline aggregate if the material has inherently high shear resistance or if the existing state of stress inhibits plastic deformation A material is ductile when large deformations occur before fracture Glass concrete and cast iron are brittle Copper and soft steel are ductile

[W J KR]

Broaching

The machine shaping of metal by pushing or pulling a multiple-tooth barlike tool across a surface or through an existing hole in a workpiece The peripheries or cutting edges of the broach teeth



Dual ram type vertical broaching machine with fixtures (*Colonial Broach and Machine Co*)

are shaped to give a desired surface or contour whereas cutting action results from the fact that each tooth is progressively higher or projects further than the preceding one

Broaching machines are classed as either horizontals or verticals depending on the mounting plane of the broach Most horizontal machines are of the pull type while vertical models are made to use pull up pull down push or surface broaches Multiple rams increase output as illustrated Continuous broaching machines permit large quantity production by moving the workpieces on rotary tables or chain conveyors past stationary broaches *See* MACHINING OPERATIONS [A T]

Broccoli

A cool season biennial crucifer (*Brassica oleracea* var *italica*) of Mediterranean origin belonging to the plant order Papaverales Broccoli is grown for its thick branching flower stalks which terminate in clusters of loose green flower buds Cultural practices for broccoli are similar to those used for cabbage Popular varieties are Italian Green Sprouting and Waltham 29 Broccoli is slightly tolerant of acid soils and has high requirements for boron and molybdenum Terminal and axillary clusters are cut 80–140 days after planting California and Texas are important broccoli producing states The total annual farm value in the United States is $16 000 000 *See* CABBAGE PAPAVERALES VEGETABLE GROWING [H J C]

Brochantite

A mineral with the chemical composition $Cu_4(SO_4)(OH)_6$ Brochantite occurs in light to dark green prismatic or loosely coherent aggregates of needlelike monoclinic crystals or granular masses It is a secondary mineral found in the oxidized zone of copper deposits especially in arid regions Fracture is conchoidal to uneven and luster is vitreous Hardness is 3 5–4 on Mohs scale and specific gravity is 3 97 It fuses and is soluble in acids

The occurrence of brochantite indicates the presence of other copper minerals notably *malachite* and azurite but brochantite itself has no particular commercial value It is found in many parts of Europe Africa South America and Australia In the United States it is found in the Bisbee district Cochise County Arizona and in Colorado Utah Oregon New Mexico and California

[E C T C]

Brocken specter

An illusory magnification to gigantic proportions of an observer s shadow when it is projected on cloud surfaces particularly when the surfaces extend upward about mountain peaks The name Brocken specter is derived from the Brocken the highest peak of the Harz Mountains in Saxony where the phenomenon is sometimes seen Rings of colored light known as the Brocken bow or glory are to be seen surrounding the Brocken specter

The apparent magnification of the observer s shadow occurs when he overestimates the distance between himself and his shadow In Fig 1 the specter surrounded by its glory can be seen on the surface of the cloud between the shadows of two radio towers The cloud bank is a considerable distance beyond the trees which are about 50 yards away As the cloud surface approaches the observer the specter increases rapidly in size The radio towers are behind the observer and spacing of their shadows increases at a slower rate

In Fig 2 the cloud surface is at the site of the observer and the specter is seven times larger The apparent size of the specter is 30 ft in height when compared to the known height and spacing of the radio towers The camera could not glimpse as does the eye by means of peripheral vision the closer and apparently even larger specter shadow This latter shadow creates an occasional illusion of a nearby giant because the eye focuses at a distance on large objects such as trees which appear quite small when compared to the specter shadow glimpsed by peripheral vision *See* Meteorological Optics

[P A A]



Fig 1 A specter image surrounded by a semblance of its glory is visible between the shadows of two radio towers (P A Allee U S Weather Bureau)



Fig 2 View of proportionately huge (seven times that of Fig 1) specter image resulting from advance of the cloud surface to the observer s position Note well-developed rings of glory in rainbow hues on original color photograph (P A Allee U S Weather Bureau)

Bromate

A negative ion having the formula BrO_3 and derived from bromic acid $HBrO_3$

Bromic acid exists only in aqueous solution The solid bromates are stable and can be prepared by passing bromine into a warm solution of sodium carbonate

$$3Br_2 + 3Na_2CO_3 \rightarrow 5NaBr + NaBrO_3 + 3CO$$

Since bromine has the oxidation state of 5+ in bromates and these bromates are strong oxidizing agents these compounds are useful in analytical chemistry Commercially they are used in permanent wave preparations and in flour treatment *See* Bromine

[E E W]

Brome grass

A common name used to designate a number of grasses found in the North Temperate Zone that produce highly palatable and nutritious forage Of these smooth brome grass (*Bromus inermis*) is the most important It is a long lived perennial spreads by underground creeping stems and is fairly deep rooted and drought tolerant Top growth is 2–4 ft tall and is used for hay or pasture Regional strains are available for Canada and the northern two thirds of the United States Brome grass tolerates a wide range of soil conditions but responds well to higher levels of fertility Where the moisture supply is adequate smooth brome grass grows well in mixtures with alfalfa and red clover The seeds of brome grass are large



Smooth brome grass *Bromus inermis* (a) Entire plant (b) Inflorescence (c) Fruit

light and chaffy Successful planting of these seeds requires special seeders *See* GRASS CROPS [H B S]

Bromide

A compound which is derived from hydrobromic acid HBr and contains the bromine atom in the $1-$ oxidation state The chemistry of the bromine atom and its ability to form covalent and ionic bromides is very similar to that of chlorine *See* CHLORIDE

The properties of bromides are intermediate between those of chlorides and iodides The bromide ion is a better reducing agent and forms less stable complexes than chloride

The solubilities of bromides are very similar to those of *chlorides and* $PbBr_2$ *CuBr AgBr and* Hg_2Br_2 are the common insoluble salts The bromides are usually produced from bromine which, in turn is obtained from salt brines or sea water

Bromides are used in medicine as sedatives in treatment of nervous disorders Silver bromide is used in photographic films and paper

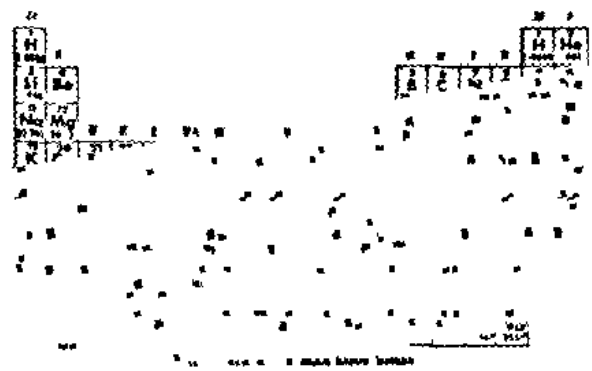
Bromide ion can be detected in aqueous solution by oxidizing it to the free element with chlorine When extracted into carbon tetrachloride it imparts an amber color to the solvent *See* BROMINE

COMPLEX COMPOUNDS IODIDE PHOTOGRAPHIC MATERIALS SEDATION [E E WR]

Bromine

Element number 35 bromine Br exists under ordinary conditions as a dark red low boiling high density liquid of intensely irritating odor It is the only nonmetallic element that is liquid at ordinary conditions of temperature and pressure Bromine is very reactive chemically and has properties intermediate between those of chlorine and iodine *The most stable valence states of bromine in its salts are* $1-$ *and* $5+$ *although* $1+$ *and* $3+$ *are* known Within wide limits of temperature and pressure molecules of the liquid and vapor are diatomic Br_2 with a formula weight of 159 83 The *atomic number is* 35 *and there are two stable isotopes* (Br^{79} and Br^{81}) that occur naturally in nearly equal proportion so that the atomic weight is 79 910 The discovery of bromine is generally credited to Jerome Balard in 1826 *See* HALOGEN ELEMENTS

Production and uses The U S Bureau of Mines reports that in 1957 sales of bromine and bromine compounds amounted to 225 386 000 lb Of this 9 180 000 lb was sold as elemental bromine The major part of the total bromine manufactured was converted to ethylene dibromide an ingredient of antiknock gasoline The use of ethylene dibromide with tetraethyllead in antiknock gasolines prevents lead deposits on the engine cylinders by forming volatile lead bromide which escapes from the engine with the exhaust gases The discovery of this phenomenon by Thomas Midgley and coworkers in 1921 made bromine a major chemical commodity



is important as ethylene dibromide is among the compounds of bromine there are many other important uses for products of this versatile commodity Of prime importance for many years has been the use of alkali bromides such as those of sodium and potassium in the photographic industry Bromides have long been of importance to the pharmaceutical industry both because of their sedative action and because their extreme reactivity makes them ideal as intermediates for more complex chemicals Bromates are used as mild oxidizing agents in hair waving preparations and in the baking of bread Methyl bromide dibromochloro-

propane and ethylene dibromide have found wide application in agriculture as fumigants

Other uses are many and varied Bromine and its compounds have found use in bleaching and disinfecting as high density substances for use in level gages flotation and hydraulic fluids in dyes in storage batteries in vaporizing fire extinguishers as a self extinguishing agent in various materials as refrigerants as solvents and in air conditioning Elemental bromine is used in the treatment of swimming pools Such versatility is emphasized by the fact that more than 100 compounds of bromine are available commercially

Bromine compounds have a number of properties that make them useful Compounds high in bromine content are nonflammable and often have the ability to impart self extinguishing characteristics to other materials when present in small amounts High specific gravity is a general characteristic that finds usefulness and some bromine compounds are among the most dense organic liquids known Acetylene tetrabromide has a specific gravity of 2 96 for instance Many of the compounds possess bacteriological and fungicidal activity and the ability of some such as aluminum bromide to act as catalysts has been utilized The ease of the addition of bromine to a molecule and its subsequent replacement by a more complex molecule makes bromine a useful tool in organic synthesis

Natural occurrence Bromine is widely distributed in nature but is present in relatively small proportions It is never found uncombined in nature and it occurs normally as an inorganic bromide Although sea water contains an average of only 65 parts per million (ppm) this represents 99% of all the recoverable bromine in the world Sea water contains 308 000 tons of bromine per cubic mile but more than 15 000 tons of sea water must be processed to obtain one ton of bromine In spite of this sea water is the major commercial source of bromine in the world today Underground brines and salt lakes are the other major sources of bromine in the United States and commercial pro

[illegible] mined as deep as 1 mile to obtain it Chlorine is 300 times more abundant in both brines and sea water This same ratio is maintained generally in the earth s crust which contains an average of 1 6 ppm bromine

Physical properties The solubility of bromine in water at 20°C is 3 41 g/100 g solution but its solubility is increased tremendously in the presence of its salts and in hydrobromic acid Thus in a solution of 359 g/liter of sodium bromide the solubility of bromine is 641 6 g/liter Bromine is completely miscible with 48% hydrobromic acid and with common solvents such as carbon disulfide carbon tetrachloride chloroform ether and glacial acetic acid The ability of this inorganic ele

Table 1 Physical properties of bromine

Melting point	−7 2°C
Boiling point at 760 mm Hg	58 78°C
Specific gravity at 20/4°C	3 1193
at 25/4°C	3 1023
Refractive index n_D^{25}	1 6472
Viscosity 20°C	0 99 centipoise
Surface tension 20°C	41 5 dynes cm
Specific heat, crystals −20 7°C	0 0899 cal g
liquid 0°C	0 107 cal g
vapor 83 228°C	0 0553 cal g
Heat of fusion at mp	16 14 cal g
Heat of vaporization at bp	44 8 cal g
Critical temperature	311°C
Expansion coefficient 20–30°C	0 0011 per °C
Compressibility factor 25°C, vapor	0 9977

ment to dissolve in organic solvents is of considerable importance in its reactions

Manufacture of bromine Commercial recovery of bromine from brines and from sea water involves the oxidation of the bromide ions in solution to free elemental bromine which is then vaporized from the solution either by air or by steam Although oxidation was accomplished at one time by electrolysis all present processes utilize chlorine according to the following reaction

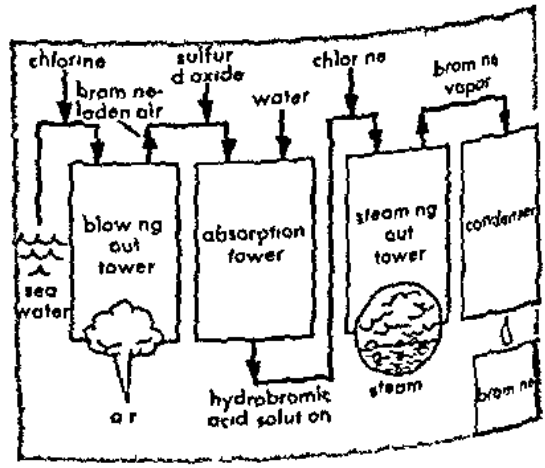
$$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$$

Vaporization by steam results in the recovery of free bromine directly Steam requirements are kept to a minimum by means of countercurrent heat exchangers

With sea water bromine must first be concentrated before the steaming out process becomes economically practical Consequently air is used to vaporize the bromine from chlorinated sea water and then SO is introduced into the dilute bromine laden air Subsequent absorption of the hydrogen bromide in a controlled amount of water produces a much more concentrated bromide solution

$$SO_2 + Br_2 + H_2O \rightarrow 2HBr + H_2SO_4$$

Elemental bromine must then be released again by chlorine and steamed from the solution The by



Extraction process for bromine

product hydrochloric and sulfuric acids are recycled to acidify the incoming sea water to the pH necessary for efficient chlorination.

The air blowing process can also be used when an alkali bromide is the desired end product. Absorption of the bromine from the air stream by sodium carbonate for instance produces sodium bromide and sodium bromate

$$3Br_2 + 3Na_2CO_3 \rightarrow 5NaBr + NaBrO_3 + 3CO_2$$

The sodium bromate may then be crystallized from solution or can be reduced with iron if NaBr is the only desired product. One process utilizes NaBr solution as the absorbing medium for bromine from bromine-laden air.

Inorganic bromides and bromates Major intermediates in the manufacture of bromides second only to bromine as a means of introducing bromine into a molecule are gaseous hydrogen bromide (HBr) and aqueous hydrobromic acid usually as the constant boiling solution containing approximately 48% HBr. The reaction of hydrogen and bromine at high temperature in the absence of air is the principal method of manufacture. HBr as the by product of an organic substitution reaction may also be utilized. Liquefied hydrogen bromide is available commercially in cylinders and various strengths of aqueous hydrobromic acid usually 48% are available in carboys drums or tank cars. The physical properties of anhydrous hydrogen bromide are listed in Table 2. With water at 760 mm Hg pressure the constant boiling solution contains 47.63% HBr and boils at 124.3°C.

Other valuable inorganic brominating agents include phosphorus tribromide bromine chloride aluminum bromide barium bromide thionyl bromide and sulfur bromide.

The alkali bromides can be manufactured by several processes. Thus ammonia bromine and an alkali hydroxide or carbonate will react according to the following type reaction

$$2NH_3 + 6NaOH + 3Br_2 \rightarrow 6NaBr + N_2 + 6H_2O$$

Also the reaction of HBr with an alkali hydroxide or carbonate gives the desired product

$$2HBr + Na_2CO_3 \rightarrow 2NaBr + CO_2 + H_2O$$

As shown previously absorption of bromine by alkali carbonates or hydroxides in the blowing out process of manufacture produces alkali bromide and alkali bromate in a 5:1 mole ratio. If bromate is the desired product it may be formed from the bromide electrolytically or by the oxidative action of chlorine by the following reaction

$$NaBr + 6NaOH + 3Cl_2 \rightarrow NaBrO_3 + 6NaCl + 3H_2O$$

Table 2 Physical properties of hydrogen bromide

Formula weight	80.924
Melting point	−86.8°C
Boiling point	−66.7°C
Specific heat liquid	0.176 cal/g
Specific heat vapor 27°C	0.085 cal/g
Heat of fusion at mp	71.1 cal/g
Heat of vaporization at 66.7°C	52.0 cal/g
Critical temperature	89.8°C

Ammonium bromide is most easily formed by the reaction of ammonia and bromine in water solution with the liberation of nitrogen. Aluminum bromide made by direct reaction of aluminum and bromine is a valuable catalyst in alkylation and isomerization reactions. It is preferable to aluminum chloride in some cases because it can be liquefied easily (mp 97.5°C) and it is more soluble and more reactive in organic liquids.

Organic bromides As numerous as are the inorganic bromides that have found industrial use the organic bromides have even wider application. Because of the ease of reaction of bromine with organic compounds and the ease of its subsequent removal or replacement organic bromides

of reactions. The ability of bromine to add into unusual places on organic molecules has added to its value as a research tool.

There are several reactions by which bromine and its bromides may be added to an organic molecule. Many of these reactions will give essentially 100% yield of the desired product. The ability of bromine to dissolve both in many common organic solvents and in inorganic bromide solutions permits easy control of the reactions.

The addition of bromine to a double or triple bond to saturate the molecule is usually very easily accomplished. It is done according to the following reaction

$$RC(H)=C(H)R + Br_2 \rightarrow RC(H)(Br)-C(H)(Br)R$$

One exception is perchloroethylene (1,1,2,2-tetrachloroethylene) which resists bromination and requires a catalyst to speed the reaction.

Substitution reactions of bromine on the ring in aromatic molecules take place readily with the aid of a catalyst such as iron iron bromide or aluminum bromide. Direct bromination of saturated aliphatic hydrocarbons requires higher temperatures with the result that a multitude of products is formed. In the presence of catalysts the substitution of bromine to the α position of aliphatic acids aldehydes and ketones takes place readily. Hydrogen bromide is a mole-for mole by product of substitution reactions

$$RCH_2CO_2H + Br_2 \rightarrow RCHBrCO_2H + HBr$$

Bromine compounds such as phosphorus tribromide N bromosuccinimide and 1 3-dibromo 5 5 dimethylhydantoin have value as brominating agents when bromine will not yield the desired product Thus the reaction of N bromosuccinimide with benzoyl peroxide catalyst and irradiation can successfully substitute bromine without disturbing the olefinic bonds in 1 5 hexadiene Phosphorus tribromide is a mild brominating agent that can be used when bromine itself acts too vigorously on a molecule

A commercially useful reaction for the replacement of hydroxyl groups on organic molecules utilizes sulfur bromide

$$S + 3Br_2 + 6ROH \rightarrow 6RBr + H_2SO_4 + 2H_2O$$

Alkyl bromides may also be prepared by the action of hydrogen bromide or hydrobromic acid on alcohols Sulfuric acid may be added to take up water and drive the reaction to completion

Another method for the manufacture of alkyl [illegible]

robromo compound as expected from Markownikoff's rule However if the reaction is carried out in the presence of free-radical type catalysts such as peroxides or in ultraviolet light the addition is reversed and the 1 3 compound formed

$$CH_2{=}CHCH_2Cl + HBr \rightarrow CH_3CHBrCH_2Cl$$

$$CH_2{=}CHCH_2Cl + HBr \xrightarrow[\text{catalyst}]{\text{Free rad cal}} CH_2BrCH_2CH_2Cl$$

This reverse reaction does not occur with hydrochloric acid (HCl) The reaction is of particular value in placing a reactive bromine on a terminal carbon of a compound for use as an intermediate Thus the 1 3 product above finds use in the production of cyclopropane an anesthetic *See* ADDITION REACTION

The preparation of alkyl bromides by replacement of chlorine with $AlBr_3$ has been used commercially particularly for the methane family However this preparation is more easily and economically accomplished by the action of hydrogen bromide in the presence of only catalytic amounts of aluminum bromide or aluminum chloride

$$CHCl_3 + 3HBr \xrightarrow{AlCl_3} CHBr_3 + 3HCl$$

Replacement of the hydrogen in such a molecule can be accomplished by high temperature vapor phase bromination

Both chlorine and bromine are ortho-para directing in their influence on aromatic molecules Thus the second bromine that will substitute in benzene will be found predominantly in the para position with some ortho [illegible]

Bromo [illegible]

comes [illegible]

compe [illegible]

to sto [illegible]

pound with aromatic compounds having saturated side chains heat light and the absence of metals such as iron favor side-chain substitution whereas lower temperatures darkness and iron favor ring brominations

The usefulness of bromine compounds as chemical intermediates is illustrated by their reactions with alkalis to form either the corresponding alcohols or olefins with ammonia to form amines and with phenols to form the corresponding ethers The carbon to carbon chain lengths of organic molecules may be increased by the action of alkyl bromides utilizing the Grignard or Friedel Crafts actions An interesting alkylating agent is bromotrichloromethane which adds to olefins by the following type reaction

$$CBrCl_3 + CH_2{=}CH_2 \rightarrow CCl_3CH_2CH_2Br$$

Many other methods for using bromine compounds as building blocks for more complex molecules are available

Bromine handling and safety Bromine is almost instantaneously injurious to the skin and it is difficult to remove quickly enough to prevent a painful burn that heals slowly Extreme precaution including protective clothing must be used when handling bromine Bromine vapor is extremely toxic but its odor gives good warning, it is difficult to remain in an area of sufficient concentration to be permanently damaging Bromine can be handled safely but the recommendations of the manufacturers should be respected

Bromine is available in 6½-lb bottles in 200-lb Monel drums, and in nickel and lead lined tank cars Wet bromine is corrosive to most metals except tantalum but dry bromine (containing 20 ppm or less water) can be handled at room temperatures with essentially no corrosion in Monel nickel and lead Iron steel and stainless steels are not satisfactory even for dry bromine Since dry bromine can absorb moisture rapidly from the air, care should be taken to prevent air from entering a metal container *See* BROMATE, BROMINE HALOGENATED HYDROCARBON HALOGENATION [A G]

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Bronchial disorders

Diseases of the bronchi comprise inflammatory processes of acute and chronic course so-called obstructive functional changes with reversible narrowing of the airways as in asthma and tumors *In most* of these diseases the airways are narrowed so that the air supply to the peripheral respiring air spaces is reduced *See* RESPIRATORY SYSTEM DISORDERS

Bronchitis Bronchitis is an inflammation of the mucous membranes of the bronchi caused by infection with various pathogenic agents Acute bronchitis is often a manifestation of the common cold but it can also have a more specific etiology as in influenza or whooping cough In chronic bronchi-

the inflammation is kept up by various bacteria The infection takes place through the airways, often descending from the upper respiratory tract, particularly from the trachea, and is known as tracheobronchitis

Acute bronchitis The mucous membranes of the larger bronchi become red and swollen from engorgement of the blood vessels and exudation of fluid into the tissue in acute bronchitis The surface is first covered by an excessive amount of clear viscous mucus, but when leukocytes accumulate in the mucous membrane and penetrate through the epithelium, the mucus becomes yellow green The swelling of the mucous membrane leads to cough, which functions to remove the abundant mucus A common cold bronchitis usually clears within 1 to 2 weeks

Chronic bronchitis In chronic bronchitis bacteria of various types become established either in the bronchial wall as in bronchiectasis, or in the upper respiratory tract The paranasal sinus in particular harbors bacteria which can continuously reinfect the bronchi over the course of many years This condition is often supported by a continuous irritation of the bronchi from smoking It can result in dilatation through destruction of the bronchial wall, or in scarring and narrowing of the bronchi

Bronchiectasis. A pathologic enlargement of the bronchi which may be diffuse or localized in occurrence characterizes bronchiectasis The infection



Fig 1 Bronchiectasis

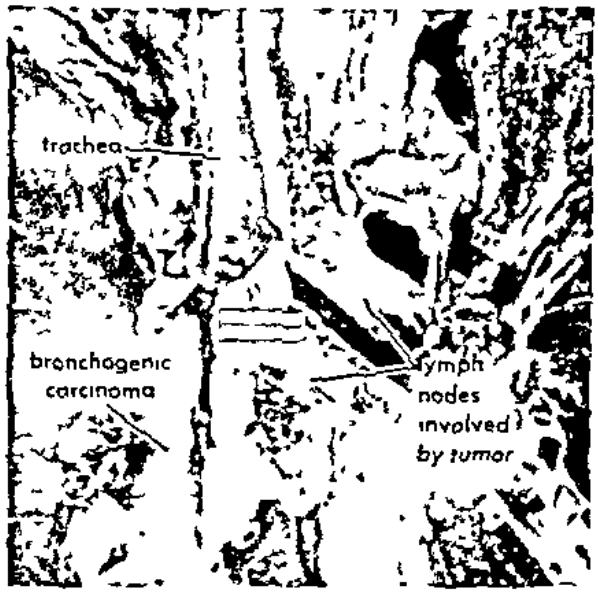


Fig 2 Bronchogenic carcinoma showing tumor in relation to other organs

persists in the partly destroyed wall It is usually associated with severe chronic bronchitis The chronically irritated mucous membrane produces abundant mucus which accumulates in the large

tis from healing More tissue is destroyed and a vicious cycle results The gradual involvement and destruction of adjacent pulmonary tissue causes loss of alveolar air spaces Bronchiectasis occurs in man and many animals It is very common in many strains of white laboratory rats

Bronchial asthma. This disease causes severe

muscles or spasm, swelling of the mucous membrane from edema, and production of a highly viscous sticky mucus It is typically accompanied by the presence of an unusual number of eosinophilic leukocytes in the blood, bronchial wall, and the

of acquired hypersensitivity, known as allergy, to proteins in various substances of the environment, particularly pollen or the hair of animals, or to some internal factors often bacterial toxins from a chronic infection of the respiratory system An emotional factor is frequently superimposed Al

known in cats and dogs Each attack causes severe shortness of breath, which results in incomplete, often very low, oxygen saturation of the arterial blood Since expiration is often more difficult than inspiration, gradual distention of the distal air spaces occurs which sometimes results in



Fig 3 (a) Adenocarcinoma of bronchus (b) Epidermoid carcinoma of bronchus (c) Bronchogenic anaplastic carcinoma

Carcinoma Bronchogenic carcinoma is a malignant tumor formation or cancer originating primarily in the lining cells or epithelium of the larger bronchi The rapidly growing tumor invades and

relatively little connective tissue with blood vessels Inadequate blood supply to the center of the tumor results frequently in central cell death and cavitation of the mass

Three types of bronchogenic carcinoma can be distinguished according to the type of cancer cells present adenocarcinoma which originates in the columnar lining of the mucus glands and their ducts simulating an atypical glandular structure, epidermoid carcinoma which often originates in areas of squamous epithelium in the bronchi and shows an epidermislike pattern and anaplastic carcinoma composed of small cells of indistinct type in an almost unorganized pattern

Incidence and etiology Bronchogenic carcinoma is a disease of civilized man it is rather rare in

Since 1950 it is estimated that it has caused approximately 24 000 deaths a year in the United States Of all cancer deaths in 1948 8 3% were caused by bronchogenic carcinoma compared with 1 1% in 1920 It is assumed that this increased incidence is at least in part due to an increase in cancer inducing substances carcinogens in man s surroundings Industry smoke exhaust gases of motor vehicles tar dust radioactive gases and dust and cigarette smoke are considered most important although little proof has been established In the cobalt and uranium mines of Schneeberg and Joachimstal in East Europe a bronchogenic carcinoma probably induced by radioactive dust develops in 50 80% of the miners Cigarette smoke is a weaker but much more important carcinogen Attempts to use it in producing lung cancer experimentally have remained practically unsuccessful Yet it can be shown statistically the tendency to develop an epidermoid or anaplastic bronchogenic carcinoma increases with the amount of tobacco smoked while the development of adenocarcinoma is not influenced It is interesting that in heavy smokers the normally columnar ciliated epithelium of the bronchi is transformed with extreme frequency to atypical squamous epithelium a process known as metaplasia Epidermoid and anaplastic carcinomas may originate in such areas *See* METAPLASIA

Sex and age Bronchogenic carcinoma has a higher incidence in males than in females the ratio being 9 1 Ninety five per cent of the bronchogenic carcinomas in males are epidermoid or anaplastic compared with 65% in females Bronchogenic carcinoma affects man at the age of 40–80 with a peak between 60 and 70 years

Course of the disease and symptoms The tumor first develops locally within the bronchial wall causing no symptoms except for some cough Narrowing of the airway finally with occlusion results in collapse of the peripheral lung portions called atelectasis, pneumonia can occur in this area If a larger portion of the lung becomes involved by the

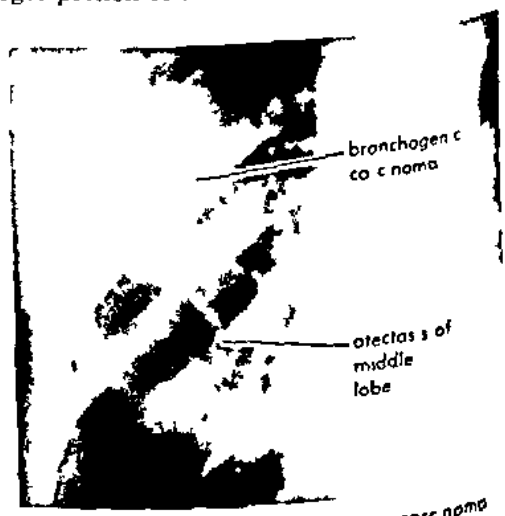


Fig 4 X ray showing bronchogenic carcinoma

growing tumor shortness of breath (dyspnea) oc curs *The destruction of blood vessels by the invad* ing tumor causes bleeding and becomes apparent in bloody sputum Extension of the tumor to the me diastinum involves the mediastinal organs such as the esophagus Distal extension to the pleura re sults in irritation and accumulation of fluid in the pleural cavity chest pain occurs in this late stage Spread of the tumor along the lymphatic vessels in volves the lymph nodes at the lung hilum and along the trachea up to the cervical nodes If tumor cells grow into the pulmonary veins metastases occur and they are transferred by the blood stream into various other organs as the brain or bone marrow where they grow independently and form new tu mors of the same type as the original cancer *See* NEOPLASIA

Diagnosis The early tumor can be seen as a rounded shadow on an x ray plate but it is later obscured by the associated atelectasis pneumonia or accumulation of pleural fluid (Fig 4) A tumor of the large bronchi can be visualized directly by bronchoscopy The examination of a piece of tissue removed at bronchoscopy or the demonstration of tumor cells in the sputum confirms the diagnosis Treatment consists of surgical removal of the in volved parts of the lung The chance of cure de pends on how early the cancer is removed [E WE]

Bronchiectasis

A chronic infection of the bronchi and bronchioles of the lungs characterized by tissue destruction suppuration and the ultimate formation of greatly dilated irregular airways

The disorder commonly develops as a sequela to infection or the obstruction of airways by mucus pus blood tumor cells and other long standing obstructive conditions Poor drainage abnormal d latation and the presence of noninfectious disor ders such as forms of asthma bronchitis and tu mors may contribute to the development of bron chiectasis *See* LUNG DISORDERS

Any age group may be affected but children and older people especially those with pulmonary dis ease are more liable to be affected Usually both the lower lung lobes are primarily involved but bronchiectasis can occur in other lung regions and as s ngle or *multiple lesions The most severe dam* age is found in the smaller bronchi and bronchio les They are dilated irregularly in either a saccu lar or a cylindrical manner and show destructive changes in their walls the lumens are filled with a heavy pus that may contain blood This exudate is coughed up in paroxysmal attacks Such attacks are typically accompanied by respiratory distress and constitutional symptoms

Other lung changes which may be associated with bronchiectasis are emphysema atelectasis lung abscesses pneumonia and the occasional for mation of emboli capable of lodging in a distant organ such as the brain

The course and severity of bronchiectasis vary considerably depending upon the conditions of each case and related disease processes [E G ST]

Bronchus

One of the main branches of the trachea or subdi visions of the main branches whose walls contain cartilage The trachea branches into a right and left main stem bronchus at the level of the third rib The left main bronchus is smaller in diameter longer and less vertical than the right Each di vides into smaller bronchi which pass to the major lung lobes three on the right and two on the left These lobar bronchi in turn branch into smaller bronchi which supply the lobules of each lobe and then successively smaller regions When the diame ter of the airways narrows to less than 1 mm they have lost their cartilage and are called bronchioles The bronchioles pass to the clusters of air sacs or alveoli which constitute the functional units of the lungs

The histologic structures of the trachea and the larger bronchi are practically the same Each is lined with ciliated columnar epithelium and is gen erously supplied with both serous and mucinous glands There is a thick muscular coat which con tains incomplete rings of cartilage As the smaller bronchi are reached the cartilage is less and less well developed and may be present only as scat tered plaques Numerous blood vessels and nerves supply the bronchi and there is an extensive lym phatic system which follows the course of the larger tubes

As would be expected with the constant move ment of lungs all these airways have a consider able amount of elastic tissue which is largely re sponsible for the marked resilience of the normal lung *See* RESPIRATORY SYSTEM [E G ST]

Bronze

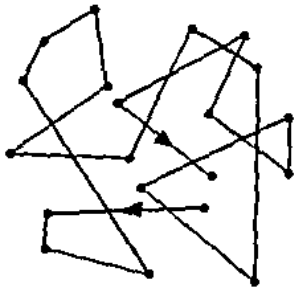
An alloy of copper and tin Lead zinc silver and other metals are often added for special purpose bronze Tin bronze including statuary bronze con tains 2 20% tin bell metal up to 25% and spec ulum metal as much as 33%

Phosphor bronze is tin bronze hardened and strengthened with traces of phosphorus Lead bronze may contain up to 30% lead manganese bronze contains 0 5 5% manganese plus other met als but often no tin and aluminum bronze also

the few copper alloys that can be strengthened by heat treatment It becomes almost three times as strong as structural steel *See* ALLOY BELL COP PER TIN [G CO]

Brownian movement

The irregular motion of a body arising from the thermal motion of the molecules of the material in which the body is immersed Such a body will of course suffer many collisions with the molecules which will impart energy and momentum to it Be cause however there will be fluctuations in the *magnitude and direction of the average momentum*



Random Brownian movement of a particle

transferred the motion of the body will appear irregular and erratic as shown in the diagram

In principle this motion exists for any foreign body suspended in gases liquids or solids To observe it one needs first of all a macroscopically visible body however the mass of the body cannot be too large If its mass is M one can estimate the root mean square velocity v by the equipartition law

$$\tfrac{1}{2}M\overline{v^2} = \tfrac{3}{2}kT \qquad \sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{M}} \tag{1}$$

Here k is the Boltzmann constant and T is the absolute temperature (*see* KINETIC THEORY OF MATTER) Hence for a large mass the velocity becomes small For example a 0 01 g mass has at 300°K a root mean square velocity of $3\,5 \times 10^{-6}$ cm sec

Mirror in a gas A simple observable example of Brownian motion is the motion of a mirror in a gas If a mirror of moment of inertia I is suspended by a fine fiber this mirror will execute a simple harmonic motion of natural frequency ω_0 Its mechanical equation of motion is

$$\frac{d^2\theta}{dt^2} + \omega_0^2\theta = 0 \tag{2}$$

where θ is the angular displacement and $\omega = d\theta/dt$ the angular velocity (*see* HARMONIC MOTION) If this mirror is placed in the gas the unequal forces on the two sides of it which are due to the fluctuations in the momentum transferred by the molecules will cause fluctuations around the harmonic oscillations After a time one will have equipartition of energy For the rotational kinetic energy one has

$$\tfrac{1}{2}I\overline{\omega^2} = \tfrac{1}{2}kT \tag{3a}$$

For the rotational potential energy one has

$$\tfrac{1}{2}M\omega_0^2\overline{\theta^2} = \tfrac{1}{2}kT \tag{3b}$$

By careful measurement relations such as (3*a*) and (3*b*) may be checked Brownian motion also yields a limit for the accuracy which may be obtained in a given experiment

Langevin equation If a small particle is suspended in a liquid its displacement x in the course of time can be observed The displacement will of course be erratic but one can still calculate the average displacements or root mean square displacements at any time t It is possible to compare these experimental results with theoretical calculations If a small body moves through a liquid it will experience the usual viscous drag $-\beta Mv$, where M is the mass v is the velocity and β is a numerical coefficient depending on the viscosity For a sphere of radius R $M\beta$ has the value given by Stokes law $M\beta = 6\pi R\eta$ where η is the coefficient of viscosity (*see* VISCOSITY OF GASES VISCOSITY OF LIQUIDS) In addition a fluctuating force $MA(t)$ varying rapidly in the course of time but of average value zero acts on the particle One may therefore write an equation of motion

$$\frac{dv}{dt} = -\beta v + A(t) \tag{4}$$

If one now multiplies Eq (4) the Langevin equation by x averages over time and applies the equipartition law one obtains for a Stokes case

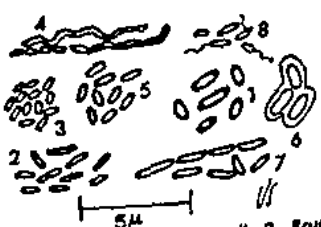
$$\overline{x^2} = \frac{kTt}{3\pi R\eta} \tag{5}$$

This result was originally derived by Albert Einstein it expresses the root mean square displacement explicitly in terms of observable parameters Equation (5) has been verified with an accuracy of about 0 5% *See* COLLOID ULTRAMICROSCOPE [M DI

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Brucellaceae

A family of aerobic gram negative bacteria of the order Eubacteriales causing disease in animals and man Mucous membranes the respiratory tract the liver and the spleen are usual sites of infection Some species are pathogens causing plague tularemia and brucellosis in man cholera in chickens and glanders in horses These bacteria commonly are intracellular thereby being more



1 – *Pasteurella* 2 – *Bordetella* 3 – *Brucella*
4 – *Haemophilus* 5 – *Actinobacillus*
6 – *Calymmatobacterium* 7 – *Moraxella*
8 – *Noguchia*

Representative genera of the Brucellaceae (V B O Skerman)

Key to differentiation of family Brucellaceae

Nonmotile types	Growth on nutrient agar	Requires or stimulated by	Hemolysis	Acid in glucose broth	Acid in lactose broth	Fermentation of	Other biochemical tests
Pasteurella[a]	+	Hemin nicotinic acid cystine	*P haemolytica* + Others −	+	−	Sucrose xylose rhamnose	Indole gelatin nitrate
Brucella[b]	+	Hemin nicotinic acid thiamin CO_2	−	−	−	Inositol maltose trehalose	Urease
Bordetella	Pertussis − parapertussis +	Blood	+	−	−	−	Citrate litmus milk urease
Haemophilus[c]	−	X V	+ −[d]	+	−	Mannitol xylose maltose	Indole litmus milk
Actinobacillus	+	Serum blood CO_2	−	+	+ −[d]	−	Nitrate litmus milk
Calymmatobacterium	−	Chick embryo	−	−	−	−	−
Moraxella	−	Serum ascitic fluid	+ −[d]	*M lacunata* + Others −	−	−	Gelatin litmus milk

Motile types	Optimal temperature °C	Growth on nutrient agar	Hemolysis	Carbohydrates attacked	Cross agglutination with pertussis
Bordetella	37	+	+	−	+
Noguchia	30	−	−	±[e]	−
P pseudotuberculosis	22	+	−	+	−

[a] Can be differentiated by phage typing further differentiation based on antigens A D
[b] Can be differentiated by dye sensitivity test
[c] Can be differentiated by satellite phenomenon further differentiation based on antigens a f
[d] + − indicates some species + some −
[e] ± indicates variation among strains

resistant to treatment with drugs Individual microorganisms are small (0 1–0 5 by 0 3–1 5 microns) ovoid bacilli All genera exhibit pleomorphism (variable shape and size) in artificial culture Alterations in medium and aging of cultures favor variant forms Enriched media usually are required for primary isolation (*see* CULTURE MEDIA COMPONENTS OF)

Growth is best between 30 and 37°C Colonies formed on solid media are small being 0 5–4 0 mm in diameter and they develop slowly requiring 1 5 days Mucoid to smooth to rough dissociation patterns occur in colonial morphology L forms and protoplasts are found in some genera

Pasteurella This genus is named for Louis Pasteur and distinguished by its tendency for bipolar staining growth on nutrient agar and fermentation of carbohydrates Nine species are recognized including *P pestis* the cause of plague in man and rodents and *P tularense* the agent of tularemia

P pestis primarily infects rats and is transmitted by fleas Man is a highly susceptible accidental host Blood agar is recommended for primary isolation The organism is encapsulated in tissues and freshly isolated cultures Of the at least 10 antigens the capsular antigen which inhibits phagocytosis and a somatic antigen or endotoxin are significant in immunity and in pathogenesis *P pestis* is sensitive to sulfonamides streptomycin chloramphenicol and the tetracyclines *See* PLAGUE

P tularensis is an extremely virulent organism transmitted among wild animals by flies fleas and ticks Cystine is required for growth The chick embryo and blood glucose cystine medium are recommended for isolation All strains are of one general antigenic type but contain several protein and polysaccharide antigens *See* TULAREMIA

The hemorrhagic septicemia group contains three species of *Pasteurella* causing infection in animals *P multocida* causes chicken cholera *P pseudotuberculosis* causes pseudotuberculosis in rodents It shares somatic antigens with *P pestis* differentiation is principally on the basis of growth rate and motility at 22°C *P haemolytica* causes pneumonia in sheep and cattle and is characterized by hemolysis of blood agar *See* HEMORRHAGIC SEPTICEMIA PSEUDOTUBERCULOSIS

Brucella These species primarily cause disease of domestic animals Man contracts undulant fever (brucellosis) accidentally by association with infected animals or animal products Three species are recognized on the basis of biochemical reactions *B abortus* is responsible for contagious abortion or Bang s disease in cattle *B melitensis* usually infects goats and *B suis* swine Primary isolation of *Brucella* is favored by media enriched

with thiamin nicotinamide and hemin An atmosphere of 10% CO_2 is required for growth of some strains of *B abortus* *B melitensis* differs slightly in antigenic structure from both *B abortus* and *B suis* which are antigenically identical

Bordetella The microorganisms causing whooping cough and clinically related diseases are included in this genus All species are hemolytic and none ferment carbohydrates

B pertussis typically causes whooping cough in humans It does not grow on routine media Bordet Gengou medium containing at least 15% blood is recommended for isolation Fresh isolates are encapsulated antigenically homogeneous and contain thermolabile dermonecrotic toxin Only smooth (phase I) organisms are virulent nutritionally exacting and effective immunizing agents. *See* WHOOPING COUGH

B parapertussis resembles *B pertussis* microscopically and antigenically and causes a disease similar to whooping cough However it grows as large colonies on routine media and it forms a brown pigment on blood agar

B bronchiseptica reportedly causes bronchopneumonia in animals It is antigenically related to other *Bordetella* and to *Brucella* Differentiation is on the basis of motility and urease production

Haemophilus This genus of strict parasites requires either X (hemin) or V (phosphopyridine nucleotide) factors and sometimes both for growth It may be pathogenic Fifteen species are recognized

H influenzae requires both X and V There are six serologic types (a f) based on capsular antigens both capsulated which is usually type b and noncapsulated strains cause disease in man

H parainfluenzae requires V It is found in the upper respiratory tract of man but is usually not pathogenic

H ducreyi grows best on media containing 20–30% blood under decreased oxygen tension and

Actinobacillus These species grow on simple media but are stimulated by serum blood and an increased CO_2 tension The colonies are often mucoid or stringy Acid without gas is formed from

Clusters of bacilli in tissue resemble sulfur granules

Calymmatobacterium This genus causes granuloma inguinale in man Growth occurs best in the chick embryo or in media containing embryonic yolk However the organism may be adapted to meat infusion media It is encapsulated in place and is antigenically related to the genus *Klebsiella* See ENTEROBACTERIACEAE GRANULOMA INGUINALE KLEBSIELLA PNEUMONIAE

Moraxella These species parasites of warm blooded animals are associated with eye disease Growth is favored by serum or ascitic fluid The organisms are actively proteolytic and usually do not produce acid in carbohydrate media *M lacunata* and *M liquefaciens* cause conjunctivitis in man, *M bovis* is found in acute cases of ophthalmia of cattle

Noguchia These are encapsulated motile bacteria which cause conjunctivitis in man monkeys and rabbits Three species are recognized *N granulosis*, *N simiae* and *N cuniculi* See BACTERIA TAXONOMY OF EUBACTERIALES (E L N)

Brucellosis

An infectious disease of animals and man caused by bacteria of the genus *Brucella* The organisms are *Br melitensis*, found in sheep and goats, *Br abortus* in cattle and *Br suis* in swine Man becomes infected through direct contact with infected animals or by ingesting their unpasteurized milk The principal animal reservoirs of the disease are cattle swine goats and sheep Brucellosis occurs throughout the world and is the most important of the nearly 100 diseases of animals transmissible to man

The brucellae are small nonmotile, nonsporing gram negative coccobacilli *Br melitensis* and *Br suis* will grow aerobically in trypticase soy broth but *Br abortus* requires 10% carbon dioxide Differentiation of the three species is made by biochemical reactions growth requirements, and serological tests

Disease in animals The brucellae localize in the reproductive organs and mammary glands of animals This makes the disease of serious economic concern to livestock producers and dairymen because it causes abortions and reduces the production of milk The disease in cattle is known as Bang's disease, or contagious abortion

Disease in humans Brucellosis in man also known as undulant fever or Malta fever is primarily an occupational disease in which infection through the skin is acquired by contact with the tissues of freshly killed animals or with the contaminated environment of the animals The disease is also contracted by drinking unpasteurized milk and by eating fresh cheese prepared from unpasteurized milk

The acute illness is characterized by chills fever sweats, and weakness Chronic disease results in weakness and mental depression The usual course of the disease is less than 3 months but antibiotic therapy, including a combination of chlortetracycline dihydrostreptomycin and sulfadiazine reduces the length of the illness It may also prevent both recurrence and complications such as osteomyelitis orchitis subacute endocarditis and diseases of the kidney and liver

Diagnosis In animals the diagnosis is made by detecting brucella agglutinins in the milk (ring test or ring test) or in the blood The diagnosis in man is established by the presence of brucella agglutinins in the blood and by isolating brucellae

from blood cultures A standardized brucella an tigen is used in tests for brucella agglutinins The brucella skin test is of doubtful diagnostic value

Prevention Human brucellosis can be elimi nated only by eradicating the disease in animals The disease is controlled in cattle by el minating infected animals Successful vaccination of cattle against the disease has been achieved with a live brucella culture having stable attenuated viru lence No effective vaccine is generally available for swine goats and sheep

The incidence of human brucellosis can be re duced by using only pasteurized animal milk for human consumption Prophylactic vaccines for human use are still in the experimental stage *See* BACTERIOLOGY MEDICAL BRUCELLACEAE EPIDE MIOLOGY [W W SP]

Brucite

A mineral having composition $Mg(OH)_2$ and crystallizing in the hexagonal system Brucite crystals are usually tabular flattened on the basal pina coid There is perfect cleavage parallel to this same direction yielding flexible but nonelastic fo lia The mineral is sectile with hardness of 2 5 (Mohs scale) and specific gravity of 2 39 The lus ter is pearly on the base elsewhere it is vitreous The color is white gray or light green Brucite is associated with other magnesium minerals such as magnesite dolomite and serpentine and has been formed by the alteration of magnesium silicates Brucite is used as a raw material in the manufac ture of magnesia refractories *See* DOLOMITE MAG-NESITE SERPENTINE [C S HU]

Brush discharge

A particular form of corona discharge character ized by strongly ionized streamers It generally occurs at a field slightly less than that required for complete breakdown

The conditions for a brush discharge are as fol lows the pressure should be about atmospheric one or both of the electrodes should have a radius of curvature small compared to the gap separation and the gap itself should be large at least of the order of a few centimeters The ionized streamers take on a treelike form The light originates from recombination and radiative transitions from ex c ted states *See* BREAKDOWN POTENTIAL CORONA DISCHARGE [C H MI]

Brussels sprouts

A cool season biennial crucifer (*Brassica oleracea var gemmifera*) which is of northern European origin and belongs to the plant order Papav erales The plant is grown for its small headlike buds formed in the axils of the leaves along the plant stem These buds are eaten as a cooked vege table Cultural practices are similar to those used for cabl age however monthly mean temperatures below 70°F are necessary for firm sprouts Brus-sels sprouts are moderately tolerant of acid soils and have a high requirement for boron Popular varieties are Half Dwarf and Catskill Harvesting



Brussels sprouts *Brassica oleracea var gemmifera*

begins when the lower sprouts are firm and 1 2 in in diameter usually 3 months after planting California and New York are important producing states The total annual farm value of brussels sprouts in the United States is $5 000 000 *See* CABBAGE PAPAVERALES VEGETABLE GROWING [H J C]

Bryophyta

A relatively small phylum of the plant kingdom in cluding the mosses (Musci) the liverworts (He paticae) and the hornworts or horned liverworts (Anthrocerotae) These plants are found growing on soil rocks and upon other plants throughout the world wherever there is sufficient moisture As individuals these plants are rather inconspicuous but when closely associated in patches or beds they present a striking appearance In the tropics many of them live as epiphytes and in the cold tun dra regions vast acreages may be covered by a sin gle species

Structure Although they lack the true roots stems and leaves characteristic of the higher vas cular plants many bryophytes have structures which superficially resemble these organs *See* LEAF (BOTANY) ROOT (BOTANY) STEM (BOT ANY) Rootlike structures known as rhizoids func tion in anchorage and absorption Since the stem like and leaflike structures contain chlorophyll and manufacture food the plants are independently self sufficient (see CHLOROPHYLL PHOTOSYNTHE SIS) In structure these are the simplest land plants Being without specialized conducting and supporting tissues (xylem and phloem) they have remained small (*see* PHLOEM XYLEM)

Alternation of generations The life cycle of bry ophytes consists of a regular alternation of gener ations in which the gametophyte or gamete pro-ducing generation alternates with the sporophyte or spore producing generation The gametophyte though small is green and independent (self sus taining) The sporophyte is always attached to the gametophyte and is never entirely independent al though in a few species the sporophyte contains green plastids (chloroplasts) and can manufacture a limited amount of food The female reproductive organ of the gametophyte known as an archego-nium is a flask shaped multicellular structure



(a) A moss plant *Polytrichum juniperinum* (General Biological Supply House) (b) Male and female plants of a liverwort, *Marchantia* (after W. Russell) (c) A hornwort, *Anthoceros* (Carolina Biological Supply Co.)

which when mature contains a single egg. The male sex organ (called an antheridium) also is multicellular and it produces a large number of motile flagellated gametes (sperm). Water must be present as a medium through which the sperms can swim. The development of the fertilized egg (zygote) results in a sporophyte which in most species consists of an absorbing organ or foot imbedded in the gametophytic tissues and a stalk of varying length terminated by a sporangium or spore capsule. In the sporangium meiosis occurs producing the haploid spores which upon germination develop into green gametophytic plants (*see* MEIOSIS). In all cases the two generations are entirely different in both appearance and structure. Neither generation produces true flowers, fruits and seeds. Bryophytes are not considered to be ancestral to any other group. *See* ANTHOCEROTAE, HEPATICAE, MUSCI, TRACHEOPHYTA.

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Bryozoa

A phylum of colonial, aquatic, sessile either free living or commensal invertebrates called the moss animals, sea mats, corallines, or zoophytes. These animals are considered to form the phylum Ectoprocta by some authorities. They number about 11,000 species. Few are found in fresh water. The remainder are marine or fossil. They are known from every sea and latitude, from polar to tropic regions, from shore level down to more than 5700 meters, and from the Paleozoic to the present.

Economic importance. Bryozoa have little importance except as fouling organisms or stratigraphically useful forms. Phylactolaemata on occasion grow in water pipes, reducing pipe diameter and seriously interfering with water supply systems. *Pectinatella gelatinosa* and *Lophopodella carteri* when torn or damaged are toxic to fish. The marine genera *Electra* and *Watersipora* are common fouling organisms, which interfere with the settling of oyster spat by occupying the substratum.

Colony size. Colonies range from minute microscopic patches of few individuals as in *Hippothoa*, to huge meter long masses containing vast numbers of zooids, in *Pectinatella*. Colonies may be thin, unilaminate crusts (*Membranipora*) or bulky multilayered calcareous nodules (*Smittina*). Although colonies may be large, individual zooids are usually microscopic. Their average length is from 0.25–2 mm depending upon the species. Some stony species require thin sectioning for microscopic study.

Growth habit and color. *Pectinatella* produces soft slimy, colorless, gelatinous masses. Numerous chitinized marine and fresh water species like *Bugula* and *Plumatella*, produce yellowish to brown, firm dendritic growths. Still other marine species produce siliceous or calcareous bushlike, lacy or encrusting colonies of white or iridescent yellow, orange, rose, or violet color. Bryozoa attach to various substrates such as rocks, algae and aquatic plants and to shells of *Limulus*, turtles, mollusks, worm tubes, ascidians and other submerged objects.

Taxonomic status. Bryozoa are a group whose taxonomic status is still unsettled because of the paucity of knowledge about their embryology, hi



Hyalinella punctata, an entire colony

cycle, morphology, histology, behavior, range of variation, polymorphism, and effect of the environment on phenotype or genotype. Most of the work on the group is based on a study of the colony growth habit and external skeleton of either fossil or preserved specimens, relatively little is based on living organisms. As a result the classification is sometimes quite artificial, particularly at the family level. Several current controversies cannot be resolved until more experimental and developmental data are forthcoming. These still unsettled controversies are the Bryozoa-Polyzoa problem and the Ectoprocta-Entoprocta problem.

Bryozoa-Polyzoa problem. J. Thompson, in the 1830s used the term Polyzoae for little "animals" occurring in certain zoophytes, unaware that these animals were really only the intestinal tract or polypide, of the zoophytes. C. Ehrenberg, about 1831, more precisely distinguished the groups Anthozoa and Bryozoa from the zoophytes. Since then most British workers have continued to use the term Polyzoa while those of the European continent and elsewhere use Bryozoa for the same animals.

Ectoprocta-Entoprocta problem. Opinion among taxonomists today differs as to whether Ectoprocta and Entoprocta, the Bryozoan classes erected by H. Nitsche in 1869, should be considered bryozoan subclasses, classes, subphyla, or two independent phyla. The following classification, condensed from R. Bassler, 1953, seems most acceptable to bryozoologists.

Phylum Bryozoa
- Subphylum Entoprocta
- Subphylum Ectoprocta
  - Class Gymnolaemata
    - Order Ctenostomata
    - Order Cyclostomata
    - Order Trepostomata
    - Order Cryptostomata
    - Order Cheilostomata
      - Suborder Anasca
      - Suborder Ascophora
  - Class Phylactolaemata

Ectoprocta and Entoprocta are alike in having a tentacled lophophore about the mouth, a U- or V-shaped gut which is partially ciliated internally, and a ganglion that is placed between mouth and anus on the side which normally is uppermost.

Ectoprocta and Entoprocta differ from each other in the location of the anus with respect to the circlet of ciliated tentacles. In Entoprocta the anus is inside the tentacular circlet, protonephridia are present, and the body cavity is considerably reduced or filled with parenchyma. In Ectoprocta the anus opens outside the tentacular circlet, protonephridia are absent, and the body cavity is more extensive although parenchyma may occur (*see* ENTOPROCTA). The remainder of this account is concerned with Ectoprocta.

Morphology. In the Phylactolaemata and some marine species the body wall, also called the cystid or coenoecium, has two layers, an outer ectocyst and an inner endocyst. The ectocyst may be soft or hard, gelatinous or membranous and chitinous or encrusted with debris. The endocyst is a soft epithelial layer with underlying muscular and other tissues. Calcareous marine species have a more complex body wall because of the secretion of

one or more calcareous layers which form the exoskeleton or zooecium which houses each zooid The frontal surface of the zooecium is often elaborately decorated or patterned

The cystid encloses the body cavity or coelom in which the polypide is suspended The polypide consists of digestive tract tentacles introvert (tentacular sheath) ganglion and associated musculature

The tentacled lophophore is at the free extremity of the tentacular sheath When disturbed it can be withdrawn into the coelom by contraction of long retractor muscles The introvert is pulled in with it to form a columnar tube that encloses the tentacles

The gut attaches to the cystid at both the anal and oral ends In addition some species have one or two funiculi that attach other parts of the gut to the cystid

Polypides may degenerate into rounded dark *lumps the brown bodies* from which new polypides *can regenerate* The same zooecium can thus house

hibit a variety of related processes as polyembryony hermaphroditism protandry dioecismoneism polymorphism and regeneration from brown bodies or the body wall In Phylactolaemata the gut *anchoring funiculus* serves also as *germinal* tissue producing sperms and statoblasts (*see* STATOBLASTS) In other groups male *gonads may occur on the body wall There are also ovaries* on the body wall but they are more *distally located Fertilization* is internal in *most forms Embryos* may be extruded through a special *opening into brood* chambers the zooecia or ovicells *if such are present* where they *continue their development* into free swimming *cyphonautes* or *modified trochophore* larvae *A piriform organ of obscure function* occurs in some larvae

The larvae upon release from the ovicells *swim* about for a few *hours metamorphose and then* attach to the substratum *producing* the first individual the *ancestrula of a colony* The ancestr

mains attached at *some point to the substratum* the extent and mode of *attachment* varying with the species Some colonies *are attached only at their* origin others along their entire extent

Fresh water species *have additional* means of propagation in the *formation of hibernacula* or statoblasts These crack *open like bivalves* when conditions for germination are propitious

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zooids are the *common nutritive* zooids with complete polypides *Heterozooids* are the avicularia or vibracula which *are chitinous* or calcareous chambers containing *either vestigial polypides* or no polypides and having *strong muscles for movement* of their opercula the avicularial mandible or vibracular seta *Heterozooid* function is unknown but thought to be *defensive* The main difference between an avicularium and a vibraculum is that the avicularial mandible is considerably shorter and broader than the vibracular *seta* which sometimes becomes a seta of great length

Kenozooecia are stolons thizoids radicles or segments whose function is to connect anchor or support colonies or individuals *Kenozooecia* lack a polypide and may be without musculature operculum or aperture

Gonozooids may be either indiscernible or highly distinctive Their function is reproductive or if ovicells are present, they are incubatory *Autozooids of some species* serve both as nutritive and reproductive individuals Dwarf zooecia of reproductive or unknown function occur in some species

Variations in size location number and decoration of polymorphs are important taxonomic features (*see* ANIMAL KINGDOM, see also articles on the various orders (M.P.R.A.)

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Bryozoa fossils

Extinct forms of the phylum Bryozoa *whose geological history ranges* from Ordovician to Recent Fossil Bryozoa are one of the principal groups of rock forming organisms Representatives of the orders that secreted calcareous skeletons (Cyclostomata Trepostomata Cryptostomata and Cheilostomata) commonly are abundant in rocks formed in marine environments that favored the growth of sedentary benthonic animals Indications of the Ctenostomata which have a membranous or horny outer covering are less common but occur as far back as the Ordovician A doubtful example of fresh water Phylactolaemata is recorded from the Cretaceous and objects interpreted to be statoblasts (hard covered reproductive bodies) produced by this class occur in Quaternary rock The fresh water Entoprocta are unknown as fossils Most paleontologists consider fossil bryozoans to be indicative of normal marine environments However certain living forms tolerate brackish water and at least some of the undiversified or impoverished bryozoan assemblages in the fossil record may well point to conditions of reduced salinity (*See* BRYOZOA, CHEILOSTOMATA, CRYPTOSTOMATA, CTENOSTOMATA, CYCLOSTOMATA (BRYOZOA) ENTOPROCTA PHYLACTOLAEMATA, TREPOSTOMATA)

Bryozoan bearing rocks Fossil Bryozoa are most abundant in impure calcareous rocks *such as* thin bedded limestones alternating with shales calcareous shale and siltstone, and shell marl They are uncommon in quartzose clastic rocks dolomites and fissile black shales Bryozoan *detritus* is abundant in some limestones that originated from calcareous sand and is found even in quartz sandstones Bryozoans occur in but are not significant contributors to *Recent* coral reefs Similar facies in

the geologic past seem to have been relatively unfavorable for Bryozoa. However, they contributed extensively to organic accumulations interpreted to be ancient reefs, and they were noteworthy builders of biostromes. *See* BIOSTROME.

Paleoecology. Associated fossils are mainly sedentary benthonic organisms—articulate brachiopods, solitary corals, and echinoderms in Paleozoic rocks; mollusks in post-Paleozoic faunas. The nature of the enclosing rocks and the associated faunas suggests that bryozoans flourished best on stable bottoms in the neritic zone. Relatively shallow but not violently agitated waters would have provided the most favorable environments for many fossil assemblages. The Cheilostomata with their hydrostatic apparatus presumably had a greater bathymetric range than the other orders. Concentrations of massive and incrusting colonies suggest fairly turbulent conditions. Some jointed colonies and delicate tubular and lamellar incrustations were probably attached to algae that lived in very shallow water. Most colonies were attached throughout life to objects on the sea floor or, less commonly, to other animals or plants capable of moving or being moved. A few genera developed free colonies adapted to live on muddy or unstable sandy bottoms or in highly agitated water.

Methods and techniques. Study of bryozoans requires the use of a microscope. Although many colonies attained considerable size, the compartments occupied by individual animals rarely are as much as half a millimeter in diameter and generally are much smaller. Identification depends largely on features that cannot be seen by the unaided eye. Magnifications ranging from ×20 to ×100 or more are needed to detect critical structures. Thin sections are a prime necessity in the study of several orders. The techniques and methods used for investigation of the phylum have led some workers to include bryozoans in the field of micropaleontology even though colonies may attain dimensions of more than 1 ft and make conspicuous fossils. *See* MICROPALEONTOLOGY.

Much bryozoan material occurs in a fragmentary state. Fragile colonies were susceptible to breakage before they came to rest in sediments. Even sturdy colonies buried in growth position generally disintegrate when the enclosing rock weathers. Fragments if large enough for the preparation of necessary thin sections and for the measurement of characters that distinguish species can be identified and constitute the material used in much basic research.

At present paleontologic work on bryozoans is done by a relatively few specialists. Most paleontologists tend to neglect this group, though a number of bryozoans with distinctive growth forms are widely used as index fossils. Bryozoans have great potential application in stratigraphic work and deserve more attention. *See* INDEX FOSSIL.

Morphology and classification. Living bryozoans are classified mainly on the basis of larval relationships and features connected with the reproductive function. In the Cheilostomata the nature of the hydrostatic apparatus is of primary importance. Less significance is attached to the composition of the skeleton, whether chitinous or calcareous, than is attributed to the living organism. Fossil bryozoans must of necessity be interpreted on hard parts or other traces preserved in the rocks. Forms having skeletal deposits identical with those of living species present no great taxonomic problem. In general, the classification of fossil representatives of the dominant living orders has a much sounder basis than does the classification of extinct groups. In dealing with the latter, paleontologists have attempted to apply general concepts developed through study of living bryozoans, but considerable reliance is still placed on characters that are known to be of little significance in living forms. Consequently, the classification of the exclusively Paleozoic groups remains artificial and unsatisfactory.

Bryozoan colonies called zoaria vary greatly in size and shape. Incrusting lamellar fenestrate and small dendroid zoaria are found in all orders that secrete calcium carbonate hard parts. Massive and large branching colonies developed in the orders (Trepostomata and Cyclostomata) that have long tubular zooecia (individual compartments occupied by the minute living animals). Ordinarily zoarial form is the only character that can be determined without use of a lens or microscope. The type of zoarium is relatively constant in most species, some genera, and a few families. However, the form of the colony reflects environmental conditions rather than fundamental relationships and hence cannot be relied on.

Fossil Cheilostomata possess many skeletal features that can be interpreted with reference to the reproductive and hydrostatic functions. Numerous features exhibited on the surface of the colonies or revealed in thin sections are used in detailed classification.

All Cyclostomata secrete calcareous skeletons composed of relatively long, minutely porous zooecial tubes. Features pertaining to the reproductive function are utilized for classification whenever possible. The arrangement of zooecia in the colonies, the structure of extra- or interzooecial skeletal deposits, and characters of the zooecial orifices are used to differentiate various categories.

The gelatinous or chitinous Ctenostomata are distinguished from other orders primarily by morphology of their soft parts. Within the order zooecial and zoarial forms are used for classification. Certain living ctenostomes secrete phosphoric acid that excavates their substrate, which commonly is the shell of another organism. Some of the minute fusiform excavations, elongate or ovoid vesicles, and delicate perforated stolons that mark fossil

cluded in the Paleozoic order Trepostomata is con-
troversial. These fossils built colonies of
hesive nonporous tubes, a feature that

the order from certain Cyclostomata that build similar zoaria Zooecial walls in the Trepostomata are composed of fine calcareous lamellae and are duplex In early growth stages the tubes are prismatic and thin walled in later stages the laminated walls thicken and interstitial tubes (mesopores and acanthopores) are introduced Straight or curved partitions occur within the tubes generally becoming more abundant in later growth stages Thin sections are essential for the discernment of features used for identification of species and higher categories

In the exclusively fossil Cryptostomata considerable reliance has been placed on growth form in separating family groups Most but not all of the genera referred to the order have short boxlike zooecia as do the later Cheilostomata Surficial characters and internal microstructure are used to a considerable extent in classifying bryozoans assigned here

Geologic history A few Cambrian fossils of doubtful affinities have been described as bryozoans Forms that are confidently recognized as bryozoans are scarce in Lower Ordovician rocks A fauna that was fairly diversified appeared suddenly about the beginning of Middle Ordovician time The phylum evolved rapidly and toward the end of the period the Trepostomata and Cryptostomata became dominant elements in better known faunal assemblages Cyclostomata and Ctenostomata are less important elements in Ordovician faunas

Bryozoans are poorly represented in Silurian rocks of many regions where the principal sedimentary rocks are dolomites and evaporites Well preserved and diversified assemblages occur locally in Europe and North America Silurian faunas are characterized by the expansion of the fenestrate cryptostomatous family Fenestellidae which is barely represented in the Upper Ordovician The cyclostomatous Fistuliporidae also became a significant element

In diversity of genera and species the Paleozoic Bryozoa probably reached their apex in the Devonian period The fenestellids and other cryptostomatous genera are exceedingly abundant Fistuliporoids were on the increase Considerably fewer genera of Trepostomata are known from the Devonian than from the Ordovician but representatives of the order are common locally The incrusting tubular hederelloid Cyclostomata are far better known from Devonian than from earlier or later rocks

Many Carboniferous and Permian deposits are distinguished by the conspicuous development of fenestrate Cryptostomata and Cyclostomata Pinnate forms tiny dendroid colonies (rhombopo roids) and branching bilaminate types are also characteristic Fistuliporoids attained the greatest diversity being represented by fenestrate zoaria

[illegible] later Permian they built biostromes and reeflike structures It is generally stated that the main groups of bryozoans that flourished during the Paleozoic (Trepostomata Cryptostomata and the ceramoporoid fistuliporoid and hederelloid Cyclostomata) became extinct at the end of the era

Bryozoans are poorly known from rocks of Triassic age Paleozoic types probably ranged into the Lower Triassic, but little has been done on material from critical regions A few Triassic bryozoans identified with cyclostomatous and trepostomatous genera are described, but the dearth of information on the phylum suggests that representatives were uncommon in Triassic rocks

The Jurassic period witnessed a great expansion of the Cyclostomata This order dominated bryozoan faunas until Upper Cretaceous time The trepostomatous-like Heteroporidae are especially well developed in Jurassic faunas The Cheilostomata (suborder Anasca) are first recorded from the Middle Jurassic This suborder maintained a fairly constant role in Cretaceous and Tertiary faunas. Since their appearance in the Cretaceous representatives of the cheilostomatous suborder Ascophora have steadily increased and are the dominant forms in Recent bryozoan faunas

Phylogeny Origin and relationships of the major groups are obscure The Ctenostomata Cyclostomata Trepostomata and Cryptostomata all appeared as fossils about the same time in the early Paleozoic They evolved presumably from an earlier common ancestral stock It has been suggested that the Ctenostomata gave rise to the fresh water Phylactolaemata and that the Paleozoic Cryptostomata were ancestors of the Cheilostomata [R.B.]

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Bubble chamber

A particle detector in which the path of a fast charged particle is made visible by the formation of bubbles along the track of the particle in a superheated liquid that is a liquid which by being subjected to high pressure is heated to a temperature well above its normal boiling point (*see* PARTICLE DETECTOR) Bubble chambers are used in research in high energy nuclear physics and are particularly well adapted for use with the high energy accelerators of nuclear particles When a fast charged particle passes through a superheated liquid it loses energy to the liquid causing locally heated spots which become centers for bubble formation These bubbles can be illuminated and photographed forming a permanent record of the path of the particle (Fig 1) Bubble chambers have many applications similar to cloud chambers for discussion of these applications *see* CLOUD CHAMBER

The liquid in a bubble chamber is kept under pressure which is suddenly released Superheating will thereby be produced if the initial temperature conditions are correctly established Liquids com

monly used are propane and similar organic liquids, and liquid hydrogen Liquid xenon and liquid he lium have also been used Liquid hydrogen bubble chambers (see Fig 2) are particularly impor tant in high energy nuclear physics because the liq uid contains only protons and electrons and no heavier nuclei making it possible to study the fun damental proton electron interactions A 72 in liq uid hydrogen chamber was placed in operation at the University of California early in 1959

[W B F]

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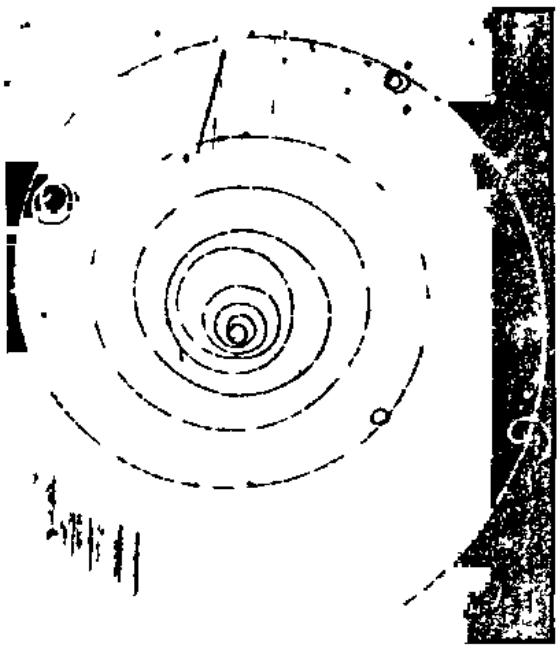


Fig 1 Electron spiraling in a magnetic field as pho tographed in the 10-in diameter bubble chamber of the University of California Radiation Laboratory (L W Alvarez)

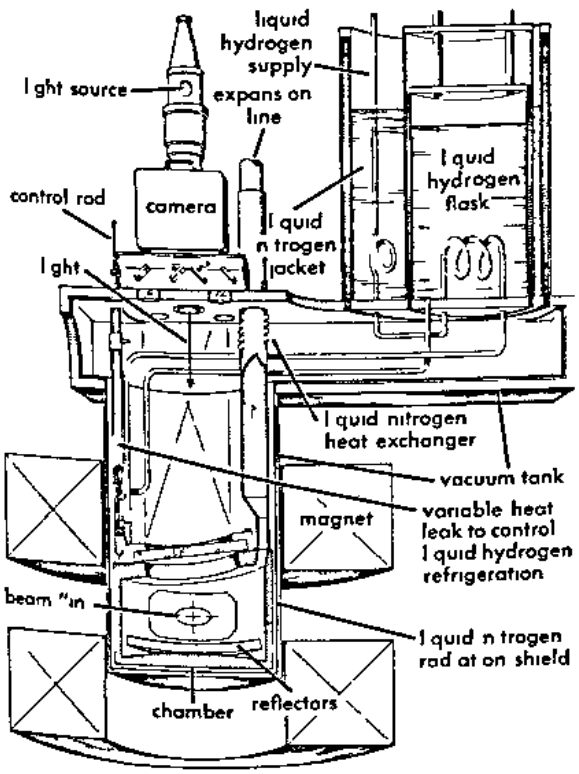
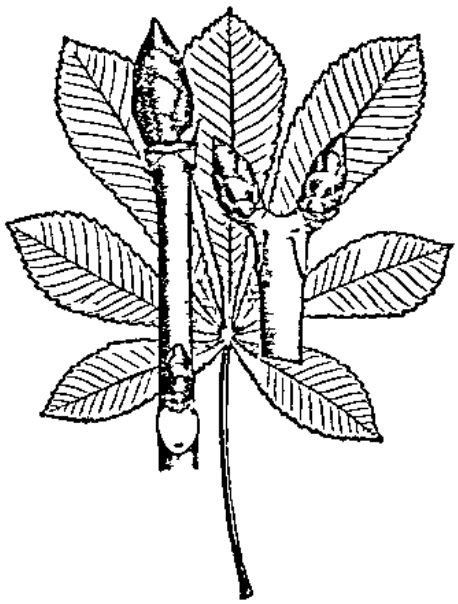


Fig 2 Liquid hydrogen bubble chamber The diam eter of this chamber is 15 in It is used with the Beva tron at the University of California Berkeley, Cali fornia (L W Alvarez)

Buckeye

A genus *Aesculus* of deciduous trees or shrubs be longing to the plant order Sapindales (*see* SAPIN DALES) Buckeyes grow in North America south east Europe and eastern Asia to India The distinc tive features are opposite palmately compound leaves and a large fruit having a firm outer coat and containing usually one large seed with a con spicuous hilum The Ohio buckeye *Aesculus glabra* a small tree which may grow to a height of 30 ft, is found mainly in the Ohio valley and in the south ern Appalachians It can be recognized by the glabrous winter buds prickly fruits 1–2 in long compound leaves having five leaflets Another im



Twig buds, and leaf of horsechestnut, *Aesculus hippocastanum* (*From A H Graves Illustrated Guide to Trees and Shrubs rev ed , Harper 1956*)

portant species the yellow buckeye *A octandra* grows 90 ft high is native in the central states has five leaflets and smooth buds but differs in its smooth larger fruit which may be 2 2½ in long The horsechestnut, *A hippocastanum*, which usu ally has seven leaflets and resinous buds, is a native of the Balkan peninsula It is planted throughout the United States and is a beautiful ornamental tree bearing cone shaped flower clus ters in early summer The seeds of all species con tain a bitter and narcotic principle The wood of the native tree species is used for furniture boxes, crates baskets and artificial legs *See* FOREST AND FORESTRY, TREE [A

Buckwheat

The plant *Fagophyrum esculentum* has a single branching stalk 2–4 ft high, triangular heart shaped leaves small white flowers tinged with purple or red and arranged in clusters and it produces small three cornered seeds Buckwheat grows best in a cool moist climate tolerates acid soil, and grows better than cereals on poor soils (*see* CEREAL GRAIN CROPS)



(a) Buckwheat mature plant Japanese variety (b) Buckwheat seed Japanese variety

The principal area of production in the United States is the northeastern and north central states Pennsylvania and New York produce about two thirds of the crop Japanese is the principal variety grown Production in the United States has slowly declined within the past century During the period 1945–1954 total production in the United States averaged 8 434 000 bushels and was valued at $10 542 500 on the farm

About 95% of the crop is harvested for grain the remainder is plowed under for soil improve ment The gra n of ha consumption i cracked grain animal feed bi cipally for poultry Buckwheat in bloom makes good bee pasture often when other nectar bearing flowers are scarce The honey pro duced has a strong taste and dark color *See* BEE AND BEEKEEPING [A B B]

Processing Buckwheat milling is similar to wheat milling in principle The grain is cleaned, crushed between a series of steel rolls and the flour and feed by products separated by sieving. On the average 100 lb of dry buckwheat will yield 60 75 lb of flour, 4–8 lb of middlings, and 18 26 lb of hulls *See* WHEAT

When buckwheat is received at the mill it is passed over sieves and subjected to aspiration and scouring to remove all foreign material If the grain possesses high moisture, it is dried The grain is cracked to loosen the hull by passing it through the first break rolls and the stock is dried in a revolving cylinder where heat can be applied After drying the cracked grain is sieved to separate the flour from the hulls this operation being repeated until the desired product is produced Some buck wheat is milled to fine flour Often however the particles are not reduced as much as possible and both middlings and particles of bran are present especially in dark flour Buckwheat flour because of the nature of the grain and the way it is proc essed generally is not as highly refined as wheat, rye or corn flour It is gritty not soft and smooth

Buckwheat flour is used almost exclusively in pancakes or as one of the ingredients in prepared pancake flour Sometimes buckwheat flour is milled for groats Two types of food products are made from buckwheat groats roasted kernels and a farina or granular product used in soup Occa ion ally groats are used in breakfast foods Buckwheat is also a source of flavonol fluoside known as rutin which has proved effective in the treatment of high blood pressure in man *See* FOOD PROCESSING [J A SH]

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Bud (botany)

A bud is an embryonic shoot It contains the growing stem tip surrounded by young leaves or flowers or both and the whole is frequently en closed by special protective leaves the bud scales

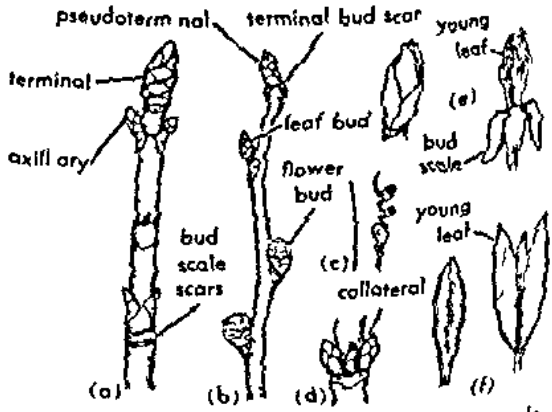


Fig 1 Bud types (a) Terminal (buckeye) (b) *Pseudo*-term nal (elm) (c) Superposed (butternut) (d) *Collateral* (red maple) (e) Closed and open scaly bud (*h ckory*) (f) Closed and open naked bud (hobble bush)

Position The bud at the apex of the stem is called a terminal bud (Fig 1) Any bud that develops on the side of a stem is a lateral bud The lateral bud borne in the axil (angle between base of leaf and stem) of a leaf is the axillary bud It develops concurrently with the leaf which subtends it but usually such buds do not unfold and grow rapidly until the next season Due to the inhibitory influence of the apical or other buds many axillary buds never develop actively or may not do so for many years (*see* PLANT GROWTH) These are known as latent or dormant buds Above or beside the axillary buds some plants regularly produce additional buds called accessory or supernumerary buds Accessory buds which occur above the axillary bud are called superposed buds and those beside it collateral buds Under certain conditions such as removal of terminal and axillary buds other buds may arise at almost any point on the stem or even on roots or leaves Such buds are known as adventitious buds

Composition Buds that give rise to flowers only are termed flower buds or in some cases fruit buds If a bud grows into a leafy shoot it is called a leaf bud or more accurately a branch bud A bud which contains both young leaves and flowers is called a mixed bud

Covering Buds of herbaceous plants and of some woody plants are covered by rudimentary foliage leaves only Such buds are called naked buds In most woody plants however the buds are covered with modified protective leaves in the form of scales These buds are called scaly buds or winter buds In the different species of plants the bud scales differ markedly They may be covered with hairs or with water repellent secretions of resin gum or wax Ordinarily when a bud opens the scales fall off leaving characteristic markings on the stem known as bud scale scars

Vernation The characteristic arrangement of young leaves within the bud is known as vernation or prefoliation (Fig 2) Within the buds the

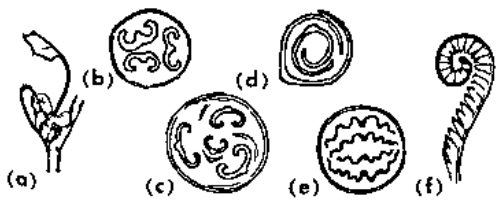


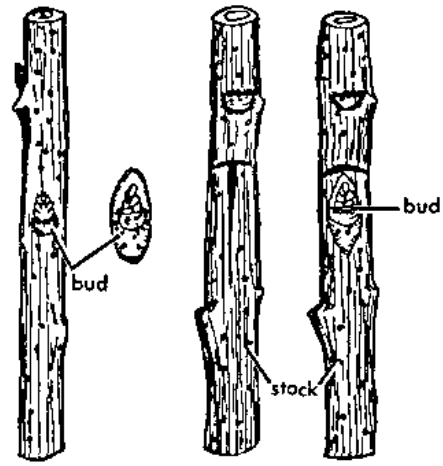
Fig 2 Types of vernation (a) Conduplicate (tulip tree) (b) Revolute (dock) (c) Involute (poplar) (d) Convolute (cherry) (e) Plicate (sycamore) (f) Circinate (fern)

leaves may be folded on the midrib plaited rolled coiled or twisted in exact order and precision each kind of plant having its distinctive inner bud pattern Many ferns have a coiled leaf arrangement which is known as circinate vernation *See* LEAF (BOTANY) PLANT ORGANS PLANT TAXONOMY [N A]

Bibliography *See* PLANT ANATOMY

Budding

A vegetative method of propagation in which a single bud serves as a scion and is grafted laterally upon a stock *Bud grafting may be performed* throughout the growing season when the bark of the stock is soft and loose but summer or early fall is usually the most satisfactory time Success depends upon joining the vascular cambia of the



T or shield method of budding (*From H J Fuller and O Tippo College Botany rev ed Holt 1954*)

stock and scion (*see* MERISTEM LATERAL VASCULAR BUNDLES) This requires genetic compatibility of stock and scion pressure to hold the scion firmly against the stock and protection from desiccation

Methods of budding used are T or shield patch or flute hinge Nicolieren and chip The T or shield method is most widely used A T shaped cut is made through the outer tissues (bark) of an internode of the stock and the bark separated from the xylem along the cambium (*see* XYLEM) On the scion a thin cut into the wood is made downstem from an inch above the bud The wood behind the bud is removed and the bud is forced into the incision and held in place by rubber strips or raffia *See* GRAFTING OF PLANTS PLANT ANATOMY REPRODUCTION PLANT [J E GU]

Buerger's disease

A progressive chronic inflammation of arteries veins and nerves of young to middle aged men Also known as thromboangiitis obliterans Buerger s disease is marked by a segmental involvement of larger arteries by inflammation fibrosis and a tendency toward formation of thromboses

The disease is relatively rare and is usually found in men of 25 40 years of age although a few women and younger males have been affected A familial susceptibility is sometimes present and the disease shows an increased incidence among Jews

Although the specific etiologic agent is unknown almost all patients with Buerger s disease can cause an increase in their symptoms by the excessive use of tobacco or exposure to cold Conversely many of those afflicted show benef

tardation of the process when these two factors are removed

Vessels of the lower extremity are usually first affected and the clinical course is marked by pain aching and tenderness brought on by exertion and relieved by rest These symptoms referred to as intermittent claudication may be accompanied or followed by sensory changes or sensitivity to extremes of temperature In advanced cases discoloration of the skin atrophy of the tissues and even gangrene result from the progressive occlusion of blood vessels *See* GANGRENE [GAS]

An irregular succession of symptomatic periods alternates with intervals of remission Progressive invalidism hastened by the necessity of amputations of affected parts is commonplace Death may follow after a long period of illness or may occur during the frequent complications Although peripheral vessels are most often damaged the arteries of certain organs may be similarly involved in which cases the prognosis is much less favorable *See* CARDIOVASCULAR SYSTEM [DISEASE]

Buffer solution

A solution selected or prepared to reduce changes in the concentration of hydrogen ion and hydroxide ion (or other important molecular species) Large increases in hydrogen ion might be produced for example in an unbuffered solution by a chemical reaction whose products include hydrogen ion Increases or decreases may also be produced inadvertently by the introduction of impurities Adsorption on or desorption from the walls of the container may be a potential source of large changes in pH Simple dilution of a solution can also cause large changes in $[H_3O^+]$ and $[OH^-]$ For example a 2 1 dilution of a solution containing HCl at a concentration of 0 00001 mole/liter would halve $[H_3O^+]$ and double $[OH^-]$

The changes in $[H_3O^+]$ arising from these sources are much smaller if the solution contains a weak acid If for example a pH of 5 is the result of the fractional dissociation of a more concentrated solution of a weak acid the change in $[H_3O^+]$ produced by a 2 1 dilution would be negligible for many purposes An even more effective solution is a mixture of a weak acid (or base) and a highly dissociated salt of that acid (or base) Such a mixture is called a buffer solution

Partially neutralized polybasic acids (or polyacidic bases) are excellent buffers because the molecule (usually an ion) can either lose or gain protons (or OH^- ions) Potassium hydrogen phthalate is an example

Buffer solutions are found in nature A well known example is the mixture of carbonic acid and bicarbonate ion which maintains a pH of 7 4 in human blood

Much attention has been directed to specifications for the preparation of a set of accurately reproducible buffer solutions Several of these are listed in the table A major reason for the careful study of these buffer solutions is the need for

Five standard aqueous buffer solutions

Solute	Concentration, moles liter	pH at 25°C
Potassium tetroxalate $KH_3(C_2O_4)_2 \cdot 2H_2O$	0 05	1 68
Potassium hydrogen tartrate $KH(C_4O_4(CHOH)_2CO_2)\cdot H_2O$	Saturated at 25°C	3 56
Potassium hydrogen phthalate $KH(C_8O_4C_6H_4CO_2)$	0 05	4 01
Potassium dihydrogen phosphate KH_2PO_4	0 025	6 86
Disodium hydrogen phosphate Na_2HPO_4	0 025	6 86
Borax $Na_2B_4O_7 \cdot 10H_2O$	0 01	9 18

standards for the calibration and testing of instruments used for the measurement of pH that is for the determination of $[H_3O^+]$ and $[OH^-]$ *See* ACID AND BASE, EQUILIBRIUM IONIC INDICATOR, ACID-BASE PH [TEST]

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Buffing

The smoothing and brightening of a surface by means of an abrasive compound pressed against the work by means of a soft wheel or belt The abrasive is a fine powder or flour mixed with tallow or wax to form a smooth composition or paste This is applied as required to the buffing wheel or belt which is made of a pliable material such as soft leather linen muslin or felt

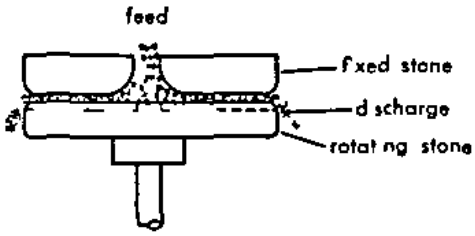
Buffing is accomplished on the same types of machines as polishing and frequently both types of wheels are included on one machine *See* POLISHING [METALWORKING]

Bug

A word which is used in widely varying senses by different groups In its most common usage bug means an insect of the order Hemiptera In the system of common names in use by entomologists and zoologists the order Hemiptera is indicated when bug stands as a separate word as in assassin bug Led bug or squash bug When the term bug is used as a suffix it applies to other orders as in doodlebug *See* HEMIPTERA, INSECTA [JDB]

Buhrstone mill

A mill for grinding or pulverizing in which a flat stone rotates against a floating stationary stone preferably both of siliceous rock and generally of cellular quartz The buhrstone mill is one of the oldest types of mill, having long been used to grind grains and hard materials Mills with the stones either horizontal or vertical were used Grooves in the stones facilitate motion of material Fineness of the product is controlled by the pressure between the stones and by the grinding speed the slower the finer Capacity of a buhrstone mill is



Grain is fed in at center of upper fixed stone and moves toward outer edge of the stones where chaff and flour are discharged

low and its power consumption high The stones require frequent maintenance when grinding even slightly abrasive materials *See* CRUSHING AND PULVERIZING [R M H]

Buildings

Fixed structures for human occupancy and use The space and structure must be planned to produce the environment and facilities required for the purpose of the building Items such as light heat air conditioning acoustics and color must be given careful consideration

Many municipalities have adopted building codes to promote safe practice in building design and construction A good code provides reasonable safety to the occupants of the building preserves the property itself and protects adjoining property Buildings are usually classified according to occupancy and use as follows (1) public (auditoriums churches theaters) (2) institutional (hospitals orphanages reformatories) (3) residential (hotels apartments studios) (4) business (stores factories office buildings) and (5) storage (garages warehouses)

In order to reduce the fire hazard building codes generally prohibit frame construction in areas that include business and manufacturing The boundaries of such areas are known as fire limits Codes also generally prescribe height and area limitations and these limitations become more severe as the fire resistance of the construction decreases Restrictions are placed on the portion of a lot which can be covered so as to provide light and air for occupants of the building and of adjoining buildings



Fig 1 Simple or conventional steel framing (American Institute of Steel Construction)

Loads The loads a building is called upon to support are dead load which includes the weight of walls columns partitions floors and roof and live load The live load on a building floor includes the weight of the physical equipment and occupants *Live loads are usually specified by the building* code and vary according to the type of occupancy Live loads for public buildings are 40–120 pounds per square foot (psf) Snow load is considered a live load on the roof Its magnitude depends upon the slope of the roof and the geographic location of the building The recommended minimum varies from 10 psf on steep roofs in the southern states to 40 psf on flat roofs in the New England area

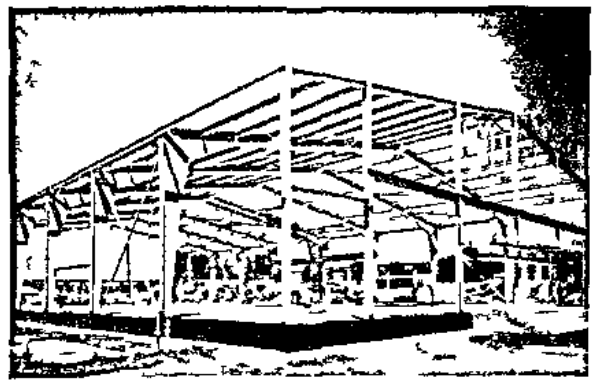


Fig 2 A rigid frame structure (*American Institute of Steel Construction*)

Building codes provide for the tendency of average live loads to decrease with an increase in the floor area by permitting a reduction in the basic design live load when the area exceeds a certain minimum A reduction in the total floor live load

age of the load

The evaluation of pressures exerted by wind on a building is complex and code requirements for wind forces are only rough approximations The recommended design wind pressure on plane surfaces normal to the wind increases with the height of the structure above ground level Wind on the windward roof slope may produce suction or pressure depending on the slope of the roof Leeward slopes are always subject to suction

Some building codes make definite provisions for earthquake shocks Structural damage may result from a structure's response to the waves set in motion by the earthquake Only horizontal components of the acceleration are considered and it

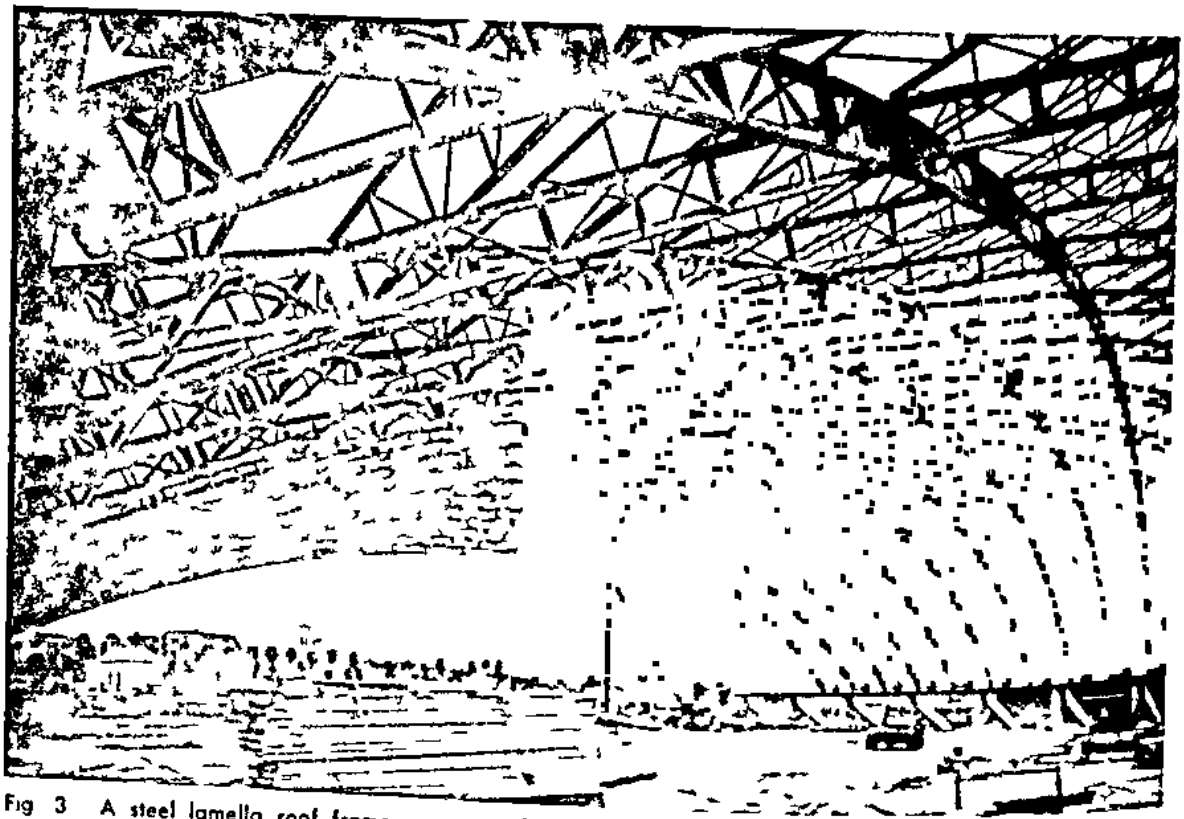


Fig 3 A steel lamella roof frame an example of long span construct on (*American Inst tute of Steel Construction*)

sometimes assumed that all parts of the building suffer an acceleration equal to that of the ground But because a building undergoes elastic distor tions that affect the acceleration of its various mem bers this assumption is not valid

The Federal Civil Defense Administration rec ommends for the design of blast resistant struc tures two classes of equivalent static loads Class I loads are for buildings housing personnel and criti cal equipment Class II loads are for buildings in which damage resulting from failure of walls or other effects of blast can be repaired easily

Design standards have been developed which set forth the minimum requirements consistent with current practice These standards cover such items as design loads design stresses methods of analy sis proportioning of structures and their compo- nents fabrication and erection

Framing systems The three types of framing systems are wall bearing skeleton frame and long span

In wall bearing construction walls support the ends of the floor and roof beams in addition to en closing and partitioning space This form of con struction is used for many types of buildings from one-family homes of the better class to industrial and commercial buildings of 1–3 stories It is sel dom economical for buildings over 3–4 stories in height *See* WALL CONSTRUCTION

In skeleton frame construction a

ports the weight of wall between it and the span- drel beam above in addition to its share of the floor load This system of framing is also known as beam and column construction Multistory skeleton- frame buildings are often called tier buildings

The three types of steel skeleton frame construc tion are simple rigid and semirigid In simple or conventional framing beams and girders are as- sumed to be free to rotate at their connections (Fig 1) In the analysis of rigid frame structures the end connections of all mem bers are assumed to be so rigid that the angles they make with each other do not change (Fig 2) Frameworks of in- termediate rigidity in which it is assumed that the connections possess a known and dependable mo- ment capacity are usually called semirigid frames

Buildings of low height width ratio with heavy continuous walls are capable of resi ting lateral forces of considerable magnitude without the help of special wind bracing If the structural frame must resist the wind forces the most economical bracing is a system of diagonals crossing in the vertical panels between the columns and beams and forming with them a series of vertical trusses The skeleton frame can resist the wind forces if mo- ment resistant connections are used between the beams and columns

Long span construction is used for aud toriums hangars gymnasiums and other structures requ r ing a wide unobstructed floor area that cannot be economically spanned with standard steel beams or typical reinforced concrete or solid timber girders. The appropriate forms of construction are plate

girders prestressed girders trusses arches rigid frames domes and cantilever suspension spans (Fig 3) *See* ARCH CANTILEVER ROOF CONSTRUCTION TRUSS

Industrial buildings It is usually economical to support industrial buildings with a steel framework consisting of a series of trusses supported on columns. A truss and its supporting columns form a bent which can resist lateral loads in its plane To resist lateral forces normal to its plane the bent must be connected to an adjacent bent by diagonal bracing in the plane of the top chord and in the plane of each pair of columns The two bents so connected form a tower Towers every fourth or fifth bay plus purlins eave struts and wall struts form a stable structure

Natural illumination in an industrial building may be increased considerably by the addition of one or more monitors along the length or width of the building Such arrangements are usually called high low bay roofs A uniform level of illu-

quiring more than 20 foot candles of illumination [C N C]

Bulk handling machines

A diversified group of materials handling machines specialized in design and construction for handling large volumes of materials in bulk Small quantities of bulk materials can be handled by other machines equipped with *containers*. *See* CONVEYING MACHINES ELEVATING MACHINES HOISTING MACHINES, INDUSTRIAL TRUCKS MATERIALS HANDLING MACHINES MONORAIL

Bulk material Materials in a solid free-flowing state are bulk materials Wet or sticky materials may also be handled successfully by some of the same machines used for bulk materials

Characteristics which are factors in the selection of equipment for handling bulk materials include (1) the size of the component particles (2) flowability (3) abrasiveness (4) corrosiveness and (5) general condition such as dryness temperature presence of dust or noxious fumes and stickiness

The size of particles range from very fine powder through fine granular lumpy and up to pieces of considerable size such as those encountered in earth moving and mining Smaller particles are classified according to the size of wire screen openings through which they will pass Thus a 100 mesh screen is one in which there are 100 openings per linear inch Larger particles are indicated by mean diameter such as ¼ in Where sizes are mixed it is customary to indicate the percentage of each in the mixture

Flowability corrosiveness abrasiveness and similar terms are relative and are usually modified by adjectives as in mildly corrosive or highly abrasive Manufacturers of bulk handling machines issue tables covering the characteristics of the materials their machines are designed to handle

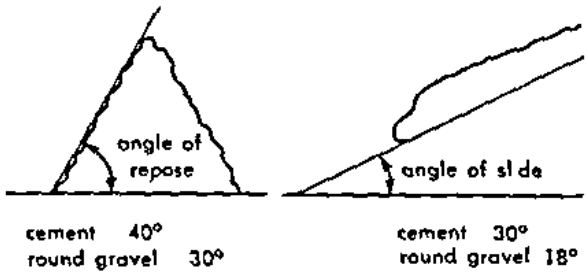


Fig 1 Critical angles for bulk materials

The angle of repose is the maximum slope expressed in degrees at which piled material will stand without sliding on itself This term should not be confused with the same designation used in connection with sliding friction The angle of slide (Fig 1) is the angle at which material will flow on an inclined surface such as a chute Both are important considerations in conveyor operations

Conveyors Equipment which moves materials over fixed horizontal inclined declined or vertical paths of travel with continuous motions are conveyors The many different means used to convey bulk materials include gravity belt bucket flight spiral or screw dragline vibrating and pneumatic conveyors

Wheel or roller conveyors cannot handle bulk materials gravity chutes are the only unpowered conveyors used in this field Plain chutes and those with cleats are employed for moving and lowering bulk materials but chutes consisting of short slanted sections called ladder chutes permit material to drop from one level to the next and can successfully control the descent of lumpy products that are not damaged by relatively short drops

Belt conveyors of many varieties move bulk materials Fabric belt conveyors have essentially the

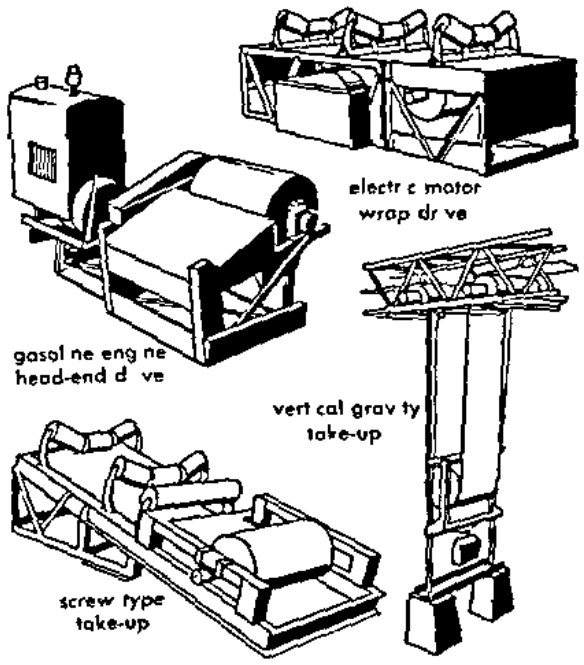


Fig 2 Components of belt conveyor (*Barber-Greene Co*)

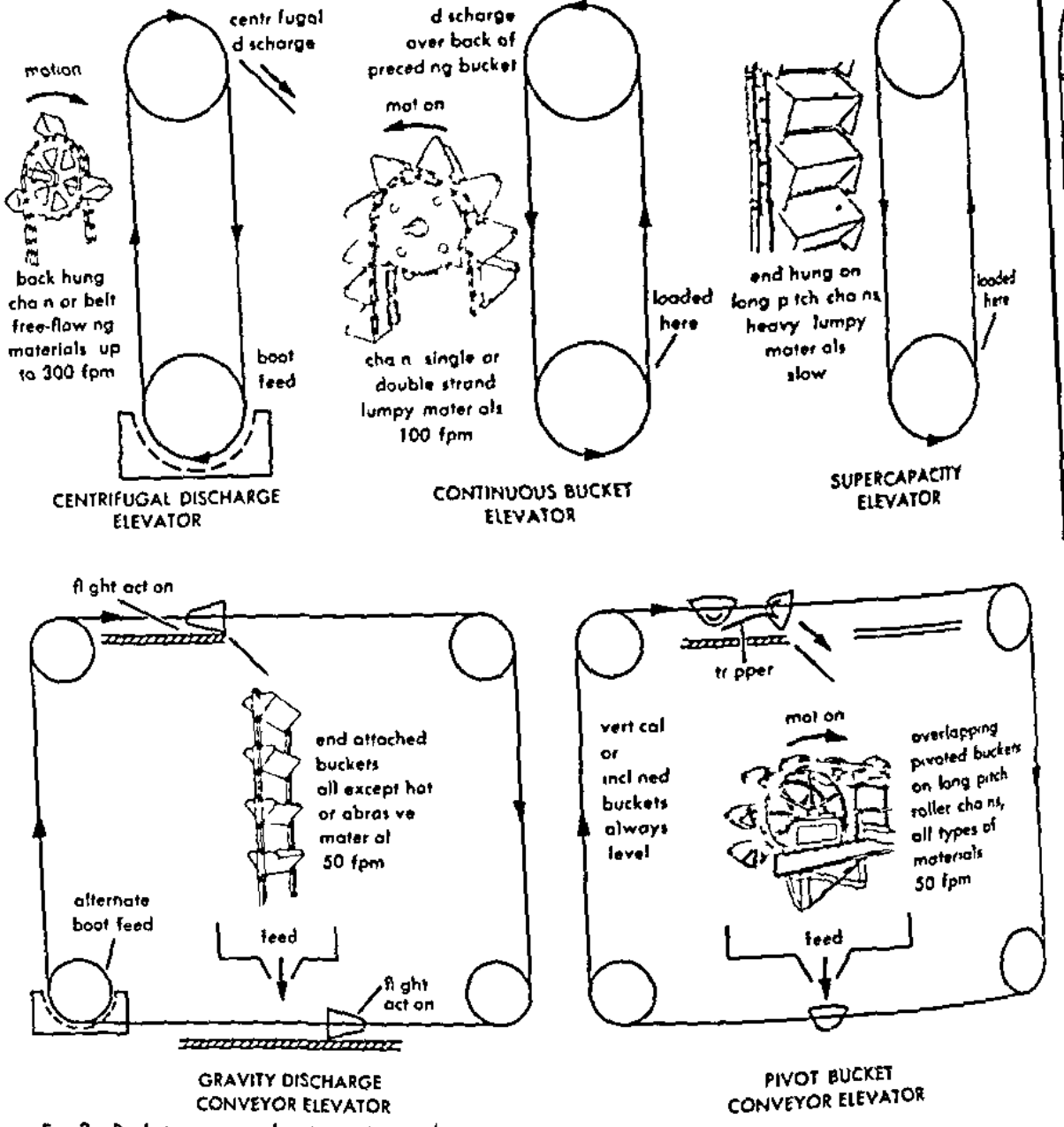


Fig 3 Bucket conveyor elevator system and components

same operating components as those used for package service however these components are constructed more ruggedly to stand up under the more rigorous conditions imposed by carrying coal gravel chemicals logs chips and similar materials (Fig 2) The belts themselves are specially constructed and treated to withstand the impact of loading abrasion and frequently high temperature They run on roller beds which are either horizontal or troughed In this field the heavy duty rollers are called carriers

The belts are not cleated but if greater capacity is required than is provided by troughing (usually about double that of flat belting) skirtboards are set longitudinally along the edges of the belt to keep the material from falling off Normally the belts provide horizontal or inclined travel although slight declines have been used

Drive mechanisms gravity and screw type take ups end rollers speed reducers and belt scrapers (to clean the belt on its return trip) are standard elements offered in a range of sizes so that a conveyor can be built up to meet any given operating condition

The nature density and angle of repose of the material and the width and angle of slope of the belt are factors which determine the safe operating speed of the conveyor and therefore its capacity to deliver material and its horsepower requirements

Materials feed onto belt conveyors from hoppers or other storage facilities from overhead Materials may discharge over the end of the belt is flat, by being diverted to one side Troughed belts can be unloaded by a car called a tripper The tripper rides above and straddles the belt scooping up ma

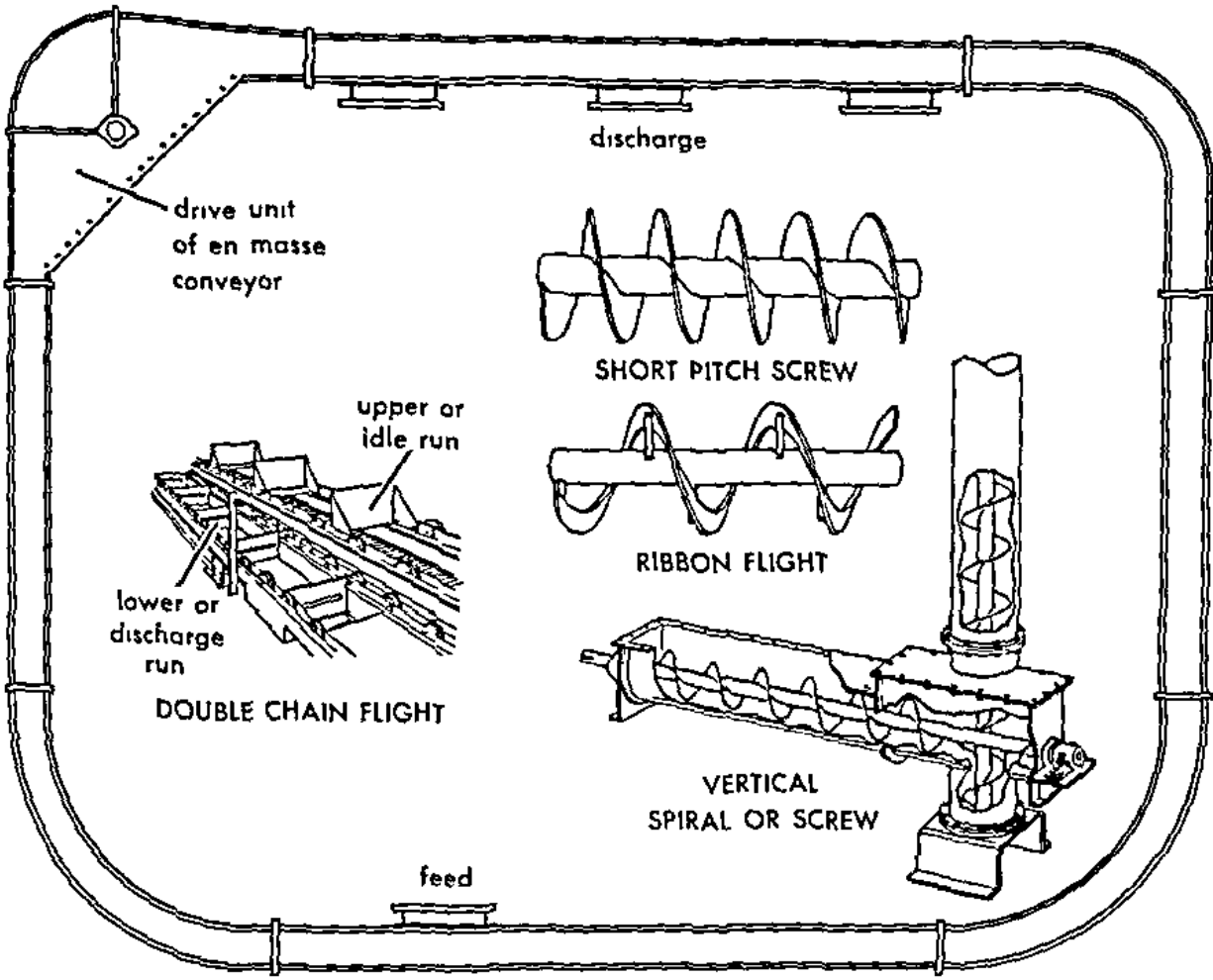


Fig 4 Flight conveyors and components

terial with a plow The tripper discharges to its right or left as desired

Steel band conveyors are used for their resistance to abrasion and ability to withstand high temperatures They, too may be run flat or troughed Run flat their smooth surface makes them peculiarly suitable for diverting to the side Their drive mechanisms are distinctive especially their large pulleys They are used in such industries as chemicals and food, and in logging operations for handling wet logs chips, and sawdust

Tubular belts equipped with zippers for feeding and d
aro
are
materials which must be kept free from contamination

Beltlike carrying surfaces are made up of metal segments called interlocking steel plates They may be constructed with the hinges on the bottom or top The former are driven by wide sprockets which engage the hinges, the latter have roller chain edges which are sprocket driven A variation of these conveyors is the hinged pan It consists of a series of pans or small V shaped carriers hinged together at their upper edges and mounted between two strands of roller chain Both interlocking steel plates and hinged pans can be perforated for drainage

Bucket conveyors An important group of bulk handling machines has V shaped buckets carried by one or two strands of chain or, in some instances by a belt The buckets themselves vary in size and shape according to service needs (Fig 3) When bucket conveyors operate at steep inclines or along vertical paths they are referred to as conveyor elevators or simply elevators but they are not true elevators because they operate with continuous motion Each machine is designed for a particular service especially as to the kinds of materials for which it is best suited In many instances the conveyor is housed in a casing In any arrangement discharge is on the side opposite to that of elevation

Skip hoists are used in mining operations for bringing to the surface materials that are too heavy or bulky to be handled by bucket conveyors They are also used in such industrial operations as charging furnaces Strictly speaking they are not hoists because their path of travel is fixed, but the name is well established from long usage

Flight conveyors A load can be advanced by pushing the material through a trough or an enclosed duct by means of flights (Fig 4)

En masse conveyors have flights that pick up the material and push it at any desired angle from horizontal to vertical and discharge it through the side or bottom of the enclosed duct Smaller varieties have circular or rectangular tubes through which are pulled flights attached at their centers to a continuous chain or cable These tubular conveyors can be selected to handle a particular kind of material and to provide a flexible path of travel

Single strand and double-strand flight or scraper conveyors are so designated according to whether they have one or two sets of supporting drive chains They operate in open troughs and differ in that the former type is used with relatively light materials and can discharge only on the lower run of the cycle whereas the latter handles heavier products and can discharge on either the upper or the lower run Inclinations up to 30° are possible but they are limited by the liability of the material to spill over the flights Speeds from 100 to 150 fpm are usual determined largely by the weight of the material

Spiral or screw conveyors A variation of the flight conveyor has the flights in the form of a helical screw which advances the material as the screw turns The trough in which the flights function may be open or enclosed Elevation may be up to 90° Many different kinds of flights are used not only to provide motion but also to mix or blend the materials being handled Batches of ice cream mix granular lumps abrasive and corrosive materials can all be handled by these versatile machines

Draglines include two types Chain drags consist of rugged chain links that run through the bottom of a concrete trough and move such materials as clinkers and slag The dragging is done entirely by the links of the chain Cable drags have circular metal or wooden disks mounted centrally on a single strand of rope and pull the material through a semicircular trough They are extensively employed in the lumber field for stock piling logs sawdust and chips

Vibrating or oscillating conveyors Load can be transported on a flat or troughed bed which is moved forward slowly and drawn back quickly The inertia of the material keeps the load from being carried back so that it is automatically placed in a more advanced position on the carrying surface Mechanical (spring) and electrical (vibrator) devices provide the oscillating motion Materials can be moved up spiral paths vertically with specially designed equipment of this type

Pneumatic or air conveyors There are several forms of conveyors that use moving air to drive material along a course Pneumatic tubes are a form of conveying machine Complete industrial systems for handling such materials as flour seeds grains and chemicals include means for unloading and loading trucks rail and marine carriers, means for moving materials in process, and means for storing materials usually in elevated facilities Air compressors are located at the feed end and suction units are at the discharge end, such installations are invariably engineered to specific requirements Smaller machines are available for spot operations A type of gravity conveyor arranged light materials so they flow down grade under the force of gravity

Many conveyors are available in portable models which are used in industry and in wholesale and retail establishments where coal building supplies and similar materials are handled in bulk

Small sections of these conveyors called feeders serve larger units and are normally permanent parts of a complete materials handling system

Aerial tramways and cableways A conveyor that closely resembles overhead chain and cable conveyors is the cableway The grooved wheels of the trolleys run along a track cable with a relatively smooth surface instead of riding on overhead rail The trolleys which support the carriers are actuated by a traction rope consisting of wire strands laid around a rope core (Fig 5) These machines normally operate over long distances particularly where the terrain is such that truck or rail transportation is impractical Back and forth shuttle service continuous travel and provisions for engaging and disengaging the carriers without stopping the system are examples of the diversified setups which can be engineered to meet the needs of such activities as dam construction bringing coal to and removing ashes from powerhouses and stockpiling in open country

Power cranes and shovels Many operations are performed by power cranes and shovels When functioning as cranes and fitted with the many below the hook devices available they are used on construction jobs and in and around industrial plants Such fittings as magnets buckets, grabs skullcrackers and pile drivers enable cranes to

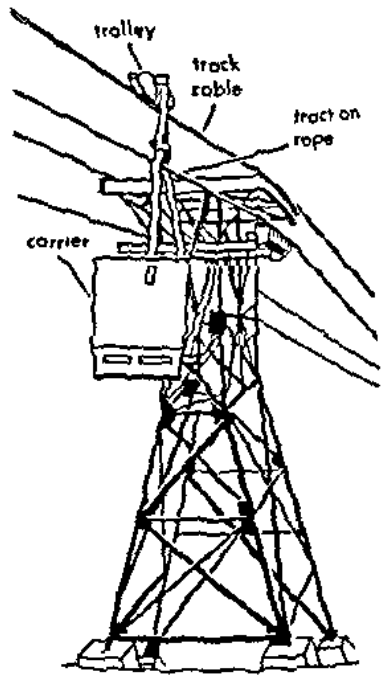


Fig 5 Cross-country aerial cableway

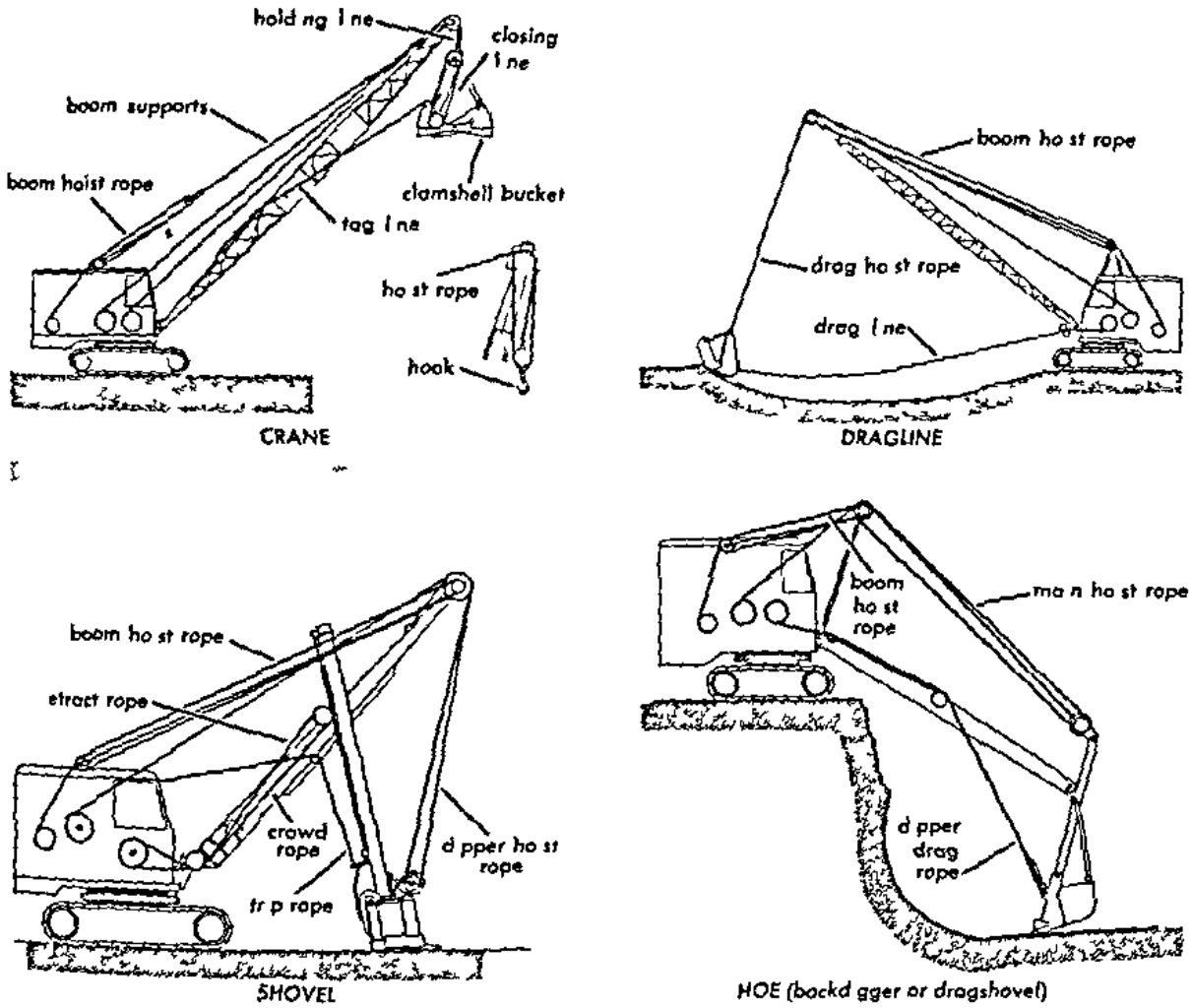


Fig 6 Reev ng d agram of power cranes and shovels (Un ted States Steel Corp)

handle many products Machines of the converti ble full revolving type are mounted on crawlers trucks or wheels Specialized front end operating equipment is required for clamshell dragline lift ing crane pile driver shovel and hoe operations Commercial sizes of these machines are nominally from ⅛ to 2¼ yd³ as shovels and from 2½ to 60 tons as cranes

The revolving superstructure consists of the rotat ng frame and the operating machinery thereon It may be carried on a crawler mount which con sists of two continuous parallel crawler belts A truck mount is a heavy framed rubber tired carrier supported by two or more axles and having the general characteristics of a heavy-duty truck The carrier may be controlled for over the-road travel from a cab mounted on the carrier or located on the revolving superstructure Machines of this gen eral type can also be secured on railroad mount ings

Six types of front end operating equipment are standard crane clamshell dragline pile driver shovel and hoe Common crane boom eq uipment is used with crane clamshell dragline and pile driver The boom usually consists of two sections between which additional sections may be inserted

Shovel and hoe equipment have their distinctive mechanisms for operation (Fig 6)

Scoops and shovels Mobile scoops and shovels are used for handling bulk materials in plants and yards Lighter models are usually wheel mounted while those for heavier duty are apt to be carried on tractors (Fig 7) Two basic types are recog nized those that load and dump at the front or the rear and those with an up and over action which permits loading at the front end and discharging at the rear This last arrangement is frequently a time-saver in that it eliminates the need for maneu vering when loading wagons

Specialized equipment for mechanized pit min ing has been developed Power cranes shovels and scoops are actively engaged in strip mines quar ries and other earth moving operations

The rapid expansion of our highway systems has led to the widespread use of road making machines (Fig 8) Some of these are modifications of equip ment standard to this kind of work others are highly specialized Among the former are machines which have evolved by the addition of attachments to wheel and crawler tractors Machines like bull dozers and graders do not function as true handling equipment in that they do not pick up and trans-

port materials but push them On the other hand self loading scrapers do transport materials and are usually constructed so that they are either side or end dumping Other general purpose machines used in highway construction are trench diggers, hole diggers for utility poles and cable laying machines Highly specialized equipment is used for surfacing the road with concrete or other material

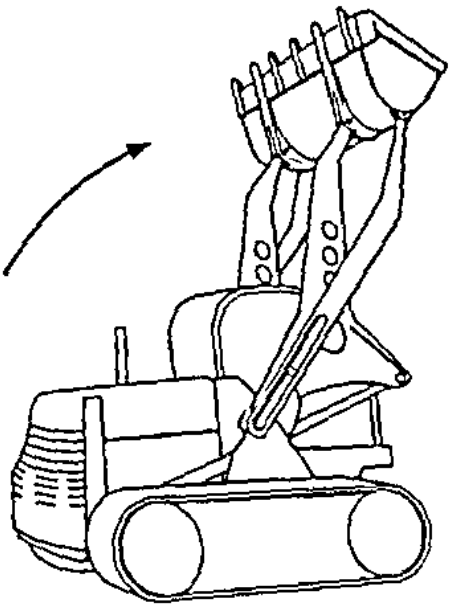


Fig 7 Up-and-over tractor shovel (*Service Supply Corp*)

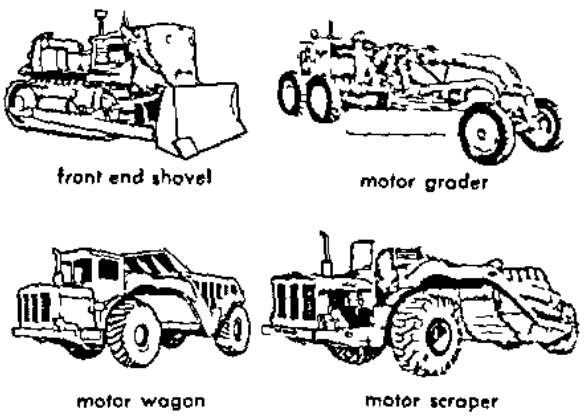


Fig 8 Earth moving and road making tractors

These marvels of mechanical ingenuity make possible the highways for our ever increasing over the road traffic [D O H]

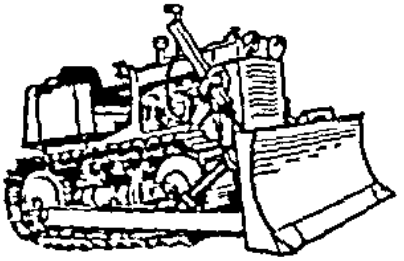
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Bulkhead

A structure primarily used to retain earth fill or protect embankments along the shore Bulkhead sometimes also serve as wharves They are usually used in comparatively sheltered areas and therefore require less strength against sea action than sea walls Sheet piling of timber, steel, or concrete is the most common form of construction with tie backs to "deadmen" buried in the earth Pile supported platforms behind sheet piling help to relieve the earth pressure against the sheeting, and platforms on the water side help to reduce the unsupported height of the sheeting Masonry or concrete gravity wall, and stone-filled crib construction are also used *See* Coastal engineering, Sea wall [L J Q]

Bulldozer

An assembly consisting of a reinforced, curved steel plate or blade and a frame which is attached to the front of a wheeled or crawler tractor for the purpose of pushing dirt, rock, or other materials as



Curved bulldozer blade mounted on crawler tractor (*Case*)

illustrated Blade widths vary from roughly 6 ft to about 25 ft and blade heights range from 2 ft to about 5 ft The blade may be straight angling or U shaped The U and straight blades mount perpendicular to the longitudinal axis of the tractor and push material straight ahead, the U blade because of its shape, can contain and move more material than the straight blade The angle blade can be set so that either of its ends is ahead of the other, thus it is useful in windrowing material or backfilling trenches Blades are controlled either by cables or hydraulic units The straight and U blades can be raised and lowered worked with one side lower than the other, and tipped forward or backward The angle blade cannot be tipped In common parlance, the term bulldozer erroneously includes the tractor *See* Earthmover [E M Y]

Bullsnake

Either of two species of moderately large constrictors of the genus *Pituophis* found in the United States Both are stout bodied, active and aggressive snakes and both produce a loud hissing sound when molested This noise can sound remarkably like the rattle of a rattlesnake Best known is *P catenifer* the gopher snake, ranging from the prairie regions of Indiana and Wisconsin westward to the Pacific

Coast and a characteristic member of the prairie fauna Its ground color is usually light brown overlaid with 40 or 50 brownish dorsal blotches The pine snake *P melanoleucas* of the eastern United States is more variable in color but is similar in pattern The ground color may vary from whitish or gray to black in different localities *See* SNAKE SQUAMATA [J D B]

Bunting

Any of several small brightly colored sparrowlike birds The North American genus *Passerina* has six species with four in the United States The indigo bunting *P cyanea* occurring over most of the eastern United States is the best known The male is brilliant blue with black wings and tail the female is brown The related lazuli bunting *P amoena* looking much like a miniature bluebird with white wing bars is found from the Great Plains westward The painted bunting *P ciris* of the southern United States is gaudily colored showing a riotous mixture of brilliant red green and indigo blue The varied bunting *P versicolor* is similar but with a plum colored body and a blue and red head it just reaches the southern border from Texas to California

The lark bunting *Calamospiza melanocorys* is a stout built prairie sparrow the breeding male of which is solid black except for a large white wing patch Females the young and autumn males are brown streaked This bunting breeds in the northern Great Plains and migrates southward into Mexico

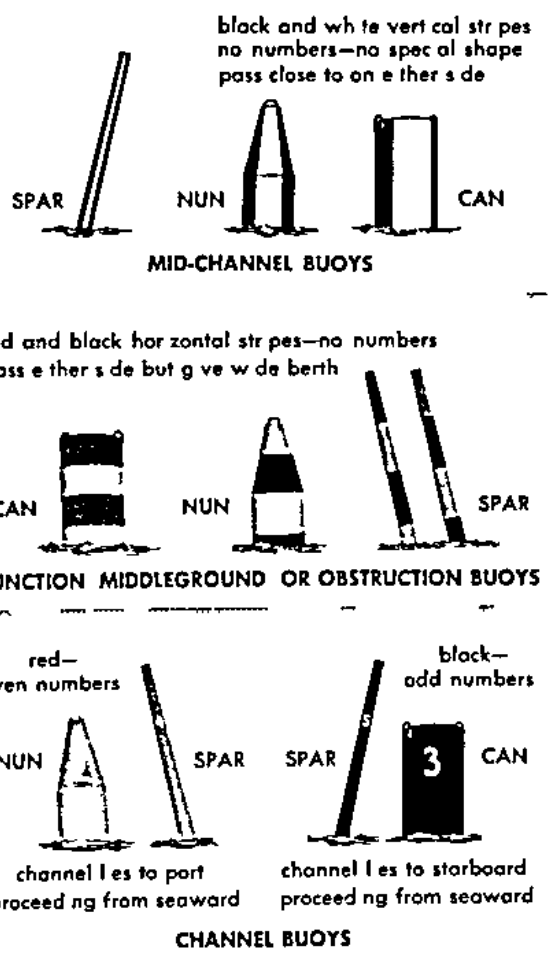
The circumpolar snow bunting *Plectrophenax nivalis* which nests in the Arctic tundra is a pale brown and white bird whitest of the songbirds showing almost all white in flight It frequently travels in large flocks and winters southward in this country to North Carolina and Colorado *See* PASSERIFORMES [J D B]

Buoy

An anchored or moored floating object other than a lightship intended as an aid to navigation Buoys are the most numerous of all man made aids to navigation there being some 20 000 in United States waters alone

A great variety of buoys are in use All are intended to serve as daymarks Some buoys particularly those at turning points in channels are provided with lights of distinctive characteristics for location and identification at night Some buoys are equipped with apparatus for providing distinctive sounds at intervals so they can be used as aids to navigation in fog and darkness Some buoys are equipped with radiobeacons and some have reflectors to make them more conspicuous to radar

Two general systems of buoyage are in use In the cardinal system buoys are assigned shape color and number in accordance with their locations relative to the nearest obstruction In the lateral system used in a modified form in United States waters buoys are assigned shape color and number in accordance with their locations relative



Representative types of buoys (*Modified Boating's Chart of the U S Buoyage S*

to navigable waters In United States waters the expression "red right returning" reminds mariners that red buoys are on the right side of the channel for a vessel entering port See PILOTAGE [A.B.W.]

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Buoyancy

The resultant vertical force exerted on a body by a static fluid in which it is submerged or floating The buoyant force F_B acts vertically upward in opposition to the gravitational force that causes it (see AEROSTATICS) Its magnitude is equal to the weight of fluid displaced and its line of action is through the centroid of the displaced volume which is known as the center of buoyancy With V the displaced volume of fluid and γ the specific weight of fluid (weight per unit volume) the buoyant force equation becomes $F_B = \gamma V$ The magnitude of the buoyant force must also be given by the difference of vertical components of fluid force on the lower and upper sides of the body See FLUID STATICS HYDROSTATICS

By weighing an object when it is suspended in two different fluids of known specific weight the volume and weight of the solid may be determined See ARCHIMEDES' PRINCIPLE

Horizontal buoyancy Another form of buoyancy called horizontal buoyancy is experienced by models tested in wind or water tunnels Horizontal buoyancy results from variations in static pressure along the test section producing a drag in closed test sections and a thrust force in open sections These extraneous forces must be subtracted from data as a boundary correction Wind tunnel test sections usually diverge slightly in a downstream direction to provide some correction for horizontal buoyancy

Stability A body floating on a static fluid has vertical stability A small upward displacement decreases the volume of fluid displaced hence decreasing the buoyant force and leaving an unbalanced force tending to return the body to its original position Similarly a small downward displacement results in a greater buoyant force which causes an unbalanced upward force

A body has rotational stability when a small angular displacement sets up a restoring couple that tends to return the body to its original position When the center of gravity of the floating body is lower than its center of buoyancy it will always have rotational stability Many a floating body such as a ship has its center of gravity above its center of buoyancy Whether such an object is rotationally stable depends upon the shape of the body When it floats in equilibrium its center of buoyancy and center of gravity are in the same vertical line When the body is tipped its center of buoyancy shifts to the new centroid of the displaced fluid and exerts its force vertically upward intersecting the original line through the center of gravity and center of buoyancy at a point called the metacenter A floating body is rotationally stable if the metacenter lies above the center of gravity The distance of the metacenter above the center of gravity is the metacentric height and is a direct measure of the stability of the object See SHIP DESIGN [H.L.S.]

Buret

An instrument used to deliver variable volumes of a liquid Burets are usually made from uniform bore glass tubing in capacities of 5–100 ml the most common being 50 ml The uniform portion is graduated in small divisions so that volumes of liquid accurate to a small fraction of a ml can be measured by reading the volumes in the buret before and after sample has been withdrawn For the most accurate use of burets the graduations should be calibrated by the user and liquid levels in the buret should be estimated to one-tenth of the smallest interval between graduations Most burets are equipped with a stopcock to control the flow of liquid A schematic drawing of a common buret is shown in the illustration Various



Buret

modifications of the basic design of a buret have been introduced to simplify its use or to increase its accuracy For example with a weight buret the quantity of liquid delivered is determined from the change in weight Special modifications have been employed in microanalysis where a capacity of 0.1 ml is frequently employed See TITRATION, VOLUMETRIC ANALYSIS [E.E.B.]

Burlap

Coarse cloth woven from jute fiber and known in Europe as hessian It is woven in varying degrees of fineness primarily in India and East Pakistan but also in Scotland Belgium and Italy All burlap used in America is imported In various grades it

is used as bagging for granulose and other prod ucts as paddings and linings for cheap clothing ing is made from a heavier jute fiber of poorer quality and is used in bags for coarse bulk prod ucts such as potatoes in strips for baling and in sheets for curing concrete for road construction *See* JUTE [C CO]

Burn

An injury to tissues caused by heat chemicals elec *tricity* or irradiation effects

Thermal injury The most common type of burn is that due to thermal injury in which some por tion of the body surface is exposed to either moist or dry heat of sufficient temperature to cause local and systemic reactions Clinically the extent of such a burn is often expressed as first degree sec ond degree and so forth Different systems of clas sification exist

First degree burns result in some redness and swelling of the injured part without necrosis of any tissue or the formation of blisters Healing is completed in a few days without scarring

Second degree burns show a variable destruction of parts of the epidermis so that blistering occurs Healing by regeneration in such superficial burns does not necessitate skin grafting unless second ary infections ensue no scarring results

Third degree burns are marked by complete de- struction of the epidermis of a region including the necrosis of accessory skin structures like hair and sweat glands A brownish black eschar marks the destroyed tissue This is sloughed off and the defect becomes filled with granulation tissue that later consolidates and changes to form a dense thick scar Complications may occur without ade quate care and grafting is not unusual sometimes being required by the contracture of the scar tis sue

In fourth degree burns tissue is destroyed to the level of or below the deep fascia lying beneath the subcutaneous fat and connective tissue of the body Muscle bone deeper nerves and even organs may be *injured or destroyed by this severe degree* of burn Healing is usually a slow involved process requiring much reparative and reconstructive work by surgical specialists

Depending on the duration extent severity and site of the burn there may be systemic reactions to injury Pain altered blood flow edema shock in fection and fluid and electrolyte imbalances are common In add tion there may be specific or non specific injury to certain organs through as yet ill understood mechanisms For example in certain cases of severe burn superficial ulceration of the stomach is found which is known as Curling s ul cer Renal damage may be related to fluid change or may appear as a serious tubular lesion called lower nephron nephrosis in which casts of red blood cells block the kidney tu

changes focal liver necrosis and direct or indirect sequelae may be seen in other organs On the other hand in certain cases of death following sudden exposure to high temperatures no tissue or organ changes are detectable

Electrical burns Electrical burns result from the amount of heat incident to the flow of a certain amount of electricity through the resistance of fered by tissues From a practical standpoint most of the resistance offered to the passage of an elec tric current is that of the skin and the interface be tween the skin and the external conductor There fore most electrothermal injuries are limited to the skin and immediately subjacent tissues al though deep penetration may follow large voltages

Such burns then are often small in area but with much tissue destruction Small pitlike depressions not seen in other forms of burns may be produced by arcing of the current The systemic effects are well known especially when used purposefully by society

Chemical burns Most chemical burns result from the action of corrosive agents which destroy tissue at the point of contact Exposure of the skin eyes and gastrointestinal tract are most common The corrosives may be either acid or alkali the main feature being the Hydrogen or hydroxyl con centration Extremes above pH 11 5 or below 2 5 are not tolerated and will almost always result in irreversible damage

Acids tend to be neutralized by the available or exposed tissue while alkalis continue to cause dam age unless neutralized by other means Protein breakdown is most prominent being marked by coagulation precipitation and actual dissolution of tissue constituents

Sulfuric acid produces blackened charred tis sue hydrochloric acid a white to gray tan discol oration while the alkalis produce a softer more edematous lesion which tends to spread unless the chemical is neutralized

For burns from various types of radiation *see* RADIATION INJURY (BIOLOGY) *see also* SHOCK SYNDROME [E G ST]

Burning velocity measurement

Experimental determination of the speed with which the region of combustion reaction moves in a flammable mixture Liberation of chemical energy by combustion is an everyday occurrence of great importance in the production of heat and power To

is affected by many factors such as fuel type air fuel ratio temperature pressure and flow condi tions *See* COMBUSTION

Because flame speed is also affected by the ap paratus used for measurement it is desirable to define a particular flame speed which is charac teristic of the combustible mixture but which is in dependent of the surroundings Such a flame speed

as the normal velocity of the reaction zone relative to nonturbulent unburned gas

Burning velocity is a characteristic of the unburned mixture that depends only on the composition temperature and pressure of the mixture Burning velocity can be expressed as the volume rate of mixture transformation per unit area of flame

Experimental difficulties in measuring burning velocity arise because of the effect the burning process has on the unburned gases The increase in temperature across a flame results in a change in density and velocity of the products which may cause motion in the unburned gas See COMBUSTION WAVE MEASUREMENT

Idealized and actual flames Experimental measurements of burning velocities have been made on both stationary and on moving flames Bunsen burners furnish a familiar example of stationary flames (Fig 1) If the inner cone of a Bunsen

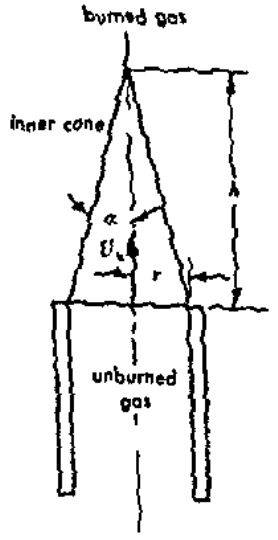


Fig 1 Geometry of Bunsen flame

flame were a geometric cone whose base *coincided* with the port the burning velocity S_u would be simply the volume of unburned gas *entering per unit* time per unit area of flame cone

$$S_u = \frac{\text{area of port} \times \text{average gas velocity}}{\text{area of flame cone}}$$

Expressed in terms of the *port radius* r cone height h angle α which one side of the *cone makes with its axis* and average gas velocity U_u this be *comes*

$$S_u = \frac{rU_u}{\sqrt{r^2 + h^2}} = U_u \sin \alpha$$

In this idealized flame *all unburned* gas m

from this ideal As an example the location of the flame cone defining the front of the combustion wave is not infinitely thin, photography by direct shadow and schlieren techniques do not coincide indicating that each measures a different location for the combustion wave See SCHLIEREN PHOTOGRAPHY

Most burning velocity measurements have been made in Bunsen burners with cylindrical tubes and the effluent gases in laminar flow Various corrections have been applied to compensate for the parabolic gas flow the distortion at the tip and the effect of the burner rim which acts as a heat sink However flame speeds obtained by measuring the cone with the schlieren technique probably approximate the burning velocity more accurately than other interpretations of Bunsen flames

Measurement techniques Measurement of burning velocity from moving flames has been made in several types of apparatus Studies of flames moving through open tubes containing combustible gases at rest are subject to error due to quenching convection and acoustic effects

Soap bubbles blown with homogeneous combustible gas mixtures have been used as a constant medium Spark ignition at the center of the bubble will propagate a combustion wave at *constant pressure* through the mixture The flame speed, however is amplified by expansion of the burned gases behind the flame front

Measurements on such a flame are made photographically by observing the growth of the flame radius through a slit as the film moves past the slit (Fig 2) If an initial volume of gas of radius r_1

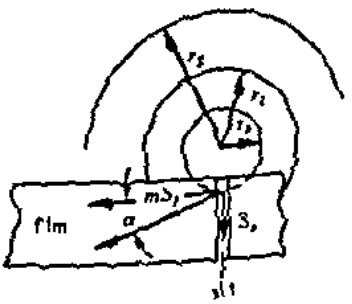


Fig 2 Film moves past slit to record growth of flame rad us

burns to a final volume of radius r_2 and is measured on a film moving with a velocity S_f and a magnification factor m the flame speed S_u in space is given by

$$S_u = mS_f \tan \alpha$$

where α is the angle made with the film axis due to growth of the flame The expansion ratio E is also a function of the burned gas density ρ_b and unburned gas density ρ_u

$$E = \left(\frac{r_2}{r_1}\right)^3 = \frac{\rho_u}{\rho_b}$$

The mass of gas entering and leaving a unit area of combustion wave per unit time is

$$S_u\rho_u = S_s\rho_b$$

or

$$S_u = S_s\rho_b/\rho_u = S_s/E$$

Afterburning which affects the precision of measurement of the final radius can be eliminated by surrounding the bubble with inert gas The method can be used at various pressures by placing the entire apparatus inside a pressure controlled chamber

Another technique for measuring burning velocity in which adequate control of gas composition is maintained is combustion in spherical bombs with central ignition Since reaction occurs under constant volume conditions in this apparatus the calculations to find the burning velocity are much more complex the references cited give an explanation

Maximum burning velocity in air mixtures of most hydrocarbons under atmospheric conditions varies from 25 to 100 cm/sec Typical gasoline hydrocarbons have burning velocities in the range of 30–40 cm/sec [R S S]

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Bursa

A simple sac containing a clear slightly sticky fluid interposed between two moving surfaces to reduce friction Subcutaneous bursae may be single or multiple They may enlarge as the result of continuous pressure or irritation as in housemaid s knee and miner s elbow

Synovial bursae are small closed sacs of fibrous tissue lined with membranes which secrete a clear lubricating fluid communicating with a regular joint cavity

Bursae may form between any two surfaces in contact and where motion occurs but commonly they occur between a tendon and another structure such as a bone ligament muscle or another tendon *See* MUSCULAR SYSTEM SKELETAL SYSTEM [E G ST]

Bursitis

Any inflammation of a bursa Bursae are connective tissue sacs cystic in appearance and filled with fluid which lie between two moving parts They occur for example around joints and between tendons muscles and ligaments In many cases they are continuous with a regular joint cavity or may extend to become continuous with one Most persons believe that bursae exist as normal but irregularly apparent structures but there is some evidence that they are pathologic alterations of connective tissue produced by irritation and friction In any case their formation is usually achieved without the production of symptoms unless inflammation occurs

Inflammatory changes produce acute or chronic swelling an increase in the fluid contents and variable degrees of pain and tenderness Although most bursitis is nonspecific it may follow the invasion of certain organisms or may result from trauma or physical stress

In chronic bursitis the wall becomes thickened shaggy and irregular with calcium deposits commonly present The fluid changes to a reddish brown or blackened gritty mass which represents repeated hemorrhages and calcium precipitation

Treatment is conservative and symptomatic unless surgery is required to restore function of a part The use of x ray and steroids in recent years has waxed and waned and both methods of therapy have their advocates and opponents *See* CONNECTIVE TISSUE [E G ST]

Bus

A wheeled trackless self propelled vehicle for mass transportation of people It is built in several models to carry from 9 to more than 50 people in city intercity suburban transcontinental and school service

Design objectives are to obtain maximum passenger carrying capacity within minimum over all vehicle length for economy of operation and best maneuverability in traffic congested areas

Motive power is provided by a gasoline or diesel fueled engine having 4–6 cylinders Brake horsepower ranges from about 36 at 3700 rpm to 254 at 2400 rpm

Small buses particularly those used for transporting school children commonly have the engine mounted in the front of the vehicle and in other respects construction is similar to that of a passenger car or lightweight truck The engine of a large bus may be placed under the floor of the vehicle or in the rear where it may be mounted crosswise on the frame This positioning leaves an uncluttered front entrance for loading and unloading of passengers (Fig 1)

A compact short wheelbase bus which seats 9–12 passengers is common in Europe It is powered by an engine mounted ahead of the front axle with drive to the front wheels or mounted in the rear with rear wheel drive (Fig 2)

Transmissions are manual semiautomatic or automatic in operation and have four or five forward speeds or infinitely variable speeds Auto

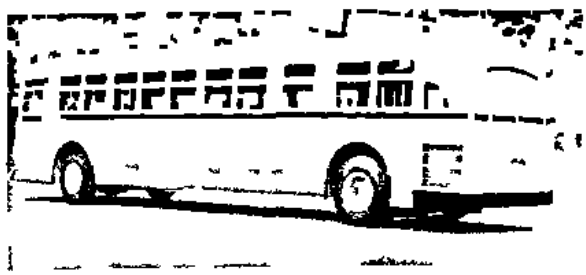


Fig 1 Bus for city transportation rear-mounted engine (*Mack Trucks Inc*)

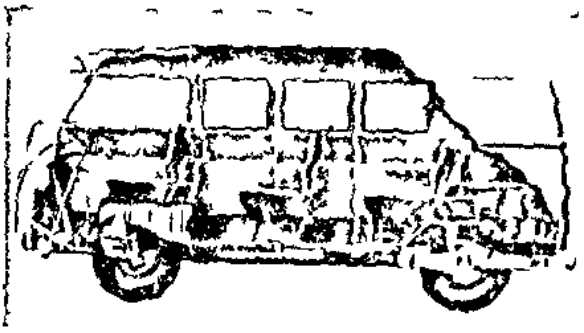


Fig 2 Nine passenger bus with rear-mounted engine and drive to rear wheels represents compact European design

matic transmissions are widely used on buses engaged in stop and go city travel

Frames resemble those used on trucks because of the need for great strength and rigidity to carry the heavy loads *See* AUTOMOTIVE FRAME

The sprung weight of the vehicle is carried on leaf springs and occasionally on air suspension

A typical bus braking system includes a hand operated brake on the propeller shaft to hold the vehicle when standing still and service brakes on all four wheels operated by compressed air *See* AUTOMOTIVE VEHICLE [P H S]

Bus bar

An electric conductor that serves as a common connection for one polarity or phase of three or more circuits Two or more bus bars, which serve all polarities or phases of the circuits are collectively called simply a bus

Bus bars are distinguished from connection bars which interconnect devices in the same circuit or connect the circuit to the bus bar

Bus bars range in physical size according to the current they are intended to carry from conductors on printed circuit boards of electronic apparatus sometimes carrying only microamperes to the huge assemblies of copper or aluminum bars that carry hundreds of thousands of amperes to the electrolytic cells of aluminum reduction plants *See* CONDUCTOR ELECTRIC WIRING (ELECTRIC) [W N C]

Bushing

A removable metal lining usually in the form of a bearing to carry a shaft Generally a bushing is a small bearing in the form of a cylinder and is made of soft metal or graphite filled sintered material Bushings are also used as cylindrical liners for holes to preserve the dimensional requirements An example of this use is the guide bearings in jigs and fixtures for drilling holes in machine parts [J J R]

Bushmaster

The largest of all New World poisonous snakes This huge snake *Lachesis mutus* attains a length of 12 ft although the average size of adults is 8 or 9 ft It ranges from Central America through tropical South America but is not common anywhere Although somewhat resembling rattlesnakes, the bushmaster is more slender than the larger rattlers Its coloration is striking varying from pale brown to pinkish and marked with a series of dark blotches It has long fangs and is extremely dangerous not only because of its fangs and size but also because it is both nocturnal and aggressive The bushmaster is the only viper that lays eggs *See* SNAKE, SQUAMATA [J J R]

1,3 Butadiene

A colorless gas at normal temperature and pressure boiling point (760 mm Hg) −4.41°C melting point −108.9°C, density 0.621, formula C_4H_6 Current production of butadiene in the United States is in the order of 1,500,000,000 lb per year making it a major product of the petrochemical industry While most butadiene is produced today by dehydrogenation of normal butylenes and butane or by steam cracking of naphthas, about 20% of the butadiene used in the production of GR S rubber during World War II was made in a two-stage process from ethyl alcohol via acetaldehyde Recovery of butadiene from crude streams is effected by fractionation extraction with ammoniacal cuprous acetate and extractive distillation At the present time, manufacture of synthetic rubber latex paints and nylon account for nearly all the butadiene consumed in this country Chemically butadiene may form addition compounds in the 1 2 or 1 4 positions, it may cyclize to heterocyclic compounds to give five-membered rings, it may dimerize and condense with other diolefins or dienophiles to give six membered rings and it may polymerize to give rubbery homopolymers or copolymers For a discussion of the commercial production of isosebacic acid and the synthesis of cyclododecatriene see CYCLODODECATRIENE, see also DIELS ALDER REACTION DIENE RUBBER. [C.A.C.]

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Butane

An alkane having the formula C_4H_{10} of which there are two isomers *n* butane $CH_3CH_2CH_2CH_3$ (boiling point −0.5°C) and isobutane $(CH_3)_2CHCH_3$ (boiling point −11.7°C) Both butanes occur in petroleum and natural gas and are produced by the cracking of petroleum The proportion of isobutane formed in catalytic cracking is greater than in thermal cracking

The butanes are components of the domestic fuel, liquefied petroleum gas (LPG) They are also important volatile constituents of gasoline

Either of the butane isomers can be catalytically converted to an equilibrium mixture of the two They can be dehydrogenated to the corresponding *n* butylene (three isomers 1 butene cis 2 butene and trans 2 butene) and isobutylene Both butanes

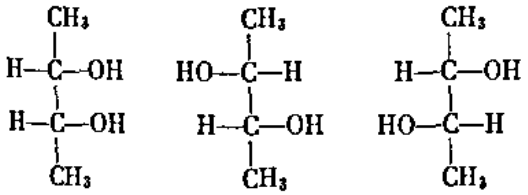
can be thermally alkylated and isobutane can be catalytically alkylated with olefins to produce branched chain alkanes *See also* ALKANE ALKYLATION DEHYDROGENATION ISOMERIZATION

[L S]

2 3 Butanediol

A possible source for 1 3 butadiene used for the production of synthetic rubber and a source for a permanent type antifreeze (*see* 1 3-BUTADIENE) Other compounds readily made from 2 3 butanediol are methyl ethyl ketone methyl vinyl carbinol and methyl vinyl ketone The last two compounds are used in the plastics industry

Preparation of 2 3-butanediol also referred to as diol or 2 3 butylene glycol has been by fermentation on a pilot plant basis It is the major fermentation product of several species of bacteria found in the genera *Aerobacter Bacillus Serratia* and *Pseudomonas* (*see* FERMENTATION) As depicted by the following planar projection formulas it exists in three stereoisomeric forms



meso 2 3 Butanediol — D(−) 2 3 Butanediol — L(+) 2 3 Butanediol

Most bacteria produce the meso isomer with only traces of the D(−) or L(+) forms (*see* CARBOHYDRATE OPTICAL ACTIVITY) However *Bacillus polymyxa* is exceptional in that it produces more than 98% of the D(−) form This is an important consideration if the glycol is to be used as antifreeze Here the meso form is useless whereas the D( ) isomer makes a good permanent type antifreeze

Fermentation Bacteria which have been studied carry out three main types of 2 3 butanediol fermentations on glucose under anaerobic conditions These fermentations may be depicted by the following equations

Diol hydrogen (1)

$$C_6H_{12}O_6 \rightarrow CH_3\,CHOH\,CHOH\,CH_3 + H_2 + 2CO_2$$

Glucose — 2 3 Butanediol — Hydrogen — Carbon dioxide

Diol formic acid (2)

$$C_6H_{12}O_6 \rightarrow CH_3\,CHOH\,CHOH\,CH_3 + HCOOH + CO_2$$

Diol glycerol (3)

$$3C_6H_{12}O_6 \rightarrow 2CH_3\,CHOH\,CHOH\,CH_3 + 2CH_2OH\,CHOH\,CH_2OH + 4CO_2$$

Glycerol

In addition to the products shown in the above equations ethyl alcohol and lactic acid are also produced in varying amounts and are indicated in Eqs (4) and (5) *See* ETHYL ALCOHOL LACTIC ACID

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (4)$$

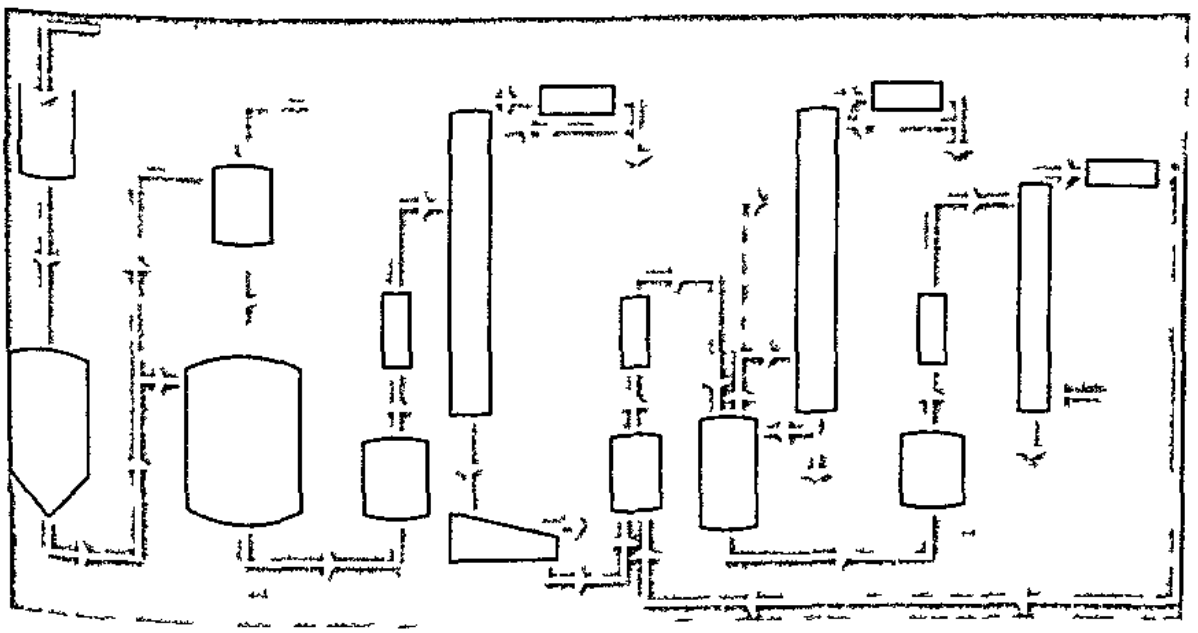
Ethyl alcohol

$$C_6H_{12}O_6 \rightarrow 2CH_3\,CHOH\,COOH \quad (5)$$

Lactic acid

A comparison of yields of the above products in fermentations brought about by five species of bacteria all grown on 5% glucose under anaerobic conditions is shown in the table

Comparison of the yields by different bacteria solely under anaerobic conditions does not give a



Flow chart of 2 3 butanediol production

Comparison of various fermentation reactions

Organism*	Sugar utilized in anaerobic production of following compounds, %				
	Diol hydrogen (1)	Diol formic acid (2)	Diol glycerol (3)	Ethyl alcohol (4)	Lactic acid (5)
Aerobacter aerogenes	52	2		23	2
Bacillus polymyxa	53			36	2
Pseudomonas hydrophila	56			26	12
Serratia marcescens	1	57	1	27	6
Bacillus subtilis (Fortune type)			84	3	8

* The difference between the percentage of sugar utilized by each organism and 100% is accounted for by the cell material produced

true picture of their real potentialities All 2,3-*butanediol* fermentations are quite sensitive to changes in conditions such as aeration pH or sugar concentration In the presence of oxygen all these organisms dissimilate glucose according to the equation

$$C_6H_{12}O_6 + 1\tfrac{1}{2}O_2 \rightarrow$$

Glucose

$$CH_3\,CHOH\,CHOH\,CH_3 + 2CO_2 + H_2O$$

Under aerobic conditions free hydrogen production is lowered for the first three bacteria listed in the table S *marcescens* gives little formic acid and *B subtilis* yields scarcely any glycerol In general aeration increases the yields of 2,3-butanediol or its oxidation product acetoin ($CH_3\,CHOH\,CO\,CH_3$) as compared to the other products Oxygen retards ethyl alcohol formation by both *B polymyxa* and *A aerogenes* Automatic pH control is necessary to achieve the highest production of diol in the shortest possible fermentation time The optimum conditions for anaerobic fermentation of sucrose by *B polymyxa* are in a medium of 8% sugar concentration at 33°C with pH held at 6 2 by automatic additions of ammonium hydroxide Fermentation is complete in 30 hours giving 130 moles of diol and 122 moles of ethyl alcohol per 100 moles of sucrose fermented

Raw materials Most raw materials suitable for the production of industrial alcohol are also satisfactory for the manufacture of 2,3-butanediol These fall into three main groups (1) starchy substrates including corn wheat barley sweet potatoes and potatoes, (2) sugars and sugar residues such as beet and cane molasses (3) wood hydrolyzates and pulp mill residues including waste sulfite liquor although the waste sulfite liquor presents some problems *B polymyxa* produces its own amylolytic enzymes which hydrolyze whole grain mashes during fermentation

Recovery Recovery of 2,3-butanediol from fermented mashes is rather difficult because of its high boiling point (179–180°C) Various procedures have been studied including spray drying drum drying chemical conversion, dialysis solvent extraction and steam stripping In most processes the initial step consists of removal of ethyl alcohol then filtration or screening followed by concentration of the liquor by evaporation One of the above processes is then used to recover the diol With *grain fermentations* the most practical method of recovery was found to be vapor phase steam extraction

Industrial production So far no commercial plants for the production of 2,3-butanediol have operated Pilot plant studies with *B polymyxa* have shown however, that a yield of approximately 9 lb of diol and 6 lb of ethyl alcohol may be obtained from a bushel of wheat With *A aerogenes* grown on acid hydrolyzed wheat mashes yields of 13–14 lb of diol and small quantities of ethyl alcohol (0 75 1 5 lb) per bushel were recovered Similar results have been obtained with corn [C A L.]

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Butanol

Any one of the four isomeric alcohols having the formula C_4H_9OH and molecular weight 74 12. The butanols are colorless toxic flammable materials which are soluble in most organic liquids the solubilities of which in water depend upon their respective structures The chemical properties of the butanols depend on the position of the hydroxyl group in the molecule *n* Butyl alcohol and isobutyl alcohol are primary alcohols and therefore may be oxidized to the respective alde-

The butanols

Name	Synonym	Structure	Bp °C	Fp °C	Specific gravity
n Butyl alcohol	1 Butanol	$CH_3CH_2CH_2CH_2OH$	117 7	−90 2	0 81337
Isobutyl alcohol	2-Methyl-1 propanol	$(CH_3)_2CHCH_2OH$	108 1	−108	0 80576
sec Butyl alcohol	2 Butanol	$CH_3CH_2CHOHCH_3$	99 5	−114 7	0 81089
tert Butyl alcohol	2 Methyl 2 propanol	$(CH_3)_3COH$	82 5	25 55	0 77620

hydes or carboxylic acids whereas *sec* butyl alcohol gives methyl ethyl ketone upon oxidation, *tert* butyl alcohol cannot be oxidized without degradation

The butanols are obtained by hydration of butenes by the Fischer Tropsch reaction by oxonation of propene by aldehyde condensations by air oxidation of butanes and by fermentation of sugars

The major uses of butanols are as chemical intermediates in the manufacture of plasticizers monomers and solvents They are also used directly as solvents and extractants About 500 000 000 lb of butanols was produced in the United States in 1957 *See* ALCOHOL [J W L]

Butter

A food fat product made exclusively from milk or cream or both with or without common salt (NaCl) and added coloring Butter contains not less than 80% milk fat It is the most important individual food fat on a world basis with production as high as 8 000 000 000 lb per year Production in the United States is in the range 1 5 2 × 10⁹ lb As a spread for bread in baked goods and in confections butter is prized for the flavor that comes from the action of selected microorganisms on cream *See* MILK

This article considers butter manufacture butter oil ghee and butter microbiology

Manufacture On the farm this process is carried out by natural ripening of the cream churning and manually working to the desired consistency Country butter is more variable in flavor than creamery butter

At the [illegible] ent of carbonate reduces the acidity to 0 10–0 25% (calculated as lactic acid) Pasteurization and spraying or stripping under vacuum remove undesirable flavors and odors and reduce action of microorganisms Ripening is carried out at 50–70°F (10–21 1°C) by introduction of a 'starter prepared from a bacterial culture and pasteurized milk Usually about 5% of starter is added After ripening overnight color is added and the cream is agitated in large rotary churns 3–10 ft in diameter and 5 or more ft long this action converts the emulsion from water in oil to an oil in water type and coalesces the fat globules Temperature of churning usually ranges from 48 to 60°F (8 9 15 6°C) depending upon the season of the year and the hardness of the butter fat (it is softer in summer)

Churns revolving at 25–30 rpm have internal baffles which lift and drop the contents to provide agitation and splashing. One thousand lb of butter may be produced from 280 gal of cream After churning to the desired consistency the buttermilk is drawn off and the butterfat quickly washed with water The butter is then worked between grooved rolls which impart a kneading action Salt is added during working and the moisture content is adjusted to produce butter with 80% fat content After it is worked the butter is packaged or formed into prints and wrapped Continuous processes also are used for butter manufacture

Butter contains 80–81% fat 1–3% salt and 1% milk solids and water Butter is graded according to a flavor score usually falling in the range of 79 to 93 The higher the score the better the flavor

Butter oil This product is made by heating butterfat is reduced to a low level by drying the butterfat content being over 99% Although little butter oil is produced in the United States it is of importance in Australia and New Zealand It is usually canned is much more stable than butter and does not require refrigeration Because it is practically anhydrous spoilage by hydrolysis and microbiological action is eliminated Butterfat consists principally of mixed glycerides of saturated and unsaturated fatty acids in approximately the following percentages butyric 3 5 caproic 1 4 caprylic 1 7 capric 2 6 lauric 4 5 myristic 14 6 palmitic 30 2 stearic 10 5 longer chain saturated 1 6 decenoic 0 3 dodecenoic 0 2 tetradecenoic 1 5 hexadecenoic 5 7 octadecenoic 18 7 octadecadienoic 2 1 and longer chain unsaturated 0 9

Ghee A common food fat in India ghee is produced from boiled buffalo milk Its manufacture is similar to that of butter oil It can be kept for months or years without refrigeration but has a more intense flavor than butter or butter oil [F C D]

BUTTER MICROBIOLOGY

This section discusses the origin of flora (microorganisms) in butter the growth of flora the origin of defects in butter and control procedures used in butter manufacture

Origin of flora Microorganisms may occur in butter from (1) contamination of milk and cream during the milking and separating processes (2) use of certain types of equipment such as wooden churns and (3) intentional addition of starter cultures Microorganisms from the first two sources are not considered beneficial

When milk and cream are contaminated during the milking and separating processes pasteurization of cream usually results in the destruction of a high percentage of the organisms present Temperatures in the heat treatment are considerably above those employed for fluid milk and more than 99 9% of the microorganisms are frequently destroyed

Contamination may occur in butter from wash water and processing equipment especially with churns made of wood The irregular surface of the wood cracks loose bolts and the built in equip

ment for working butter are often sources of yeasts and molds which thrive in the enclosed residual buttermilk Thorough cleaning and sanitization with hot water or a sanitizer can eliminate the organisms but may ruin the wood Stainless steel aluminum churns are much better in this respect and are becoming more popular

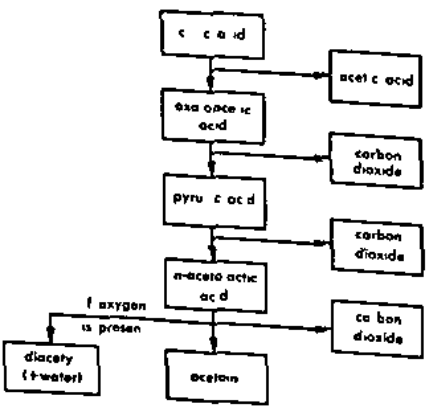
Butter cultures (starter cultures) are intentionally added to cream The cultures contain lactic acid bacteria of the *Streptococcus lactis* and *S cremoris* types to sour the cream And they contain *S diacetylactis* and *Lactobacillus citrovorum* types to develop the highly desirable flavor of butter by producing diacetyl from citric acid The illustration shows the production of diacetyl from citric acid

Procedures vary from country to country In the United States the culture is added only to the cream In many countries in Europe the cream is ripened to a high acidity In Finland the soured cream butter is sometimes neutralized by special salts

The propagation of butter cultures may be hampered by bacteriophages or antibiotics *See* ANTIBIOTIC BACTERIOPHAGE CHEESE

Growth of flora Microorganism growth in butter is limited by several factors The moisture in butter which contains most of the food for the organisms is divided by the working of butter into tiny droplets ($10–18 \times 10^9$ per gram) There are far fewer organisms than droplets so a large percentage of the droplets must be sterile even if the butter is highly contaminated O Rahn and his coworkers calculated the percentage of sterile moisture in relation to the bacterial count (see table)

Salt retards growth of various microorganisms in butter and acid impedes the growth of acid sensitive organisms Molds are restrained by the low air supply and low storage temperatures prevent multiplication of microorganisms in general Reworking of butter during printing may bring more organisms in contact with food and generally favors their growth Moreover recontamination can take place



Decompos t on of citric ac d to d acetyl the chief component of the butter aroma

Buttermilk bacterial count and sterile moisture in butter

Bacterial count	Sterile moisture %
1×10^3	45 2
1×10^4	57 1
1×10^5	62 5
1×10^6	71 0
1×10^7	88 0
1×10^8	99 0
1×10^9	99 9

Defects. Butter defects due to microorganisms include (1) a rancid taste caused by lipolytic organisms, (2) cheesy or even putrid taste caused by proteolytic organisms (surface taint) (3) musty taste caused by molds, (4) yeasty taste caused by yeasts, (5) malty taste due to *S lactis* var *maltigenes*, (6) acid taste from lactic or acetic acid bacteria, and (7) discolorations

Discolorations often are caused by molds Green, for example results from *Penicillium* black from *Cladosporium* These defects may be prevented by inhibitors in the parchment such as propionate and sorbic acid Defects in butter from ripened cream are caused most often by yeasts or molds whereas defects in butter from sweet cream are caused by asporogenous gram negative bacteria Defects may be present in the fresh butter or develop during storage Microbial defects result principally from lack of hygiene during processing

Control Keeping quality tests are used as a control procedure Butter is incubated under conditions simulating those which it is likely to encounter after leaving the creamery At regular intervals bacterial content is determined Total bacterial count can be estimated by the plate count, the microscopic count or the Burri technique But such tests give no useful information particularly if starter cultures are added Counting of harmful organisms such as proteolytic lipolytic and coliform bacteria molds and yeasts provides more valuable information Many investigators are of the opinion that the best test medium is a caseinate agar on which all microorganisms except lactic acid bacteria will grow It gives a fairly good indication of the contamination in general *See* FOOD ENGINEERING INDUSTRIAL MICROBIOLOGY MICROBIOLOGICAL METHODS [J W F]

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Butterfly

Any of a large number of species of the insect order Lepidoptera This order includes both the butterflies and moths Butterflies are distinguished by



Swallowtail butterflies (a) Black *Papilio polyxenes* wing span to 4 in (b) Tiger *Papilio glaucus turnus* wing span to 5 in (From E L Palmer Fieldbook of *Natural History* McGraw-Hill 1949)

their knobbed antennae slender bodies and diurnal habits and by holding their wings folded together over their backs when at rest

Adult butterflies have sucking mouthparts and feed primarily upon nectar The larvae called caterpillars have chewing mouthparts are plant eaters and many are highly destructive insects Many butterflies have pupae which do not spin cocoons and are called chrysalids Most species overwinter in the pupa *form but others may overwinter as* eggs larvae or adults Most species also produce a single generation each year

Butterflies are world wide in distribution and include some of the world s most colorful and showy animals *Several civilizations have used butterfly* wings as ornaments and in various art products

Although the caterpillars of many butterflies are destructive the adults frequently serve as pollinators of the very plants on which the larvae feed so that a *symbiotic arrangement occurs whereby* the butterfly and host plant are somewhat dependent upon one another for their continued existence

Among the more showy and better known butterflies are the monarchs viceroys swallowtails fritillaries, *admirals and buckeyes*

The brilliant orange and black monarch *Danaus plexippus* is one of the few insects with a regular migratory habit Adults fly southward in great flocks each fall and winter in rather dense concentrations the *survivors flying northward in the* spring

The viceroy butterfly *Basilarchia archippus* similar to the monarch in coloration is distinguished by its slightly smaller size and the black transverse band on the hindwings *It is thought that* the viceroy derives some protection from this mimicry of the monarch since the monarch is reputed to be decidedly distasteful to most birds and other insectivorous animals This is probably the best known of all examples of mimicry

The largest of the North American butterflies are the swallowtails readily distinguished by the tail like extensions on the hindwings One of these the tiger swallowtail *Papilio glaucus* occurs in two color phases In one phase represented by females only it is black with a marginal row of yellow spots in the other phase the basic color is yellow with yellow marginal spots set in black bars Both sexes occur in the yellow phase

The butterflies of the family Pieridae which includes the cabbage and alfalfa butterflies may have from three to six or seven generations a year in some species the adults of different generations have different color patterns

The fritillary butterflies of which there are several species are well known They are orange brown marked with short wavy black lines and dots above and with large silver spots beneath The fritillaries belong to the family Nymphalidae which also includes the painted lady red admiral and buckeye all common and strikingly beautiful American butterflies

Smallest of the butterflies are those in the family Lycaenidae including the blues coppers and hair streaks These frequently gather in large numbers about a damp spot and are among the more prominent insects in the late summer

Skippers are usually considered as a family of butterflies the Hesperiidae but are somewhat intermediate between moths and butterflies They are relatively small and stout bodied Most of them can be readily identified by the recurved tips of their antennae and by their habit of holding the front and hind pairs of wings at different angles when at rest *See* LEPIDOPTERA [J D B]

Bytownite

A plagioclase feldspar with a composition ranging from $Ab_{30}An_{70}$ to $Ab_{10}An_{90}$ ($Ab = NaAlSi_3O_8$ and $An = CaAl_2Si_2O_8$) In the high temperature state bytownite has albite type structure In the course of cooling natural material undergoes changes of

YO_4 tetrahedrons alternate in all directions in such a way that each XO_4 tetrahedron is surrounded by four YO_4 tetrahedrons and vice versa X and Y signify positions predominantly occupied by Al and Si respectively This type of ordering satisfactorily explains the doubling of the c axis periodicity as compared to that of the albite type structure *See* ANORTHITE FELDSPAR IGNEOUS ROCKS

[F LA]

Cabbage

A hardy cool season crucifier (*Brassica oleracea* var *capitata*) of Mediterranean origin and belonging to the plant order Papaverales Cabbage is grown for its head of overlapping leaves which are generally eaten raw in salads cooked fresh or processed into sauerkraut Because it normally produces seed the second year cabbage is considered to be a biennial by most authorities Others regard it a perennial because it will remain vegetative unless subjected to cold weather

Chinese cabbage is a related annual of Asiatic origin Two species are grown in the United States pe tsai (*B pekinensis*) and pakchoi (*B chinensis*)

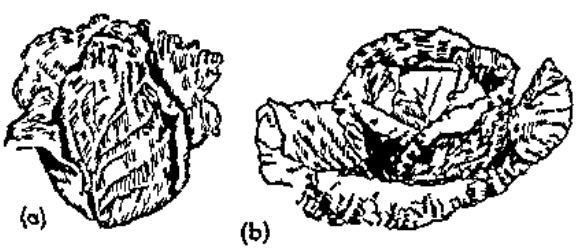
Propagation of cabbage is by seed planted in the field or in greenhouses and outdoor beds for the production of transplants Field spacing varies plants are usually 8–18 in apart in 30–36 in rows

Cool moist climate favors maximum yields of firm heads However exposure of young plants to prolonged low temperatures favors seed stalk for

tened round or pointed) and color (green or red) Round smooth leaved green heads are most common Popular varieties are Golden Acre Bonanza and strains of Danish Ballhead Principal varieties of other types are Chieftain (savoy) Jersey Wake field (pointed) Red Danish (red) and Wong Bok (Chinese cabbage) Strains of Danish Ballhead are also used for sauerkraut manufacture and for late storing Varieties differ in their resistance to disease and in the tendency for heads to crack or split in the field

Harvesting Harvesting of fresh market varieties begins when the heads are hard enough to be accepted on the market generally 60–90 days after field planting Buyer preference for heads weighing no more than 2 3 lb has encouraged close spacing and early harvesting In the northern states production of cabbage for winter storage has declined as the Texas and Florida winter areas have expanded production providing green cabbage as competition *for the white stored heads*

Texas and Florida are important winter crop producing states Georgia Mississippi and North Carolina produce large acreages in the spring and New York North Carolina and Wisconsin are important for the summer and fall crops Total annual farm value of the fresh market crop in the United States is approximately $40 000 000 New York and Wisconsin are the important kraut cab*bage states total annual farm value in the United* States is approximately $2 600 000 *See* PAPAVERALES VEGETABLE GROWING [H J C]



Cabbage (a) Conical type (b) Round headed type From L H Bailey ed *The Standard Cyclopedia of Horticulture* vol 1 Macmillan 1937)

Cabbage and cauliflower diseases Cabbage and other crops of the same species such as cauliflower brussels sprouts and collards are subject to more than 50 diseases of which only a few are widely destructive These include clubroot (*Plasmodiophora brassicae*) blackleg (*Phoma lingam*) yellows (*Fusarium oxysporum* f *conglutinans*) black rot (*Xanthomonas campestris*) and several virus diseases

Clubroot and yellows These diseases are similar in that the pathogens once introduced into the soil remain there almost permanently Neither disease is seed borne but both are often carried from place to place in infected transplants or soil

Yellows infects through the roots and becomes systemic causing leaves to turn yellow and leathery later they drop off Xylem vessels turn brown and plants die or fail to produce good heads The disease is most destructive in warm weather Yellows of cabbage may be prevented by growing resistant varieties which are commonly available This is an outstanding example of disease control by growing resistant varieties Yellows is of minor importance on other crucifers

Clubroot infects roots causing them to swell *There may be many infections on a single root* system preventing proper absorption of water and minerals from the soil and causing stunting of the plant The disease is favored by wet acid soils Infestation of the soil (usually by diseased transplants) should be avoided Once present clubroot can sometimes be reduced by liming however soil applications of pentachloronitrobenzene appear to be more successful Clubroot resistant cabbage has

been produced by breeding but not on wide scale

Blackleg and black rot Both of these diseases are seed borne and the pathogens persist in the soil for as long as 3 years Spattering rain causes secondary spread of both especially in seedlings

Black rot a bacterial disease can cause spots on the leaves but may also become systemic causing yellowed leaves and blackened vessels similar to cabbage yellows Affected leaves drop and infection of heads is often followed by soft rot

Blackleg causes gray dead spots on leaves and stems extending to the roots which are often destroyed killing the plant

Black rot and blackleg can largely be avoided by a 3 year rotation in fields and seed beds and by using disease free seed which is generally available from the Puget Sound area If seed is infected hot water treatment is very effective No resistant varieties of practical value are known

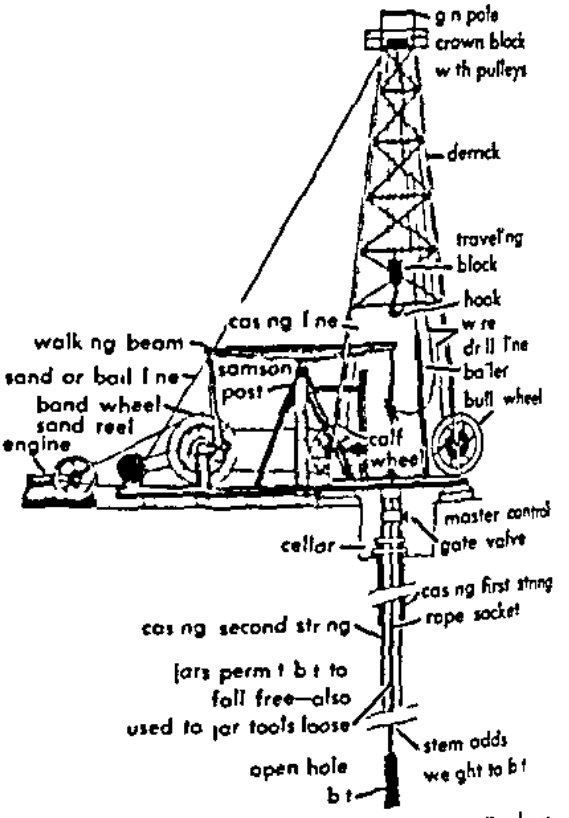
Virus diseases Four or more distinct viruses infect crucifers Symptoms include mottling ringlike dead spots stunting and black spotting in the tissues Some viruses affect various other crops and certain weeds and most are spread by plant lice These diseases may be reduced by planting seed beds away from infected weeds and other plants No resistant varieties are available *See* PLANT DISEASE PLANT VIRUS [C J F]

Cable tool drill

In drilling oil and gas wells a cutting tool or bit is suspended on a wire line and pounds through rock formations as the line is alternately raised and lowered generally 20–40 times per minute Water is poured into the bottom of the hole to keep the pulverized cuttings fluid When the slurry gets so thick that drilling is impeded the string of tools is pulled from the hole and a bucketlike *bailer* is used to remove the slurry This percussion process of drilling and bailing is continued until the desired depth is reached

The drilling string is about 40 ft long and consists of several parts A socket connects the string to the wire line and is attached to a sinker or short cylinder of steel which is used for weight This is followed by *metal links* called jars which permit movement in the string These in turn connect with a long cylindrical steel drill stem also added for weight The drill bit which cuts the hole screws to the bottom of the drill stem The bit can be of several types but generally is a heavy steel bar 7 8 ft long dressed to a blunt end on the cutting edge much like a *chisel*

Power is transmitted from an engine to a band wheel which operates a connecting rod or pitman that is anchored to one end of a walking beam The walking beam is supported at its center on a samson post so that *it resembles* a seesaw in action The drilling line is connected to the other end of the walking beam directly over the well bore and is raised and lowered alternately with each stroke of the walking beam The drilling line passes up through the derrick to a crown block and down to a bull wheel which is used to apply the power in hoisting or lowering the drill string



Cable tool or percussion drilling rig repeatedly drops bit against bottom of hole

A calf wheel lowers or lifts the heavy strings of casing or pipe used in lining the hole The cable on the calf wheel passes up through the derrick and down connecting to a hoisting or traveling block a hook and special clamps called elevators The elevators provide the means for suspending the casing from the hoisting block The sand wheel driven from the band wheel bails *out the* cuttings by means of the sand line and bailer *See* OIL AND GAS WELL DRILLING, ROTARY TOOL DRILL TURBODRILL [A L P]

Cacao

The plant *Theobroma cacao* also known as the chocolate tree is a small tropical tree of the sterculia family (Sterculiaceae) It bears flowers and fruits throughout the year (Fig 1) The fruits are fusiform (spindle-shaped) capsules containing a mucilaginous pulp and 40 or more seed The pods are picked by hand and opened *with* a knife The pulp and seeds are removed cured and usually fermented The beans are then *cleaned* sorted and roasted in iron drums After roasting the beans are passed through corrugated rollers to break the shells which are removed by winnowing Then the seeds or nibs are ground producing an oily paste which when cooled and hardened is the bitter chocolate of commerce Sugar is added to produce the sweet chocolate If the oily paste is put through a hydraulic press a white or yellowish fat cocoa butter is obtained Having the odor and flavor of chocolate cocoa butter is used to some extent in making chocolate but it is used mainly in cosmetics

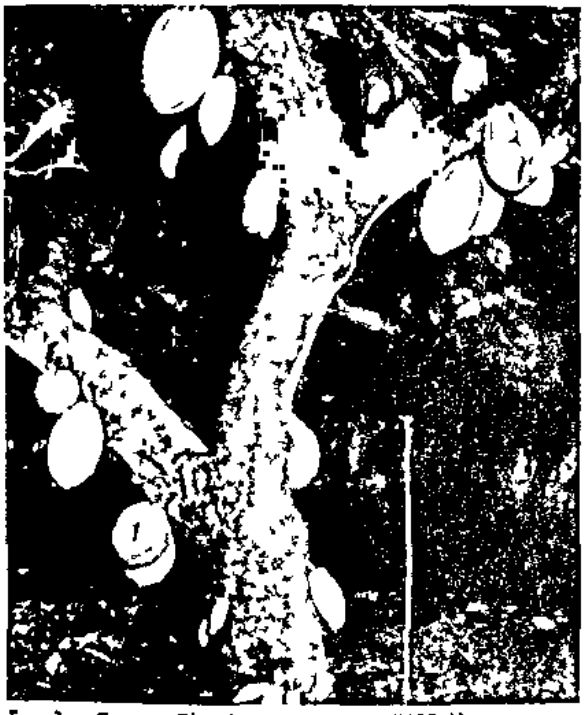


Fig 1 Cacao, *Theobroma cacao* (USDA)

and perfumes After two-thirds of the fatty oil has been expressed the residue is powdered to make the commercial cocoa The shells are used for making beverages, to adulterate cocoa and chocolate, as cattle food, and for fertilizer *See* COCOA POWDER AND CHOCOLATE, MALVALES [PDS]



Fig 2 The most widespread and severe cacao disease caused by *Phytophthora palmivora* (*Inter-American Institute of Agricultural Sciences*)

Cacao diseases. Many of the important and numerous diseases of cacao are found wherever the tree *Theobroma cacao*, is grown The organism, *Phytophthora palmivora*, is the most common and severe, causing decay of fruit, leaf, and shoot (Fig 2) The equally widespread anthracnose disease, *Glomerella cingulata*, induces fruit and leaf spots and causes chronic leaf fall or bare tip Both organisms are controlled by copper sprays Of serious concern also is the African swollen shoot caused by a virus which is confined at present to Africa

Armillaria causes bark splitting and root rot in Africa whereas black root rots, caused by *Rosellinias* are common in tropical America In many countries pellicularia web blight is found on the leaves One of the newest diseases is cushion gall, of undetermined cause It is characterized by excess growth on flowering pads and reduced fruit formation

The spectacular witches' broom, *Marasmius perniciosus*, of South America is locally destructive This disease is best controlled by resistant clones Another disease, pod rot, caused by *Monilia roreri* is reduced by spraying Once confined to Ecuador the latter disease spread to Colombia, and recently to Panama and Brazil There are other lesser troubles, including attacks by parasitic flowering plants *See* BACTERIA, FUNGI, PLANT VIRUS *see also* PLANT DISEASE CONTROL

[FLW]

Cachexia

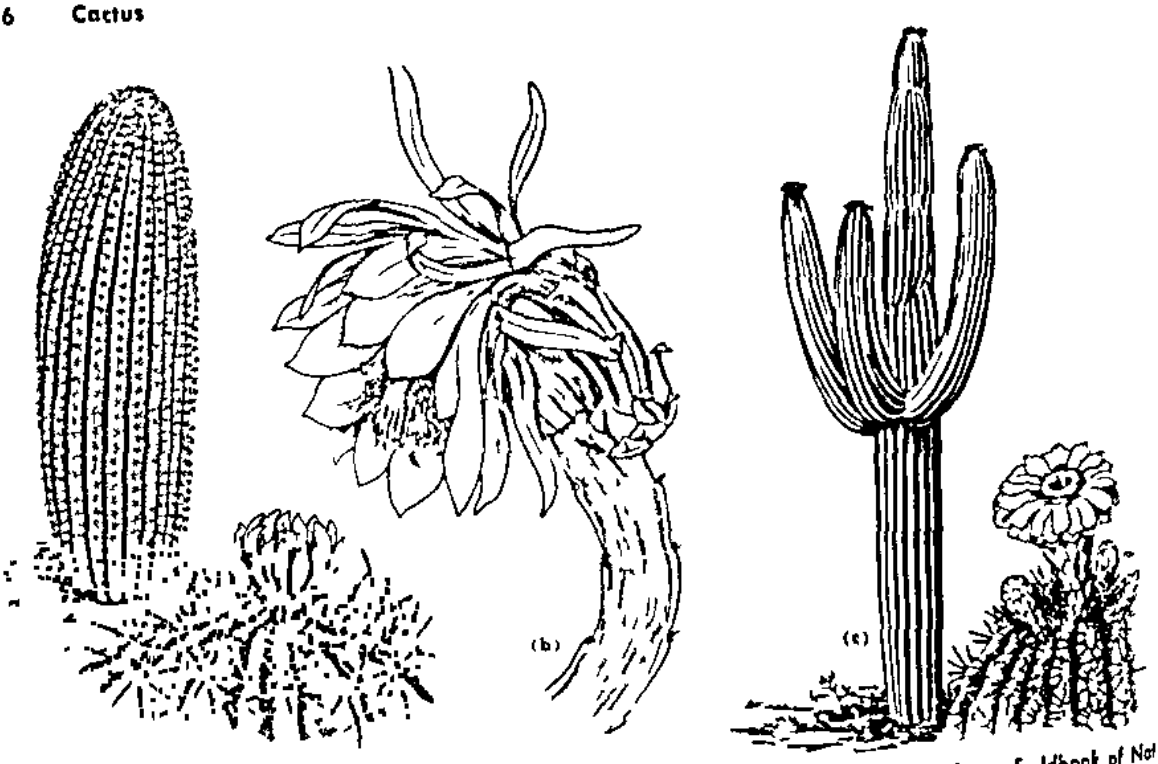
Weight loss weakness, and wasting of the body encountered in certain diseases or in terminal illnesses Cachexia is most often associated with some malignancy and appears to be the actual cause of death in many cases (*see* ONCOLOGY) Such death at a specific time is difficult to explain since often there are no obvious specific events which affect vital organs

The malignancy may be large or small, single or multiple although the frequency and degree of cachexia usually coincides with the extent of the growth No immediate explanation of such cachexia is available despite intensive investigation No specific toxins are elaborated, and the evidence for diversion of body nourishment to the tumor is unsatisfactory

Cachexia predisposes to other disorders principally infections There is little resistance to such processes and quite often the emaciated patient dies apparently as the result of a minor infection which would ordinarily not even incapacitate him *See* INFECTION

Extensive irradiation may also cause a cachexia marked by muscular weakness, poor appetite, weight loss and mental disturbances These may appear at some variable time after exposure sometimes not becoming pronounced for several months Recovery may occur or a chronic state of illness may ensue Usually death follows a gradual deterioration *See* RADIATION INJURY (BIOLOGY)

[ECST]



Types of cacti (a) Mule cactus height to 6 ft (b) Night blooming cereus, height to 40 ft (c) Saguaro height to 70 ft (*From E L Palmer, Fieldbook of Natural History, McGraw-Hill, 1949*)

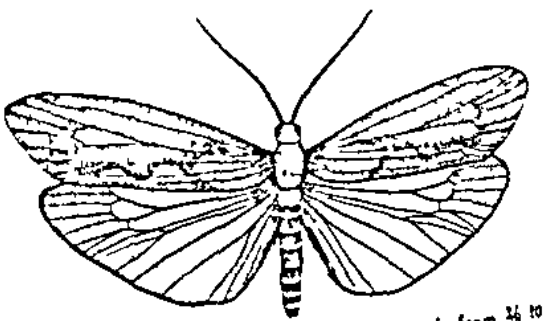
Cactus

The common name for any member of the cactus family (Cactaceae) There are 120 genera with perhaps 1700 species probably indigenous to America These are among the most extremely drought resistant plants and consequently they thrive in very arid regions The group is characterized by a fleshy habit presence of spines and bristles, and large, brightly colored, solitary flowers There is a great variety of body shapes and patterns, and many of the species are grown as ornamentals or oddities A few have edible fruits The cochineal insect, which produces a valuable red dye, is cultivated chiefly on the cochineal cactus, *Nopalea coccinellifera* The saguaro, *Cereus giganteus*, of Arizona and Sonora is the largest of the cacti, attaining a height of 70 ft *See* OPUNTIALES [P D S]

Caddis fly

Any member of the insect order Trichoptera Caddis flies resemble small moths but their wings are covered with hairs rather than scales There are two pairs of wings, held rooflike over the back when at rest Their soft bodies are well covered with hairs and their antennae are long and threadlike All are relatively small and drab in color Adults are nocturnal Caddis flies are sometimes a nuisance along rivers, and cases of allergic dermatitis from their hairs sometimes occur where they are abundant

The caddis fly larvae usually called caddis worms are aquatic They build cases from various materials, such as sand, gravel, and bits of leaves, which are bound together with silk The larvae live in these cases with their heads protruding from the open ends They capture animal and vegetable food as it drifts by. Several species are predatory upon other insects The larvae are important as fish food in some waters *See* TRICHOPTERA [J D B]



The caddis fly, *Phryganea vestita*, length from ⅜ to 1 in (*From E L Palmer, Fieldbook of Natural History McGraw Hill, 1949*)

Cadmium

Chemical element number 48, cadmium, Cd is a metallic element closely related to zinc, with which it is usually associated in nature F Strohmeyer discovered it in 1817 in a sample of zinc carbonate from Salzgitter, Germany

Cadmium does not occur uncombined in nature, and only one true cadmium mineral is known, greenockite (cadmium sulfide) found at Greenock Scotland The mineral is rare and almost all the cadmium produced is obtained as a by product of the smelting and refining of zinc ores especially zinc sulfide Zinc ores may contain as much as 0 5% cadmium *See* CADMIUM METALLURGY

The United States Mexico Canada Peru Tasmania Australia and Africa are principal sources of cadmium although not all are producers In the United States the largest producer and consumer more than 10 000 000 lb of cadmium were produced in 1956 Its purity averages 99 98% and the price in 1958 was $1 60/lb



Uses The commercial use of cadmium as an electrodeposited coating on iron and steel for corrosion protection started in 1919 and by 1941 it had become the largest use by far with pigment and chemical uses second The third largest use is as a constituent of low melting point alloys similar to Wood's metal used in automatic fire sprinklers and automatic shut offs for water heaters Relatively minor uses are in brazing and other alloys in the alkaline cadmium nickel electric storage cells and in atomic energy applications The cadmium nucleus combines very readily with thermal neutrons and was used in the first uranium pile as a reaction moderator

Physical properties Cadmium with a specific gravity (sp gr) of 8 64 is a beautiful silvery white ductile metal with a faint bluish tinge Its metallic radius is 1 54 A It is softer and much more malleable than zinc but slightly harder than tin Its melting point 321°C, and boiling point 767°C are lower than those of zinc There are eight naturally occurring isotopes 106 108 110 111 112 113 114 and 116

Chemical properties Cadmium is the middle member of group IIb (zinc cadmium and mercury) in the periodic table and its chemical properties generally are intermediate between zinc and mercury Cadmium like zinc loses its luster in moist air It is rapidly corroded by moist ammonia and moist sulfur dioxide and is readily attacked by most acids although more slowly than zinc Cadmium is unusually soluble in concentrated ammonium nitrate solutions Its oxide and hydroxide unlike those of zinc are insoluble in excess sodium hydroxide The cadmium ion is displaced by zinc metal in acidic sulfate solutions Cadmium is bivalent in all its stable compounds and its ion is colorless It forms the complex ions $Cd(NH_3)_4^{++}$ $Cd(CN)_4^{--}$ and CdI_4^{--}

Cadmium oxide CdO is a brown powder (sp gr 6 5) used mainly for makeup of cadmium electroplating baths It can be formed by burning the metal or heating the hydroxide The oxide does not melt at white heat It is more easily reduced to a metal by heating with hydrogen or carbon than zinc oxide and this as well as the fact that cadmium is more volatile than zinc is important in the recovery of cadmium in zinc smelting operations and from lead and copper smelting where zinc and cadmium are also present

Cadmium sulfide CdS is obtained as a bright yellow precipitate by passing hydrogen sulfide through a solution containing cadmium ions The precipitate is insoluble in cold dilute acids which distinguishes it from the yellow sulfides of arsenic and tin CdS (cadmium yellow) is one of the finest and most permanent pigments The sulfoselenide is cadmium red pigment *See* PIGMENT

Cadmium sulfate $3CdSO_4 \cdot 8H_2O$ is the electrolyte used in the Weston cell which gives a nearly constant potential (1 0186 volts)

Cadmium chloride $2CdCl_2 \cdot 5H_2O$ is effloresceent and unlike zinc chloride is not hydrolyzed during dehydration or in solution The cadmium halides are less ionized than are the corresponding halides of most other metals except mercury This is true of the iodide in particular and even the sulfide cannot be precipitated completely from a solution of the iodide Cadmium iodide is soluble in alcohol The cadmium halides are used to a small extent in photography

Electroplating of cadmium The principal use of cadmium is in the plating of iron and steel and to a much less extent of copper brass and other alloys to protect them from corrosion Although cadmium can be deposited from acidic baths such as the sulfate (used in electrowinning of cadmium) and fluoborate most all commercial plating for protective coatings is done in cyanide baths (20–25 g/liter of cadmium oxide dissolved in about 100–125 g/liter of sodium cyanide) because of its ease of operation and its good throwing power (good distribution of plate over a complex shape) Cadmium anodes 99 95% pure are used to replenish the metal as it is deposited on the cathodes and the plating process is usually done at room temperatures and low voltages (2–12 volts) and current densities of about 1–6 amps/dm² (approximately 10–60 amps/ft²) depending mainly on the metal concentration stirring and temperature Certain organic compounds (dextrins glue and surface-active materials) are used in the baths to decrease the grain size and improve the brightness of the deposit and the covering power Also the plated coatings are often given dips in chromic acid solutions for further brightening and antitarnishing effects or for formation of visible passive films which help improve the corrosion protection Cadmium even with thin plate (0 0002 in) offers good protection to iron and steel especially in rural and marine exposure Unlike zinc it is resistant to attack by alkali and also solders easily It does not form as voluminous corrosion products as does zinc and is therefore preferred for plating bolts nuts and fasteners It plates much more readily on malleable iron and cast iron than zinc and for all these reasons is used extensively *See* ELECTROPLATING OF METALS

Toxicity The fumes of cadmium and its compounds and solutions of its compounds are very toxic and cadmium coated articles should not be used in contact with food nor should cadmium plated articles be welded or used in ovens

Analytical methods The two most accurate methods of determining cadmium are the gravimetric determination of the sulfate and electrodeposition of cadmium from faintly alkaline cyanide solution

In 1954 the titration of cadmium ion with the chelating agent ethylenediaminetetraacetate (EDTA) came into use for rapid determinations Cadmium is also easily determined polarographically and this method is suitable for the determination of cadmium in the presence of zinc *See* ALLOY MERCURY (ELEMENT) METAL COATINGS ZINC [H BR]

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Cadmium metallurgy

The commercial occurrence of cadmium is exclusively in combination with zinc ores including complex ores of zinc copper and lead The normal cadmium content of zinc concentrates is less than 0 5% although in a few rare cases it may run to 1–2% Cadmium is therefore a by product of zinc lead and copper smelting The by products result in several ways (1) Cadmium is precipitated from the electrolyte of electrolytic zinc plants by the addition of zinc dust The sludge formed is a mixture of metallic cadmium and metallic zinc (2) A similar product results from the purification of zinc sulfate solutions in the manufacture of zinc salts and pigments (3) The fume from plants sintering zinc calcines contains some cadmium Salt (sodium chloride) is sometimes added to the sinter charge to increase the elimination of cadmium in which case the cadmium in the fume is predominantly cadmium chloride (4) Fume recovered from copper and lead smelting operations may contain sufficient amounts of cadmium to warrant recovery (5) The refining of zinc by distillation yields a fraction of high cadmium content The cadmium content of these cadmium by products may run from as little as 2 3% to 25% or more

The methods for recovering metallic cadmium from these by products vary widely in detail depending on the raw material or combination of raw materials being treated All the commonly used processes employ one or more of the steps discussed below

If the cadmium is present as chloride it may be leached directly If cadmium is present in metallic or partly oxidized form it is oxidized [illegible] expel the two major impurities by controlled additions of zinc dust and the lead and copper content may be recovered Sulfate solutions are similarly freed from copper The cadmium may then be precipitated by cementation with zinc in slab form the cadmium sponge being periodically recovered washed filtered and melted down with caustic, or briquetted and distilled Further purification may be carried out by simple distillation

Cadmium in a purified sulfate solution may be electrolyzed and the cathode cadmium melted for casting into finished product

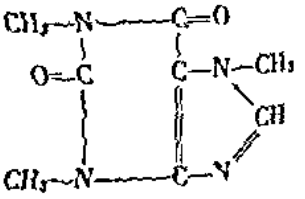
The cadmium metal is cast into bars or anode shapes such as balls, because the major use is for cadmium plating. For this purpose a high degree of purity particularly with respect to lead and thallium is required

Cadmium is highly toxic and highly volatile The melting of cadmium must therefore be carried out with the utmost precaution regarding ventilation and the use of respirators In some cases cadmium by products also contain significant amounts of arsenic and some methods of processing therefore involve a hazard from arsine *See* CADMIUM ELECTROPLATING OF METALS, ZINC METALLURGY [W MF]

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Caffeine

An alkaloid found in a large number of plants used throughout the world in beverages, such as tea coffee cocoa and mate Caffeine was first isolated by F Runge in 1820 and was later synthesized by a variety of methods Its chemical structure is



Caffeine is readily obtained by the extraction of tea dust and as a by product in the manufacture of decaffeinated coffee

Wherever caffeine-bearing plants are indigenous natives use their aqueous extracts as beverages. Legends telling of their discovery indicate that the stimulant action of the plant's constituent has been appreciated for many centuries The stimulant action is the chief basis for the continuing popularity of caffeine containing beverages

Caffeine possesses other pharmacological properties useful in therapy It is often employed as an ingredient of mixtures for treating headaches It is also useful as a diuretic drug and as an effec-

tive antidote against poisoning by narcotics such as morphine *See* ALKALOID [S M K]

Caiman

Any of five different members of the order Crocodilia found in Central America and tropical South America east of the Andes

Caimans resemble the alligator with the fourth tooth in the lower jaw concealed in a pit of the skull when the jaw is closed and with blunt rounded snouts although three of the five species have the snout somewhat more pointed than the alligator Caimans lack the bony septum formed by the nasal bone a characteristic of the alligator

Four of the five caimans are 8 ft or less in length *Caiman niger*, of the upper Amazon has been reported to reach a length of 20 ft *See* CROCODILIA [J D B]

Caisson foundation

A permanent substructure that while being sunk into position permits excavation to proceed inside *and also provides protection for the workers against* water pressure and collapse of soil The term caisson covers a wide range of foundation structures Caissons may be open pneumatic or floating type deep or shallow large or small and of circular square or rectangular cross section The walls may consist of timber temporary or permanent steel shells or thin or massive concrete Large caissons are used as foundations for bridge piers deep-water wharves and other structures (*see* BRIDGE) Small caissons are used singly or in groups to carry such loads as building columns (*see* PILE FOUNDATION) Caissons are used where they provide the most feasible method of passing obstructions where soil cannot otherwise be kept out of the bottom or where cofferdams cannot be used

The bottom rim of the caisson is called the cutting edge (Fig 1) The edge is sharp or narrow and is made of or faced with structural steel The narrowness of the edge facilitates removal of ground under the shell and reduces the resistance of the soil to descent of the caisson



Fig 1 Underside of an open caisson for the Greater New Orleans bridge over the Mississippi River Note the prefabricated steel cutting edge (*Dravo Corp*)

Open caisson An open caisson is a shaft open at both ends It is used in dry ground or in moderate amounts of water A bottom section having a cutting edge is set on the ground and soil is removed from inside while the caisson sinks by its own weight Sections are added as excavation and sinking proceed After excavation is completed the hollow interior of the shaft is filled with concrete Open caissons are usually constructed of reinforced concrete but if steel shells are used concrete may also be required to provide weight When an open caisson is to be towed into place hollow walls or false bottoms are provided to give it buoyancy they are removed after the caisson is in position Open caissons can be sunk in water to practically any depth

In deep water an open caisson is sometimes sunk by the sand island method A cofferdam is constructed and filled with sand to form an artificial island The island serves as a working platform and guide for sinking the caisson This method also avoids the necessity of transporting a fabricated *shell and holding it in position*

Figure 2 shows the major types of caissons in use

Chicago caissons (open well) are formed by excavating a few feet of soil installing short vertical pieces of wood or concrete lagging beveled to form a circle bracing with segmental hoops and repeating Such caissons are used in clay that is not strong enough to carry the permanent load alone but will permit excavation for the lagging without flowing in at the bottom The clay is hoisted out in buckets or elevators The bottom may be belled out Lagging and bracing are generally left in place

Sheeted caissons are similar to Chicago caissons except that vertical sheeting is continuous and is driven by hand or pile driving hammers either in advance of excavation or as it proceeds Bracing rings are placed every few feet Sheeting may be wood concrete plank or steel and is left in place Sheeted caissons may be round or square

Small cylindrical caissons 2 12 ft in diameter consist of a concrete shell or steel pipe sunk into the ground by its own or by a temporarily superimposed weight Excavation is done by hand or mechanically and the caisson is finally filled with concrete

Drilled caissons are drilled holes that are filled with concrete Rock socketing may be used at the bottom or the bottom may be belled up to 30 ft in diameter The caisson may be as long as 150 ft Cohesive soils are drilled with augers or bucket type drills Granular soils are drilled in the same manner with the aid of a binding agent or by rotary drills using drilling mud or water to keep the hole from caving in Steel shaft casings are used where needed to shut off water or keep soil out of the hole Casings are removed before concreting or during concreting in unstable ground

Driven caissons are formed by driving a cylindrical steel shell with one or more pile-driving hammers After excavation by grabs buckets or jet

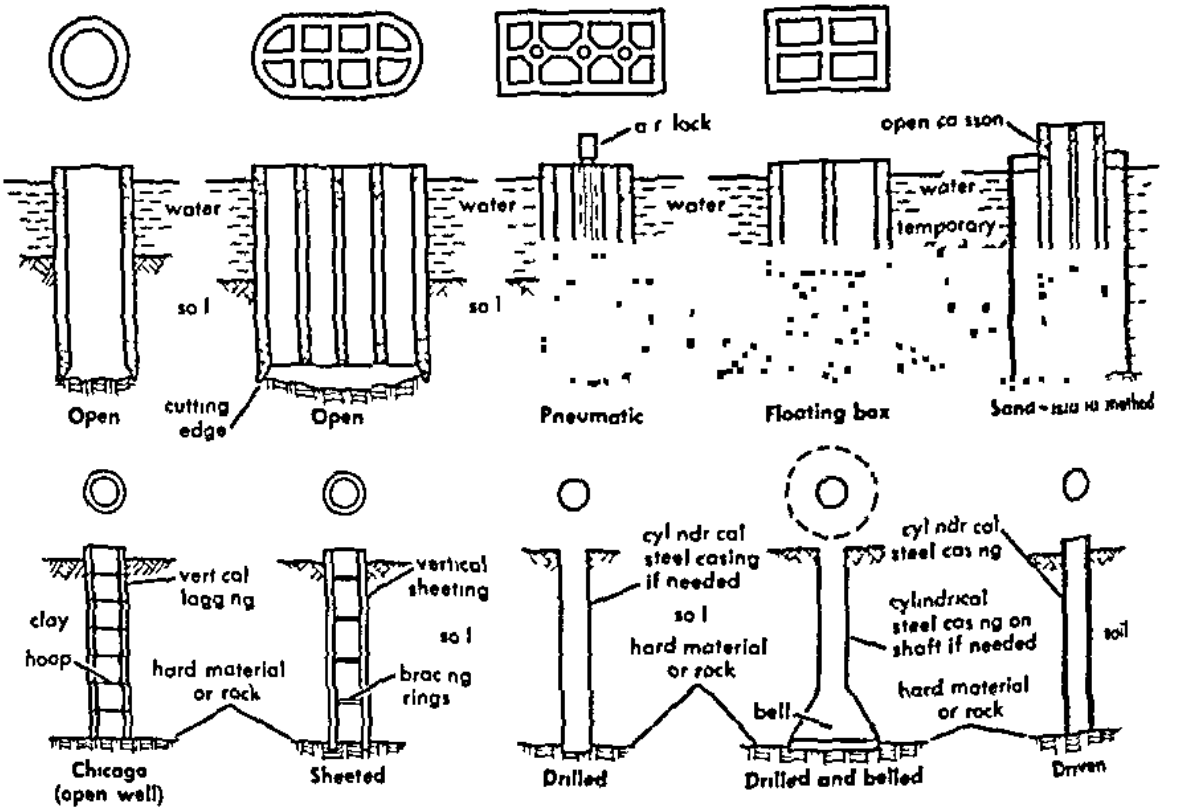


Fig 2 Major types of caissons as they appear from the top and in cross sect on from the side

ting concrete is placed inside The shells usually are withdrawn as the concrete rises unless the soil is so soft or water conditions are such that they must be left in place

Pneumatic caisson A pneumatic caisson is like a box or cylinder in shape but the top is closed and thus compressed air can be forced inside to keep water and soil from entering the bottom of the shaft A pneumatic caisson is used where the soil cannot be excavated through open shafts (for instance where there are concrete timbers boulders or masonry lying underwater) or where soil conditions are such that the upward pressure must be balanced The air pressure must balance or slightly exceed the hydrostatic head and is increased as the caisson descends The maximum depth is about 120 ft corresponding to an air pressure of 52 psi or about 3½ atmospheres which is about the limit of human endurance Men and materials must pass through air locks Too rapid decompression may result in caisson disease or 'bends' resulting from the expansion of bubbles of air trapped in joints muscles or blood The length of time men can work under pressure and the speed of decompression are regulated by law Pneumatic caissons may be started as open caissons then closed and air applied They are made of reinforced concrete which may be faced on one or both sides with steel plates

Floating caisson A floating or box caisson consists of an open box with sides and closed bottom but no
to the
bed pr
then filled with sand gravel or concrete This type is most suitable where there is no danger of scour Floating caissons may be built of reinforced concrete steel or wood

Small box caissons usually consist of a single cell Large caissons are usually divided into compartments, this braces the side walls and permits more accurate control during loading and sinking [R D C]

See FOUNDATIONS

Bibliography See FOUNDATIONS

Calamine

A term that may refer to either a zinc mineral, $Zn_4Si_2O_7(OH)_2 H_2O$, which is also known as hemimorphite, or to zinc oxide, ZnO which is used in medicinal or pharmaceutical products and in cosmetics *See* HEMIMORPHITE, ZINC [E E W S]

Calamitales

An extinct group of reedlike plants of the subphylum Sphenopsida They are known to have existed in the Devonian and persisted into the Permian During the Carboniferous they were a conspicuous and prominent part of the flora In habit they resembled the giant equisetums The calamites possessed a horizontal rhizome from which grew roots and tall (up to 30 ft), upright grooved articulated stems (Fig 1) bearing verticillated branches at the nodes, the ultimate branches bore verticils of photosynthetic leaves (Fig 2) *See* SPHENOPSIDA

Stems Anatomically the young stems resembled modern equisetums in their main characters A large pith which soon became hollow was surrounded by a cylinder of small and separate conducting strands each having on its inner margin a

vert cal canal (carinal canal) made by the disinte gration of the protoxylem (Fig 3) As the plant grew cambial activity added new wood to the pri mary bundles and formed a thick cylinder of sec ondary wood composed of regularly disposed tra cheids traversed by vertical plates of shorter cells (wood rays) In the older stems the wood reached a considerable thickness which with the simultaneously developed cortex produced stems up to 1 ft in diameter *See* STEM (BOTANY)



Fig 1 Fossil calamite showing grooved segmented stem (Chicago Natural History Museum)

Leaves The leaves arranged in whorls of 8–20 or more have been separated into two main types *Annularia* and *Asterophyllites* *Annularia* are known from impressions only Their leaves are simple linear or spatulate with a single vein and range in length from 0 25 cm to several centimeters (Fig 4) *Asterophyllites* known both from impressions and cellular preservation are simple and acicular with their bases fused to form a coherent sheath about the node The transverse section of the individual leaf shows a central vascular strand surrounded by a bundle sheath of thick walled cells next a layer of assimilating tissue of radially arranged palisade cells and this in turn is surrounded by an epidermis with laterally disposed stomata

Roots The roots named *Astromyelon* before their connection with *Calamites* was known have been found attached to both rhizome and upright stems They were inserted at the nodes on a level with the leaf traces Their stelar tissues are organized much as are those of the stem with the following exceptions the pith is solid there are no carinal canals the primary wood is centripetally developed and there is a radial arrangement of the protoxylem and phloem In the cortex are found schizogenously formed lacunar areas of a type seen today in organs of aquatic plants *See* CORTEX PLANT

Reproduction The *Calamites* reproduced by spores formed in sporangia which were aggregated

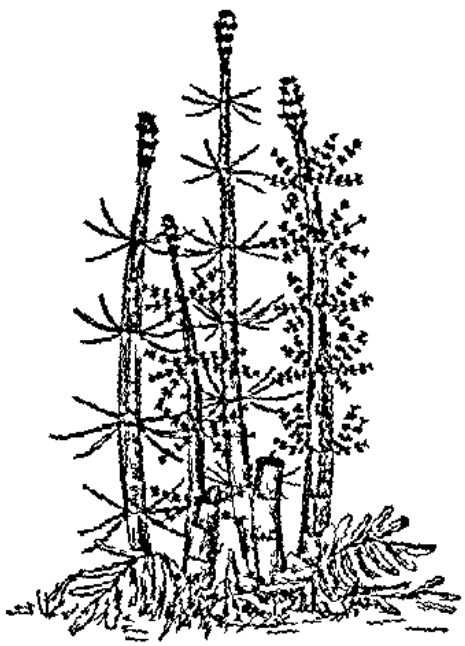


Fig 2 Restoration of *Calamites* a scouring rush Whorls of branches are shown at each joint of articulate stems. (*From R C Hussey Historical Geology 2d ed McGraw Hill 1947*)

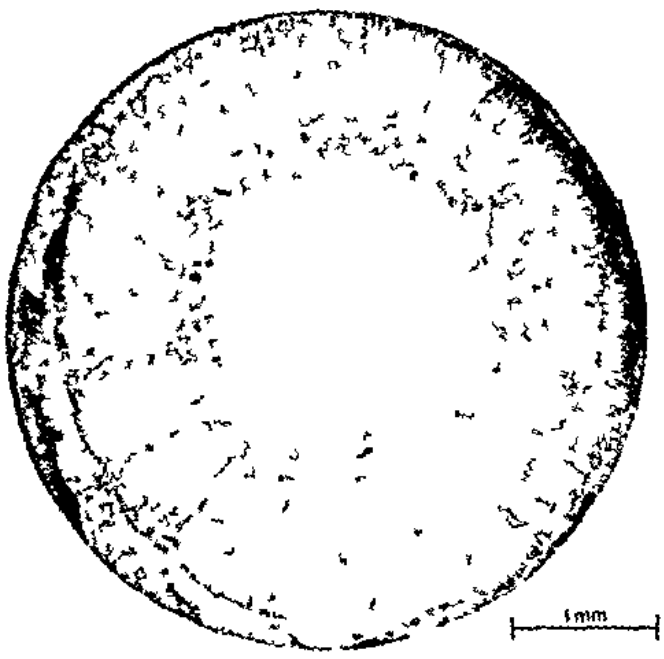


Fig 3 Stem of *Calamites* Transverse section showing hollow pith cylinder of wood (mostly secondary) with carinal canal at apex of each wedge of wood Note absence of growth rings

into strobili of various forms Despite the variation all strobili possess a central articulated axis bearing whorls of peltate sporangiophores Most of the strobili fall into two types *Calamostachys* and *Palaeostachya* (Fig 5) *Calamostachys* is characterized by the fact that the successive pairs of whorls are separated by equidistant verticils of sterile bracts whereas in *Palaeostachya* the sporangiophores are inserted immediately above each verticil of sterile bracts as if they were axillary in origin Each sporangiophore had an expanded peltate tip bearing four sporangia attached in a pendant position The sporangia are elongated sacs stretching from the peltate top to the axis of the strobilus Both homosporous and heterosporous forms have been found but homospory seems to have been prevalent

Ecology Clues to their environment and the climate are to be found in the vegetative structure of the *Calamites* The bulk of calamitean remains are pith casts made by mud and sand that filled the hollow stems indicating that they had been growing in an aquatic habitat This is supported by the

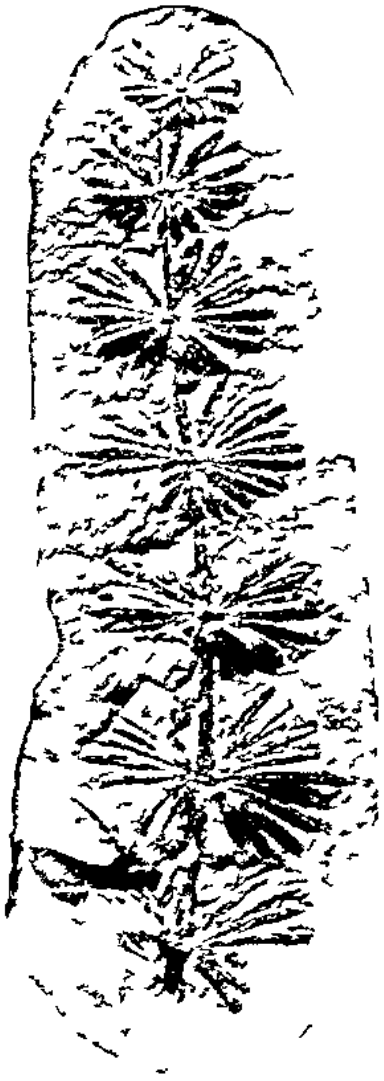


Fig 4 Leaves of Pennsylvanian horsetail rush (*Annularia*) (Chicago Natural History Museum)

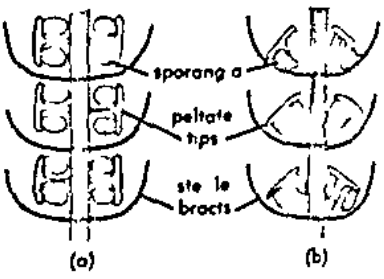


Fig 5 Diagrams showing the relation of the sporangiophores and sterile bracts in (a) *Calamostachys* and (b) *Palaeostachya* (From C A Arnold *An Introduction to Paleobotany* McGraw Hill 1947)

presence of lacunar areas in the roots and by the fact that the anatomy of the leaves is that of a bog xerophyte The absence of growth rings in stems of any age or from any latitude points to an equable climate

Affinity In their habit structure and method of reproduction the calamites bear such close resemblance to the equisetums that there can be no doubt of their close relationship From the geological evidence one might suppose the *Calamites* to be the ancestral form But their structure does not support the supposition It is more likely that the two groups had their origin from a common ancestor and that the *Calamites* became extinct because of a high degree of specialization developed from a frail structural plan *See* EQUISETALES PALEOBOTANY PLANT KINGDOM SPHENOPHYLLALES

(T.D.R.)

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Calanoida

A suborder of Copepoda that includes the larger and more abundant of the pelagic species In the food cycles of the sea these copepods are the most important group of marine animals because of their overwhelming numbers ubiquitous distribution and position at the base of the animal food chain *See* COPEPODA

In this suborder there are 120 or more recognized genera some with numerous species In the fresh water genus *Diaptomus* about 100 species are known However except in surveys over very wide geographic areas the number of species found in any one genus is usually less than 10 or 15

Calanus is the most outstanding genus in boreal and arctic seas *Calanus finmarchicus* (Gunnerus) was the first copepod to be described It is a cosmopolitan cold water species 3–6 mm long which ranks first among North Atlantic copepods and is frequently abundant elsewhere in both the Atlantic and Pacific oceans However in some cold water areas of the Northern Hemisphere notably the Arctic Bering Sea and North Pacific it is commonly exceeded in numbers and mass by other species of the genus such as *C hyperboreus* *C tonsus* *C cristatus* or by other genera

In biomass the calanoids exceed all other co pepod groups In the Gulf of Maine alone the total standing crop of calanoids has been calcu lated at 4 000 000 tons

All calanoids are planktonic and as a group oc cur in all parts of the oceans from the surface to abyssal depths The geographic and bathymetric ranges of many species are however restricted by the nature of water currents and the chemical and physical conditions of the water In their southern most range the northern species are found at greater depths

Many species live at depths of 200–300 meters during the day but migrate upward at night and return to usual levels again at dawn These diurnal migrations are doubtless in response to conditions of light but are modified by the temperature toler ances of the species and by other factors

In keeping with their planktonic habit many calanoids are provided with long plumose setae and long antennae to aid in flotation Often the body or plumes are brightly pigmented Common colors are pink red green blue and violet Some are mostly black or entirely hyaline A number of species especially of the genera *Metridia* and *Pleuromomma* are bioluminescent emitting flashes of phosphorescent light *See* COMMUNITY *see also* BIOLUMINESCENCE

[M W J]

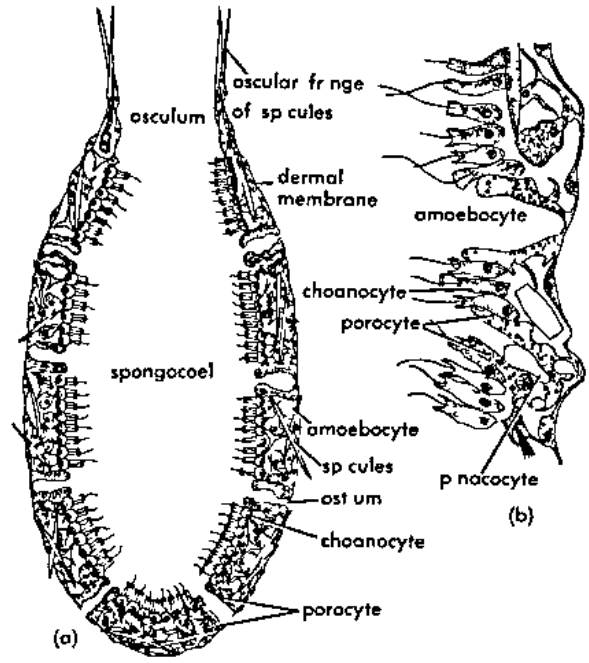
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Calcarea

A class of the phylum Porifera including sponges with a skeleton composed of spicules of calcium carbonate Calcarea vary from radially symmetri cal vase shaped species to colonies made up of a reticulum of thin tubes to irregular massive forms Calcareous sponges are mostly of small size and in habit the shallow waters of all seas from tidal areas to depths of 200 meters with a few species extending down to at least 800 meters

Morphology Primitive calcareous sponges with an ascon grade of construction consist of colonies of upright tubes with unfolded walls made up of an outer epidermis of pinacocytes and an inner lining of choanocytes Between these layers of cells is a stratum of mesoglea containing amoebocytes and spicules Cells called porocytes each perforated by a tubular canal pierce the walls at intervals and al low water to enter the central cavity or spongocoel Water leaves by way of a terminal osculum

A somewhat more complicated structure is seen in calcareous sponges of the sycon grade of con struction Syconoid sponges are usually individual vase shaped forms with a thick wall enclosing a large central spongocoel opening out through a terminal osculum In the simplest forms the wall is pushed out at intervals into fingerlike projections called radial canals in which the choanocytes are local zed Water enters the radial canals directly through pores without the intervention of special inhalant canals In most syconoid species however



F g 1 (*a*) D agram of an asconoid calcareous sponge shown in long tud nal sect on (*after Hyman 1940*) (*b*) Cross sect on through *Clathr na* an ascono d Calcarea showing cell types (*from Hyman 1940 after Prenant 1925*)

a dermal membrane made up of pinacocytes and mesenchyme forms a cortex of greater or less thick ness which joins the outer ends of the radial canals Pores or ostia pierce the dermis and open into in halant canals which are simply the spaces be tween the radial canals in some cases In forms with a thick cortex the inhalant canals run a course through the cortical mesenchyme before reaching the outer ends of the radial canals (flag ellated chambers)

The leuconoid grade of construction has prob ably evolved independently among the several lines of calcareous sponges In those with a syconoid an cestry the radial canals subdivide into many small flagellated chambers which arise as outpocketings of the radial canal wall A common intermediate stage is seen in genera in which each radial canal is subdivided into elongate flagellated chambers grouped around a common exhalant canal Several lines of calcareous sponges have apparently reached the leuconoid grade of construction during the course of evolution through the anastomosis of ascon tubes rather than by the branching of the radial canals of a syconoid sponge

Spicules Calcareous sponge spicules are mon axonid triradiate or quadriradiate in form Mon axons where present tend to occur in the cortex from which they may project to form a bristly sur face In some species monaxons project around the osculum Either triradiates or quadriradiates or both depending on the species are distributed in the mesenchyme often arranged in definite pat terns with relation to the cortex and internal struc tures It has been found in *Leucosolenia* an asco

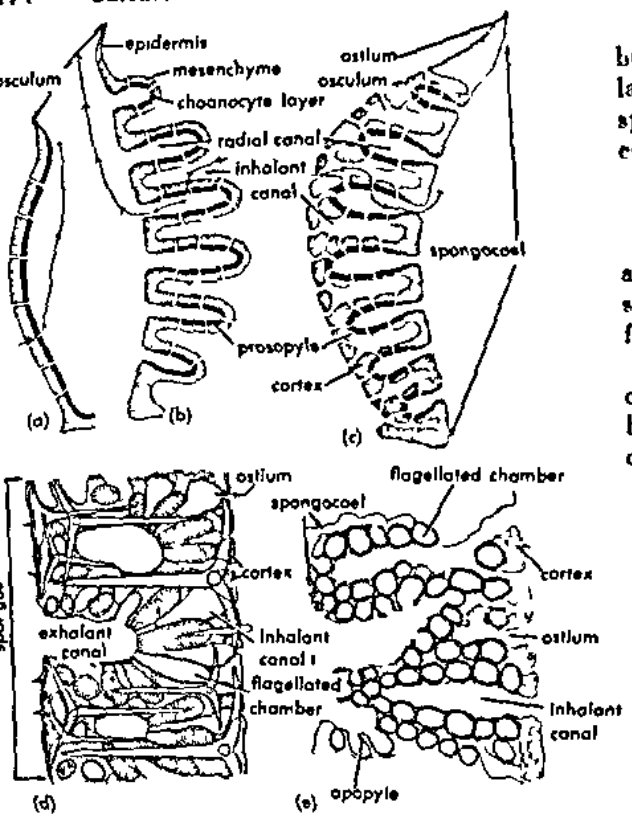


Fig 2 Grades of construction of the water-current system in Calcarea (a) Asconoid type (b) Syconoid type without cortex (c) Syconoid type with cortex (d) Stage transitional between syconoid and leuconoid type (after Dendy, 1893) (e) Leuconoid type (From Hyman, 1940)

noid sponge, that the mesoglea alone is capable of supporting this tubular sponge after the spicules have been dissolved The spicules provide increased rigidity for the tube and serve as protective ele ments They may also buffer the mesoglea against a fall in pH which would lead to hardening of this substance

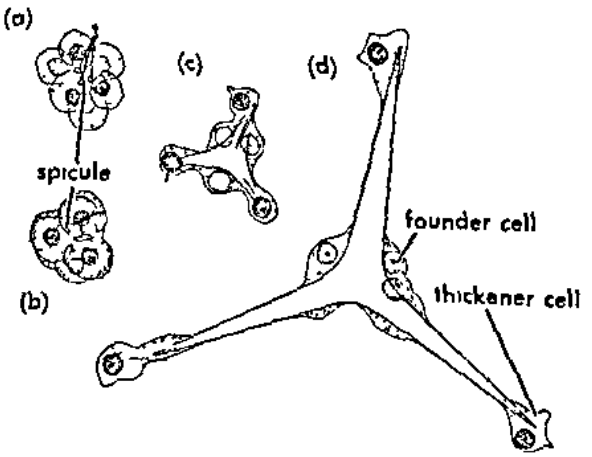


Fig 3 Spicule formation in calcareous sponges (a,b c) Early stages in secretion of triradiate spicule, showing founder and thickener cells (d) Late stage of same (From Hyman, 1940, after Woodland, 1905)

Monaxonid calcareous spicules are secreted by binucleate scleroblasts The calcium carbonate is laid down around an organic axial thread As the spicule grows in length the cell divides One cell establishes the length and shape of the spicule,



as described above. The groups of scleroblasts are so oriented that the individual rays fuse basally to form a triradiate or quadriradiate pattern

Phylogeny. As in the Demospongiae the Calcarea may be divided into two evolutionary lines based on differences in development. In the subclass Calcaronea, including the asconoid genus

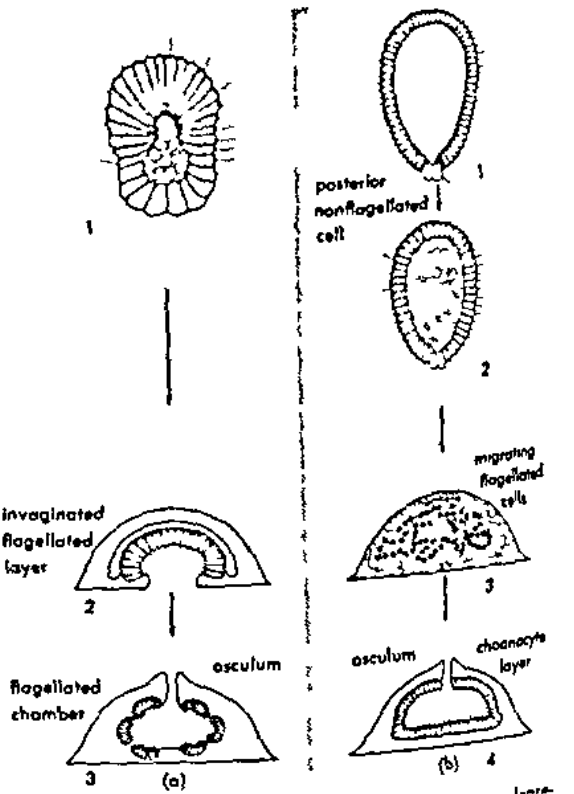


Fig 4 Larval structure and metamorphosis in calcareous sponges (a) Developmental stages characteristic of the Calcaronea 1, amphiblastula larva 2, newly settled larva showing metamorphosis, 3, young syconoid stage (b) Developmental stages characteristic of the Calcinea 1, coelablastula larvae, 2, parenchymula larvae, 3, newly settled larva showing gastrulation, 4, young sponge of asconoid grade (From Hartman, 1958, after Brien, 1943, and Minchin, 1900)

Leucosolenia and its syconoid and leuconoid relatives, the free swimming larvae are amphiblastulae These are hollow larvae, each with an anterior hemisphere of flagellated cells and a posterior mass of nonflagellated cells The fate of these two categories of cells is determined at an early stage of cleavage The egg cells always lie just beneath the maternal choanocyte layer. After fertilization three successive meridional cleavages are followed by an equatorial cleavage to produce a 16 celled embryo

(*see* PORIFERA) The eight cells which lie next to the maternal choanocyte layer are future epidermal cells the other eight cells are future choanocytes After a short free-swimming period the amphiblastula larva settles down on its anterior end and gastrulation occurs by invagination of the flagellated hemisphere or by downgrowth of the nonflagellated cells A small tubular asconoid sponge called an olynthus results and this may retain the asconoid structure or differentiate later into a syconoid or leuconoid structure according to the species The nonflagellated cells of the larva give rise to pinacocytes and their derivatives and scleroblasts the flagellated cells become choanocytes amoebocytes or archaeocytes Mesenchymal elements thus come from both embryonic layers *See* DEMOSPONGIAE

In the subclass Calcinea including the asconoid genus *Clathrina* and its leuconoid relatives *Leucetta* and others the free swimming larva is a stereogastrula or parenchymula In this case cleavage results in a hollow blastula made up of a single layer of flagellated cells One to several cells at the posterior pole may be nonflagellated Cells now wander into the interior of the embryo from all points except the anterior pole or from the posterior pole only The parenchymula larva so produced leads a short free swimming life and then settles to the bottom where it attaches by the anterior pole and flattens out The peripheral flagellated cells now migrate through the central mass of nonflagellated cells to take up their position as the cells lining the spongocoel A young asconoid sponge or olynthus is thus formed which will develop into an adult colony *See* CALCARONEA CALCINEA

[W D H]

Bibliography W D Hartman A re examination of Bidder's classification of the Calcarea *Syst Zool* 7(3) 97 110 1958

Calcarenite

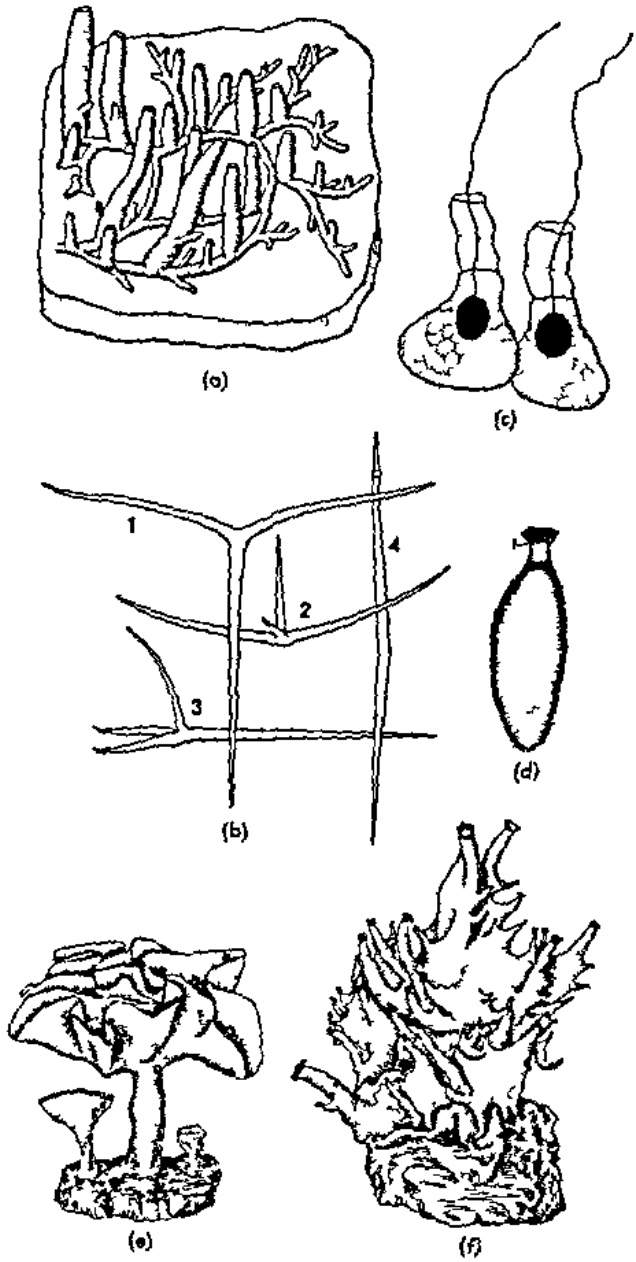
A mechanically deposited (clastic) limestone in which the constituent particles of carbonate are sand grain size If the grains are larger than 2 mm the rock is a calcirudite If the grains are smaller than 1/16 mm it is a calcilutite The calcarenites are normally cemented by clear calcite The detrital carbonate grains are fossil fragments broken fragments of calcilutite oolites, and fecal pellets The detritus is fairly well sorted as to size and many grains show slightly abraded edges, indicating a normal current deposited sediment. Where oolites are dominant the rock is called an oolite or oolitic limestone Calcarenites are often found with orthoquartzites either interbedded or grading laterally into them They have the same sedimentary structures as the orthoquartzites dominantly cross bedding

The fine grained equivalent of calcarenite calcilutite, is called lithographic limestone if it is homogeneous dense very fine grained and breaks with conchoidal or subconchoidal fracture the name is derived from the use of the rock for lithography The very fine grain[illegible]

the product of inorganic precipitation or of finely comminuted algal debris *See* COQUINA LIME STONE SEDIMENTARY ROCKS [R S]

Calcaronea

A subclass of sponges of the class Calcarea in which the larvae are amphiblastulae The nucleus of the choanocytes is apical in position and the flagellum arises directly from the nucleus The tri



Representative calcaronean sponges (a) Leucosolenia botryoides (after Minchin 1900) (b) Spicules of Leucosolenia complicata 1 triradiate with one long ray 2 3 quadriradiates 4 monaxon (from Hartman 1958 after Haeckel 1872) (c) Choanocytes of Leucosolenia complicata showing apical nucleus from which the flagellum arises (from Hartman 1958 after Minchin 1909) (d) Sycon (after Hyman 1940) (e) Trichoanapsis labyrinthica (from Minchin 1900 after Dendy 1891) (f) Leucandra aspera (after Minchin 1900

radiate spicules in species of this subclass characteristically have one ray longer than the other two Monaxonid spicules are usually present The canal system is asconoid syconoid or leuconoid Species with a leuconoid structure give evidence of having had a syconoid ancestry

Species of the family Lelapiidae have a rigid skeleton composed of tracts or bundles of modified triradiates They bear a superficial resemblance to pharetronid sponges with which they are often erroneously classified (*see* CALCINEA) The fossil history of the Lelapiidae extends back to the Permian period A doubtful asconoid calcaronean sponge has been reported from the Cambrian period and there are scattered records of syconoid and leuconoid species probably belonging to this subclass from the Jurassic period upward

The subclass Calcaronea may be divided into the following orders Leucosolenida and Sycettida *See* CALCAREA LEUCOSOLENIDA SYCETTIDA

[W D H]

Calcinea

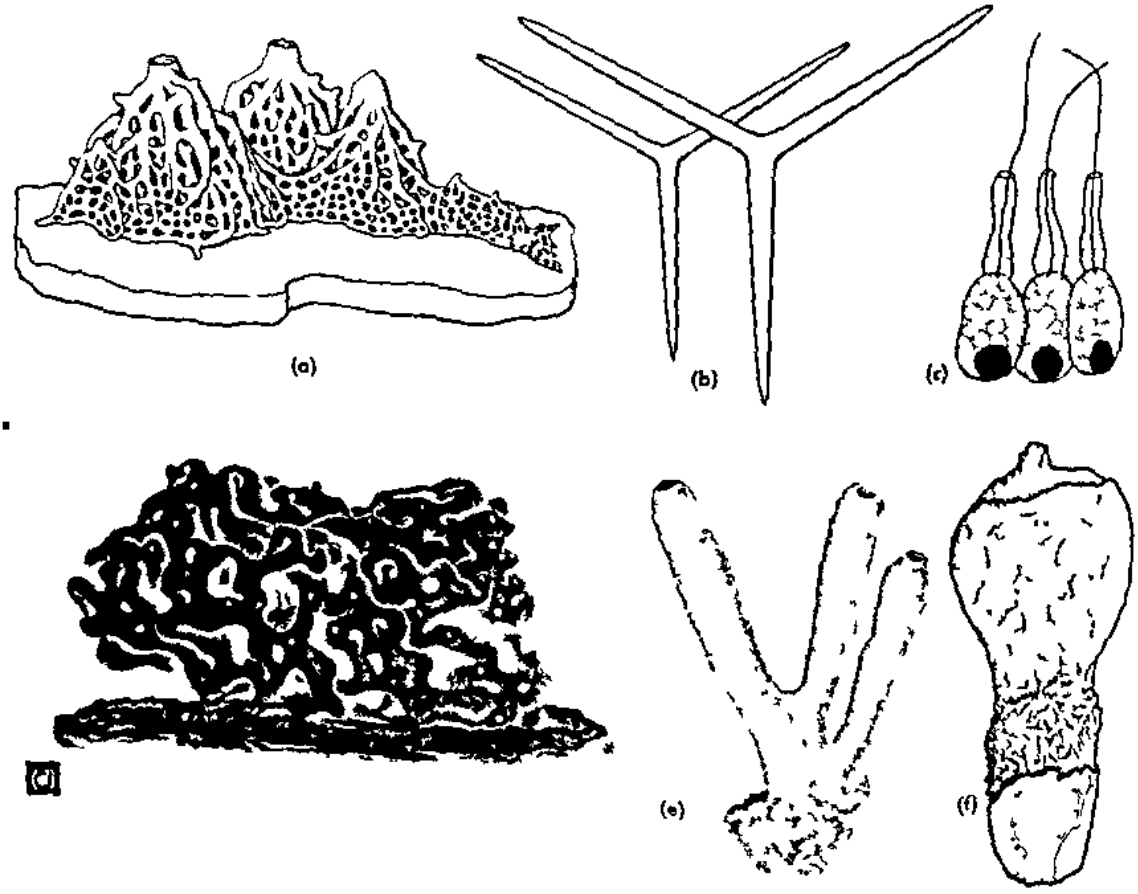
A subclass of sponges of the class Calcarea in which the larvae are parenchymulae The flagellum in the choanocytes arises independently of the nucleus, which occupies a basal position in the cells Most species possess at least some triradiate spicules which have equal rays and equal angles between the rays Monaxonid spicules are present or absent The leuconoid grade of construction shows no trace of syconoid ancestry in this group but has apparently been derived from reticulate asconoid species

Included in this subclass are three orders the Clathrinida, Leucettida, and Pharetronida. The pharetronid sponges, because of their rigid skeleton composed of fused spicules or of a calcareous network, are commonly preserved as fossils The pharetronids, which range from the Permian period to recent times, are the only known fossil representatives of this subclass *See* CALCAREA CALCARONEA, CLATHRINIDA; LEUCETTIDA, PHARETRONIDA

[W D H]

Calcite

One of the most common and widespread minerals in the earth's crust Calcite ($CaCO_3$) may be found in a variety of sedimentary, metamorphic, and igneous rocks It is also an important rock forming mineral in calcite marbles, carbonatites, and pure limestones

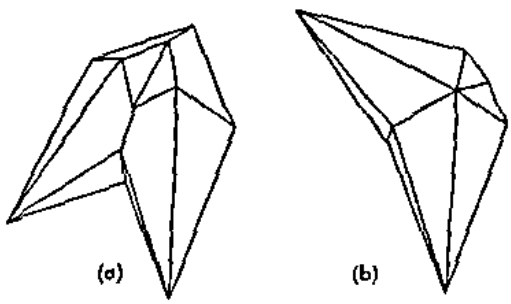


Representative calcinean sponges (a) *Clathrina clathrus* (after Minchin 1900) (b) Equiangular triradiate spicules of *Clathrina coriacea* (from Hartman 1958 after Haeckel 1872) (c) Choanocytes of *Clathrina coriacea* showing basal nuclei and independent flagella (from Hartman, 1958, after Minchin 1909) (d) *Leucaltis clathria* (after Poléjaeff, 1883) (e) *Leucettusa tubulosa* (after Dendy, 1924) (f) *Petrobiona massiliana* a pharetronid (after Vacelet and Lévi 1958)

Although it is commonly of high purity calcite it elf may contain other cations such as manganese iron magnesium cobalt barium and strontium substituting for the calci im in variable amounts Well developed crystals of calcite are common in cavities in limestones and basic igneous rocks Of special interest are the large crystals of optical quality obtained from near the Eskefiord Iceland This material is known as Iceland spar and single crystals several feet across have been reported In the United States very large crystals have been mined in Taos County New Mexico

Calcite in the form of pure limestones is the main source of the world s quicklime and hydrated or slaked lime It is also used as a metallurgical flux and in the manufacture of cement and glass Material which is less pure may be used as dimen sion stone soil conditioners industrial acid neu tralizers and as aggregate in concrete and road bu ilding Calcite in transparent well formed crys tals is used in certain optical instruments *See* CRYSTAL OPTICS LIME (INDUSTRIAL) STONE AND STONE PRODUCTS

Calcite has hexagonal (rhombohedral) symmetry and a structure built up of alternate layers of Ca ++ ions and CO_3 groups stacked up so that the



Twinned crystals of calcite (a) Twin on (0221) (b) Twin on (0112) (*From C Palache H Berman and C Frondel Dana s System of Mineralogy vol 2 Wiley 1951*)

layers lie in planes perpendicular to the main axis of symmetry Calcite may exhibit a wide variety of forms in addition to simple and complex rhombo-hedra Tabular prismatic and scalenohedral varie ties are common and twinned crystals are often found

Some fibrous varieties of calcite have gem value as a kind of satin spar Deposits in streams in cal careous areas and in limestone caves as stalactites and stalagmites occur as masses with over all rounded forms made up of very small crystals Travertine and onyx are often of such material *See* ONYX TRAVERTINE

When pure calcite is either colorless or white but impurities can introduce a wide variety of col ors blues pinks yellow browns greens and grays have all been reported Hardness is 3 on Mohs scale The specific gravity of pure calcite is 2 7102 ± 0 0002 at 20°C.

Calcite can be readily synthesized in a variety of ways. It is trimorphous aragonite and vaterite be ing the other polymorphs of $CaCO_3$ The stability of calcite with respect to aragonite as a function of temperature and pressure has been determined by three independent laboratories in three different ways All show that calcite is the stable form of $CaCO_3$ under atmospheric conditions aragonite is stable at lower temperatures and higher pressures than calcite Two very high pressure types of cal cite were detected by P W Bridgman

Calcite has a very low solubility in pure water but the solubility increases greatly with the pres sure of carbon dioxide in the water as a result of the formation of carbonic acid

The equilibrium amounts of certain cations that replace calcium in the calcite structure have been determined experimentally for magnesium iron and manganese The amounts of each have been found to increase with temperature At a fixed tem perature the equilibrium amounts for these three increase in the order Mg Fe-Mn as the size of the substituting cation approaches that of calcium

The temperature at which calcite dissociates to calcium oxide and carbon dioxide at atmospheric pressure depends on the heating rate grain size presence of moisture and partial pressure of car bon dioxide Dissociation temperatures range from 700 to 1000°C The equilibrium thermal dissocia tion temperatures have been determined experi mentally and nearly pure calcite has been melted at approximately 1340°C and 15 000 psi of carbon dioxide

Partly because it is available in pure clear well developed crystals calcite has played an important role in the formation of certain fundamental con cepts in crystallography and mineralogy The phe nomenon of double refraction was first observed in calcite and the discovery of the polarization of light resulted from studies of this mineral Detailed work has shown anisotropism in most of its physical properties Calcite is somewhat less hard on certain faces {0001} than on others {1010} Single crystals of calcite have different coefficients of expansion and show variations in magnetic susceptibility and electrical conductivity which are dependent upon the crystallographic directions involved *See* BIRE FRINGENCE POLARIZED LIGHT

See CARBONATE MINERALS *see also* CALCIUM CARBONATE LIMESTONE [R I H]

Calcium

Chemical element number 20 calcium Ca is fifth among elements and third among metals in abun dance in the earth s crust Its compounds make up 3 64% of the earth s crust Its occurrence is very widespread because it is found in every major land area of the world This element is essential to plant and animal life and is present in bones teeth egg shell coral and many soils Calcium chloride is present in sea water to the extent of 0 15% In Table 1 are listed the major calcium minerals and their formulas

Lime calcium oxide was known and used by the ancient Greeks and Egyptians in the manufacture of mortar

Table 1 *Calcium minerals*

Mineral	Formula
Marble	$CaCO_3$
Limestone	$CaCO_3$
Iceland spar	$CaCO_3$
Calcite	$CaCO_3$
Dolomite	$MgCO_3 CaCO_3$
Fluorspar	CaF_2
Anhydrite	$CaSO_4$
Gypsum	$CaSO_4 2H_2O$
Apatite	$Ca_4(PO_4)_2F$
Asbestos	$CaMg_3(SiO_3)_4$

Extraction of the metal Calcium metal is prepared *industrially* by the electrolysis of molten *calcium chloride* although the reduction of lime *with aluminum* metal in vacuum followed by distillation of the calcium metal has been used in times *of short* supply Calcium chloride the raw material *is obtained either by* treatment of a carbonate ore *with hydrochloric* acid or as a waste product from the Solvay carbonate process *See* ELECTROMETALLURGY



The physical properties *of calcium* metal are given in Table 2

The metal is *trimorphous* and *is harder than sodium but* softer than aluminum *Like beryllium* and aluminum but unlike the alkali metals it will not cause burns on the skin *It is* less reactive chemically than the alkali metals and the other alkaline earth metals The *pure metal* may be machined in a lathe threaded sawed *extruded drawn into* wire pressed and hammered into plates The wire may be extruded at temperatures as low as 420–460°C Calcium has a *tensile* strength of 8700 psi and may be cast *If one of the* suitable *protective* fluxes is employed

Table 2 Properties of calcium metal

Atomic number	20
Atomic weight	10 08
Isotopes (stable)	40 42 43 44 46 48
Atomic volume $cm^3/g\ atom$	25 9
Crystal form	Face-centered cubic
Valence	2+
Ionic radius, A	0 99
Electron configuration	2 8 8 2
Boiling point °C	1487 (?)
Melting point °C	810 (?)
Density g/cm^3	1 55
Latent heat of vaporization at boiling point kilojoules/*g-atom*	399

In air, calcium forms a thin film of oxide and nitride which protects it from further attack At elevated temperatures it burns in air to form largely the nitride The commercially produced metal reacts easily with water and acids yielding hydrogen that contains noticeable amounts of ammonia and hydrocarbons as impurities

The metal is employed as an alloying agent for aluminum bearing metal to remove *bismuth from* lead and as a controller for graphitic carbon in cast iron It is also used as a deoxidizer in the manufacture of many steels as a reducing agent in preparation of such metals as chromium thorium zirconium and uranium and as a *separating material* for gaseous mixtures of nitrogen and argon When added to magnesium alloys (0 25%) it refines the grain structure, reduces their tendency to take fire and modifies the strengthening heat treatment It finds use also in the precipitation hardening lead calcium alloys Alloys of lead calcium, and barium are produced by the electrolysis of fused salts in which the fused chlorides of barium and calcium are electrolyzed over a bath of molten lead as a cathode The ability of calcium to fix the residual gases nitrogen and oxygen in vacuum tubes makes it important as a getter The phase diagrams of the systems composed of calcium + aluminum copper hydrogen gold lead magnesium nickel silicon silver, tin and zinc have been investigated

Principal compounds In general sodium compounds are to be preferred over calcium compounds if they may be substituted for a particular application because the former cost approximately one-fifth or one sixth as much However lime *CaO* is a cheaper alkali than is sodium hydroxide Calcium metal reacts directly with hydrogen at *400°C to* form calcium hydride CaH_2 The product is stable in dry oxygen to 400–500°C, and at elevated temperatures it becomes an excellent reducing agent It will reduce many inorganic oxides such as rutile and baddeleyite (ZrO_2) to their metals (*Hydrimet* process) Sodium chloride may be reduced *to sodium* and *carbon monoxide* to formaldehyde *The* hydride also acts as a condensing agent in converting acetone to mesitylene oxide and as a hydrogenation catalyst in converting ethylene to ethane It has also served as a portable source of hydrogen for cooking and meteorological balloons the trade names are Hydrolith and Hydrogenate In this capacity the reaction of *1 lb of* the hydride with water gives 16 cubic feet (STP) of hydrogen at pressures as high as 1800 psi at rates as high as 1 5 cfm/lb

Oxide and hydroxide Calcium oxide is made by the thermal decomposition of carbonate minerals in tall kilns using a continuous feed process *Care* must be taken during the heating to decompose the limestone at a low enough temperature so that the oxide will slake freely with water If too high a temperature is used the so called dead burnt lime is formed The oxide is used in high intensity arc lights (lime lights) because of its unusual spectral

features and as an industrial dehydrating agent At high temperatures lime combines with sand and other siliceous material to form fusible slags hence the metallurgical industry makes wide use of it during the reduction of ferrous alloys

The slaking or hydrolysis process for lime produces the slightly soluble (0 219 g $Ca(OH)_2$/ 100 g H_2O) calcium hydroxide whose basicity is limited only by its insolubility Because of the low cost of calcium hydroxide it is used in many applications where hydroxide ion is needed During the slaking process the volume of the slaked lime produced expands to twice that of quicklime and because of this it can be used for the splitting of rock or wood Slaked lime is an excellent absorbent for carbon dioxide to produce the carbonate Because of the great insolubility of the carbonate gases are easily tested qualitatively for carbon dioxide by passing them through a saturated lime water solution and watching for a carbonate cloudiness The hydroxide is also used in the formation of mortar the latter is composed of slaked lime (1 volume) sand (3–4 volumes) and enough water to make a thick paste The mortar gradually hardens because of the evaporation of the water and the cementing action of the deposition of calcium hydroxide and because of the absorption of carbon dioxide. *See* LIME (INDUSTRIAL)

Silicide and carbide Calcium silicide $CaSi$ is an electric furnace product made from lime silica and a carbonaceous reducing agent This material is useful as a steel deoxidizer because of its ability to form calcium silicate which has a low melting point Calcium carbide is produced in enormous quantities each year by heating a mixture of lime and carbon to 3000°C in an electric furnace The compound CaC_2 is an acetylide which contains the ionic structure $[C{\equiv}C]^{2-}$ and it yields acetylene upon hydrolysis Acetylene is the starting material for a great number of chemicals important in the organic chemicals industry The carbide absorbs atmospheric nitrogen at red heat to form calcium cyanamide and this reaction is the basis for the Cyanamide process for the fixation of atmospheric nitrogen

Carbonate Pure calcium carbonate exists in two crystalline forms calcite the hexagonal form which possesses the property of birefringence and aragonite the rhombohedral form Naturally occurring carbonates are the most abundant of the calcium minerals as is indicated in Table 1 Iceland spar and calcite are essentially pure carbonate forms whereas marble is a somewhat impure and much more compact variety which because it may be given a high polish is much in demand as a construction stone Although calcium carbonate is quite insoluble in water it has considerable solubility in water containing dissolved carbon dioxide because in these solutions it dissolves to form the bicarbonate This fact accounts for cave formation in which limestone deposits have been leached away by the acidic ground waters *See* CAVE KARST TOPOGRAPHY

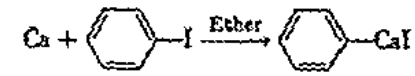
Halides The halides of calcium include the phosphorescent fluoride which is the most widely distributed calcium compound and which because of its transparency to ultraviolet and infrared radiation has important applications in spectroscopy Calcium chloride obtained as a waste product in the Solvay process has in the anhydrous form important deliquescent properties which make it useful as an industrial drying agent and as a dust quieter on roads The equilibrium vapor pressure of water vapor in contact with the following system is 0 34 mm at 25°C

$$CaCl_2 + 2H_2O \rightleftharpoons CaCl\ 2H_2O$$

Also this halide finds use in refrigeration plants because of its high solubility in water at low temperatures The calcium chloride hexahydrate and water system has a eutectic point at −54 9°C. Calcium chloride hypochlorite (bleaching powder) is produced industrially by passing chlorine into slaked lime and has been used as a bleaching agent and a water purifier *See* BLEACHING CHLORINE

Sulfate Calcium sulfate dihydrate is called gypsum this mineral is mined in New York Michigan Texas Iowa and Ohio It constitutes the major portion of portland cement and has been used to help reduce soil alkalinity A hemihydrate of calcium sulfate produced by heating gypsum at elevated temperatures is sold under the commercial name plaster of paris When mixed with water the hemihydrate reforms the dihydrate evolving considerable heat and expanding in the process so a very sharp imprint of the mold is formed Thus plaster of paris finds use in the casting of small art objects and mold testing *See* PLASTER OF PARIS

Miscellaneous compounds Calcium sulfide is formed industrially by the reduction of the sulfate with carbon and because it will dissolve hair has found some use as a depilatory Calcium forms a mixed alkyl with diethyl zinc $CaZn(CH\ CH_3)_4$ which is exceedingly reactive The reaction of calcium metal with phenyl iodide given below shows the formation of a calcium Grignard reagent



Calcium boride CaB_6 has a metallic lattice with interstitial boron atoms and has been shown to have metallic conductivity

Analytical methods The presence of calcium may be detected qualitatively either by forming its insoluble carbonate or by igniting the unknown in a burner flame to which the calcium imparts a brilliant crimson color Quantitatively calcium is determined by precipitation as the oxalate after separation of the strontium and barium The oxalate is then either ignited to the oxide or oxidized with a standardized solution of potassium permanganate

Calcium in the biosphere Calcium is an invariable constituent of all plants because it is essential for their growth It is contained both as a structural constituent and as a physiological ion The calcium

ion is able to counteract the toxic effects of potassium sodium and magnesium ions Calcium may also affect the growth of plants because its presence in soil affects the alkalinity of the latter

Calcium is found in all animals in the soft tissues in tissue fluid and in the skeletal structures The bones of vertebrates contain calcium as calcium fluoride as calcium carbonate and as calcium phosphate In some lower animals magnesium replaces either totally or partially the skeletal calcium The importance of calcium in animals as a structural constituent is based on its abundance and on the low solubility of the three calcium salts listed above Calcium is also essential in many biological functions of the vertebrates *See* ALKALINE EARTH METALS CARBONATE MINERALS, HYDRIDE METAL [R S R]

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Calcium metabolism

The maintenance of an approximately constant concentration of calcium in the circulating fluids of the body (about 10 mg per cent) is essential to the proper performance of its functions among which are the regulation of the heart beat the coagulation of the blood and the functioning of nerve and muscle tissue This is attained first by the parathyroid glands which control the dissolution of the stable bone mineral second by the rapid transfers in both directions between the blood and the labile fraction of the bone mineral probably mediated by both the parathyroid hormone and vitamin D Calcium is excreted from the body mainly by the kidneys and the intestinal mucosa the relative excretion rate depending upon the acid base equilibrium in the blood plasma *See* BIOCHEMISTRY BLOOD, HORMONE MUSCULAR SYSTEM NERVOUS SYSTEM PARATHYROID GLAND VITAMIN D [H H MI]

Calculating machines

Any mechanical electromechanical or electronic devices for performing arithmetical operations

Although the terms calculator and computer have been used interchangeably the tendency in recent years in the United States is to restrict the term calculator to digital devices which are manually operated or externally programmed Although any classification is arbitrary in this article only key operated manually controlled desk adding and calculating machines and wired program electronic calculators are discussed All of these devices come under the heading of digital computers *See* COMPUTER

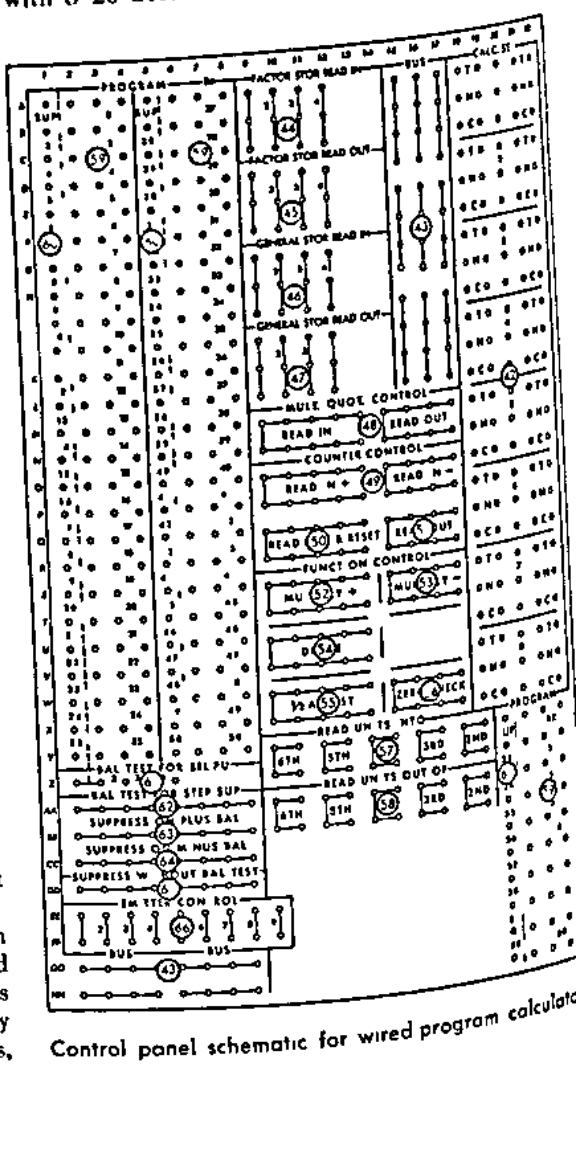
The distinctive property of calculators is that they perform arithmetic essentially by counting Addition for example is generally performed in the mechanical type equipment by lever actuated displacement of counter wheels a number of steps equal in value to the addend the augend is any number already registered in the counter wheels, which in an assembly of stages or orders is called an accumulator

Adding machines. These key-operated calculators only add (in some cases also subtract) in most common forms they print each summand and the total Adding and printing takes place in three steps (1) a key (or keys) is depressed which sets up a mechanism for printing and for limiting the movement of a rack gear to a number of increments equal to the value of the key, (2) an operating handle or bar is actuated downward moving a centrally pivoted lever up, bringing the appropriate type figure into printing position, (3) forward motion of the handle brings the lever with attached rack into gear with the counter wheel which is rotated a number of teeth equal to the key

Adding machines are either of the 10-key type in which successive orders (units tens hundreds and so on) are operated by set up or of the full keyboard or multiple key type The latter consists usually of 10 columns of 9 keys each, a column to each order

Desk calculating machines. These machines which perform all arithmetical operations are of either the key driven or the rotary, or key set types

In a key-driven calculator (usually constructed with 8–20 decimal orders) counter wheels are ro-



Control panel schematic for wired program calculato

tated by depressing a key and thereby moving a lever which is pivoted at the rear of the machine and which is provided with a segmental gear rack The rack engages a pinion associated with a numeral wheel (the counter) which is rotated an appropriate amount An additional crank or motor to drive the action to completion is not required The means required to stop the driven wheel from rotating beyond the appropriate position and for carrying from order to order (even when all orders of keys are depressed simultaneously) is exceedingly intricate The carry mechanism must be designed to operate within 6 milliseconds

Subtraction is accomplished by adding tens complements and inhibiting the carry by a finger operated cut off device Multiplication is done by positioning the fingers over keys one to a column (which establishes the multiplicand) and depressing the keys a number of times equal to the number in the one's position of the multiplier shifting the hands and again depressing keys a number of times corresponding to the number in the tens position of the multiplier and so on Most machines of this type display answers directly on numeral wheels

Key setting or rotary, calculators are perhaps the most common calculators In general adding wheels are set up by depression of keys either on a 10-key or multiple-key manual A crank or a motor driven mechanism then turns the wheels which are geared to the counter Subtraction is usually achieved directly by a reverse motion while multiplication is achieved by repeated addition In present day machines all arithmetical operations including division are completely automatic

Wired program electronic calculators These are similar in switching and arithmetic means to stored program digital computers (*see* DIGITAL COMPUTER) except for limited memory capacity and for the fact that programs are not loaded into the memory of the machine along with the data to be operated on *See* DIGITAL COMPUTER PROGRAMMING

On such machines, wiring from a program step section to a storage selection region (of a removable panel attached to the machine) and to other regions which correspond to operations such as reset and add to accumulator and store in register R may be set up manually by plug in wires A typical wiring panel is depicted in the illustration

Wired program machines are limited to relatively few program steps Although they are able to execute branching instructions address modification and in general the performance of arithmetical operations on instructions are not possible Therefore the programming of loops and other powerful methods available to stored program machines are not available on wired program calculators

[R J N]

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Calculus, differential and integral

The branch of mathematics dealing with two fundamental operations differentiation and integration, which are carried out on functions The subject as traditionally developed in college textbooks is partly an elementary development of the purely theoretical aspects of these operations and their interrelation partly a development of rules and formulas for applying calculus to the standard functions which arise in algebra and trigonometry (with exponentials and logarithms included) and partly a collection of applications to problems of geometry physics chemistry engineering economics and perhaps a few other subjects

Derivative The fundamental concept of differential calculus is that of the derivative of a function of one variable The classical physical prototype of this concept is that of instantaneous velocity which is the derivative of distance as a function of time The derivative also has a highly significant geometrical realization which depends upon the graphical representation of a function in rectangular coordinates $(x\,y)$ If y is a differentiable function of x perhaps as x increases from x_1 to x_2 the graph of the function is a continuous curve with exactly one y for each x and at each point the curve has a tangent line which is not parallel to the y axis If ϕ is the angle measured counterclockwise from the positive x direction to the tangent (see Fig 1) then $\tan\phi$ is equal to the derivative of y with respect to x (This is on the supposition that the same unit of length is used along the two axes) This $\tan\phi$ is also called the slope of the curve

The standard notation for the derivative of y with respect to x is dy/dx If the functional notation $y = f(x)$ is used the derivative is often denoted by $f'(x)$ Modern practice is to use f for the function as an abstract entity while $f(x)$ denotes the value of f at x Then f' denotes the derivative as a function and $f'(x)$ is the value of f' at x For a precise definition of the derivative *see* DIFFERENTIATION

Functions To say that y is a function of x means that as a consequence of some rule or definite agreement there is a designated collection of permissible values of x (called the domain of the function) and an associated set of corresponding values of y (called the range of the function) of such a

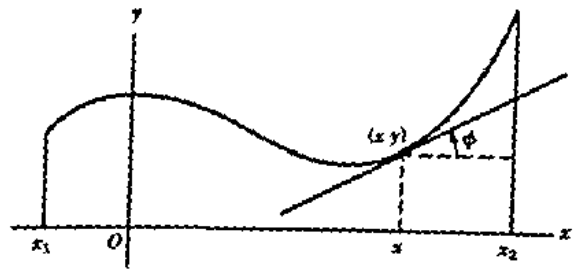


Fig 1 The derivative of $f(x)$

character that with each permissible value of x is paired a unique well determined value of y The function itself is the collection of all the pairs (x,y) which arise in this way This collection exemplifies the rule or agreement If f denotes the function it is customary to write $y = f(x)$ to represent the dependence of y on x

In calculus the domain of the function is usually composed of one or more intervals of the x axis

Definite integral If f is a function defined on the finite interval from x_1 to x_2 inclusive the definite integral of f from x_1 to x_2 denoted by

$$\int_{x_1}^{x_2} f(x)\,dx$$

is defined by applying to f a rather intricate process which entails the consideration of what are called *approximating sums* When the function f is subjected to certain restrictions this process culminates in the determination of a number as the *limit* of the approximating sums and this number is called the definite integral of f from x_1 to x_2 The integral is not defined unless the approximating sums do converge to a well defined limit A sufficient condition that this be so is that the function f be continuous

There is a geometrical representation of the process of defining the definite integral and it furnishes a plausible argument for the convergence of the approximating sums to a limit Divide the interval from x_1 to x_2 into a finite number N of not necessarily equal parts Let the lengths of these parts be h_1 h_2 $\cdots$ h_N and let t_k be a value of x in the kth part (see Fig 2) Then the expression

$$f(t_1)h_1 + f(t_2)h_2 + \cdots + f(t_N)h_N$$

is called an approximating sum In Fig 2, where the function is continuous and the function values are all positive each term $f(t_k)h_k$ in the approximating sum is equal to the area of a certain shaded rectangle and the whole sum is an approximation of the area between the graph of the function and the x axis from x_1 to x_2 inclusive The limiting process is carried on by increasing N and making the largest of the h_k's approach 0 It is then intuitively clear that the definite integral is the number which represents the exact area between the x axis and the graph This geometrical interpretation of the integral is the basis of one of the important applications of integral calculus to the calculation of areas.

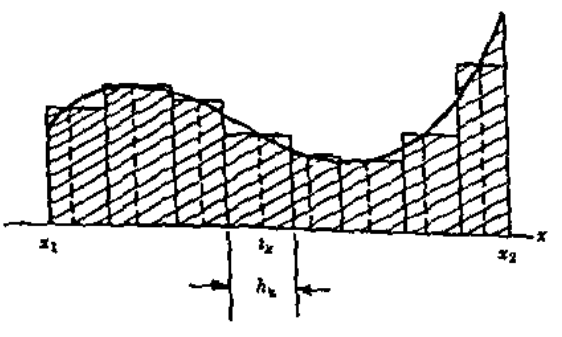


Fig 2 The definite integral

It would be tedious and difficult in practice to compute definite integrals by actually working out the limits of approximating sums It is therefore fortunate that by purely mathematical reasoning it is possible to demonstrate a theorem which links derivatives and integrals and makes it possible in a great many important instances to compute definite integrals by an easier procedure *See* INTEGRATION

In the next paragraph are stated the two fundamental theorems of calculus In these statements the adjective "continuous" appears For a function $y = f(x)$ to be continuous means roughly *that as x changes gradually y must* either change gradually or not at all *Absolutely abrupt jumps* are forbidden and so are many more bizarre modes of irregular behavior For a precise definition of continuity *see* DIFFERENTIATION

Fundamental theorems of calculus To calculate

$$\int_{x_1}^{x_2} f(x)\,dx$$

find if possible a function F with continuous derivative F' such that $F'(x) = f(x)$ where $x_1 \leq x \leq x_2$ Then

$$\int_{x_1}^{x_2} f(x)\,dx = F(x_2) - F(x_1)$$

This is one of the two central theorems The other is stated as follows Suppose f is continuous and consider the function F defined by

$$F(x) = \int_{x_1}^{x} f(t)\,dt$$

Then F has a derivative given by $F'(x) = f(x)$

Law of the mean The most important theorem about derivatives exclusive of those which resolve integrals is variously called 'the law of the mean' and the mean value theorem of differential calculus' It is stated in this form Suppose f is continuous for x from x_1 to x_2 inclusive and suppose f has a derivative for each x between x_1 and x_2 Then there is some x of this kind for which

$$f'(x) = \frac{f(x_2) - f(x_1)}{x_2 - x_1}$$

This theorem enables one to prove that if $f'(x)$ is always positive then $f(x)$ increases as x increases Also that if $f'(x)$ is always zero then $f(x)$ remains constant as x changes The first of these results is important for applications to the investigations of graphs The second is virtually indispensable in the proof of the fundamental theorems of calculus stated above and in establishing the uniqueness of the solutions of certain problems which involve antidifferentiation (the process of surmising what a function is from a knowledge of its derivative) Such problems abound in the applications of calculus to problems of motion

Applications of derivatives If y is a function of x the derivative dy/dx is interpretable as the rate of change of y with respect to x If y is distance and x is time dy/dx is velocity If y is velocity and x is time dy/dx is acceleration If y is work done by a force and x is time dy/dx is power Many motion problems such as those arising in mechanics and formulated by Newton s second law are expressible by posing an equation which a function and its derivative or derivatives must satisfy These are called differential equations The study of such equations is an extension and ramification of calculus Differential equations are important in all branches of physics They also arise in many problems of engineering and chemistry for example in the deformation of columns and beams in the study of chemical reactions and in radioactive decay *See* DIFFERENTIAL EQUATION

Problems of maximizing or minimizing a function usually involve derivatives If a differentiable function f reaches a relative maximum or minimum at a point in the interior of an interval of its domain then $f'(x)$ must be zero there This helps in finding extreme values of f

Applications of integrals Integrals are used to compute areas bounded by curves in a plane They are also used to compute other geometrical quantities such as lengths of curves areas of surfaces and volumes of solids For computing volumes and surface areas the natural tools are multiple integrals

Integrals are also used to compute quantities which occur in physics such as center of mass moment of inertia work done by a variable force and attraction due to gravitation The concepts of first second and higher moments of a function as used in statistics are formulated in terms of integrals

Functions of several variables To each pair $(x_1\ x_2)$ in a specified collection of number pairs let there correspond a certain definite number y This defines $y = f(x_1\ x_2)$ as a function of two variables Functions of three or more variables may also be considered Differential calculus is extended to such functions through the study of partial derivatives with respect to the separate variables $x_1\ x_2$ A concept of total differential is also relevant For details *see* PARTIAL DIFFERENTIATION Integral calculus for functions of several variables is developed through the concept of a multiple integral For instance in the case of functions of two variables there is a concept of double integral The theory of the subject deals with how the double integral is expressible in terms of two successive definite integrals of the sort occurring in calculus of functions of one variable There is also a concept of a line integral which is a kind of integral along a curve There are relations between this concept the concept of total differential and the concept of double integral

New developments Calculus belongs to the branch of mathematics called analysis One characteristic of analysis is its concern with infinite limiting processes Current research in analysis is mostly on a level of development far beyond the elements of calculus However the ideas of calculus persist though in much more generalized and abstract form in the theory of functions and in functional analysis [A E T]

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Calculus of tensors

The systematic study of tensors which led to an extension and generalization of vectors begun in 1900 by two Italian mathematicians G Ricci and T Levi Civita following Riemann s proposal concerning a generalization of euclidean geometry The principal aim of the tensor calculus (absolute differential calculus) is to construct relationships which are generally covariant in the sense that these relationships or laws remain valid in all coordinate systems The differential equations for the geodesics in a Riemannian space are covariant expressions they yield a description of the geodesics which is valid for all coordinate systems On the other hand Newton s equations of motion require a preferred coordinate system for their description namely one for which force is proportional to acceleration (an inertial frame of reference) Thus Albert Einstein was led to a study of Riemannian geometry and the tensor calculus in order to construct the general theory of relativity

Arithmetic or vector n space The coordinates of a point in a three dimensional euclidean space are given by the triple of numbers $(x\ y\ z)$ or $(x^1\ x^2\ x^3)$ with $x = x^1\ y = x^2\ z = x^3$ The superscripts in $x^i\ i = 1\ 2\ 3$ are simply labels which enable one to distinguish and order the various elements in the triple of numbers The totality of all number triples of the form $(x^1\ x^2\ x^3)$ with the $x^i\ i = 1\ 2\ 3$ real yields the arithmetic 3 space designated as V_3 A simple generalization yields the arithmetic n space V_n This space or manifold consists of all n tuples of the form $(x^1\ x^2 \quad x^n)$ the $x^i\ i = 1\ 2 \quad n$ taken as real numbers Now a space of n dimensions is defined as any set of objects which can be put in 1 1 reciprocal correspondence with the arithmetic n space The 1 1 correspondence between the elements or points of the n space and the arithmetic n space can be chosen in many ways and in general the choice depends on the nature of the physical problem In the special theory of relativity an event is specified by the three space coordinates and the time so that each event corresponds to a four tuple $(x^1\ x^2, x^3\ x^4 = ct)$

Let a point P of an n space correspond to the n tuple $(x^1, x^2 \quad , x^n)$ Now consider the n equations

$$y^i = y^i(x^1, x^2 \quad , x^n) \quad i = 1\ 2 \quad n \qquad (1)$$

and assume that one can solve for each x^i, yielding

$$x^i = x^i(y^1\ y^2 \quad y^n) \quad i = 1\ 2 \quad n \qquad (2)$$

t is assumed that Eqs (1) and (2) are single alued and that the partial derivatives $\partial y^i/\partial x^j$ $\partial x^i/\partial y^j$ where $i, j = 1, 2, \ldots, n$ exist and are continuous The n space of which P is an ele ment can also be put into 1 1 correspondence with the arithmetic n space $(y^1, y^2, \ldots, y^n)$ Thus one has a new description of every point in the n space The points or elements of the n space have not changed one merely has a new description (coordinate system) of these points Thus Eq (1) is called a transformation of coordinates

The algebra of tensors is simplified by use of Einstein's summation convention From the calcu lus Eq (1) yields

$$\frac{\partial y^i}{\partial y^j} = \sum_{\alpha=1}^{n} \frac{\partial y^i}{\partial x^\alpha} \frac{\partial x^\alpha}{\partial y^j} = \frac{\partial y}{\partial x^\alpha} \frac{\partial x^\alpha}{\partial y^j} \qquad i, j = 1, 2, \ldots, n \tag{3}$$

The index α occurs just twice in the last expression of Eq (3) thus indicating a summation over this index In a space of three dimensions the expres sion $S = a_{\alpha\beta} x^\alpha x^\beta$ requires a double summation be cause the indices α and β occur exactly twice Thus,

$$S = \sum_{\beta=1}^{3} \sum_{\alpha=1}^{3} a_{\alpha\beta} x^\alpha x^\beta$$

and Einstein found it convenient to remove the summation signs A further convenience occurs if the Kronecker delta is introduced Thus δ_j^i $i, j = 1, 2, \ldots, n$ is a set of quantities whose numeri cal values are given by

$$\delta_j^i = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases} \tag{4}$$

In particular

$$\delta_1^1 = \delta_2^2 = \cdots = \delta_n^n = 1$$
$$\delta_2^1 = \delta_3^1 = \cdots = \delta_n^{n-1} = 0$$

and for an n space

$$\delta_\alpha^\alpha = \delta_1^1 + \delta_2^2 + \cdots + \delta_n^n = n$$

Equation (3) may be written

$$\delta_j^i = \frac{\partial y^i}{\partial x^\alpha} \frac{\partial x^\alpha}{\partial y^j}$$

This expression yields

$$\left|\frac{\partial y^i}{\partial x^j}\right| \left|\frac{\partial x^\alpha}{\partial y^\beta}\right| = 1$$

applying the rule for the product of two determi nants with

$$\left|\frac{\partial y^i}{\partial x^j}\right|$$

the Jacobian of the transformation (1), and

$$\left|\frac{\partial x^i}{\partial y^j}\right|$$

the Jacobian of the inverse transformation (2)

Contravariant vectors In an n space the locus of elements given by

$$x^i = x^i(\lambda) \qquad i = 1, 2, \ldots, n \qquad \lambda_0 \leq \lambda \leq \lambda_1 \tag{5}$$

represents a space curve Γ with λ a parameter The n tuple

$$\left(\frac{dx^1}{d\lambda}, \frac{dx^2}{d\lambda}, \ldots, \frac{dx^n}{d\lambda}\right) \tag{6}$$

designated by $dx^i/d\lambda$, is defined to be a tangent element to the space curve (5) Under an allowable coordinate transformation (1) the space curve Γ can be represented by

$$y^i = y^i(x^1(\lambda), x^2(\lambda), \ldots, x^n(\lambda)) = y^i(\lambda) \qquad i = 1, 2, \ldots, n \tag{7}$$

The components of the tangent vector for the $y = (y^1, y^2, \ldots, y^n)$ coordinate system are given by

$$\frac{dy^i}{d\lambda} \qquad i = 1, 2, \ldots, n \tag{8}$$

which represent the elements of the n tuple

$$\left(\frac{dy^1}{d\lambda}, \frac{dy^2}{d\lambda}, \ldots, \frac{dy^n}{d\lambda}\right)$$

Certainly the x coordinate system is no more im portant than the y coordinate system as a descrip tion of the space curve Γ One cannot say that $dx^1/d\lambda$ is the tangent vector, nor can one say that $dy^1/d\lambda$ is the tangent vector If one considers a l allowable coordinate systems one obtains the en tire class of tangent elements each element (n tuple) claiming to be the tangent vector for its particular coordinate system It is the abstract col lection of all these tangent elements that is speci fied as the tangent vector To find what relation h p exists between the components of the tangent vec tor when described by two different coordinate systems Eq (7) can be used to give

$$\frac{dy^i}{d\lambda} = \frac{\partial y^i}{\partial x^\alpha} \frac{dx^\alpha}{d\lambda} \qquad i = 1, 2, \ldots, n \tag{9}$$

Note that at any point each component $dy^i/d\lambda$ de pends linearly on every component of $dx^i/d\lambda$ Moreover

$$\frac{dx^i}{d\lambda} = \frac{\partial x^i}{\partial y^\alpha} \frac{dy^\alpha}{d\lambda} \qquad i = 1, 2, \ldots, n \tag{10}$$

One can now form the following generalization Any set of numbers $A^i(x^1, x^2, \ldots, x^n)$ $i = 1, 2, \ldots, n$ which transform according to the law

$$\bar{A}^i(\bar{x}^1, \bar{x}^2, \ldots, \bar{x}^n) = A^\alpha(x^1, x^2, \ldots, x^n) \frac{\partial \bar{x}^i}{\partial x^\alpha} \qquad i = 1, 2, \ldots, n \tag{11}$$

under the coordinate transformation $\bar{x}^i = \bar{x}^i(x^1, x^2, \ldots, x^n)$, $i = 1, 2, \ldots, n$ is said to be a con travariant vector The vector is not just the set o components in any coordinate system but is rathe

the abstract element which is represented in each coordinate system x by the set of numbers $A^i(x)$ The $\bar{A}^i(\bar{x})$ depend linearly on the $A^\alpha(x)$, therefore the sum and difference of two vectors in an n space are also vectors

One immediately sees that the law of transformation for a contravariant vector is transitive Let

$$\bar{A}^i = A^\alpha \frac{\partial \bar{x}^i}{\partial x^\alpha} \qquad \bar{\bar{A}}^i = \bar{A}^\alpha \frac{\partial \bar{\bar{x}}^i}{\partial \bar{x}^\alpha}$$

so that

$$\bar{\bar{A}}^i = \bar{A}^\beta \frac{\partial \bar{\bar{x}}^i}{\partial \bar{x}^\beta} = A^\alpha \frac{\partial \bar{x}^\beta}{\partial x^\alpha} \frac{\partial \bar{\bar{x}}^i}{\partial \bar{x}^\beta} = A^\alpha \frac{\partial \bar{\bar{x}}^i}{\partial x^\alpha}$$

which proves the statement

If the components of a contravariant vector are known in one coordinate system the components are known in all allowable coordinate systems from Eq (11) A coordinate transformation does not yield a *new vector, it merely changes the com* ponents of the same vector Thus, a vector is said to be invariant under a coordinate transformation Any object which is not changed under a coordinate transformation is called an invariant

If $\phi(x^1,x^2, \quad ,x^n)$ is a scalar point function, $\phi(x^1,x^2, \quad ,x^n) = \phi(x^1(\bar{x}),x^2(\bar{x}), \quad ,x^n(\bar{x}))$
$= \bar{\phi}(\bar{x}^1,\bar{x}^2, \quad ,x^n)$

then

$$\frac{\partial \bar{\phi}}{\partial \bar{x}^i} = \frac{\partial \phi}{\partial x^\alpha} \frac{\partial x^\alpha}{\partial \bar{x}^i} \tag{12}$$

The n tuple

$$\left(\frac{\partial \phi}{\partial x^1}, \frac{\partial \phi}{\partial x^2}, \quad , \frac{\partial \phi}{\partial x^n}\right)$$

yields the components of a covariant vector, called the gradient of ϕ

More generally, if

$$\bar{A}_i(\bar{x}^1,\bar{x}^2, \quad ,\bar{x}^n) = A_\alpha(x^1,x^2, \quad ,x^n) \frac{\partial x^\alpha}{\partial \bar{x}^i}$$
$$i = 1, 2, \quad , n \tag{13}$$

one says that the $A_\alpha(x)$ are the components of a covariant vector

The law of transformation (13) differs from that of (11) because in general,

$$\frac{\partial x^\alpha}{\partial \bar{x}^i} \neq \frac{\partial \bar{x}^i}{\partial x^\alpha}$$

However, for the group of orthogonal transformations $x^i = a_\alpha{}^i x^\alpha$ such that $A = \|a_i{}^j\|$ satisfies $A^T = A^{-1}$, one can show that $\partial \bar{x}^i/\partial x^\alpha = \partial x^\alpha/\partial \bar{x}^i$, and for this reason no distinction occurs between contravariant and covariant vectors in elementary vector analysis

An important scalar invariant can be formed from a contravariant vector A^i and a covariant vector B From their laws of transformation it follows that

$$\bar{A}^i \bar{B}_i = A^\alpha B_\beta \frac{\partial x^\alpha}{\partial \bar{x}^i} \frac{\partial x^\beta}{\partial \bar{x}^i} = A^\alpha B_\beta \delta_\alpha{}^\beta = A^\alpha B_\alpha = A^i B_i \tag{14}$$

Thus, the expression

$$A^i B_i = \sum_{i=1}^{n} A^i B_i$$

is invariant both in form and in its numerical value under a transformation of coordinates One calls $A^\alpha B_\alpha$ the scalar, or inner, product, of the two vectors A^i, B_i

Tensors. *The contravariant and covariant vectors discussed above are special cases of differential invariants called tensors* The components of a tensor are of the form

$$T_{b_1 b_2 \quad b_s}^{a_1 a_2 \quad a_r}(x^1,x^2, \quad ,x^n)$$

and the indices $a_1, a_2, \quad , a_r, b_1, b_2, \quad , b_s$ run through the integers 1, 2, $\quad , n$ The components transform according to the rule

$$\bar{T}_{b_1 b_2 \quad b_s}^{a_1 a_2 \quad a_r} = \left|\frac{\partial x}{\partial \bar{x}}\right|^N T_{\beta_1 \beta_2 \quad \beta_s}^{\alpha_1 \alpha_2 \quad \alpha_r} \frac{\partial \bar{x}^{a_1}}{\partial x^{\alpha_1}} \frac{\partial \bar{x}^{a_2}}{\partial x^{\alpha_2}} \quad \frac{\partial \bar{x}^{a_r}}{\partial x^{\alpha_r}} \frac{\partial x^{\beta_1}}{\partial \bar{x}^{b_1}} \quad \frac{\partial x^{\beta_s}}{\partial \bar{x}^{b_s}} \tag{15}$$

The exponent N of the Jacobian $\left|\frac{\partial x}{\partial \bar{x}}\right|$ is called the weight of the tensor field For $N = 0$ the tensor field is absolute, otherwise the tensor field is of weight N A tensor density occurs for $N = 1$ The number of indices is $r + s$ the rank of the tensor Vectors are tensors of rank one The tensor of Eq (15) is contravariant of order r and covariant of order s

An important property of tensors is immediately evident from Eq (15) If every component of a tensor vanishes in one coordinate system, the com *ponents vanish in all coordinate systems*

Two tensors are said to be of the same kind if they have the same order in their contravariant and covariant indices and if they are of the same weight Additional tensors can be constructed as follows

1 *The sum and difference of two tensors of the* same kind yields a new tensor of the same kind This is apparent from the linear property of Eq (15)

2 The product of two tensors is a new tensor This can be shown for a special case Let

$$\bar{T}_b{}^a = \left|\frac{\partial x}{\partial \bar{x}}\right| T_\beta{}^\alpha \frac{\partial x^\beta}{\partial \bar{x}^b} \frac{\partial \bar{x}^a}{\partial x^\alpha} \qquad \bar{S}^c = \left|\frac{\partial x}{\partial \bar{x}}\right|^2 S^\gamma \frac{\partial \bar{x}^c}{\partial x^\gamma}$$

Then $\bar{W}_b{}^{ac} = \bar{T}_b{}^a \bar{S}^c = \left|\frac{\partial x}{\partial \bar{x}}\right|^3 (T_\beta{}^\alpha S^\gamma) \frac{\partial x^\alpha}{\partial x^\gamma} \frac{\partial \bar{x}^c}{\partial x^\gamma} \frac{\partial x^\beta}{\partial \bar{x}^b}$

$$= \left|\frac{\partial x}{\partial \bar{x}}\right|^3 W_\beta{}^{\alpha\gamma} \frac{\partial \bar{x}^a}{\partial x^\alpha} \frac{\partial x^c}{\partial x^\gamma} \frac{\partial x^\beta}{\partial \bar{x}^b}$$

To illustrate the concept of contraction, consider the absolute tensor

$$\bar{A}_{kl}{}^{ij} = A_{\alpha\gamma}{}^{\alpha\beta} \frac{\partial \bar{x}^i}{\partial x^\alpha} \frac{\partial \bar{x}^j}{\partial x^\beta} \frac{\partial x^\gamma}{\partial \bar{x}^k} \frac{\partial x^\gamma}{\partial \bar{x}^l}$$

Replacing k by i and summing yields

$$\bar{B}_l^j \equiv \bar{A}_{rl}{}^{rj} = A_{\sigma\tau}{}^{\alpha\beta}\frac{\partial \bar{x}^j}{\partial x^\alpha}\frac{\partial x^\beta}{\partial \bar{x}^r}\frac{\partial x^\sigma}{\partial \bar{x}^l}\frac{\partial \bar{x}^\tau}{\partial x^\gamma}$$

$$= A_{\sigma\tau}{}^{\alpha\beta}\frac{\partial x^\sigma}{\partial x^\alpha}\frac{\partial \bar{x}^j}{\partial x^\beta}\frac{\partial x^\tau}{\partial \bar{x}^l}$$

$$= A_{\sigma\tau}{}^{\alpha\beta}\,\delta_\alpha{}^\sigma\frac{\partial \bar{x}^j}{\partial x^\beta}\frac{\partial x^\tau}{\partial \bar{x}^l}$$

$$= A_{\sigma\tau}{}^{\sigma\beta}\frac{\partial \bar{x}^j}{\partial x^\beta}\frac{\partial x^\tau}{\partial \bar{x}^l} \equiv B_\tau{}^\beta\frac{\partial \bar{x}^j}{\partial x^\beta}\frac{\partial x^\tau}{\partial \bar{x}^l}$$

so that $B^\beta{}_\tau \equiv A_{\sigma\tau}{}^{\sigma\beta}$ is a mixed tensor In general one equates a certain covariant index with a contravariant index sums on this repeated index and obtains a new tensor whose rank is two less than that of the original tensor This process of producing a new tensor is called the method of contraction

A few examples of tensors can be listed

1 The Kronecker delta is a mixed absolute tensor because

$$\delta_j{}^i\frac{\partial \bar{x}^j}{\partial x^\alpha}\frac{\partial x^\beta}{\partial \bar{x}^i} = \frac{\partial \bar{x}^i}{\partial x^\alpha}\frac{\partial \bar{x}^\beta}{\partial \bar{x}^i} = \frac{\partial \bar{x}^\beta}{\partial x^\alpha} = \delta_\alpha{}^\beta$$

2 If A_i and B_i are absolute covariant vectors then

$$\bar{C}_{ij} \equiv \bar{A}_i\bar{B}_j = A_\alpha B_\beta\frac{\partial x^\alpha}{\partial \bar{x}^i}\frac{\partial x^\beta}{\partial \bar{x}^j} = C_{\alpha\beta}\frac{\partial x^\alpha}{\partial \bar{x}^i}\frac{\partial x^\beta}{\partial \bar{x}^j}$$

so that $C_{\alpha\beta} \equiv A_\alpha B_\beta$ are the components of an absolute covariant tensor of rank two

3 Let ϕ be the components of an absolute covariant vector From $\bar{\phi}_i = \phi_\alpha(\partial x^\alpha/\partial \bar{x}^i)$ it follows that

$$\bar{F}_{ij} \equiv \frac{\partial \bar{\phi}_i}{\partial \bar{x}^j} - \frac{\partial \bar{\phi}_j}{\partial \bar{x}^i} = \left(\frac{\partial \phi_\alpha}{\partial x^\beta} - \frac{\partial \phi_\beta}{\partial x^\alpha}\right)\frac{\partial x^\alpha}{\partial \bar{x}^i}\frac{\partial x^\beta}{\partial \bar{x}^j}$$

$$= F_{\alpha\beta}\frac{\partial x^\alpha}{\partial \bar{x}^i}\frac{\partial x^\beta}{\partial \bar{x}^j}$$

so that

$$F_{\alpha\beta} \equiv \frac{\partial \phi_\alpha}{\partial x^\beta} - \frac{\partial \phi_\beta}{\partial x^\alpha}$$

are the components of an absolute covariant tensor Note that $F_{\alpha\beta} = -F_{\beta\alpha}$ so that the tensor is skew symmetric If the ϕ_i $i = 1\ 2\ 3\ 4$ are the components of the electromagnetic vector potential the F_{ij} are the components of the electromagnetic field tensor

Line element of Riemannian geometry A simple generalization of the euclidean metric or line element $ds^2 = dx^2 + dy^2 + dz^2$, led G F B Riemann to consider an n space such that a metric is imposed on the space which yields the invariant distance ds between two nearby points whose coordinates differ by dx^i The line element in a Riemannian n space is given by

$$ds^2 = g_{\alpha\beta}(x^1\ x^2,\quad ,x^n)\,dx^\alpha\,dx^\beta \qquad g_{\alpha\beta} = g_{\beta\alpha} \qquad (16)$$

Under a coordinate transformation $x^\alpha = x^\alpha(\bar{x})$ Eq (16) becomes

$$ds^2 = g_{\alpha\beta}\frac{\partial x^\alpha}{\partial \bar{x}^\sigma}\frac{\partial x^\beta}{\partial \bar{x}^\tau}d\bar{x}^\sigma\,d\bar{x}^\tau = \bar{g}_{\sigma\tau}\,d\bar{x}^\sigma\,d\bar{x}^\tau$$

with

$$\bar{g}_{\sigma\tau} = g_{\alpha\beta}\frac{\partial x^\alpha}{\partial \bar{x}^\sigma}\frac{\partial x^\beta}{\partial \bar{x}^\tau} \qquad (17)$$

Hence the $g_{ij}(x)$ are the components of an absolute covariant tensor of rank two One can show that the $g^{ij}(x)$ defined by $g^{ij}g_{jk} = \delta_k{}^i$ are the components of an absolute contravariant tensor provided $|g_{ij}| \neq 0$ Furthermore, it can be shown that

$$|g_{ij}| = |g_{ij}|\left|\frac{\partial x}{\partial \bar{x}}\right|^2$$

Thus if A^i are the components of an absolute contravariant vector, then $|g_{\alpha\beta}|^{1/2}A^i$ are the components of a contravariant vector density

Geodesics in a Riemannian space If a space curve in a Riemannian n space is given by $x^i = x^i(\lambda)$, $\lambda_0 \leqq \lambda \leqq \lambda_1$, the distance along the curve between the end points is given by

$$L = \int_{\lambda_0}^{\lambda_1}\left(g_{\alpha\beta}\frac{dx^\alpha}{d\lambda}\frac{dx^\beta}{d\lambda}\right)^{1/2}d\lambda \qquad (18)$$

The geodesic path between two fixed points of a Riemannian space is that curve joining the two points which yields a minimum value for the integral of Eq (18) The same path is obtained if one minimizes

$$\int_{P_0}^{P_1}\left(g_{\alpha\beta}\frac{dx^\alpha}{ds}\frac{dx^\beta}{ds}\right)ds \qquad (19)$$

Applying the Euler Lagrange equations of the calculus of variations,

$$\frac{d}{ds}\left(\frac{\partial L}{\partial \dot{x}^i}\right) = \frac{\partial L}{\partial x^i}$$

with $L = g_{\alpha\beta}\dot{x}^\alpha\dot{x}^\beta$, yields the differential equations of the geodesics,

$$\frac{d^2x^i}{ds^2} + \Gamma_{jk}{}^i(x)\frac{dx^j}{ds}\frac{dx^k}{ds} = 0$$

with

$$\Gamma_{jk}{}^i = \frac{1}{2}g^{i\sigma}\left(\frac{\partial g_{\sigma j}}{\partial x^k} + \frac{\partial g_{k\sigma}}{\partial x^j} - \frac{\partial g_{jk}}{\partial x^\sigma}\right)$$

The important elements $\Gamma_{jk}{}^i$ are called the Christoffel symbols of the second kind The elements $\{i,jk\} = g_{i\sigma}\Gamma_{jk}{}^\sigma$ are the Christoffel symbols of the first kind Under a coordinate transformation the Christoffel symbols transform according to the law

$$\bar{\Gamma}_{jk}{}^i(\bar{x}) = \Gamma_{\beta\gamma}{}^\alpha(x)\frac{\partial x^\beta}{\partial \bar{x}^j}\frac{\partial x^\gamma}{\partial \bar{x}^k}\frac{\partial \bar{x}^i}{\partial x^\alpha} + \frac{\partial^2 x^\alpha}{\partial \bar{x}^j\partial \bar{x}^k}\frac{\partial \bar{x}^i}{\partial x^\alpha}$$

Thus the Christoffel symbols are not the components of a mixed tensor However if the Γ are given in an x coordinate system then they can be computed in an x coordinate system (22)

Covariant differentiation. From Eq (11) it follows that

$$\frac{\partial \bar{A}^i}{\partial \bar{x}^j} = \frac{\partial A^\alpha}{\partial x^\beta}\frac{\partial \bar{x}^i}{\partial x^\alpha}\frac{\partial x^\beta}{\partial \bar{x}^j} + A^\alpha \frac{\partial^2 \bar{x}^i}{\partial x^\beta \partial x^\alpha}\frac{\partial x^\beta}{\partial \bar{x}^j} \tag{23}$$

so that $\partial A^\alpha/\partial x^\beta$ are not the components of a mixed tensor This is not surprising, in a euclidean space using coordinates other than rectangular coordinates, the unit vectors change directions from point to point A differentiation process which yields a new tensor can be introduced by combining Eqs (22) and (23) It can be shown that

$$A_{,j}^i = \frac{\partial A^i}{\partial x^j} + A^\alpha \Gamma_{\alpha j}^i \tag{24}$$

are the components of a mixed tensor The term $A_{,j}^i$ is called the covariant derivative of A^i (the comma denoting covariant differentiation)

In a euclidean space using rectangular coordinates,

$$ds^2 = \sum_{i=1}^{n} (dx^i)^2$$

the Γ_{jk}^i vanish from Eq (21), and the covariant derivative reduces to the ordinary partial derivative

The intrinsic derivative of A^i along a path $x^i = x^i(s)$, with s arc length, is given by

$$\frac{\delta A^i}{\delta s} \equiv A_{,j}^i \frac{dx^j}{ds} = \frac{dA^i}{ds} + A^\alpha \Gamma_{\alpha j}^i \frac{dx^j}{ds} \tag{25}$$

The covariant derivative of the general tensor given by Eq (15) is

$$\begin{aligned} T^{\alpha_1\alpha_2\ \ \alpha_r}_{\beta_1\beta_2\ \ \beta_s,\ i} &= \frac{\partial T^{\alpha_1\alpha_2\ \ \alpha_r}_{\beta_1\beta_2\ \ \beta_s}}{\partial x^i} + T^{\mu\alpha_2\ \ \alpha_r}_{\beta_1\beta_2\ \ \beta_s}\Gamma^{\alpha_1}_{\mu i} \\ &+ \cdots + T^{\alpha_1\alpha_2\ \ \alpha_{r-1}\mu}_{\beta_1\beta_2\ \ \beta_s}\Gamma^{\alpha_r}_{\mu i} - T^{\alpha_1\alpha_2\ \ \alpha_r}_{\mu\beta_2\ \ \beta_s}\Gamma^{\mu}_{\beta_1 i} \\ &- \cdots - T^{\alpha_1\alpha_2\ \ \alpha_r}_{\beta_1\beta_2\ \ \beta_{s-1}\mu}\Gamma^{\mu}_{\beta_s i} - NT^{\alpha_1\alpha_2\ \ \alpha_r}_{\beta_1\beta_2\ \ \beta_s}\Gamma^{\mu}_{\mu i} \end{aligned} \tag{26}$$

A few examples of covariant differentiation now follow

1 Let A_i be an absolute covariant vector The curl of A_i is defined by

$$\begin{aligned} \operatorname{curl} A_i &= A_{i,j} - A_{j,i} \\ &= \frac{\partial A_i}{\partial x^j} - A_\alpha \Gamma_{ij}^\alpha - \frac{\partial A_j}{\partial x^i} + A_\alpha \Gamma_{ji}^\alpha \\ &= \frac{\partial A_i}{\partial x^j} - \frac{\partial A_j}{\partial x^i} \end{aligned} \tag{27}$$

2 The divergence of A^i is defined by

$$\begin{aligned} \operatorname{div} A^i &= A^\alpha_{\ ,\alpha} = \frac{\partial A^\alpha}{\partial x^\alpha} + A^\alpha \Gamma_{\alpha\beta}^\beta \\ &= \frac{1}{\sqrt{|g|}}\frac{\partial}{\partial x^\alpha}\left(\sqrt{|g|}\, A^\alpha\right) \end{aligned} \tag{28}$$

with $|g| = |g_{ij}|$ The proof of Eq (28) is omitted

3 If ϕ is an absolute scalar, the gradient of ϕ is defined by $\phi_{,i} = \partial\phi/\partial x^i$ The associated vector of $\phi_{,i}$ is $g^{\alpha\beta}\phi_{,\beta} = g^{\alpha\beta}(\partial\phi/\partial x^\beta) = A^\alpha$ Applying Eq (28) to A^α yields the Laplacian of ϕ given by

$$\operatorname{Lap}\phi = \frac{1}{\sqrt{|g|}}\frac{\partial}{\partial x^\alpha}\left(\sqrt{|g|}\, g^{\alpha\beta}\frac{\partial\phi}{\partial x^\beta}\right) \tag{29}$$

See CALCULUS OF VECTORS, GEOMETRY, RIEMANNIAN [H LA]

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Calculus of variations

An extension of the part of differential calculus which deals with maxima and minima of functions of a single variable The functions of the calculus of variations depend in an essential way upon infinitely many independent variables Classically these functions are usually integrals whose integrand depends on a function whose specification by any finite number of parameters is impossible For example let R be a smooth bounded region of a space of m variables, $x_1\ x_2\ \cdots\ x_m$, let y be any function of some smooth class on R and its boundary into real numbers or into n tuples of real numbers and taking specified values on the boundary, and let $f(x,y,p)$ be a smooth function of $2m+1$ variables $x_1\ x_2,\ \cdots\ x_m, y, p_1, p_2,\ \cdots\ , p_m$ Then the integral

$$J = \int \cdots \int_R f(x\, y, y_x)$$

is a function on the space of functions y to the real numbers and this space of functions is infinitely dimensional unless excessive restrictions are placed on it Here y_x denotes the derivatives $\partial y/\partial x$, and throughout this article subscripts will be used to denote derivatives and occasionally where the context is clear to denote particular values

The calculus of variations studies such functions and then *maxima and minima*. The *limitation* of the competing functions is made realistically, and with sufficient restrictions it is possible to arrive at a rewarding theory, these restrictions do not always include the fixed boundary conditions stated above

Principal applications may be to physical systems involving flexible components or time dependent orbits, equilibrium positions or orbits may be determined by minimizing energy or action integrals The problems are of mathematical interest because of intrinsic difficulties (largely related to lack of topological compactness of bounded regions in spaces of infinitely many dimensions) and possibly because more progress with difficult nonlinear

are

1 Necessary conditions for a function f of a single variable x to attain a local minimum at $x = x_0$ are $f'(x_0) = 0$ if the derivative exists at x_0 and if there are neighboring points of definition of f for arguments on each side of x_0 $f'(x_0) \geq 0$ if the derivative exists at x_0 and if there are neighboring points of definition of f for arguments larger than x_0

2 If $f'(x_0) = 0$ if f is defined at some points neighboring x_0 and if $f'(x_0)$ exists then a necessary condition for f to attain a local minimum at $x = x_0$ is $f'(x_0) \geqq 0$ conversely the conditions $f'(x_0) = 0$ and $f(x_0) > 0$ guarantee a local minimum at x_0

One standard technique of the calculus of variations is to derive necessary conditions for minima by restricting variations to a set of admissible variations depending smoothly on a single parameter and then to apply these theorems 1 and 2 from differential calculus

For example in the integral above suppose that the function $f(x, y, p)$ is defined for all (x, y) in some region of $(m + 1)$ space and for all p and that f and all its first and second partial derivatives are continuous in this region Suppose that the admissible functions y are restricted to functions which have continuous second derivatives in R and which take on the required boundary values Let $g(x)$ be such an admissible function lying in the interior of the region over which $f(x, y, p)$ is defined and let $z(x)$ be any function with continuous second derivatives on R and taking the value 0 at all points on the boundary of R Then for ϵ neighboring zero the function $y = g(x) + \epsilon z(x)$ is admissible in the problem (it has continuous second derivatives and takes the prescribed values on the boundary) Then $z(x)$ is an admissible variation If g does indeed afford a local minimum to J and if it is specified that the functions $y = g(x) + \epsilon z(x)$ are close to g for ϵ neighboring zero then propositions 1 and 2 above may be applied to the function $J(\epsilon)$ of the single variable ϵ where $J(\epsilon)$ is the value taken by J for y defined in terms of g and z as above Under the conditions stated the derivative $J'(0)$ does exist and it may be computed by differentiating under the integral sign The result is

$$J'(0) = \int \cdots \int_R [z(x) f_y(x, g, g_x) + \sum_i z_{x_i} f_{p_i}(x, g, g_x)]$$

This expression must be zero for any admissible $z(x)$ according to proposition 1 Under the restrictions set here each term of the expression to be summed may be integrated by parts the integration of the term with factor z_{x_i} being with respect to the single variable x_i for the formula $\int u\,dv = uv - \int v\,du$ (with boundary values assigned to the term uv) one sets $dv = z_{x_i}\,dx_i$ and takes the remainder of the term as u This yields after due account is taken of the vanishing of z on the boundary

$$J'(0) = \int \cdots \int_R z(x) \left[f_y(x, g, g_x) - \sum_i \frac{\partial}{\partial x_i} f_{p_i}(x, g, g_x) \right]$$

A fundamental technique of the calculus of variations lies in exploiting the necessity of this last integral being zero independent of the admissible variation $z(x)$ The integral divided by the measure of R is the average over R of z times the expression in brackets and the requirement that any function of a sufficiently wide class times a given function averages to zero is met only if the given function is itself zero Care must be taken to assure that this fundamental condition is met—that is that the admissible variations are sufficiently general to permit invoking this lemma In this case the bracketed expression must be zero and the necessary condition becomes a differential equation, the Euler equation For the function

$$f(x, y, p) = p_1^2 + p_2^2$$

so that

$$J = \int\int \left[\left(\frac{\partial y}{\partial x_1} \right)^2 + \left(\frac{\partial y}{\partial x_2} \right)^2 \right]$$

the Euler equation is just the Laplace equation

$$\partial^2 y / \partial x_1^2 + \partial^2 y / \partial x_2^2 = 0$$

Second variations are studied in a similar way applying proposition 2 above to $J''(0)$ These give rise to conditions of Jacobi for a minimum. Generally there are a set of conditions including Euler's condition above a condition of Weierstrass a condition of Legendre which may be derived from the Weierstrass condition and the Jacobi condition, all known as necessary conditions for a minimum These are generally set in terms of inequalities and when the conditions are strengthened to demand strong inequalities (excluding equality) the conditions become sufficient for many interesting problems

Multidimensional derivatives Much of the work on the calculus of variations is devoted to meticulous detail with regard to the number of derivatives assumed to be available for various functions particularly the competitive admissible functions $y(x)$ If too many derivatives are assumed, minima may not exist, if too few are assumed, the solution might not be sufficiently smooth to be acceptable in the light of the original statement of the problem In an attempt to use fewer derivatives different approaches are used depending on the number of independent variables x For the multidimensional case an approach has been presented by A Haar, it leads to extended complications which are not amenable to description here Haar introduced an additional function which has the effect of replacing the Laplace equation in the simple Dirichlet problem stated above by the Cauchy-Riemann equations

For the case of single integrals however a lemma of du Bois Reymond is applicable This lemma states that a function must be a constant if the average of its product with every function of a sufficiently broad class is zero where the class may be restricted to have average value zero The proof takes the given function to be $u(x)$ its average over the interval to be some constant c and requires that $u(x) - c$ be one of the admissible functions for comparison This leads to a requirement that $[u(x) - c]^2$ average zero and this means that $u(x)$ is essentially c

Additional illustrative material of general results obtainable will now be presented in terms of single integral problems Here take

$$J = \int_a^b f(x\, y\, y')\, dx$$

and enlarge the class of admissible curves somewhat The precise nature of this enlargement will not be important for the moment but assume that among the admissible curves $y \quad g(x) \quad a(0) \leq x \leq b(0)$ affords a minimum to J Assume also that a family of curves $y = z(x\, e) \quad a(e) \leq x \leq b(e)$ is admissible and that the limiting value of $z(x\, e)$ as e tends to zero is $g(x)$ Most particularly however it is desired to avoid the restriction that $z_x(x\, e) \to g'(x)$ which was implied above by the variation $y - g(x) + ez(x)$ This allows variations more general than the ones above with regard to the variations of the end points of the curve the limits of integration and the behavior of the derivatives

Curves of the type of $z(x\, e)$ introduced here may be admitted as neighboring $y(x)$ for e neighboring zero either by using $\max |z(x\, e) - y(x)|$ (possibly modified by some measure of disparity between the intervals of definition) or $\int [z(x\, e) - y(x)]^2$ as a measure of distance between two points in the function space In either case $J(e)$ may be defined as the value of the integral J with f evaluated for $x \; z(x\, e)$ and $z_x(x\, e)$ and it is again possible to study $J'(0)$ if it exists However it should be noted that there is no reason for expecting $J'(0)$ to exist in this case for the integrand involves derivatives z_x which may not vary continuously Actually a simple example of length shows what may happen if J is a length integral the z curves may be taken as zigzagging broken lines approaching a straight line segment but always making an angle of perhaps 45° with it Then $J(e)$ for any e not zero is $\sqrt{2}$ times $J(0)$ There is illustrated here an important property known as lower semicontinuity Although $J(e)$ is not continuous its limit as the argument varies is never less than its value for the limiting value of the argument This property along with some compactness properties suffices for all purposes of the calculus of variations but it must be noted that it is reasonable to expect semicontinuity but not continuity in problems of the calculus of variations

The method used before may be used to derive a formula for $J'(0)$ it is

$$J'(0) = f[b_0\, g(b_0) \quad {}_x(b_0\, 0)] \quad b'(0) - f[a_0\, g(a_0)\; z_x(a_0\, 0)]a'(0) + J$$

where

$$J = \int_{a_0}^{b_0} \{ {}_eJ_y[x\, g \quad {}_x(x\, 0)] + z_{xe}J_p[x, g\, z_x(x\, 0)] \}$$

This may be integrated by parts to give either

$$J = \left\{ z_e J_p[x\, g\, z_x] \right\}_{a_0}^{b_0} + \int_{a_0}^{b_0} z_e \left\{ J_y - \frac{d}{dx} J_p \right\}$$

or

$$J = \left\{ z_e H \right\}_{a_0}^{b_0} + \int_{a_0}^{b_0} z_{xe} \{ J_p - H \}$$

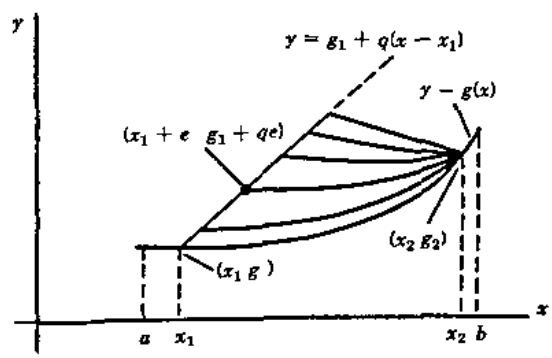
where H is a function of x such that

$$H = J_y[x\, g(x)\, g'(x)]$$

In all these formulas $z_x(x\, 0)$ has been retained instead of $g'(x)$ to indicate ambiguity in case of discontinuous derivatives

End point problems If variations with fixed end points are admissible near g it is possible to choose z with $z_e = 0$ at the end points and so that a and b are zero for $e \quad 0$ and only J is left so that $J'(0) \quad 0$ implies $J = 0$ In the last expression above for J the first term is zero since $z - 0$ at the end points the average of z_{xe} over the interval is zero since $z = 0$ at both end points and the lemma of du Bois Reymond mentioned above may be applied This means that the expression in curly brackets in the integrand is constant whether $J_p(x\, g\, g')$ is known to be differentiable or not Since H is obviously differentiable if g and z have first derivatives which are continuous on each of a finite set of closed intervals covering $[a\, b]$ then the whole expression is differentiable and the Euler equation follows under these weakened conditions Furthermore under some conditions of regularity it is demonstrable that the solutions of this Euler equation have two continuous derivatives so that minimizing functions in a wide class of functions are comfortably smooth

The same formula may be used to get conditions which must exist in a corner It is also applicable to problems with variable end conditions It may be applied to a special variation of the following form to get the Weierstrass condition



We erstrass cond t on

These are curves with no general properties ex ept that they vary slowly approaching straight ness at the top and conforming with the continu ng curve at the bottom

Here the lower curve $y = g(x)$ is assumed to l e the extremal and at a point $x = x_1$ on this curve a line with slope q is erected The variations corresponding to e are taken by proceeding along g to x_1 then up the line to a point with al scissa $x_1 + e$ then along a curve of a smooth family rejoining g at a fixed point x_2 and then along g to b The family between the line and the point of rejoining g is assumed to be smooth and to approach g with the $z_x(x\,e)$ approaching g' Thus the difficulty about limits of $z\ (x\,0)$ are avoided except at the point $x = x_1$ Note that the variation is defined only for nonnegative values of e and hence the value $J\ (0)$ must be nonneg itive if g is a minimum l ut not necessarily zero Intelligent straightforward application of the formulas developed just above yields this condition in the form

$$E(x\,g\,g'\,q) = f(x\,g\,q) - f(x,g\,q') - (q - g')F_p(x\,q,g') \geqq 0$$

In problems with variable end points (which end points may for example be constrained to lie on prescribed curves) the end point conditions which appear in these formulas must be taken into ac count Here it is frequently possible to assume that J in the formula is zero because of admissibility of sufficiently large classes of variations with fixed end points The remaining conditions are called transversality conditions

Single integral problems In classical single-integral problems it is frequently possible to inte grate the Euler equations into a family of curves depending on a finite set of parameters (the initial conditions for example) However in other cases it is not possible to do this and a solution must be arrived at or proved to exist in more direct ways Fre quently a minimizing sequence of func tions is used that is a set of functions y_n is chosen so that the values of J corresponding to y_n ap proach their greatest lower bound If there is a con vergent subsequence of these y_n and if J itself is lower semicontinuous then a limit y to the sequence must afford a minimum to J

Other methods of solution and of proving the ex istence of solutions depend on general studies of Hilbert spaces In these studies the integrals ap pear as operators in Hilbert space and they are frequently reduced to quadratic forms by some ma jorizing process

Problem of Bolza Here the admissible class of functions is restricted by differential conditions

Fig that if the rank of a matrix which can be caused to arise is maximal then the restrictions im posed on admissible curves may be retained un changed (in particular or more generally they may be changed arbitrarily) and the function J may still be changed arbitrarily, hence reduced A suffici nal rank for this matrix is a necessary condition for a minimum, using this result the problem of Bolza may be transformed to an ordinary problem whose integral is a linear combination of the in e grand of J and functions describing the original restrictions The coefficients of this linear combi nation are initially undetermined they are called Lagrange multipliers

Finally studies in the spirit of differential cal culus but not restricted to local minima should be noted Here the interest includes not only minima but all critical points (that is all functions satisfying the Euler condition) and also other studies It is true that classical problems in mechanics may have stable solutions corresponding to nonmini mizing critical points For sufficiently restricted problems it can be shown that the homology group of the space for which $J \leqq c$ for any c does not change as c varies until a critical level is reached this is a level of J at which a critical point exists The change in homology groups at critical points is related closely to the nature of the critical point For example in a finite di mensional space on a sphere the number of p ts minus the number of simple passes plus the number of peaks is two on a torus the corresponding num ber is zero a pass with three grooves running down and three ridges running up from it is to be counted as two simple passes for topological reasons This is the Morse theory *See* CONFORMAL MAPPING; DIFFERENTIATION; INTEGRATION; TOPOLOGY [C.B.T.]

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Calculus of vectors

In its simplest form a vector is a directed line segment Physical quantities such as velocity ac celeration force and displacement are ve tor quantities or simply vectors because they can be represented by directed line segments The alge bra of vectors was initiated principally through the works of W R Hamilton and H G Grassmann in the middle of the nineteenth century and brought to the form presented here by the efforts of O Heaviside and J W Gibbs in the late nine teenth century Vector analysis is a tool of the mathematical physicist because many physical laws can be expressed in vector form

Addition of vectors Two vectors a and b are added according to the parallelogram law (Fig 1) An equivalent definition is as follows From the end point of a a vector is constructed parallel to b of the same magnitude and direction as b The vector from the origin of a to the end point of b

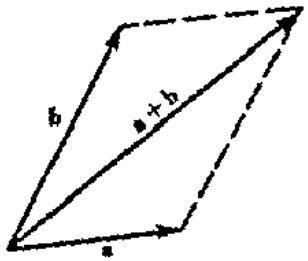


Fig 1 Addition of two vectors

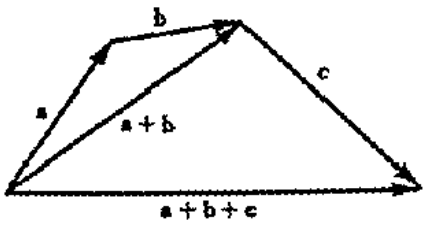


Fig 2 Addition of three vectors

yields the vector sum $\mathbf{s} = \mathbf{a} + \mathbf{b}$ (Fig 2) Any number of vectors can be added by this rule

Given a vector $\mathbf{a}$ a class of vectors can be formed which are parallel to $\mathbf{a}$ but of different magnitudes If x is a real number the vector $x\mathbf{a}$ is defined to be parallel to $\mathbf{a}$ of magnitude $|x|$ times that of $\mathbf{a}$ For $x > 0$ the two vectors $\mathbf{a}$ and $x\mathbf{a}$ have the same sense of direction whereas for $x < 0$ the vector $x\mathbf{a}$ is in a reverse direction from that of $\mathbf{a}$ The vector $-\mathbf{a}$ is the negative of the vector $\mathbf{a}$ such that $\mathbf{a} + (-\mathbf{a}) = \mathbf{0}$ with $\mathbf{0}$ designated as the zero vector (a vector with zero magnitude) Subtraction of two vectors is defined by

$$\mathbf{a} - \mathbf{b} = \mathbf{a} + (-\mathbf{b})$$

The following rules which conform to the rules of elementary arithmetic can be readily deduced

$$\begin{gathered}\mathbf{a} + \mathbf{b} = \mathbf{b} + \mathbf{a} \\ (\mathbf{a} + \mathbf{b}) + \mathbf{c} = \mathbf{a} + (\mathbf{b} + \mathbf{c}) \\ x(\mathbf{a} + \mathbf{b}) = x\mathbf{a} + x\mathbf{b} \\ x(y\mathbf{a}) = (xy)\mathbf{a} \\ (x + y)\mathbf{a} = x\mathbf{a} + y\mathbf{a} \\ 0 \cdot \mathbf{a} = \mathbf{0} \\ \mathbf{a} + \mathbf{0} = \mathbf{a} \\ \mathbf{a} + \mathbf{b} = \mathbf{a} + \mathbf{c} \text{ implies } \mathbf{b} = \mathbf{c} \\ \mathbf{a} = \mathbf{c} \quad \mathbf{b} = \mathbf{d} \text{ implies } \mathbf{a} + \mathbf{b} = \mathbf{c} + \mathbf{d} \\ |\mathbf{a} + \mathbf{b}| \leq |\mathbf{a}| + |\mathbf{b}| \text{ with } |\mathbf{a}| = \text{magnitude of } \mathbf{a} \text{ etc}\end{gathered} \tag{1}$$

Coordinate systems The cartesian coordinate frame of analytic geometry is very useful for yielding a description of a vector (Fig 3) The unit vectors $\mathbf{i}$ $\mathbf{j}$ $\mathbf{k}$ lie parallel to the positive x y and z axes respectively Any vector can be written as a linear combination of $\mathbf{i}$, $\mathbf{j}$ $\mathbf{k}$ From Fig 3 it is noted that

$$\mathbf{a} = a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k} \tag{2}$$

Furthermore the scalars a_x a_y a_z are simply the projections of $\mathbf{a}$ on the x y and z axes respectively and are designated as the components of $\mathbf{a}$ Thus a_x is the x component of $\mathbf{a}$ and so on

If the vector $\mathbf{b}$ is described by $\mathbf{b} = b_x\mathbf{i} + b_y\mathbf{j} + b_z\mathbf{k}$ then

$$\begin{aligned}\alpha\mathbf{a} + \beta\mathbf{b} = {} & (\alpha a_x + \beta b_x)\mathbf{i} \\ & + (\alpha a_y + \beta b_y)\mathbf{j} + (\alpha a_z + \beta b_z)\mathbf{k}\end{aligned} \tag{3}$$

In general the components of a vector will be functions of the space coordinates and the time To be more specific consider a fluid in motion At any time t the particle which is located at the point $P(x,y,z)$ will have velocity components which depend on the coordinates x y z as well as the time t Thus the velocity field $\mathbf{v}$ of the fluid is represented by

$$\mathbf{v} = v_x(x,y,z,t)\mathbf{i} + v_y(x,y,z,t)\mathbf{j} + v_z(x,y,z,t)\mathbf{k} \tag{4}$$

A steady-state vector field exists if the components are time independent The force field of a fixed gravitating particle is of this type

It is not necessary to describe a vector in terms of rectangular coordinates (Fig 4) Let $\mathbf{a}$ be a vector in the xy plane with origin at the point $P(x,y)$ The point P can also be described in terms of polar coordinates (r,θ) Let $\mathbf{u}$ $\mathbf{u}_\theta$ be unit vectors in the directions of increasing r and θ respectively From Fig 4 it follows that

$$\mathbf{a} = a_x\mathbf{i} + a_y\mathbf{j} = a_r\mathbf{u}_r + a_\theta\mathbf{u}_\theta \tag{5}$$

with

$$a_r = a_x\cos\theta + a_y\sin\theta \quad a_\theta = -a_x\sin\theta + a_y\cos\theta$$

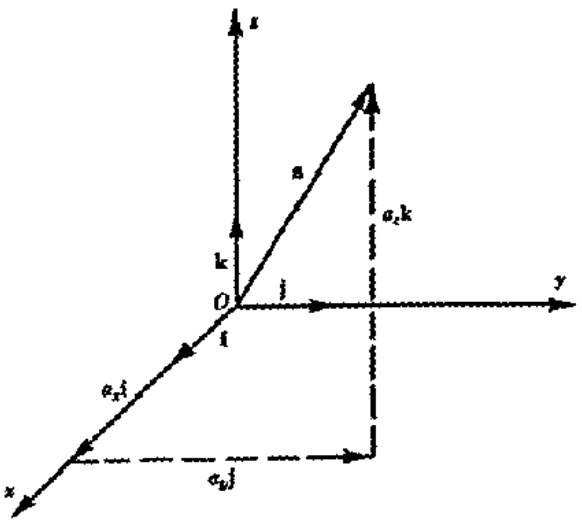


Fig 3 Vectors in cartesian coordinate system

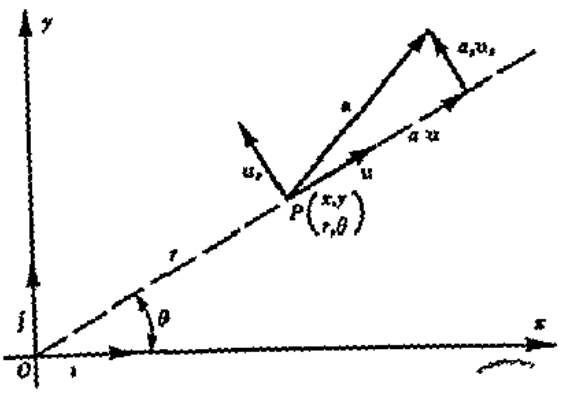


Fig 4 Vectors in polar coordinate system

The components a_x a_y yield a description of the same vector a Thus coordinate systems are simply a means of describing a vector The vector is independent of the description

Scalar or dot product of two vectors From two vectors a and b a scalar quantity is formed from the definition

$$\mathbf{a} \cdot \mathbf{b} = |\mathbf{a}| \cdot |\mathbf{b}| \cos\theta \tag{6}$$

where θ is the angle between the two vectors when drawn from a common origin (Fig 5) It is quickly verified that

$$\begin{aligned} \mathbf{a} \cdot \mathbf{b} &= \mathbf{b} \cdot \mathbf{a} \\ \mathbf{a} \cdot \mathbf{a} &= |\mathbf{a}|^2 \\ (\mathbf{a} + \mathbf{b}) \cdot (\mathbf{c} + \mathbf{d}) &= \mathbf{a} \cdot \mathbf{c} + \mathbf{a} \cdot \mathbf{d} + \mathbf{b} \cdot \mathbf{c} + \mathbf{b} \cdot \mathbf{d} \\ \mathbf{i} \cdot \mathbf{i} &= \mathbf{j} \cdot \mathbf{j} = \mathbf{k} \cdot \mathbf{k} = 1 \\ \mathbf{i} \cdot \mathbf{j} &= \mathbf{j} \cdot \mathbf{k} = \mathbf{k} \cdot \mathbf{i} = 0 \end{aligned} \tag{7}$$

$\mathbf{a} \perp \mathbf{b}$ implies $\mathbf{a} \cdot \mathbf{b} = 0$ and conversely provided $|\mathbf{a}| \cdot |\mathbf{b}| \neq 0$

For $\mathbf{a} = a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k}$ $\mathbf{b} = b_x\mathbf{i} + b_y\mathbf{j} + b_z\mathbf{k}$ it follows from Eq (7) that

$$\mathbf{a} \cdot \mathbf{b} = a_x b_x + a_y b_y + a_z b_z \tag{8}$$

If a is a force field displaced along the vector b then $\mathbf{a} \cdot \mathbf{b}$ represents the work performed by this force field

Referring to Eq (5) let $\mathbf{b} = b_x\mathbf{i} + b_y\mathbf{j} = b_x\mathbf{u}_x + b_y\mathbf{u}_y$ Then

$$\begin{aligned} \mathbf{a} \cdot \mathbf{b} &= a_x b_x + a_y b_y = a_x b_x + a_y b_y \\ &= (a_x \cos\theta + a_y \sin\theta)(b_x \cos\theta + b_y \sin\theta) \\ &\quad + (-a_x \sin\theta + a_y \cos\theta)(-b_x \sin\theta + b_y \cos\theta) \end{aligned}$$

Thus the scalar product of two vectors is independent of the descriptive coordinate system as is evident from the definition of the scalar product given by Eq (6)

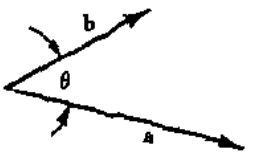


Fig 5 Scalar product of two vectors

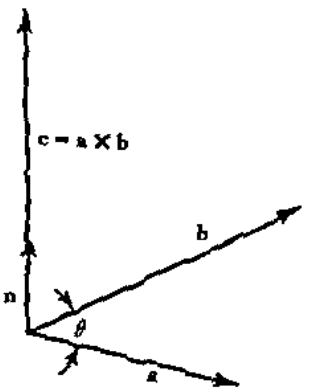


Fig 6 Vector product of two vectors

Vector or cross product of two vectors In three dimensional space a vector can be formed from two vectors a and b in the following manner if they are nonparallel Let a and b have a common origin defining a plane and let c be that vector perpendicular to this plane of magnitude $|\mathbf{c}| = |\mathbf{a}|\,|\mathbf{b}| \sin\theta$ If a is rotated into b through the angle θ a right hand screw will advance in the direction of c (Fig 6) Thus

$$\mathbf{c} = \mathbf{a} \times \mathbf{b} = |\mathbf{a}|\,|\mathbf{b}| \sin\theta\, \mathbf{n} \tag{9}$$

It follows that $\mathbf{a} \times \mathbf{b} = -(\mathbf{b} \times \mathbf{a})$ and that if a is parallel to b $\mathbf{a} \times \mathbf{b} = 0$ Conversely if $\mathbf{a} \times \mathbf{b} = 0$ then a is parallel to b provided $|\mathbf{a}|\,|\mathbf{b}| \neq 0$

The distributive law can be shown to hold for the vector product so that

$$(\mathbf{a} + \mathbf{b}) \times (\mathbf{c} + \mathbf{d}) = \mathbf{a} \times \mathbf{c} + \mathbf{a} \times \mathbf{d} + \mathbf{b} \times \mathbf{c} + \mathbf{b} \times \mathbf{d} \tag{10}$$

It follows from

$$\begin{aligned} \mathbf{i} \times \mathbf{i} = \mathbf{j} \times \mathbf{j} = \mathbf{k} \times \mathbf{k} &= 0 \\ \mathbf{i} \times \mathbf{j} = \mathbf{k} \quad \mathbf{j} \times \mathbf{k} = \mathbf{i} \quad \mathbf{k} \times \mathbf{i} &= \mathbf{j} \end{aligned}$$

that for

$$\mathbf{a} = a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k} \qquad \mathbf{b} = b_x\mathbf{i} + b_y\mathbf{j} + b_z\mathbf{k}$$

$$\mathbf{a} \times \mathbf{b} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} \tag{11}$$

The expression in Eq (11) is to be expanded by the ordinary rules governing determinants

Multiple products involving vector and scalar products can be generated The triple scalar product $\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c})$ is given by

$$\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c}) = \begin{vmatrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{vmatrix} \tag{12}$$

It can be shown that

$$\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c}) = (\mathbf{a} \times \mathbf{b}) \cdot \mathbf{c} = (\mathbf{abc}) \tag{13}$$

Geometrically the scalar triple product represents the volume of a parallelepiped formed with a b c as coterminous sides

$$V = |\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c})|$$

Of importance in the study of rigid body motions is the triple vector product

$$\begin{aligned} \mathbf{a} \times (\mathbf{b} \times \mathbf{c}) &= (\mathbf{a} \cdot \mathbf{c})\mathbf{b} - (\mathbf{a} \cdot \mathbf{b})\mathbf{c} \\ (\mathbf{a} \times \mathbf{b}) \times \mathbf{c} &= (\mathbf{a} \cdot \mathbf{c})\mathbf{b} - (\mathbf{b} \cdot \mathbf{c})\mathbf{a} \end{aligned} \tag{14}$$

From Eqs (13) and (14) it follows that

$$\begin{aligned} (\mathbf{a} \times \mathbf{b}) \cdot (\mathbf{c} \times \mathbf{d}) &= \mathbf{a} \cdot [\mathbf{b} \times (\mathbf{c} \times \mathbf{d})] \\ &= (\mathbf{a} \cdot \mathbf{c})(\mathbf{b} \cdot \mathbf{d}) - (\mathbf{a} \cdot \mathbf{d})(\mathbf{b} \cdot \mathbf{c}) \end{aligned} \tag{15}$$

$$\begin{aligned} (\mathbf{a} \times \mathbf{b}) \times (\mathbf{c} \times \mathbf{d}) &= (\mathbf{acd})\mathbf{b} - (\mathbf{bcd})\mathbf{a} \\ &= (\mathbf{abd})\mathbf{c} - (\mathbf{abc})\mathbf{d} \end{aligned} \tag{16}$$

Pseudovectors It is easy to verify that a reflection of the space coordinates given by $x = -x$ $y = -y$ $z = -z$ reverses the sign of the components of a vector Under a space reflection however

the components of the vector $\mathbf{a} \times \mathbf{b}$ do not change sign This is seen from Eq (11), for if a_x, a_y, a_z are replaced by $-a_x, -a_y, -a_z$, and if b_x, b_y, b_z are replaced by $-b_x, -b_y, -b_z$, the components of $\mathbf{a} \times \mathbf{b}$ remain invariant Hence, $\mathbf{a} \times \mathbf{b}$ is not a true vector and therefore is given the title pseudovector In electricity theory, the magnetic field vector $\mathbf{B}$ is a pseudovector, whereas the electric field vector is a true vector provided the electric charge is a true scalar under a reflection of axes The discussion of pseudovectors belongs properly to the domain of the tensor calculus In general, vectors associated with rotations belong to the category of pseudovectors In particular, the angular velocity vector associated with the motion of a rigid body is a pseudovector *See* CALCULUS OF TENSORS

Differentiation. There are three differentiation processes that are of conceptual value in the study of vectors the gradient of a scalar, the divergence of a vector, and the curl of a vector

Gradient of a scalar The vector field $\mathbf{v}$ given by

$$\mathbf{v} = v_1(x,y,z)\mathbf{i} + v_2(x,y,z)\mathbf{j} + v_3(x,y,z)\mathbf{k} \quad (17)$$

has the property that the components of $\mathbf{v}$ differ at individual points $P(x,y,z)$ The differential change in the individual components of $\mathbf{v}$ in moving from $P(x,y,z)$ to $Q(x + dx, y + dy, z + dz)$ is given by

$$dv_i = \frac{\partial v_i}{\partial x}dx + \frac{\partial v_i}{\partial y}dy + \frac{\partial v_i}{\partial z}dz \qquad i = 1, 2, 3 \quad (18)$$

It is suggestive to define the differential of $\mathbf{v}$ by the expression

$$d\mathbf{v} = dv_1\mathbf{i} + dv_2\mathbf{j} + dv_3\mathbf{k} \quad (19)$$

because $\mathbf{i}$ $\mathbf{j}$ $\mathbf{k}$ are constant vectors (both in magnitude and direction)

If the components of a vector $\mathbf{v}$ are functions of a single parameter λ, the derivative of $\mathbf{v}$ with respect to λ is defined by

$$\frac{d\mathbf{v}}{d\lambda} = \frac{dv_1}{d\lambda}\mathbf{i} + \frac{dv_2}{d\lambda}\mathbf{j} + \frac{dv_3}{d\lambda}\mathbf{k} \quad (20)$$

The position vector of a particle is designated by $\mathbf{r} = x\mathbf{i} + y\mathbf{j} + z\mathbf{k}$ If the particle moves along a trajectory, the velocity and acceleration vectors associated with the motion of the particle are described by

$$\begin{aligned} \mathbf{v} &= \frac{d\mathbf{r}}{dt} = \frac{dx}{dt}\mathbf{i} + \frac{dy}{dt}\mathbf{j} + \frac{dz}{dt}\mathbf{k} \\ \mathbf{a} &= \frac{d\mathbf{v}}{dt} = \frac{d^2\mathbf{r}}{dt^2} = \frac{d^2x}{dt^2}\mathbf{i} + \frac{d^2y}{dt^2}\mathbf{j} + \frac{d^2z}{dt^2}\mathbf{k} \end{aligned} \quad (21)$$

The expression for the derivative of a vector described in curvilinear coordinates becomes more involved simply because the unit vectors in the curvilinear coordinate system need not remain fixed in space Referring to Eq (5),

$$\begin{aligned} \frac{d\mathbf{a}}{dt} &= \frac{da_x}{dt}\mathbf{i} + \frac{da_y}{dt}\mathbf{j} \\ &= \frac{da_r}{dt}\mathbf{u}_r + \frac{da_\theta}{dt}\mathbf{u}_\theta + a_r\frac{d\mathbf{u}_r}{dt} + a_\theta\frac{d\mathbf{u}_\theta}{dt} \end{aligned}$$

From $\mathbf{u}_r = \mathbf{i}\cos\theta + \mathbf{j}\sin\theta$ and $\mathbf{u}_\theta = -\mathbf{i}\sin\theta + \mathbf{j}\cos\theta$ it follows that

$$\frac{d\mathbf{a}}{dt} = \left(\frac{da_r}{dt} - a_\theta\frac{d\theta}{dt}\right)\mathbf{u}_r + \left(\frac{da_\theta}{dt} + a_r\frac{d\theta}{dt}\right)\mathbf{u}_\theta$$

The following differentiation rules exist

$$\begin{aligned} \frac{d}{d\lambda}(\mathbf{u}\cdot\mathbf{v}) &= \mathbf{u}\cdot\frac{d\mathbf{v}}{d\lambda} + \frac{d\mathbf{u}}{d\lambda}\cdot\mathbf{v} \\ \frac{d}{d\lambda}(\mathbf{u}\times\mathbf{v}) &= \mathbf{u}\times\frac{d\mathbf{v}}{d\lambda} + \frac{d\mathbf{u}}{d\lambda}\times\mathbf{v} \\ \frac{d}{d\lambda}(f\mathbf{v}) &= f\frac{d\mathbf{v}}{d\lambda} + \frac{df}{d\lambda}\mathbf{v} \end{aligned} \quad (22)$$

From the scalar $\phi(x,y,z)$ one can form the three partial derivatives $\partial\phi/\partial x$, $\partial\phi/\partial y$, $\partial\phi/\partial z$, from which the vector

$$\left\{\begin{matrix}\text{gradient of } \phi \\ \text{grad } \phi \\ \text{del } \phi = \nabla\phi\end{matrix}\right\} = \frac{\partial\phi}{\partial x}\mathbf{i} + \frac{\partial\phi}{\partial y}\mathbf{j} + \frac{\partial\phi}{\partial z}\mathbf{k} \quad (23)$$

can be formed The vector, grad ϕ, has two important properties Grad ϕ is a vector field normal to the surface $\phi(x,y,z) = \text{constant}$ at every point of the surface Moreover grad ϕ yields that unique direction such that ϕ increases at its greatest rate If $T(x,y,z)$ is the temperature at any point in space then ∇T at any point yields that direction for which the temperature increases most rapidly If $\phi(x,y,z)$ represents the electrostatic potential, then $\mathbf{E} = -\nabla\phi$ yields the electric field vector

Divergence and curl of a vector The del operator defined by

$$\nabla = \mathbf{i}\frac{\partial}{\partial x} + \mathbf{j}\frac{\partial}{\partial y} + \mathbf{k}\frac{\partial}{\partial z} \quad (24)$$

plays an important role in the development of the differential vector calculus For the vector field of Eq (17) the divergence of $\mathbf{v}$ is defined by

$$\text{div } \mathbf{v} = \nabla\cdot\mathbf{v} = \frac{\partial v_1}{\partial x} + \frac{\partial v_2}{\partial y} + \frac{\partial v_3}{\partial z} \quad (25)$$

The divergence of a vector is a scalar

If ρ is the density of a fluid and $\mathbf{v}$ the velocity field of the fluid then div $(\rho\mathbf{v})$ represents the rate of loss of mass of fluid per unit time per unit volume The total loss of mass of fluid per unit time for a fixed volume V is given by the volume integral

$$\iiint_V \text{div } (\rho\mathbf{v})\, dz\, dv\, dx \quad (26)$$

In electricity theory, the divergence of the displacement vector $\mathbf{D}$ is a measure of the charge density, $\nabla\cdot\mathbf{D} = \rho$

By use of the del operator one obtains quite formally the result

$$\nabla \times \mathbf{v} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ v_1 & v_2 & v_3 \end{vmatrix} = \left(\frac{\partial v_3}{\partial y} - \frac{\partial v_2}{\partial z}\right)\mathbf{i} + \left(\frac{\partial v_1}{\partial z} - \frac{\partial v_3}{\partial x}\right)\mathbf{j} + \left(\frac{\partial v_2}{\partial x} - \frac{\partial v_1}{\partial y}\right)\mathbf{k} \tag{27}$$

The vector $\nabla \times \mathbf{v}$ *is called the curl of* $\mathbf{v}$ (curl $\mathbf{v}$) Under a reflection of space coordinates $\partial v_1/\partial y \to \partial(-v_3)/\partial(-y) = \partial v_3/\partial y$ and so on so that the curl of $\mathbf{v}$ is a pseudovector As has been noted previously the class of pseudovectors is associated *with rotations in space* thus it is not strange that *the curl of a velocity field is closely* associated with an angular velocity vector *field The velocity* of a fluid at a point $Q(x + dx, y + dy, z + dz)$ *near* $P(x, y, z)$ can be characterized as follows

$$\mathbf{v}_Q = \mathbf{v}_P + \tfrac{1}{2}(\nabla \times \mathbf{v})_P \times \mathbf{r} + \tfrac{1}{2}\nabla(\mathbf{r} \cdot \mathbf{w}) \tag{28}$$

where $\mathbf{r}$ is the vector from P *to* Q *and*

$$\mathbf{w} = [(\mathbf{r} \cdot \nabla)\mathbf{v}]_P = \left(x\frac{\partial \mathbf{v}}{\partial x} + y\frac{\partial \mathbf{v}}{\partial y} + z\frac{\partial \mathbf{v}}{\partial z}\right)_P \tag{29}$$

Now in general $\boldsymbol{\omega} \times \mathbf{r}$ is the velocity of a point due to the angular *velocity* $\boldsymbol{\omega}$ *thus* $\nabla \times \mathbf{v} = 2\boldsymbol{\omega}$ The velocity at Q is *simply the sum* of a translatory velocity $\mathbf{v}_P$ plus a rigid body rotational *velocity* $\boldsymbol{\omega} \times \mathbf{r}$, plus a nonrigid body deformation $\frac{1}{2}\nabla(\mathbf{r} \cdot \mathbf{w})$

Formulas involving gradient, divergence, curl

1 $\nabla(ut) = u\,\nabla t + t\,\nabla u$
2 $\nabla \cdot (\phi \mathbf{v}) = \phi\,\nabla \cdot \mathbf{v} + (\nabla\phi) \cdot \mathbf{v}$
3 $\nabla \times (\nabla\phi) = 0$
4 $\nabla \cdot (\nabla \times \mathbf{v}) = 0$
5 $\nabla \times (\phi \mathbf{v}) = \phi\,\nabla \times \mathbf{v} + (\nabla\phi) \times \mathbf{v}$
6 $\nabla \cdot (\mathbf{u} \times \mathbf{v}) = (\nabla \times \mathbf{u}) \cdot \mathbf{v} - (\nabla \times \mathbf{v}) \cdot \mathbf{u}$
7 $\nabla \times (\mathbf{u} \times \mathbf{v}) = (\mathbf{v} \cdot \nabla)\mathbf{u} - \mathbf{v}(\nabla \cdot \mathbf{u}) + \mathbf{u}(\nabla \cdot \mathbf{v}) - (\mathbf{u} \cdot \nabla)\mathbf{v}$
8 $\nabla(\mathbf{u} \cdot \mathbf{v}) = \mathbf{u} \times (\nabla \times \mathbf{v}) + \mathbf{v} \times (\nabla \times \mathbf{u}) + (\mathbf{u} \cdot \nabla)\mathbf{v} + (\mathbf{v} \cdot \nabla)\mathbf{u}$
9 $\nabla \times (\nabla \times \mathbf{v}) = \nabla(\nabla \cdot \mathbf{v}) - \nabla^2\mathbf{v}$
10 $d\phi = d\mathbf{r} \cdot \nabla\phi + \dfrac{\partial\phi}{\partial t}\,dt$ for $\phi = \phi(x, y, z, t)$
11 $\nabla \cdot (\nabla\phi) = \nabla^2\phi = \dfrac{\partial^2\phi}{\partial x^2} + \dfrac{\partial^2\phi}{\partial y^2} + \dfrac{\partial^2\phi}{\partial z^2}$
12 If $\nabla \cdot \mathbf{f} = 0$ then $\mathbf{f} = \nabla \times \mathbf{A}$ ($\mathbf{A}$ is called the vector potential)
13 If $\nabla \times \mathbf{f} = 0$ then $\mathbf{f} = \nabla\phi$ (ϕ is called the scalar potential)

Integration. If a closed surface is decomposed into a large number of *small surfaces* a vector field normal to the surface can be *constructed* each normal element being represented by $d\boldsymbol{\sigma}$ The magnitude of $d\boldsymbol{\sigma}$ is the area of the surface element dS, $d\boldsymbol{\sigma} = \mathbf{N}\,dS$

If $\mathbf{f}$ is a vector field defined at every point of the surface, then

$$\iint_S \mathbf{f} \cdot d\boldsymbol{\sigma} \tag{30}$$

represents the total flux of $\mathbf{f}$ through the surface S The elements $d\boldsymbol{\sigma}$ point outward from the interior of S.

The divergence theorem of Gauss states that

$$\iint_S \mathbf{f} \cdot d\boldsymbol{\sigma} = \iiint_R (\nabla \cdot \mathbf{f})\,d\tau \tag{31}$$

where R is the region enclosed by S, $d\tau$ a volume element of R For $\mathbf{f} = \rho\mathbf{v}$, the divergence theorem states that the net loss of fluid per unit time can be accounted for by measuring the total outward flux of the vector $\rho\mathbf{v}$ through the closed surface S *bounding* R *See* GAUSS' THEOREM

The line integral of a vector field is described as follows Let Γ be a space curve, and let $\mathbf{t}$ be the unit vector field tangent to Γ at every point of Γ in progressing from A to B, the initial and end points of the trajectory Γ

The scalar integral

$$\int_A^B (\mathbf{f} \cdot \mathbf{t})\,ds \tag{32}$$

is called the line integral of $\mathbf{f}$ along Γ, with arc length s measured along Γ If $\mathbf{f}$ is a force *field Eq* (32) *represents the work* performed by the force field if a unit test particle is taken from A to B along Γ

The value of the integral of Eq (32) will generally depend on the path from A to B However if $\mathbf{f} = \nabla\phi$ then

$$\int_A^B (\mathbf{f} \cdot \mathbf{t})\,ds = \int_A^B \nabla\phi \cdot d\mathbf{r} = \int_A^B d\phi = \phi(B) - \phi(A)$$

and the line integral is independent of the path *of integration*

The theorem of Stokes states that

$$\oint_\Gamma \mathbf{f} \cdot d\mathbf{r} = \iint_S (\nabla \times \mathbf{f}) \cdot d\boldsymbol{\sigma} \tag{33}$$

where Γ is the boundary of the open surface S If S is a closed surface, then

$$\oiint_S (\nabla \times \mathbf{f}) \cdot d\boldsymbol{\sigma} = 0$$

In electricity theory, a time-changing magnetic flux through an open surface induces a voltage in the boundary of the surface so that

$$-\frac{\partial}{\partial t}\iint_S \mathbf{B} \cdot d\boldsymbol{\sigma} = \oint_\Gamma \mathbf{E} \cdot d\mathbf{r}$$

Applying Stokes' theorem yields one of Maxwell's equations

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

See OPERATOR THEORY, POTENTIALS (MATHEMATICS)

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Calendar

A list, usually in the form of a table showing the correspondence between days of the week and days of the month; also, a list of special observances with their dates, especially those that fall on different dates in different years, as a church calendar, also, a set of rules that serves to attach to any day a specific number or name or combination of number and name

Perpetual calendar*

Day of the week for any known date from the beginning of the Christian Era to the year 2100

Year	Century			Julian Calendar							Gregorian Calendar				
				0	100	200	300	400	500	600	1500‡	1600	1700	1800	1900
				700	800	900	1000	1100	1200	1300		2000	2100	2200	2300
				1400	1500†										
0					ED	FE	GF	AG	BA	CB		BA	C	E	G
1	29	57	85	B	C	D	E	F	G	A	F	G	B	D	F
2	30	58	86	A	B	C	D	E	F	G	E	F	A	C	E
3	31	59	87	G	A	B	C	D	E	F	D	E	G	B	D
4	32	60	88	FE	GF	AG	BA	CB	DC	ED	CB	DC	FE	AG	CB
5	33	61	89	D	E	F	G	A	B	C	A	B	D	F	A
6	34	62	90	C	D	E	F	G	A	B	G	A	C	E	G
7	35	63	91	B	C	D	E	F	G	A	F	G	B	D	F
8	36	64	92	AG	BA	CB	DC	ED	FE	GF	ED	FE	AG	CB	ED
9	37	65	93	F	G	A	B	C	D	E	C	D	F	A	C
10	38	66	94	E	F	G	A	B	C	D	B	C	E	G	B
11	39	67	95	D	E	F	G	A	B	C	A	B	D	F	A
12	40	68	96	CB	DC	ED	FE	GF	AG	BA	GF	AG	CB	ED	GF
13	41	69	97	A	B	C	D	E	F	G	E	F	A	C	E
14	42	70	98	G	A	B	C	D	E	F	D	E	G	B	D
15	43	71	99	F	G	A	B	C	D	E	C	D	F	A	C
16	44	72		ED	FE	GF	AG	BA	CB	DC		CB	ED	GF	BA
17	45	73		C	D	E	F	G	A	B		A	C	E	G
18	46	74		B	C	D	E	F	G	A		G	B	D	F
19	47	75		A	B	C	D	E	F	G		F	A	C	E
20	48	76		GF	AG	BA	CB	DC	ED	FE		ED	GF	BA	DC
21	49	77		E	F	G	A	B	C	D		C	E	G	B
22	50	78		D	E	F	G	A	B	C		B	D	F	A
23	51	79		C	D	E	F	G	A	B		A	C	E	G
24	52	80		BA	CB	DC	ED	FE	GF	AG		GF	BA	DC	FE
25	53	81		G	A	B	C	D	E	F		E	G	B	D
26	54	82		F	G	A	B	C	D	E	C	D	F	A	C
27	55	83		E	F	G	A	B	C	D	B	C	E	G	B
28	56	84		DC	ED	FE	GF	AG	BA	CB	AG	BA	DC	FE	AG

Month	Dominical letter						
Jan, Oct	A	B	C	D	E	F	G
Feb, Mar, Nov	D	E	F	G	A	B	C
Apr, July	G	A	B	C	D	E	F
May	B	C	D	E	F	G	A
June	E	F	G	A	B	C	D
Aug	C	D	E	F	G	A	B
Sept, Dec	F	G	A	B	C	D	E

1	8	15	22	29	Sun	Sat	Fri	Thurs	Wed	Tues	Mon
2	9	16	23	30	Mon	Sun	Sat	Fri	Thurs	Wed	Tues
3	10	17	24	31	Tues	Mon	Sun	Sat	Fri	Thurs	Wed
4	11	18	25		Wed	Tues	Mon	Sun	Sat	Fri	Thurs
5	12	19	26		Thurs	Wed	Tues	Mon	Sun	Sat	Fri
6	13	20	27		Fri	Thurs	Wed	Tues	Mon	Sun	Sat
7	14	21	28		Sat	Fri	Thurs	Wed	Tues	Mon	Sun

To [illegible] the dominical letter for the year in the [illegible] section [illegible] to the [illegible] week [illegible] G [illegible] 1962 is

* [illegible]

† [illegible]

The calendars that have been used at various times and places are numerous and diverse Most of them represent attempts to divide the synodic month or the tropical year into numbered days Ac cording to whether the emphasis is on month or year calendars are called lunar or solar

Gregorian calendar The calendar used for civil purposes throughout the world known in western countries as the Gregorian calendar was established by Pope Gregory XIII who decreed that the day following Thursday October 4 1582 should be Friday October 15 1582 and that thereafter centennial years (1600 1700 and so on) should be leap years only when divisible by 400 (1600 2000 and so on) other years being leap years when divisible by four as previously The effect of the reform was to restore the vernal equinox (beginning of spring which governs the observance of Easter) to March 21 and to reduce the number of days in 400 calendar years by three making the average number of days in the calendar year 365 2425 instead of 365 25 as formerly and bringing it into closer agreement with the tropical year which has 365 24220 days The new calendar was adopted by Great Britain in 1752 but did not become universal until well into the twentieth century

Although the Gregorian calendar is a solar calendar lunar vestiges remain in it as is shown by the division of the year into months The week is independent of any astronomical phenomenon it was established before the beginning of the Christian era and the cyclical succession of the days of the week has not since been disturbed The connection between the week and the ancient Jewish cycle of seven days has not been established for example it is not known whether our Saturday is identical with the ancient seventh day or not

The calendar generally used before the adoption of the Gregorian calendar is called the Julian calendar Dates recorded for civil and commercial purposes before October 4 1582 may be assumed to be in the Julian calendar but dates recorded since then may require considerable care in interpretation

Calendar reform The Gregorian calendar is not perfectly adjusted to the tropical year the error accumulating to one day after about 3300 years Numerous proposals for calendar reform have been made with the object of reducing the error and there have also been many proposals for altering the succession of days for the purpose of bringing greater regularity into the calendar For example one proposal would divide the year into 13 months of 4 weeks each which would make 364 days The 365th day and the 366th in leap years would have a special name and would not belong to any month or to any week Thus every month of every year would begin on Sunday and end with Saturday and annual calendars would become unnecessary The 13-month calendar has the disadvantage serious from the standpoint of business of not being divisible into quarters Another proposal which overcomes this difficulty retains 12 months but would give them successively 31, 30 30 31 30 30 31 30 30 31, 30 30 days, the extra day or days again being outside the system No attempt to regularize the calendar can succeed if the succession of week days and the average length of the calendar year are both preserved *See* TIME. [G.M.C.]

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Calibration

The process of determining by measurement or by comparison with a standard the correct value of each scale reading on a meter or the correct value of each setting of a control knob In a radio re- [illegible] the frequencies of the incoming signals

With measuring instruments calibration generally involves adjusting the values of internal components so that the indication is correct at a specified number of points on the indicating scale and approximately correct between these points With highly accurate instruments calibration involves the preparation of a graph or table that gives the exact value corresponding to each line on the indicating scale *See* INSTRUMENTATION [J.MR.]

Caliche

A term used to describe the crude soda niter of the Chilean nitrate deposits It is a variable admixture of salts including, in addition to the soda niter bloedite anhydrite gypsum polyhalite halite glauberite darapskite and minor amounts of various iodate chromate and borate minerals *See* BORATE MINERALS SODA NITER

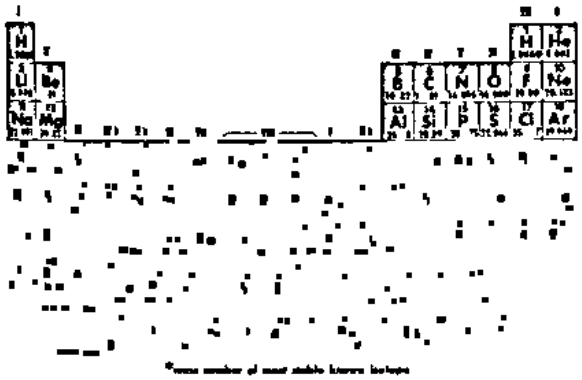
The term caliche has several other meanings It is commonly used in Mexico and the southwestern United States to designate gravel sand or desert debris cemented by porous calcium carbonate Other uses of the term include a thin layer of clayey soil capping auriferous veins, whitish clay in the selvage of veins, feldspar and a white mineral vein recently discovered, and in placer mining a bank composed of clay, sand and gravel [C.S.]

Californium

Element number 98 californium Cf is a member of the actinide series of elements Its discovery and production have been based upon artificial nuclear transmutation of lighter elements Isotopes of californium are radioactive with half lives ranging from a few minutes to about 1000 years Because of its nuclear instability californium does not exist in the earth's crust The world's supply of californium is in the range of millionths of a gram its application is therefore usually limited to use as a tracer material in nuclear research *See* ACTINIDE ELEMENTS RADIOACTIVITY

Californium was discovered in 1950 by S G Thompson K Street A Ghiorso and G T Seaborg The experiments were carried out at the University of California Radiation Laboratory and

the new element was named in honor of the University and the state The discoverers bombarded a target consisting of a few millionths of a gram of Cm^{242} (curium 242), with helium ions accelerated in a cyclotron Combination of helium nuclei with nuclei of Cm^{242} followed by loss of a neutron gave the mass 245 isotope of element 98 Californium 245 was found to decay partly by capture of an orbital electron and partly by emission of an α particle with a half life of 45 min



Several other isotopes of californium (mass numbers 244–254) have been discovered using a variety of combinations of target isotopes and bombarding particles The production of Cf^{246} by bombardment of U^{238} with carbon ions is an example of the possibility of using comparatively heavy bombarding particles and more abundant target isotopes for synthesis of new elements For production of amounts of californium isotopes ranging up to a few millionths of a gram several grams of Pu^{239} have been irradiated with neutrons in a nuclear reactor Successive capture of neutrons by newly formed isotopes and subsequent β decay to next heavier elements leads eventually to formation of berkelium and californium isotopes *See* BERKELIUM

An interesting nuclear property which is observed in californium isotopes especially in Cf^{25} and Cf^{54} is that of decay by spontaneous fission with the emission of neutrons Spontaneous fission becomes increasingly more probable in the heavier elements for Cf^{254} no other decay mode has been observed The isotope Cf^{252} is useful in research on the mechanism of spontaneous fission It presents possibilities for practical application as a neutron source

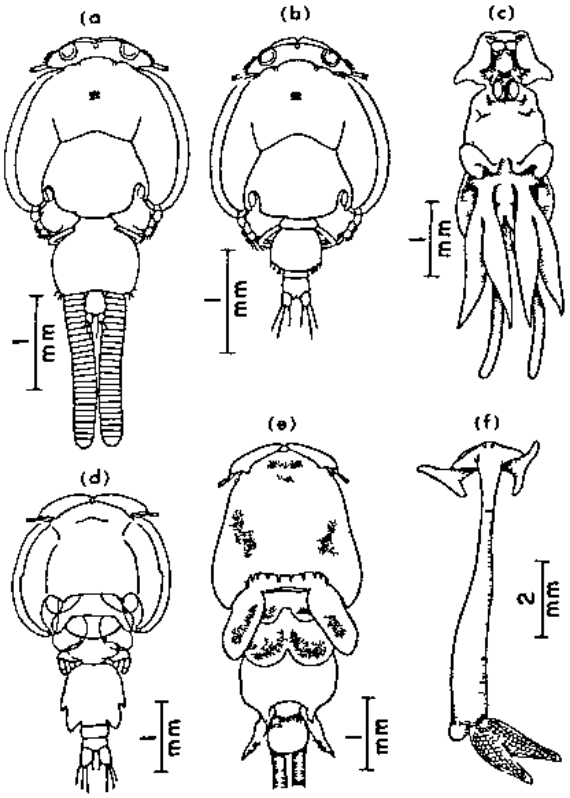
The chemical properties of californium are similar to those observed for other actinide elements a 3+ oxidation state in aqueous solution and a water soluble nitrate sulfate chloride and perchlorate Californium is coprecipitated with lanthanum fluoride oxalate or hydroxide Ion exchange chromatography has been essential for the isolation and identification of californium in the presence of other actinide elements A solution of a complexing agent (α hydroxyisobutyric acid for example) desorbs actinides from a cation exchange resin at different rates the elements leave the column of resin in distinct fractions and can be identified by their characteristic radioactivities *See* ION EXCHANGE NUCLEAR CHEMISTRY, NUCLEAR REACTION TRANSURANIUM ELEMENTS [SCT]

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Caligoida

A suborder of the Copepoda which are external parasites widely distributed on fish They feed on the blood of the host These crustaceans vary in their location on the host Their parasitic mode of existence is accompanied by a modification of their normal structure The carapace is distinct in many cases but other segments are often fused The mouth is a sucking type and possesses styliform mandibles adapted for piercing the host s skin Second antennae and second maxillipeds are prehensile while other mouthparts may be subsidiary prehensile organs but often are absent Swimmerets exhibit various modifications such as a loss of setae fusion or reduction of joints loss of the endopodite reduction in size or number of the limbs Nauplius and succeeding infective larvae are free living The suborder comprises numerous genera and species contained in 11 families

Caligus a few millimeters long is the least modified genus This animal has a flat body and crawls over the surface of various fishes often on the gills but can leave the host to swim about freely It bears a pair of anterior adhesive disks It may become a



Caligoida (a) *Caligus brevis* Shiino female (b) male (c) *Lernanthropus chrysophrys* Shishido female (d) *Pandarus satyrus* Dana male (e) female (f) *Lernaea cyprinacea* L female

Families representative genera and hosts of Caligoida

Families	Genera	Hosts
Caligidae	*Caligus*	Various fish external or gills
Trebiidae	*Trebius*	Selachians external
Euryphoridae	*Elytrophora*	Tunnies etc inside the operculum
Pandaridae	*Pandarus*	Sharks, external
Cecropidae	*Cecrops*	Sunfish gills
Anthosomi lae	*Lernanthropus*	Various fish gills
Eudactylini lae	*Kröyeria*	Sharks gills
Pseudocycnidae	*Pseudocycnus*	Tunnies, gills
Dichelesthii lae	*Hatschekia*	Various fish gills
Lernaeidae	*Lernaea*	Fresh water fish pene trates the skin
Pennellidae	*Pennella*	Various marine fish an l wl ales penetrates the skin

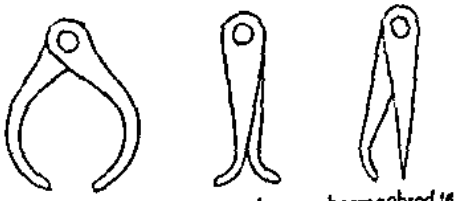
menace to fishes confined in fish ponds when it con centrates upon a host which is in any way weak ened *Elytrophora* is gregarious and although pro vided with natatory legs it is not likely to swim *Pandarus* exhibits pronounced sexual dimorphism The male resembles *Caligus* and has a flat body and natatory legs while the female is dorsally arched has nonnatatory legs and clings firmly to the host *Lernanthropus* is strongly modified and is a gill parasite It sucks blood so plentifully that it be comes scarlet in color The posterior swimmerets are transformed into lanceolate lamellae *Hatsche kia* similarly clings to gills but has an elongate body which scarcely shows metamerism except for the distinctness of the carapace Swimmerets are reduced in size and number *Lernaea* is found on fresh water fishes It is a fixed parasite and inserts the anterior region of its unsegmented cylindrical body deep into the flesh of the host Branched proc esses of the head anchor this parasite It attaches everywhere on the surface of the host even the gills or buccal cavity When a great number of par asites occur in the buccal cavity they prevent the fish f

further development but the female leaves the temporary host to reach the final host where it matures into the adult Allied genera oc cur on marine fishes *Pennella* is the largest cope pod being 20 cm or more in length and it resem bles *Lernaea* in both structure and habitat How ever it carries tufts of filiform appendages on the abdomen It is remarkable because some species attack aquatic mammals [S M S]

Bibliography J C Baer, *Ecology of Animal Parasites* 1952 M Caullery *Parasitism and Sym biosis* 1952 C B Wilson *The Copepods of the Woods Hole Region Massachusetts* U S Natl Mu seum Bull 158 1932

Caliper

An instrument with two legs used for measuring linear dimensions Calipers may be fixed adjusta ble or movable Fixed calipers are used in routine inspection of standard products, adjustable cal pers are used similarly but can be reset to slightly different dimensions if necessary Movable calipers can be set to match the distance being measured The legs may pivot about a rivet or screw in a firm joint pair of calipers, they may pivot about a pin being held against the pin by a spring and set in position by a knurled nut on a threaded rod or the legs may slide either directly (caliper rule) or along a screw (micrometer caliper) relative to each other *See* MICROMETER



Typical machinist s calipers (*R J Sweeney Measure ment Techniques in Mechanical Engineering* Wiley 1953)

The legs may be shaped to facilitate measuring outside dimensions, inside dimensions, surface d mensions as between points on a plate or from a surface into a hole as in a keyway (see illus tration) Other forms are adapted to special needs [F H R]

See GAGES

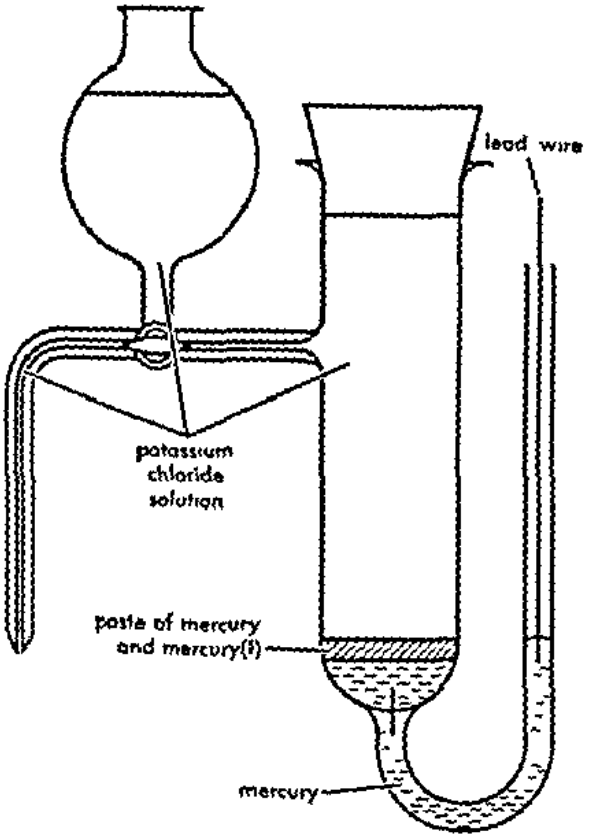
Calomel

Mercury(I) chloride Hg_2Cl_2, which is a covalent compound it is insoluble in water and sublimes before melting when heated Calomel is manufac tured by precipitation when sodium chloride is added to a solution of mercury(I) nitrate or by di rect combination of the elements

Calomel is used in preparing insecticides and medicines It is well known in the laboratory as the constituent of the calomel reference electrodes which are commonly used in conjunction with a glass electrode to measure pH *See* CALOMEL ELEC TRODE, MERCURY (ELEMENT) [E E W R]

Calomel electrode

An electrode used widely as a reference electrode of known potential for example in electrometric measurements of acidity and alkalinity in corro sion studies and in the measurements of the po tentials of other electrodes The calomel electrode consists of mercury covered with a layer of paste of mercury(I) chloride in an aqueous solution of potassium chloride A small amount of mercury is dispersed in the paste of mercury(I) chloride It is made in three well known types (1) the saturated (2) the normal and (3) the one tenth normal These designations refer to the concentrations of the potassium chloride solutions used in the prepa ration The first type is more widely used than the other two because of the ease with which it may be reassembled, no analysis of the concentration is re quired Crystals of potassium chloride are placed above the layer of mercury(I) chloride in the



Calomel electrode

saturated type The calomel electrode is commonly referred to as a half cell because it includes an aqueous phase of potassium chloride as one arm of the cell to be used in the electric circuit In some types, a reservoir for the solution of potassium chloride is provided for ease in flushing and replacing the solution in the side arm with new solution

The potentials of the three types in terms of the standard hydrogen electrode are:

Saturated type	$-0.2440 + 0.00076(t - 25°C)$ volts
1.0 *N* type	$-0.2834 + 0.00024(t - 25°C)$ volts
0.1 *N* type	$-0.3371 + 0.00007(t - 25°C)$ volts

Frequently, calomel electrodes are used in assemblies such as pH meters, in which it is not essential to know their actual potential In this case the overall system is calibrated with a solution of known pH *See* ELECTRODE POTENTIAL, HYDROGEN ELECTRODE, HYDROGEN ION, SILVER CHLORIDE ELECTRODE [W J H]

Calorie

A unit of measure for energy often designated by "c" or the abbreviation "cal" Previously the calorie was defined as the quantity of energy as heat required to raise one gram of water one degree centigrade under a constant pressure of one atmosphere The magnitude of the calorie depends on the place on the centigrade temperature scale at which the measurement is made So-called 15° calories refer to determinations made at 14.5–15.5°C Like the Btu the calorie is more exactly defined in terms of electrical units At the International Steam Table Conference in London, 1929, one calorie was by definition made equal to 1/860 of a watthour The calorie defined by the older experimental procedure is roughly equal in magnitude to the newer IT Steam Table calorie defined in electrical units Since the calorie is a relatively small unit of energy the abbreviation kcal, referred to as a large or kilocalorie, is used to designate 1000 calories *See* ELECTRIC ENERGY MEASUREMENT, HEAT [H C W]

Calorimetry

The measurement of the quantity of heat involved in various processes such as chemical reactions, changes of state and formation of solutions or in the determination of the heat capacities of substances The fundamental unit for these heat measurements is the joule but many workers prefer to use the calorie defined as 4.184 absolute joules

Types of calorimeters. A calorimeter is an apparatus for measuring these heat quantities Since the problem involves various kinds of processes and experimental work over a range of temperatures calorimeters have been developed in great variety

Many calorimeters use a liquid as a heat reservoir since uniformity of temperature thus can be realized easily by proper stirring, and the temperature change for the system can be evaluated readily Water is the substance most commonly employed, it is especially satisfactory in measurements near room temperature However various organic liquids also have been used For example, G B Kistiakowsky and co-workers in their measurements of heats of hydrogenation selected diethylene glycol, which permitted them to operate at temperatures up to 150°C

In contrast the aneroid type depends on the use of a metal of high thermal conductivity, such as copper to promote rapid equalization of temperature In the Nernst method of measuring heat capacities to low temperatures the calorimeter is usually constructed so that none of the material under study is more than a few millimeters from a metal surface Such an aneroid calorimeter can be used over a temperature range of 300 centigrade degrees or more

These types represent nonisothermal calorimeters in which the heat quantities are evaluated by the temperature changes they produce Various isothermal calorimeters also have been developed in which the heat reservoir contains a liquid in equilibrium with its crystalline solid at the melting point or with its vapor at the boiling point The Bunsen ice calorimeter, which operates at 0°C with a mixture of ice and water, is a good example It can receive or give up heat, as the case requires, and the magnitude of this heat quantity can be evaluated by a dilatometric measurement of the volume change in the ice water mixture The isothermal calorimeter is simple, and yet it can yield excellent data Its disadvantage is that it operated only at the equilibrium temp the two phase system involved

All these types of calorimetric apparatus contain (1) the calorimeter proper or heat reservoir for measuring the amount of heat in the process under study and (2) a jacket which can be used to control thermal exchange between the calorimeter and its environment In many cases this jacket is a hollow vessel which may be filled with a liquid such as water that can be stirred and accurately regulated in temperature In the aneroid type the jacket usually is a hollow cylindrical block of metal with a top and bottom electrical heating coils and a suitable thermometer system

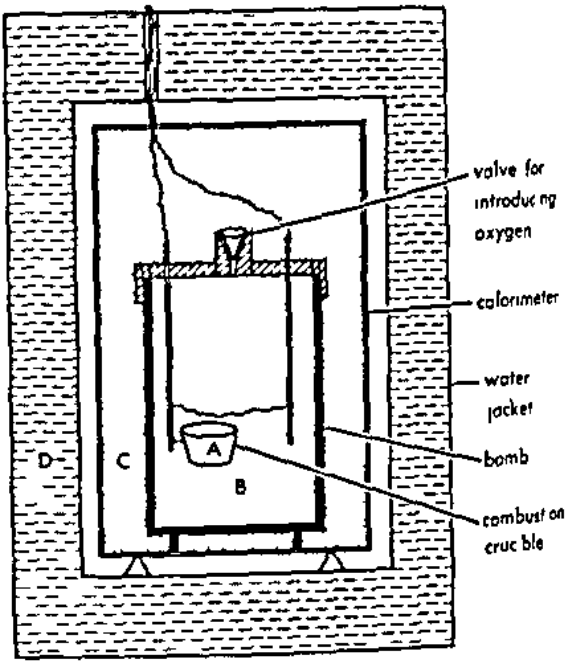
In both the liquid and aneroid types of calorimeters the jacket is frequently kept at constant temperature by a thermostat Thus there is some heat exchange between the calorimeter and jacket during an experiment and this requires that a correction be made to the observed temperature change within the calorimeter The ordinary method determines this correction by making a series of temperature readings on the calorimeter before and after the thermal process with the assumption of Newton s law of cooling which states that the rate of heat flow is proportional to the temperature difference between an object and its environment A second method avoids such a correction by keeping the temperature of the jacket during the thermal process equal to that of the calorimeter Thus there should be no heat flow between the two This is adiabatic calorimetry At first glance it appears more elegant than the ordinary method but in practice, the two methods have been found to yield equally accurate results

Thermometry The measurement of temperature is an important factor of calorimetry which has been greatly refined since 1920 Prior to that time, reliance was placed mainly on mercury and other expansion thermometers The Beckmann thermometer represents the acme among these It is a differential instrument with a temperature range of about 5° It can be read to 0 001°C

Today resistance thermometers and thermocouples have largely taken over the field in high grade, precision measurements They are competitive and one may have advantages over the other in particular situations Both types can be used over wide ranges of temperature that is from about −260° to above 700°C In general however the platinum resistance now has become the standard Such an instrument with a resistance of 25 ohms at 0° can be read to better than 0 0001°C *See* TEMPERATURE MEASUREMENT

The bomb calorimeter This is used extensively in determining the heats of combustion of organic compounds and has been developed to yield measurements reproducible to within ±0 01% Its operation is fairly typical of calorimetric processes carried out near room temperature

Some of the essential features of the apparatus are illustrated in the accompanying schematic figure The bomb a strong walled metal container of 0 3–0 4 liter capacity is constructed of a corrosion resistant alloy It is fitted with a screw head,



Schematic diagram of the bomb calorimeter *A* crucible *B* bomb, *C*, calorimeter, *D*, jacket

which contains a valve for introducing oxygen to a pressure of about 30 atm The weighed sample liquid or solid is placed in the combustion crucible and ignited by electrical connections which pass through the head

The bomb is immersed in about 2 5 liters of water in the calorimeter This is a metal container which is equipped with a platinum resistance thermometer a stirrer, and a tightly fitting cover to prevent evaporation of its water It rests on small ivory pegs within the jacket, the two being separated by a 1 cm air space

This bomb calorimeter is calibrated either electrically or, more frequently, by burning a sample of standard benzoic acid supplied by the U S National Bureau of Standards After the heat capacity of the calorimeter has been evaluated the unknown heat value can be computed from the measured temperature rise The result so obtained corrected to 1 atm pressure and computed for 1 mole of the substance, represents ΔE, the heat of combustion at constant volume The corresponding heat effect at constant pressure can be derived by the relation $\Delta H = \Delta E + P\Delta V$ *See* HEAT CAPACITY, HEAT TRANSFER, THERMOCHEMISTRY THERMODYNAMICS (CHEMICAL) [G S P]

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Cam mechanism

A mechanical linkage whose purpose is to produce by means of a contoured cam surface a prescribed motion of the output link of the linkage called the follower A familiar application of a cam mechanism is in the opening and closing of valves in an

automotive engine (Fig 1) The cam rotates with the cam shaft usually at constant angular velocity while the follower moves up and down as required by the cam surface A cam is sometimes made in the form of a translating cam (Fig 2a)

Other cam mechanisms employed in analog computers are simple memory devices in which the position of the cam (input) determines the position of the follower (output or readout)

While many requisite motions in machinery are accomplished by use of a pin jointed mechanism such as the four bar linkage a cam mechanism frequently is the only practical solution to the problem of converting the available input usually rotating or reciprocating to a desired output which may be an exceedingly complex motion No other mechanism is as versatile as capable of endless variation as straightforward in design

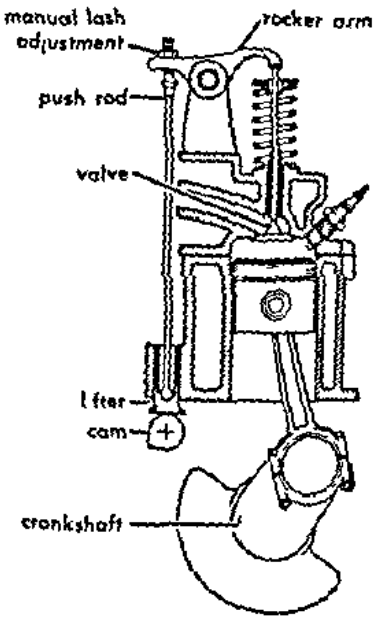


Fig 1 Cam mechanism in automotive engine (Texaco Inc)

Cams are found in nearly all machines They are most numerous in automatic packaging shoe making, typesetting machines, and the like but are often found in machine tools reciprocating engines and compressors and are less frequently encountered though still used in rotating machinery

Cam The link having the contoured surface that prescribes the motion of the follower is called the cam Cams are usually made of steel often hardened to resist wear and for high speed applications ground to precise dimensions Cams are classified as translating disk or plate and cylindrical or drum (Fig 2)

Follower The output link, which is maintained in contact with the cam surface is the follower Followers are classified by their shape as roller flat face and spherical face (Fig 3) The knife-edge follower is of academic interest in developing cam profile relationships Followers are also described

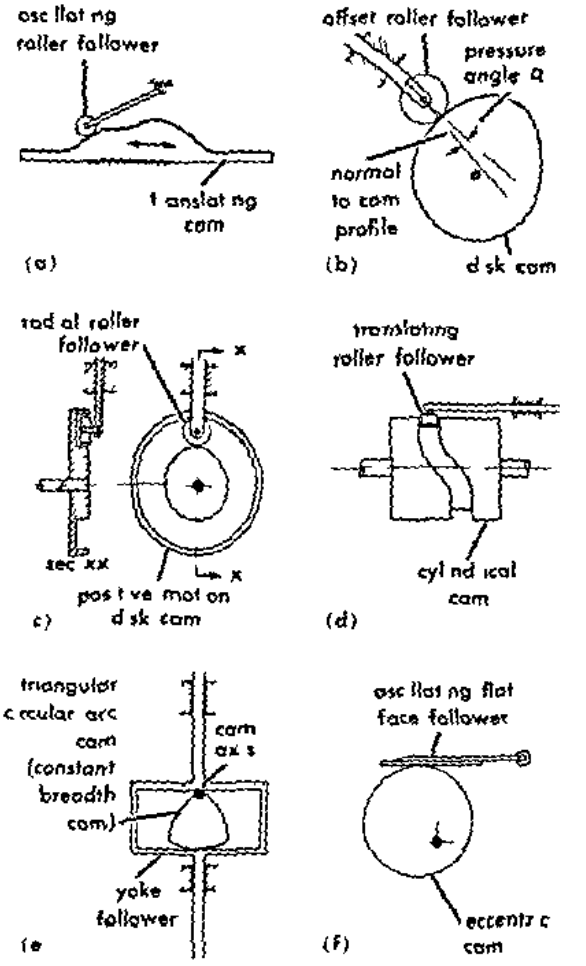


Fig 2 Cams (a) Translating (b) Disk (c) Positive motion (d) Cylindrical (e) With yoke follower (f) With flat face follower

by the nature of their constraint as for example radial in which motion is reciprocating along a radius from the cam s axis of rotation (Fig 1) offset in which motion is reciprocating along a line that does not intersect the axis of rotation (Fig 2b) and oscillating or pivoted (Fig 2a)

Motion of cam follower The first step in the design of a cam mechanism is the determination of the motion of the cam follower In a packaging machine for example the ends of a carton may be folded by cam operated fingers that advance at the proper time retract as soon as the fold has been made and then rest or dwell until the next carton is in position The motion of the cam follower which in turn moves the folder fingers can

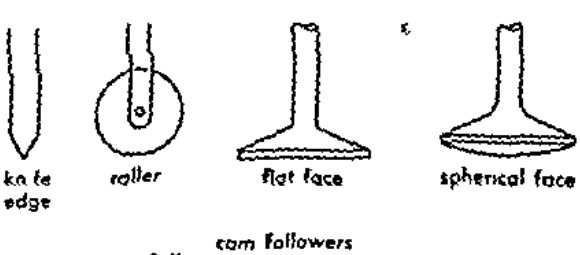


Fig 3 Cam followers

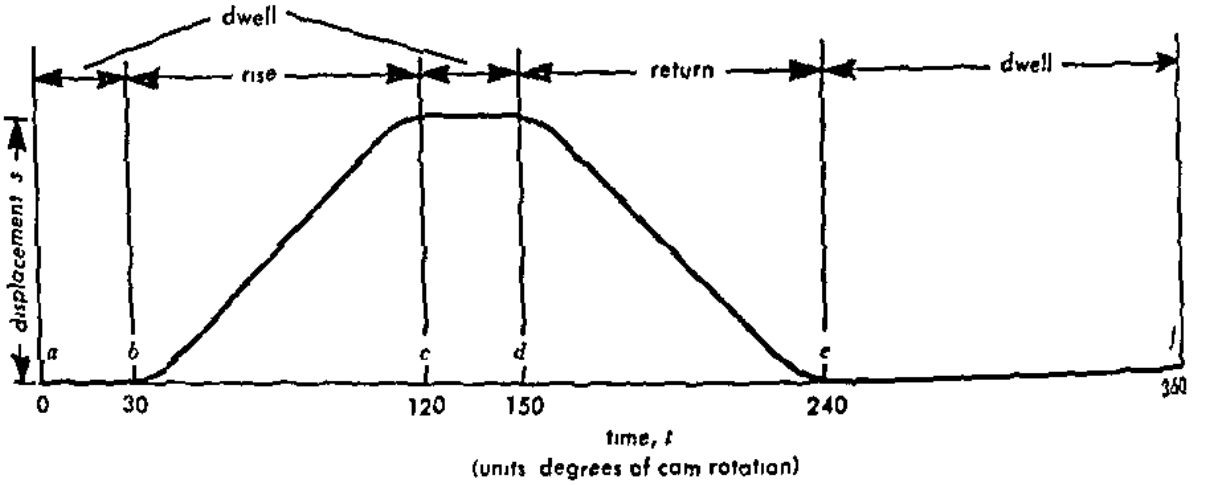


Fig 4 Displacement time diagram for a cam

be represented by a displacement time diagram (*Fig 4*) The time axis is usually laid off in degrees of cam rotation The conventional meanings of follower dwell rise and return are indicated in the figure

The maximum displacement of the follower and the periods of dwell are determined more or less arbitrarily by the designer He has the choice of any curve to connect the dwell portions of the complete displacement time diagram The practical form for this curve is determined largely by the maximum acceleration that can be tolerated by the follower linkage In addition the pressure angle (α in Fig 2*b*) must be kept fairly small usually less than 30° in order to avoid undue friction and possible jamming of the reciprocating follower in its guides The space that is available for the cam will affect the maximum pressure angle The larger the cam can be made (which in effect physically increases the length of the time axis for the same time interval) the smaller the maximum pressure angle will be The final form may also represent a compromise in order to make possible the economical manufacture of the cam

If the diagram of Fig 4 were laid out on and cut out of steel and a knife edge follower were constrained to move vertically, the translating cam mechanism of Fig 5*a* would result The process of wrapping this translating cam around a disk (Fig 5*b*) thus producing a disk cam whose follower action would be similar to that of Fig 5*a* can be visualized readily The introduction of a roller or

[illegible] displacement time diagram and the final cam contour makes it easier to visualize the conditions that must be met in order to design a cam that will operate satisfactorily

Consider now the dwell rise dwell portion of the curve of Fig 4 Displacement of the follower might be plotted arbitrarily as a straight line (Fig 6*a*)

Because the slope of a displacement time ($s - t$) curve is equal to velocity ds/dt at any point it follows that the velocity of the follower from A to B (dwell) will be zero, from B to C will be constant and finite, and from C to D will be zero again (Fig 6*b*)

The slope of the velocity time curve is equal to acceleration dv/dt or d^2s/dt^2 Thus the acceleration of the follower necessary to increase velocity from zero to a finite value in zero time (B to B in Fig 6*b*) is infinite Likewise, the deceleration that occurs at C must also be infinite The acceleration along the constant velocity line, from B to C would be zero Thus the curve chosen in Fig 6*a* for displacement is unsatisfactory because of the high inertial forces that would result from abrupt changes of velocity The cam mechanism would operate without immediate breakage only if elements of the mechanism were sufficiently resilient to reduce the slope of the acceleration curve to a finite value

Therefore a curve having a gradual transition from dwell to maximum velocity is necessary Three such curves are plotted in Fig 7 and are superimposed in Fig 8 for comparison The derived curves for velocity and acceleration are also plotted so comparisons may be made

The constant acceleration constant deceleration curve in which displacement s is proportional to t^2, is desirable except for the instantaneous reversal of acceleration at the point of maximum velocity because such a reversal would cause high stresses in the mechanism If the follower were spring

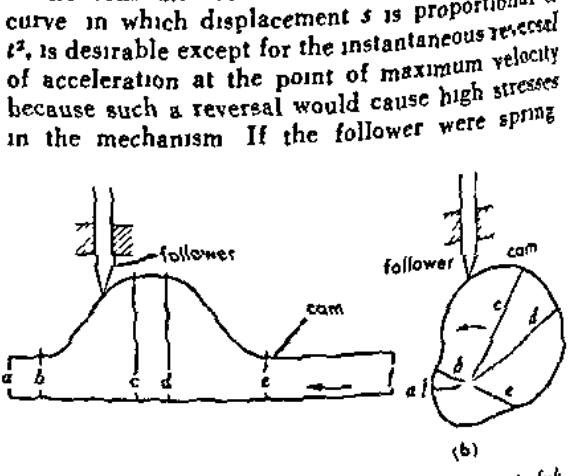


Fig 5 Conversion of (*a*) translating cam to (*b*) disk cam

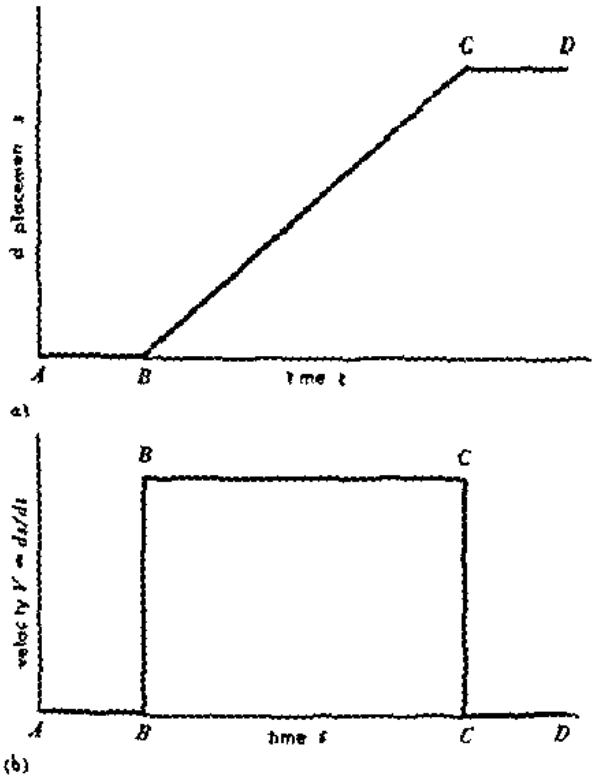
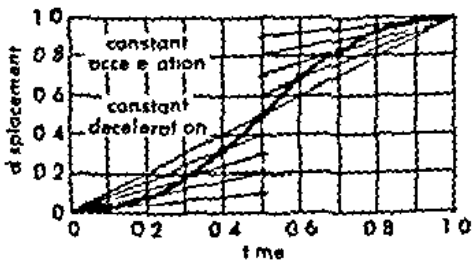


Fig 6 Effect of displacement (a) on velocity (b)

loaded a heavy spring would be required to prevent the follower a leaving the cam face momentarily with resulting shock to the linkage as it returned The simple harmonic displacement curve is plotted by projecting onto a diameter of a circle (whose diameter is equal to follower displacement) a point moving with constant velocity around the circle s circumference While the maximum acceleration is higher than in the preceding curve the abrupt changes of acceleration occur only at the beginning and end of rise Both of these curves have been used in cam design both are satisfactory if speeds are low to moderate and follower mass is not large However serious difficulties are encountered when high speeds or heavy followers accentuate the stresses resulting from acceleration



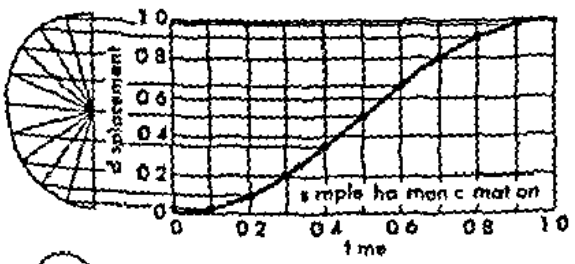


Fig 7 Displacement-time diagrams for cam cont

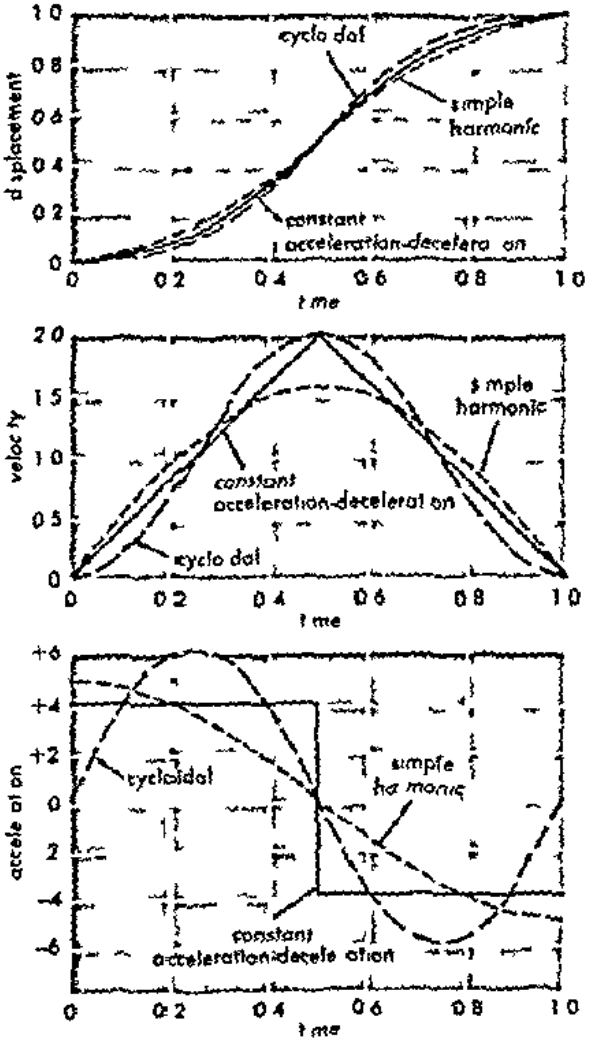


Fig 8 Comparison of motions for three shapes of rise return segments (From G L Guillet and A H Church Kinematics of Machines 5th ed Wiley 1950)

The cycloidal curve is plotted by projecting points from a cycloid whose generating circle has a diameter equal to follower displacement divided by π as shown in Fig 7 This curve has desirable acceleration characteristics but requires that the cam face be very accurately machined at the beginning and end of rise in order to accomplish in fact the theoretical performance

Comparison of the three curves is shown in Fig 8 The cycloidal curve exhibits a higher pressure an ... ng follower than the other

curves but its acceleration characteristics are much superior

Construction of cam profile Empirically a cam profile can be plotted to as large a scale as desired if the displacement curve and the configuration of the follower linkage are known The method consists essentially in inverting the mechanism by fixing the cam and rotating the follower linkage about it plotting only enough of the follower linkage to establish the successive positions of the follower face that will bear on the cam Figure 9 shows the method of constructing the profile for a disk cam having a radial translating roller follower whose displacement curve is given The cam profile is fastest in being at every point tangent to the follower roller (Accuracy is improved by using a larger scale and by plotting additional positions)

The method of constructing a cam profile for a flat face offset or oscillating follower is similar to that shown in the figure It is important however that the location of the point in the follower linkage whose displacement is described by the displacement time curve be kept constantly in view as the follower linkage is plotted in successive positions

Analytically a profile can be calculated to any desired accuracy and the cam profile may be shown in tabular form giving for example displacement of the follower for each degree of cam rotation If a milling cutter or grinding wheel of the same size and shape as the follower is then used to cut the cam contour the resulting contour will be true except for the small ridges that remain between given positions These ridges can be removed by hand using a file or a stone

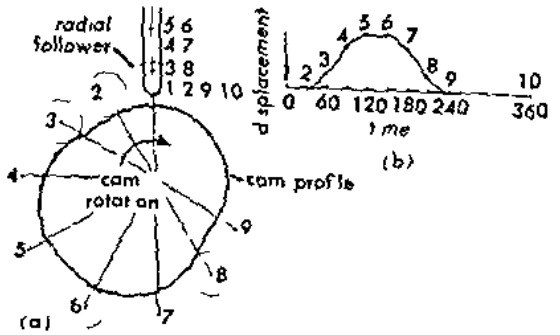


Fig 9 Construction of cam profile (a) for disk cam with radial translating roller follower from displacement curve (b)

Polydyne cams In certain high speed cam mechanisms for example an automotive engine valve gear the elasticity and vibration characteristics of the follower linkage must be taken into account if faulty operation is to be avoided Presented by W M Dudley in 1948 and elaborated by D A Stoddart in 1953 the polydyne method derives its name from employment of a polynomial displacement curve that suits the dynamic characteristics of the follower linkage [F S F]

Bibliography H A Rothbart *Cams* 1956

Camarodonta

[illegible] and H R Jackson

[illegible]

DEA, HEMICIDAROIDA, [illegible]

Cambrian

The lowest geologic system that contains abundant fossils of animals and the first (earliest) geologic period of the Paleozoic Era More exactly the term is applied to fossil bearing strata (and unfossiliferous rock thought to have formed simultaneously) in which occur species that by common agreement are said to be Cambrian Both the lower and upper

PRE CAMBRIAN		PALEOZOIC								MESOZOIC			CENOZOIC	
ARCHEOZOIC (EARLY PRECAMBRIAN)	PROTEROZOIC (LATE PRECAMBRIAN)	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFEROUS		PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY	QUATERNARY	
						Mississippian	Pennsylvanian							

limits of the Cambrian have been and are in dispute The Cambrian Period is that interval of geologic time during which Cambrian species lived It is assumed to precede Ordovician time and succeed Precambrian time Although there is little doubt that the greater part of Cambrian time did in fact precede Ordovician time there is no way at present to prove that the last Cambrian species were not contemporaneous with the first Ordovician species For purposes of applied geology this question poses no problems and is almost universally ignored

The name and concept of the Cambrian System were proposed in 1835 by A Sedgwick who described in general terms a succession of strata in Wales and divided it into Lower Middle and Upper Cambrian Subsequently most of this succession has been assigned to the Precambrian and Ordovician and Sedgwick's type sections have no scientific significance In fact the British Cambrian is so complicated and poorly exposed that it is not as yet satisfactorily understood and it has not significantly influenced the present concept of the Cambrian and its subdivisions these have been derived almost exclusively from Sweden Norway and North America The British have consistently retained the Tremadoc Series in the Cambrian but almost universally elsewhere the Tremadoc is regarded as the first (lowest) series of the Ordovician

Base of the Cambrian The Cambrian is unique among geologic systems in that its base must be defined not in terms of differences between fossil

species, but in terms of the first appearance in the rock record of any fossils other than tracks trails and plants (algae) The earliest common Cambrian forms (trilobites and archaeocyathids) are highly organized animals that must have evolved for a long time before they acquired hard parts capable of be ing fossilized and there is no reason to suppose that this ability was acquired simultaneously by all existing animal phyla or even by all genera and species in any one phylum The earliest animal fos sils are archaeocyathids in Morocco nonolenellid trilobites in eastern Asia and Australia and olenel lid trilobites belonging to different genera in dif ferent areas over the rest of the world Thus it is highly unlikely that any biologically defined base assigned to the Cambrian can ever be considered to comprise a level of even approximate contempo raneity *See* ARCHAEOCYATHA TRILOBITA

Attempts to define the base of the Cambrian Sys tem nonbiologically have met with little or no more success. In most areas the problem does not arise for commonly fossil bearing Cambrian strata un conformably overlie igneous or metamorphic rock that is universally accepted as Precambrian with at most a few hundred feet of unfossiliferous sand stone intervening This situation provides a clear distinction between Precambrian and Cambrian rocks that are separated by a hiatus of unknown magnitude but equally clear is the fact that these Cambrian strata are not the oldest Cambrian strata *See* PRECAMBRIAN UNCONFORMITY

To account for the hiatus one must look to other areas that evidently were sinking and receiving sed iment at about this time but again the evidence does n In d I F — In n Norway

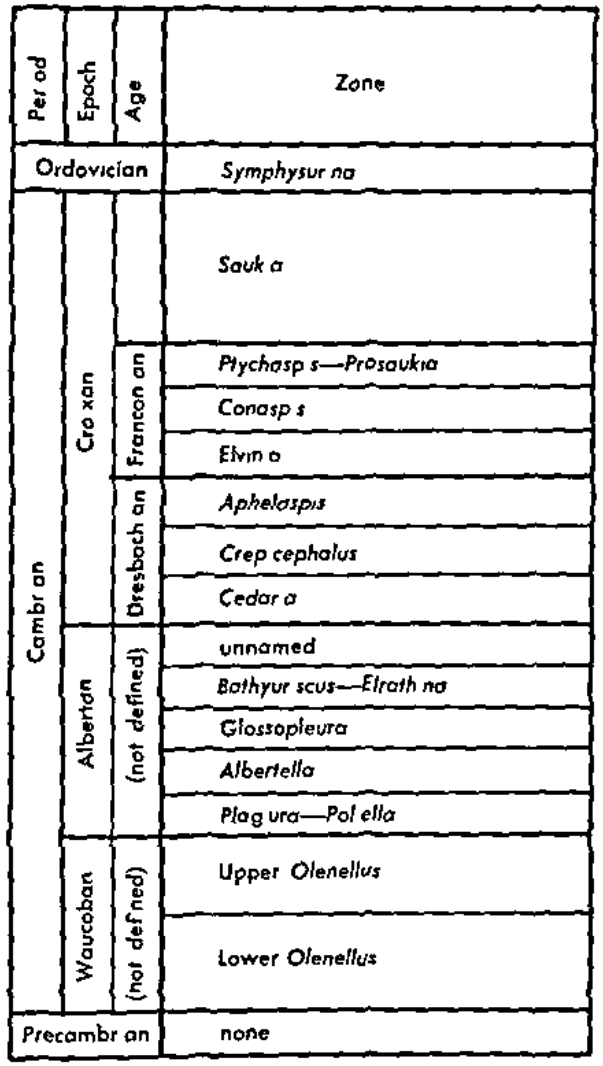


Fig 1 Cambrian time scale

strata conformably underlie the lowest primitive Lower Cambrian olenellid trilobites and in turn are underlain conformably by as much as 10 000 ft of limestone that contains only stromatolites (algae) in eastern United States almost 3000 ft of strata conformably underlie the lowest olenellids and in the Inyo Mts of California more than 14 000 ft of strata contain *Olenellus* and archaeocyathids and are underlain conformably by 7000 ft of unfossil ti

Eocambrian and Infracambrian have been applied to the thick sequences of strata conformably un derlying Lower Cambrian fossils However neither the top nor bottom of such a series (or system) can be argued to be contemporaneous over any sub stantial area *See* ALGAE FOSSILS STROMATOLITE

Classification For more than a half century the Cambrian of the classical area extending from Es tonia in the east to maritime Canada in the west has been divided into three series Lower charac terized by olenellid trilobites Middle characterized by the trilobite genus *Paradoxides* and Upper characterized by olenid trilobites The overlying

GRAPTOLITHINA ORDOVICIAN

Because neither the *Paradoxides* nor olenid faunas have been found in North America anywhere m me C nada and n eastern

workers as follows Lower (Waucoban) character ized by the full range of olenellid trilobites Up per (Croixan) characterized by the sequence of Cambrian faunas first described from Wisconsin

logically and paleontologically Currently the Al bertan Croixan boundary is the subject of serious discussion and at least three writers have suggested moving it upward to the top of the Dresbachian now the lowest stage of the Croixan Argum

are complex and based on meager evidence, but the object is to bring the classification in North America in line with that of Norway and Sweden

Top of the Cambrian. By current definition lowest Ordovician rocks in most of North America are characterized by trilobite faunas containing *Symphysurina Bellefontia* and *Hystricurus* Wherever this boundary has been investigated critically it is found to be transitional lithologically and paleontologically there is a sharp change in the trilobites but little or no change in the brachiopods and gastropods

Stratigraphic correlation The geologic history of each Cambrian area is interpreted from its combined succession of rocks and fossils In order to compare one area with another particularly if they are more than a few tens of miles apart, the fossil succession must be relied upon to give some measure of time relationships Cambrian faunas contain representatives of every important invertebrate animal phylum but the only groups that are

both local and intercontinental time scales

The sequence of trilobites is not the same in different areas Each sequence is the record of the occupation of that area through 100 000 000 years or more by successive populations of trilobites Some species evolved in situ through longer or shorter periods of time and the record of their successive changes is preserved in the strata Others migrated into an area and later moved on and their prior and later evolutionary histories are preserved in other stratigraphic sequences Histories of some migrating populations can be interpreted if the proper rocks are discovered and properly studied More often the critical record has been destroyed by subsequent erosion is deeply buried by later strata and is therefore inaccessible or has not as yet been properly studied Altogether a surprising number of consistent biologic sequences has been discovered some of which persist over rather large areas Today one of the best understood Cambrian histories is that of North America particularly that of the western two thirds of the continent

Zones Trilobites that occur in successive layers of strata are for convenience assigned to zones and subdivisions of zones called subzones Each zone comprises a thickness of rock that is characterized by specimens of one or more genera and each is named for one or more genera that may or may not be restricted to it These zones are in no sense natural units; they are defined empirically by paleontologists and exist only because they are accepted by other paleontologists who find them useful in interpreting biologic and stratigraphic history Consequently their definitions and names are constantly tentative

Boundaries between adjacent trilobite zones in continuously deposited strata range in character between two extremes At one extreme the adjacent zones may be distinguished only by the presence of one or a few species in one zone and their absence in the other, whereas the bulk of the fauna may be the same in both zones, this can be the consequence either of evolution in situ or of the migration of one or a few species without disturbing the rest of the inhabitants At the other extreme the total fauna may be different in the two adjacent zones, this can be the consequence of one population replacing another, either by moving into an area already abandoned by the previous one, or by moving in and destroying or driving out the former inhabitants If adjacent zones are separated by an unconformity, the faunas may be totally different solely because they are widely separated timewise by a gap (hiatus) in the record

About 15 trilobite zones currently form the "calendar" by which the Cambrian history of North America is interpreted This is not to say that all or any of them are truly time-stratigraphic units They do, however, constitute the only consistent succession of elements possessed in common by sequences of Cambrian strata over large parts of the continent, and by default they must be so used if any reasonable history is to be written The boundaries between some are sharp, and between others are vague Some that are sharp in one area are vague or nonexistent in other areas. The result is that a zonal classification that serves well in one area may turn out to be only in part usable in another and both may have to be modified in order to distill from them a common essence

North American Cambrian history The Cambrian record in North America as it is now broadly outlined by those actively engaged in its study, is relatively simple

Early Cambrian Prior to the appearance of animals with hard parts marine waters flooded sub-

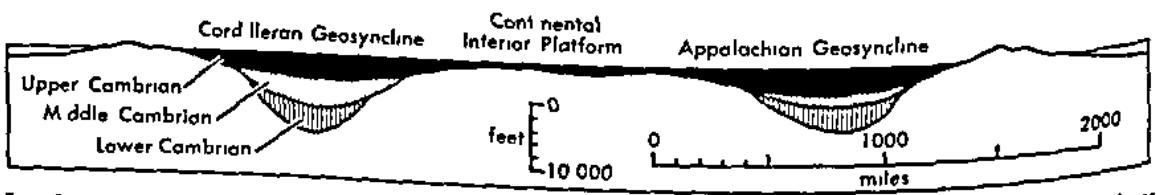


Fig 2 Diagrammatic section across the middle part of North America in an east-west direction, showing Cambrian deposits and configuration of the Precambrian floor This figure indicates important distinctions between Cambrian deposits of the continental interior platform and of the two adjacent north-south trending geosynclines Repeated uplift of the borderlands or volcanic archipelagoes furnished the source for some of the sediments carried to the geosynclines The vertical scale is greatly exaggerated (*Adopted from R C Moore, Introduction to Historical Geology, McGraw Hill 2d ed , 1958*)

iding troughs along the western (Cordilleran) and astern (Appalachian) margins of what is now the ontinent (Fig 2) Thousands of feet of sediment (sand clay, limey mud) accumulated as the troughs ank preserving only tracks trails and stromato ites (algae) to give fossil evidence of any living hings At some point in time not necessarily the ame in both troughs olenellid trilobites brachio pods and archaeocyathids acquired skeletons that became fossilized as more thousands of feet of sedi ment accumulated under conditions no different so far as can be determined from those previously existing The olenellids were joined in time by other types of trilobites and moved with them in waters that began to flood the ancient North American continent This marine advance had barely begun when olenellid trilobites disappeared and (by definition) the Early Cambrian came to an end There is some evidence that subsidence slowed and the seas became shallower at about this time but evidently there was no appreciable interruption in the advance of the shore line and certainly no significant retreat

Middle Cambrian During Middle Cambrian time the advance continued, the waters were populated by successive assemblages of trilobites and brachio pods that are now assigned to zones By the time the last of these forms disappeared the western shoreline lay roughly along the 110° meridian—through Arizona eastern Utah central Wyoming eastern Montana and northward through Canada The advance of the eastern shoreline was not nearly so extensive, and Middle Cambrian strata are con fined to the Appalachian Mountains of today Just before the disappearance of Middle Cam brian trilobites there is evidence that subsidence slowed and the seas became shallower again but at most the shoreline retreated only a few tens of miles The Middle Cambrian (Albertan) Series is not bounded below or above by unconformities except possibly very locally its definition is en tirely paleontologic and its boundaries are grada tional

Late Cambrian The marine advance resumed and by the end of the Dresbachian Stage all of North America was flooded except Canada north of the Great Lakes and an island which included the area of the present states of Nebraska Kan sas Colorado New Mexico Oklahoma and West Texas The only substantial retreat of the shore line during the Cambrian occurred at this time This retreat can be measured in distances from a few tens of miles to almost 500 miles in Montana and Wyoming Some freshly deposited sediment was removed but not much and again the sea re turned to its former position and farther, leaving an even smaller island in the middle of the United States by the end of Cambrian time Although there was some shoaling and shoreline retreat during late Franconian and early Trempealeauan time in West Texas and during late Trempealeauan time in Minnesota and Wisconsin the flooding of North America continued without serious inter ruption into the Ordovician and by the end Early Ordovician time very little of the continent lay above water The usual relationship between highest Cambrian and lowest Ordovician strata in North America is one of transition and conforma bility [W C B]

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Camel

Either of two species of large ruminants of the ge nus *Camelus* family Camelidae There are numer ous fossil forms especially in North America but only the dromedary or Arabian camel *C drome darius* and the Bactrian camel *C bactrianus* have survived among the true camels The llamas of South America belong to the same family *See* LLAMA



Camel *Camelus dromedarius* height at shoulder to 7 ft

Camels are highly specialized for life on desert sands having the ability to go for a week or more without water They have padded feet which have undivided soles although these animals are two toed *See* ARTIODACTYLA [J D B]

Camel's hair

A fine hair known to the American consumer chiefly in the form of high quality coat fabrics This tex

tor of both heat and cold, it is also a natural water repellent In the spring the year s growth of hair which hangs from the camel in matted strands and tufts falls off in clumps This growth plus the masses of hair shed throughout the year is the chief source of supply The camel is sometimes plucked to obtain the down or underhair

Camel s hair fabrics are ideal for comfort par ticularly when used for overcoating as they ar especially warm and light in weight Camel's characterized by strength luster, and s

ness The best quality is expensive It is often mixed with wool to improve the quality of the wool fabric The price of such a mixed cloth is much less than that of a 100% camel s hair fabric

In the textile industry camel s hair is divided into three grades Grade 1 is the soft and silky light tan underhair This is short staple or noil of 1 5 in but is the choicest quality This was once the only true camel s hair used in the manufacture of apparel Grade 2 is the intermediate growth consisting partly of short hairs and partly of coarse outer hairs Grade 3 consists entirely of coarse outer hairs measuring up to 15 in in length and varying in color from brownish black to reddish brown This grade has no value for apparel manufacture it is suitable only for cordage and for low quality rugs *See* ALPACA CAMEL CASHMERE LLAMA MOHAIR VICUNA WOOL *see also* FIBER NATURAL

[M D P]

Cameo

A type of carved gem stone in which the background is cut away to leave the subject in relief Often cameos are cut from stones in which the coloring is layered resulting in a figure of one color and a background of another The term cameo when used without qualification is usually reserved for those cut from a gem mineral although they are known also as stone cameos The commonly encountered cameo cut from shell is properly called a shell cameo

Most cameos are cut from onyx or agate but many other varieties of quartz such as tiger s eye bloodstone sard carnelian and amethyst are used other materials used include beryl malachite hematite, labradorite and moonstone *See* GEM *see also* INTAGLIO (GEMOLOGY)

[R T L]

Camera

A light tight enclosure containing in its simplest form an aperture (or usually an optical lens

photography Nearly all modern cameras contain a glass lens to focus an image of a subject onto a sensitive film or plate at the other side a shutter to enable exposures of predetermined time to be made a finder to show the area of the subject being photographed and a holder for the sensitive material (Fig 1) A great variety of auxiliary camera apparatus is used

Chief camera types Most cameras are used by amateur professional and commercial photographers although many are designed for specific purposes especially for scientific and technical photography Modern cameras follow the basic design but have developed into a number of types having well defined

Press cameras view cameras Polaroid Land cameras rapid sequence cameras one shot color cameras panoramic cameras underwater cameras stereo cameras high speed cameras document copying cameras motion picture cameras and television cameras The first six types are treated in this article For a discussion of Polaroid Land cameras *see* PHOTOGRAPHIC MATERIALS for information on underwater cameras see UNDERWATER PHOTOGRAPHY, for details on stereo cameras high-speed cameras and document copying cameras *see* PHOTOGRAPHY for information on motion picture cameras *see* CINEMATOGRAPHY for television cameras and auxiliary apparatus see TELEVISION CAMERA *See also* OPTICAL TRACKING INSTRUMENTS SCHMIDT CAMERA

Box cameras These consist of a box now usually of molded plastic with an arrangement for loading and winding film a simple lens of fixed focus and relative aperture of f/14 to f/11 and a simple shutter with a speed of about 1/30 sec although in some models two or three aperture settings can be made and there may be provision for long or time" exposures Many models have provision for flash photography using separate or built in flash attachments and the view finders are usually of the optical eye level type although some cameras have waist level reflex finders Box cameras generally take pictures 2¼ by 3¼ 2¼ by 2¼ 1⅝ by 1⅝ or 1⅝ by 2½ in in size

higher aperture and means for focusing by a scale on the bed or by rotating a ring on the front of the lens and usually have shutters giving a range of exposure times down to 1/400 sec Rangefinders are sometimes included and may be coupled to the focusing control Double exposure prevention devices may be incorporated and the film advance mechanism is sometimes coupled to the shutter cocking

Miniature cameras These are usually roll film cameras taking perforated 35 mm film in rolls giving 20 or 36 exposures in most cases 24 by 36 mm in size They are small and portable and range from simple models of low cost to complex highly precise cameras with a great variety of attachments The lens apertures are generally high (f 3 5 or more) Apertures up to f/1 9 are common and f/1 1 has been used The focal length of the standard lenses is 50 mm or thereabouts Many cameras are provided with interchangeable lenses of a range of focal lengths or in some cases interchangeable front lens elements to permit changing the effective focal length *See* LENS OPTICAL

Many 35 mm miniature cameras have focal plane shutters giving a range of speeds up to 1/1 000 sec while some have between the-lens shutters giving a somewhat lower range of speeds and permitting lens interchangeability only by changing the front element Most cameras have built in range-finders coupled with the focusing mechanism and all have optical view finders Essentially all have flash synchronization built into the shutter Many

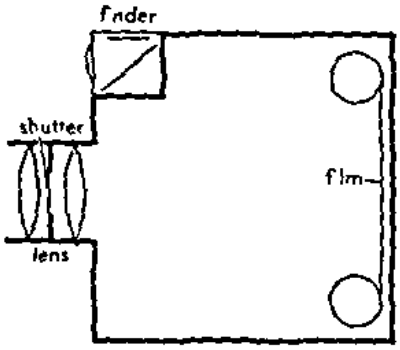


Fig 1 Elementary diagram of a camera

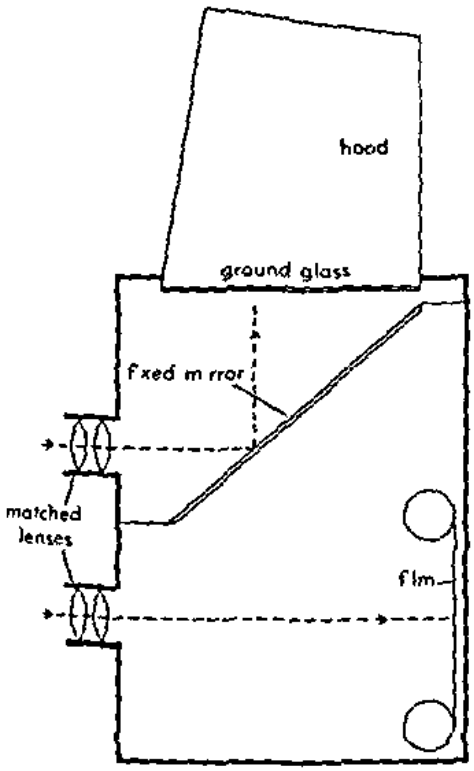


Fig 2 Diagram of twin lens reflex camera

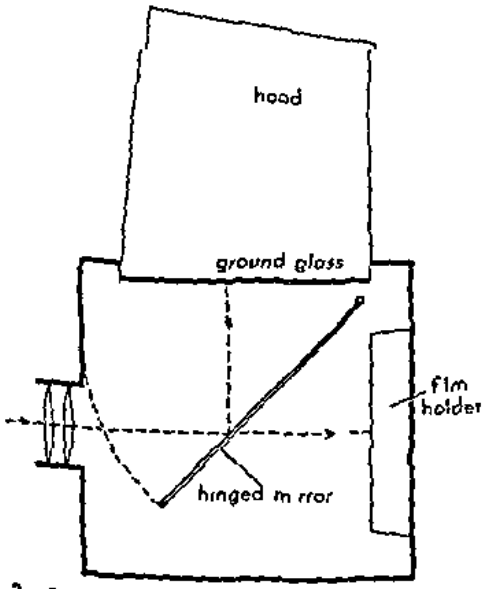


Fig 3 Diagram of single lens reflex camera

have built in exposure meters, in some instances coupled with the lens diaphragm to adjust it to an aperture corresponding to the integrated luminance of the scene Most have automatic shutter winding or setting combined with the film advance mechanism Frequently provided are dials to indicate the type of film in the camera depth of field scales exposure counters coupled lens aperature–shutter mechanisms and automatic diaphragms, permitting focusing at full aperture and closing the diaphragm to a predetermined value on pressing the shutter release

Some miniature cameras, frequently referred to as subminiature are of very small size and use 16, 9 5 or 8 mm roll film Some fall in the category of novelties but others are precise instruments, used mainly because they are portable and readily concealed The small size of the negatives limits the size of enlarged print to about 5 by 7 in in the best cases

Reflex cameras In these a mirror is used to reflect a full size image of the scene on a ground glass so that composition and focus may be judged The twin lens reflex camera (Fig 2) is essentially two similar cameras coupled together one of which has a mirror and ground glass in place of the film holder The two lenses are coupled and focusing the camera lens also focuses the finder lens so that the picture falling on the film is seen on the ground glass (but with slight parallax) and can be framed composed and focused These cameras are much used by newspaper reporters Most have 75 or 80 mm focal length lenses of f/3 5 aperture and

cepts the light through the lens and reflects it to

that the image falls on the film plane and the shutter operates immediately afterward There is no parallax Cameras with a mirror and ground glass are used at chest or waist level and in larger sizes (up to 5 by 7 in) have been much used for sports and nature photography They are made in sizes down to 35 mm which at the present time is the most used single-lens reflex camera With focal

each stop value is passed) The pentaprism (Fig

ter

Press cameras These types provide photographs for newspaper and magazine reproduction although

twin lens reflex and miniature cameras are also much used Press cameras are usually fairly bulky hand cameras and give negatives up to 4 by 5 in on sheet film film packs or roll film They all have flash attachments interchangeable lenses and rangefinders and in skilled hands are quite versa tile Many use focal plane shutters l ut sometimes between the lens shutters in general they have a range of camera movements (camera movements are discussed later)

I iew cameras These are used largely by com mercial photographers and are mounted on a tri pod or other support They are large rigid and ex tremely flexil le with a range of camera movements and usually have a l ellows and ground glass focus ing interchangeal le lenses and between the lens shutters View cameras are used in studios or out doors Studio cameras are usually bulky take large sheet films have great flexibility and are always used on a rigid support Their main use is for por traiture

Other types Polaroid Land cameras represent an important innovation about 1 min after an ex posure is made a positive print on paper or film is obtained Rapid sequence cameras typified by the 35 mm Robot cameras are conventional in most re spects but permit a number of photographs to be obtained in rapid succession with one winding of the shutter One shot color cameras are l eam split ting cameras provided with partially reflecting partially transmitting mirrors and color filters to permit three color separation negatives to be ex posed simultaneously (*see* PHOTOGRAPHY COLOR) Panoramic cameras are used for photographing wide groups of people or a wide span of the hori zon The lens scans the view in a sweep from one s de to the other the film moving in synchronism with the moving image and the exposure being made through a narrow slit Underwater cameras are usually conventional types enclosed in a housing to withstand water pressure preferably with a cor rection lens to compensate for aberrations caused by refraction in the water Provision is made for external operation of the shutter film transport and flash

Film holders and transport Film must be po- sitioned in the focal plane it must be possible to remove or change the film after exposure In roll film cameras the film is wound from one spool to another (and sometimes back onto the original spool before unloading) to permit a series of pic tures to be made on a roll Indexing of the position of the film is effected by a counter driven by the film or by numbers on the film backing paper viewed through a window in the camera back

Plates and sheet films are loaded into holders which fit into the camera back and are provided with drawslides to be removed before exposure and replaced after it Sometimes film is loaded into simple metal sheaths of which 12 or 18 may be as

of thin film each of which is attached to the mid

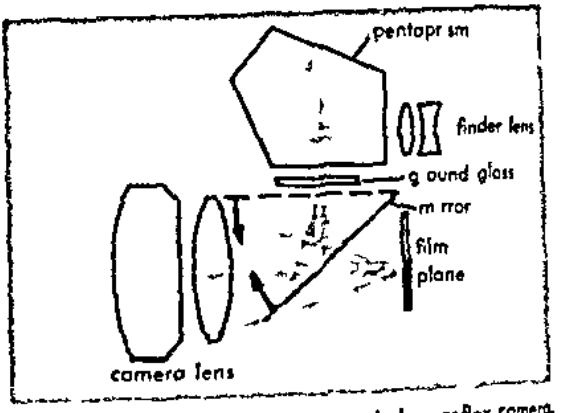


Fig 4 Pentaprism finder for single-lens reflex camera

dle of a sheet of black paper which serves as back ing paper to prevent exposure of the film beh nd and a leader by which the film is pulled to the back of the pack after exposure Film packs are used in an adapter with drawslide to fit in place of a normal film holder in the camera back

Camera movements In a simple camera the panel carrying the lens is parallel to the plane of the film and the optical axis of the lens is vertical to the film and passes through its center In cam eras for commercial and portrait photography and to some extent for press photography movement are introduced in the camera front and back to per mit control of vertical lines perspective and focus They consist of rise and cross front (referring to up and down and sideways movements of the lens panel) swing back and swing front (the back and the lens panel are hinged to turn about vertical and horizontal axes) and revolving back (rotation of the film holder)

Focusing Arrangements must be provided for the lens to focus the image on the film Lenses mu t produce a sharp image that is a picture in good focus Maximum sharpness over the whole negative is necessary in many cases but it is sometimes de- sirable to have sharpness in the middle of the pic ture with fuzziness tolerable at the edges (for ex ample in portraiture) Focusing is accompl hed by moving the lens in relation to the film (or vice versa) and viewing the image on a ground gla s screen by moving the lens accord ng to a scale marked in distances the distance being judged by experience or by a rangefinder and the scale be ng on the camera bed or on the lens mount or by a focusing finder in which the rangefinder is coupled to the focusing mechanism of the lens Fresnel type field lenses in sheet form are sometimes u ed at the ground glass to increase brill ance of the image and give more uniform illumination

There are many factors which affect defini ion n a photograph but for the best definition the len must be sharply focused Even the best lenses do not reproduce a point as a point but as a small d k known as the circle of confusion At a viewing d s tance of 10 in a circle of 1/100 in diameter or les usually appears as a point so that a picture ap pears at its sharpest if each point is represented by a circle not larger than this The size perm tted

is a function of the lens aperture, its focal length and the degree of enlargement of the print In the cases of normal lenses for 8 mm movie cameras it may even be as small as 1/1000 in There may be some latitude in focusing in which there is no apparent change in sharpness This distance is known as the depth of focus The depth of field of a lens is the distance between two planes one on either side of the plane focused on, in which all subjects appear sharp Focusing scales of many cameras are associated with depth of field indicators

Finders Unless the image is focused on a ground glass it cannot be seen and a finder (view finder) must be used to provide the photographer with the view of the subject seen by the lens The simplest type is the frame finder (Fig 5*a*), which is a wire rectangle of appropriate dimensions mounted on the front of the camera with a small peep sight on the top of the camera above the film plane The optical axis is parallel to that of the lens Some cameras have smaller frame finders closer to the peep sight to reduce space the angle of view being the same but the frame somewhat

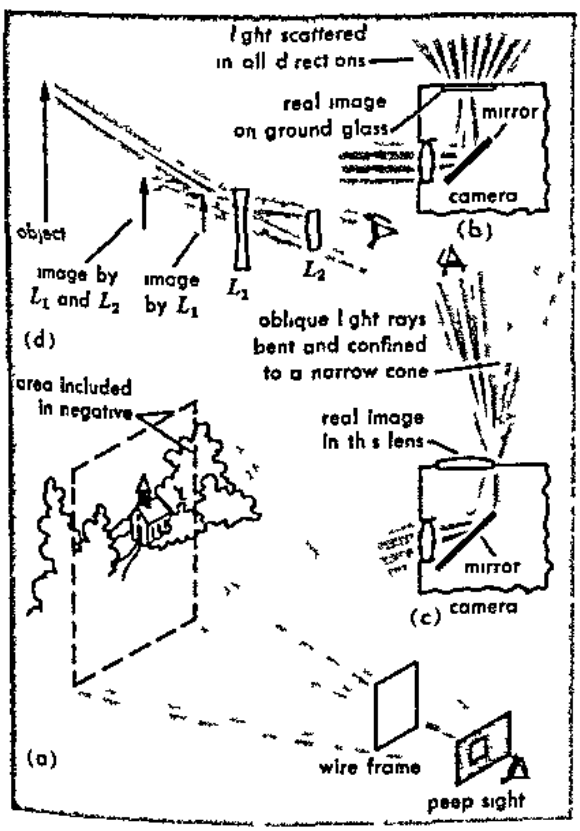


Fig 5 View finder systems (*a*) Frame finder or peep sight finder (*b*) Ground glass finder Image is reversed from left to right (*c*) Brilliant finder so-called because the image when viewed from above is more brilliant than on ground glass because of concentration of light beam (*d*) Direct vision optical finder Lenses L_1 and L_2 may be collapsible or may be at either end of a tubular pseudotelescope (*From Willard D Morgan ed, The Complete Photographer National Educational Alliance 1941–1943 Illustration provided by Eastman Kodak Co*)

blurred in use Optical view finders that is, view finders utilizing lenses are in most common use Earlier and inexpensive box cameras used at waist level include a finder consisting of a lens and a mirror reflecting the scene to a small ground glass (Fig 5*b*) or to a second positive lens on the camera top Finders of this type have largely given way to so called brilliant finders (Fig 5*c*) in which the viewing lens on top presents an image often as large as the actual negative frame size and to direct vision finders (Fig 5*d*) in which what amounts to an erecting telescope is attached to or built into the camera The latter type is used at eye level and gives a brilliant erect image which is not reversed

Shutters The shutter is the device that admits for a selected time the light from the subject through the lens to the film Shutters are associated with the lens itself or with the film plane The simplest shutter used only for long exposures is the lens cap which is removed from and replaced on the front of the lens by hand In automatic or even set shutters pressure on the release first sets and then releases the shutter in one operation Shutters open remain open for a time and then close with a retarding mechanism similar to an escapement a gear train or a governor used to control the time Shutters vary in the range of exposures available which may be from several seconds down to 1/800 sec Arrangements are made for keeping the shutter open for long times if needed (bulb and time or B and T)

Shutters located near the film plane are called focal plane shutters They consist of one or two roller blinds of opaque cloth with one or more slits which travel under tension from one roller to another just in front of the film The maximum slit width is the full width of the film and a wide range of exposure times is made available by varying the slit width and the rate of travel of the slit by variation of the spring tension Focal plane shutters, especially for miniature cameras may have a range of speeds from several seconds to 1/12 0 sec, with means for giving long exposures

Many shutters have provision for synchronizing flash exposures with the opening of the shutter electrical contacts being provided to close the flash lamp circuit at a predetermined time in the shutter cycle

Auxiliary camera equipment Best known adjuncts to the camera are the separate rangefinder, the exposure meter and color temperature meter, attachments for flash exposures, light (color) filters interchangeable lenses of different focal lengths, angle of view and aperture, with appropriate adaptors and extension tubes or bellows supplementary lenses for close ups, lens hoods to shield the lens and reduce flare interchangeable camera backs (especially backs to permit use of 35 mm film on larger cameras), exposure and depth of field guides cable releases for operating the shutter, carrying cases and straps, gadget bags, *and camera supports in particular the tripod*

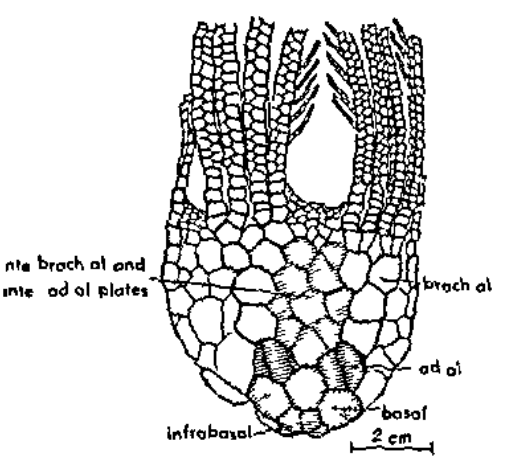
camera movement (in general hand held exposures of longer than 1/30 sec are liable to show signs of movement) *See* EXPOSURE METER FILTER

switch for closing the circuit at the appropriate point in the cycle of the shutter operation External synchronizers solenoids or mechanical types have largely given way to internal synchronizers the electrical circuit being closed by contacts in the shutter Reflectors are built into the camera or may be separate and attached to the battery case Dry cell batteries (3 6 volts) battery capacitor units consisting of a small 22 5 30 volt battery and a 50–100 μf capacitor or house current is used for foil or wire flashbulbs Small storage batteries or *mains* supply associated with a capacitor and means for producing high voltage dc are used for *electronic flash* units Reflectors are specially designed to give most effective use of the light the configuration being related to the size and position of the flash bulb with the surface polished or satin finished Rotary flash holders have been made that permit rapid changing by rotating a ring of bulbs in the reflector Extension units operating from one shutter or synchronizer are used for multiple flash [W C]

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Camerata

An extinct subclass of stalked Crinoidea comprising about 140 Paleozoic genera ranging from the Ordovician to Permian The calyx was invested by a rigid boxlike theca composed of numerous small polygonal plates together with some of the lower brachial ossicles and some other small interradial and interbrachial plates, these plates were all firmly sutured together The tegmen was plated and included some plates which roofed over the mouth and ambulacral grooves The anus was placed on a siphon The uniserial or biserial arms branched several times and carried pinnules The stem was sometimes unanchored and in such cases served as a prehensile limb *See* CRINOIDEA [H B F]



Thyalocrinus a camerate crinoid (Based on Bather and Oehlert)

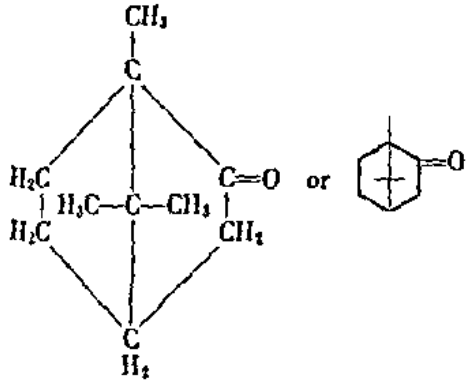
Campanulales

The most advanced and the largest order of the plant subclass Dicotyledoneae including six families with 1136 genera and 22625 species The gourd family (Cucurbitaceae) is a group of tendril bearing annual herbs some having economic importance such as watermelon muskmelon cucumber squash and pumpkin The bellflower family (Campanulaceae) and the lobelia family (Lobeliaceae) contain a number of ornamentals The dominant most advanced and largest family (20000 species) of dicotyledons is the composite family (Compositae) In this group the flowers are arranged as to resemble a single (1) Tubuliflorae having tubular disk flowers (disk heads) or also ligulate (strap shaped) corollas in the marginal or ray flowers (radiate heads) and (2) Liguliflorae having ligulate corollas only (ray heads) The sepals are modified to form a pappus which is extremely variable The anthers are united and the fruit is an achene The family contains many ornamentals (daisy chrysanthemum dahlia miller aster blazing star, mistflower strawflower zinnia cosmos dahlia and cornflower) numerous noxious weeds (dandelion hawkweed cocklebur thistle ragweed Spanish needle and elephant's foot), guavule (a source of rubber) some food plants (lettuce sunflower true artichoke Jerusalem artichoke and chicory) and a number of drug plants (pyrethrum safflower) See separate articles for food and drug plants of the families Cucurbitaceae and Compositae *see also* DICOTYLEDONEAE EMBRYOPHYTA, MELON GROWING, VEGETABLE GROWING [P D S]

Camphor

A bicyclic saturated terpene ketone It exists in the optically active dextro and levo forms, and as the racemic mixture of these two forms All of these melt within a degree of 178°C The principal form is *dextro* camphor which occurs in the wood and leaves of the camphor tree (*Cinnamomum camphora*) Formosa is the chief source of natural camphor which is distilled from the wood of this tree Camphor is also synthesized commercially on a large scale from pinene which yields mainly the racemic variety

Camphor has a characteristic odor it crystallizes in thin plates and sublimes readily at ordinary temperatures



Camphor

Camphor has a wide use in liniments and as a mild rubefacient analgesic and antipruritic It has a local action on the gastrointestinal tract producing a feeling of warmth and comfort in the stomach It is also used in photographic film and as a plasticizer in the manufacture of plastics *See* Pinene Turpentine [E L S]

Camphor tree

This plant *Cinnomomum camphora* is a member of the laurel family (Lauraceae) and is a native of China Japan and Formosa The tree grows to a height of 40 ft, is dense-topped and has shiny dark evergreen leaves It is widely planted as an ornamental tree All parts of the tree contain the essential oil camphor which is obtained from the finely ground wood and leaves by distillation with steam The crude camphor crystallizes on the surface of the still After it is removed and refined it is the commercial gum camphor which is used medicinally in perfumes and in the manufacture of celluloid and nitrocellulose compounds *See* Camphor Ranales [P D S]



Camphor tree (*Cinnomomum camphora*) (a) Fruits (b) Stamen (c) Flower (*From P Dejanville Atlas de Poche des Plantes Utiles des Pays Chauds Librairie des Sciences Naturelles 1902*)

Canal

An artificial open channel used to convey water from one point to another Canals are generally classified according to use as irrigation power drainage or navigation canals The first three types are usually regarded as conveyance canals

Canals may be lined or unlined Linings may consist of plain or reinforced concrete cement mortar asphalt brick stone buried synthetic membranes or compacted earth materials Linings serve to reduce losses by seepage or percolation through pervious foundations or embankments and to lessen the cost of weed control and cleaning Concrete and other hard surface linings also permit steeper gradients smaller cross sections and therefore higher water velocities In earth or earth lined canals especially navigation canals the banks near the water surface are often provided with rock riprap or some other protection against wave action

Conveyance canals The character of the material in the bottom and sides of a canal must be taken into account in selecting the velocity of flow For example the velocity in an irrigation canal must be sufficiently low to prevent the cutting of the cross sectional area (canal prism) and it must be high enough to prevent the deposition of silt Velocities of 1 5–3 5 ft/sec are normally used for earth canals (including earth lined canals) the higher velocities are associated with larger canals About 7 ft/sec is the usual maximum for concrete lined canals The velocity depends on the gradient the roughness of the surface in contact with the water and the proportions of the water prism The capacity of a canal Q in ft^3/sec may be expressed by the formula $Q = AV$ where A is the area of the water prism and V the velocity in ft/sec

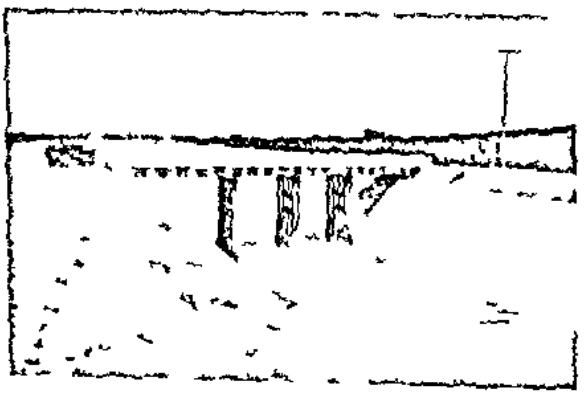
Most canals are trapezoidal in cross section Side slopes for earth canals have generally been standardized at either 1½ 1 or 2 1 (horizontal to vertical) depending on the type of soil but flatter slopes are often used in unstable materials Side slopes of concrete lined canals are generally 1¼ 1 or 1½ 1

An earth canal must be sufficiently wide at bends to inhibit erosion of the outer bank and to control ride-up of the flowing stream at the outside of the curve under severe conditions of flow The radius of curvature from the centerline usually varies from three to seven times the width of the water surface the larger values being associated with the greater flows Approximately the same radii are used for concrete lined canals to control ride-up of the flowing water and minimize construction difficulties

Freeboard or the vertical distance between the water surface and the top of the canal bank generally ranges from 1 ft for small earth laterals to

4 ft for large earth canals Freeboard for concrete lined canals ranges from ½ to 1½ ft to the top of the lining

Canal intakes usually consist of a headworks with some form of intake gates to regulate the quantity of water admitted into the canal and to close the intake when desired Frequently where a canal diverts from a stream which carries quantities of silt the intake may be designed to keep out as much silt as possible This may be accomplished by (1) locating the canal intake at a point on the stream where the silt load is the lowest (2) the use of skimming weirs which divert water from the less silty upper levels of the flowing stream or (3) the use of settling basins in which much of the sand and silt are deposited before the water enters the canal The deposited material is removed from these settling or desilting basins by sluicing or dredging



A concrete lined section of the Friant Kern irrigation canal in California The canal is 152 miles long with a maximum capacity of 5000 ft³/sec (U S Bureau of Reclamation)

Although generally similar in design to irrigation canals power and drainage canals have special requirements Power canals are placed on minimum grade to conserve head for power development hence velocities are usually low Rectangular flume sections with high ratio of depth to width are often used for this purpose Because power canals are subject to sudden changes in flow wasteways for overflow are usually provided as well as ample freeboard

Drainage canals are deeply cut to facilitate the drainage of surrounding land They usually have a minimum grade and a shallow flow of water

Navigation canals and canalized rivers Navigation canals are artificial inland waterways for boats barges or ships A canalized river is one that has been made navigable by construction of one or more
flow of w
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such rivers They are adapted to the topography by a series of level reaches connected by locks

The dimensions of a navigation canal are determined primarily by the size and to some extent by the speed of the vessels which are to use it The depth must be sufficient to assure bottom clearance under all operating conditions and ordinarily the width allows vessels to pass each other The cross section is usually trapezoidal the side slopes ranging from 1½ 1 to 3 1 or flatter depending on the material of the cut Sections in rock cut may have vertical or near vertical sides

Locks These are used both in navigation canals and canalized rivers A lock is a chamber equipped with gates at both the upstream and downstream ends Water impounded in the chamber is used to raise or lower vessels from one elevation to another The lock chamber is filled and emptied by means of small auxiliary filling and emptying gates

After a vessel enters the lock chamber the gates are closed and the water level is lowered (if the vessel is headed downstream) or raised (if the vessel is headed upstream) When the water in the chamber reaches the level of the water forward of the vessel the forward set of gates is opened and the vessel leaves the lock

Lock lifts vary from about 1 ft to more than 90 ft The lock at McNary Dam on the Columbia River has a vertical lift of 92 ft a net clear width of 86 ft and a length of 675 ft The lock at Ice Harbor Dam on the Snake River will have a vertical lift of 103 ft upon completion of the dam in 1961

On most canalized rivers locks are used only during periods of low flow The dams contain movable sections which may be lowered during periods of moderate or high flow to permit the unobstructed passage of boats and barges over the dam *See* DAM [L V M]

Canal rays

The name given in early gaseous discharge experiments to the particles passing through a hole or canal in the cathode Canal rays are also called positive rays or anode rays Since these particles are attracted to the cathode they are positively charged and hence are positive ions of the gas being used in the discharge

The most important experiments in connection with canal rays were performed by J J Thomson around 1910 Some of the positive ions produced in a cold cathode discharge in neon were allowed to pass through the cathode canal into a region on the other side There they struck a fluorescent screen oriented normal to the path to produce a luminous spot This spot could be deflected by electric and magnetic fields applied in the region between the canal and the screen With these fields parallel to each other and perpendicular to the path of the ions particles of the same mass and charge were separated according to velocity In particular all particles with the same mass charge ratio e/m would arrive at the screen on a line which was a segment of a parabola The higher velocity ions were deflected the least Ions having different

e m ratio would form a different parabolic segment Thus the e/m ratio for an ion could l e determined by finding to which parabola it belonged In the case of neon several parabolic segments were observed This furnished the first direct observation of the presence of different isotopes of the same element for a nonradioactive material

The importance of the experiments with canal rays is far greater than this however The apparatus just discussed has formed the basis of most modern mass spectrometers Although such a spectrometer is vastly more complicated expensive and precise than Thomson s canal ray tube the idea of creating ions and deflecting them in electric and magnetic fields is basic Furthermore the ion source consisting of a discharge tube with the cathode canal has served as the basis for many ion sources constructed since then *See* ELECTRICAL CONDUCTION IN GASES, MASS SPECTROSCOPE

[G H MI]

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Canary

A European sparrow *Serinus canarius* originally native to the Canary Islands Madeira and the Azores but now found as a pet throughout the world There are numerous domestic strains which are commonly divided into two groups The German breeds are smaller and less colorful than the English strains but are more adept as singers Canaries vary widely in color but most commonly are yellow or some mixture with yellow



The canary *Serinus canarius* length to about 6 in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

The so-called wild canary in the United States is the common goldfinch *Spinus tristis* a yellow and black American sparrow *See* PASSERIFORMES

[J D B]

Cancer (biology)

The common term for malignant neoplasms or tumors Neoplasias are new growths which occur in some organ or tissue These can be roughly divided into benign and malignant forms although in certain cases the distinction is unclear

Cancer is probably of more significance to most people today than any other form of disease In the United States almost 250 000 persons die each year from cancer The death rate continually rises despite advances in diagnosis and treatment This is largely because of the increased longevity of the population more and more persons are living to the ages where certain cancers show their highest incidence Although some of this seeming increase in cancer occurrence is a result of better diagnosis and awareness on the part of the public there is an actual increase as well

Cancer may appear in tissues of mesenchymal origin that is bone muscle connective tissue and so forth in which case it is called a sarcoma Malignancy of epithelial origin such as skin mucosal lining and glandular tissue is designated as carcinoma

Malignant growths from different tissues usually display certain characteristic clinical and pathologic features which aid in their diagnosis Differences in the degree of malignancy are seen between cancers from various tissues and also in many case between those from the same organ of several individuals The major characteristics which are used to differentiate between benign and malignant growths are (1) malignancies often show an atypical structure (2) malignancies usually grow by expansion and also by infiltration so that encapsulation is absent (3) malignancies tend to show more rapid growth with the presence of more numerous and often abnormal mitotic figures (4) malignancies tend to grow progressively without self limitation and (5) malignancies tend to metastasize or spread to other structures by way of direct extension the blood stream or lymphatics and other means of dissemination *See* MITOSIS

Cancer incidence varies in regard to race geographic location sex age hereditary factors occupation socioeconomic status and many other factors The causes of human malignancy are unknown at present although contributing or predisposing conditions are well established in many cases In addition the multiplicity of types and grades of malignancy makes it improbable that a single factor or group of factors will be found which causes cancer Therefore in spite of the tremendous clinical and research efforts being made the rates of occurrence of most forms of malignancy will continue to increase unless a major breakthrough is made in therapy *See* ONCOLOGY [E C ST]

Cancer (constellation)

The Crab in astronomy a winter constellation and the faintest of the zodiacal groups Cancer the fourth sign of the Zodiac is important because

during early times it marked the northernmost limit of the ecliptic when the zodiacal system was adopted The Tropic of Cancer takes its name from this constellation The faint stars form a rough Y outline which is suggestive of a crab In the center of Cancer is a hazy object This is a magnificent cluster of faint stars called Praesepe (the Beehive) or the Manger *See* CONSTELLATION

[C S Y]

Cancrinite

A mineral tectosilicate belonging to the feldspathoid group and crystallizing in the hexagonal system The rare crystals are prismatic and have a perfect prismatic cleavage the mineral is usually in compact or disseminated masses The hardness is 5–6 on Mohs scale and the specific gravity is 2 45 The luster is pearly on the cleavages and the color is usually brownish yellow but may be reddish green white or colorless The composition is expressed by the formula $Na_7CaAl_3Si_3O_{12}CO_3(OH)_2$ but there is considerable variation with SO_4 substituting for CO Cancrinite occurs in nepheline syenites where it may be a primary mineral but more commonly it is formed by the alteration of nepheline It is found at Miask in the Ural Mountains in Finland Sweden and Ontario Canada and at Litchfield Maine *See* FELDSPATHOID NEPHELINE SYENITE SILICATE MINERALS

[C S HU]

Candidiasis

A fungus infection of man caused by a species of *Candida* usually *Candida albicans* The disease also called moniliasis is an infection of the mucous membranes skin lungs or viscera When the mucous membranes are affected the disease is known as thrush The causative organisms are yeasts and exist as saprophytes in the healthy individual Under certain conditions however they may become pathogenic Such infections are almost invariably secondary to some preexisting disease such as tuberculosis malignancy or diabetes The cutaneous form of candidiasis is seen on those areas of the skin where moisture and irritation are common Candidiasis has recently become a problem for some patients who have received certain antibiotics or steroids for long periods of time

Candida species grow well on most laboratory media but usually require certain biochemical studies for complete identification Although there is no satisfactory treatment for the disseminated form Mycostatin an antibiotic is useful in the treatment of lesions of the skin and mucous membranes *See* ANTIBIOTIC MONILIALES MYCOLOGY MEDICAL STEROID TUBERCULOSIS, YEAST

[L D H]

Candle

The unit of luminous intensity Originally the candle was the luminous intensity of a wax candle of standard specifications In 1909 this unit was superseded by the international candle which was established by agreement between the national standardizing laboratories of France Great Britain and the United States This international candle as used in the United States was a specified fraction of the average horizontal candlepower of a group of 45 carbon filament lamps preserved at the National Bureau of Standards when the lamps were operated at specified voltages

The international candle was replaced by a new unit that was agreed upon at the biennial meeting of the International Committee on Weights and Measures in 1937 but because of World War II was not actually adopted until 1948 This unit of luminous intensity is defined as $^1/_{60}$ of the luminous intensity per square centimeter of a blackbody radiator operating at the temperature of solidification of platinum The word candela has been given to this new unit by the International Commission on Illumination (C I E) but in American practice it is still known as the candle

This new unit can be reproduced from specifications and thus is used for a primary standard in photometry A secondary standard is a light source that is calibrated by comparison with the primary standard *See* LUMINOUS INTENSITY PHOTOMETRY

[R C P]

Candlepower

The luminous intensity expressed in candles It refers only to the intensity in a particular direction and by itself does not give an indication of the total light emitted The candlepower in a given direction from a light source is equal to the illumination in foot candles falling on a surface normal to that direction multiplied by the square of the distance from the light source in feet

The apparent candlepower is the candlepower of a point source which will produce the same illumination at a given distance as produced by a given light source

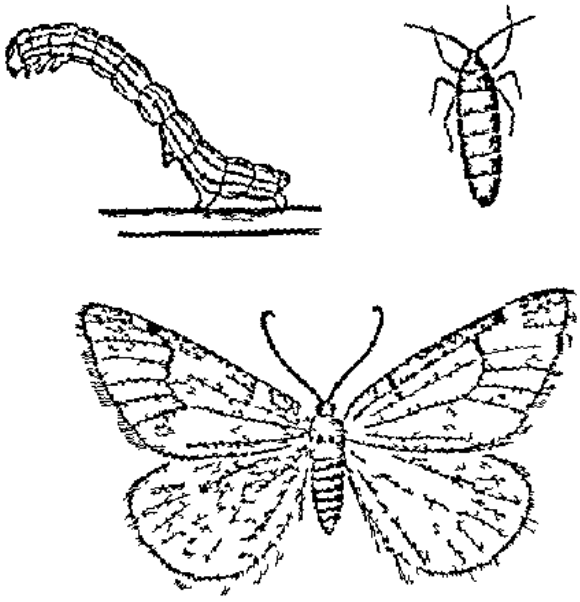
The mean horizontal candlepower is the average candlepower of a light source in the horizontal plane passing through the luminous center of the light source

The mean spherical candlepower is the average candlepower in all directions from a light source at a center Since there are 4π solid angles coming from a point the mean spherical candlepower is equal to the total luminous flux (lumens) of a light source divided by 4π *See* CANDLE LUMEN PHOTOMETRY

[R C P]

Cankerworm

Either of two common species of moths of the family Geometridae whose larvae do extensive damage to the foliage of deciduous trees The fall cankerworm *Alsophila pometaria* occurs over most of the northeastern and north central United States The adult male is a dull gray moth about 1¼ in across The female is dull gray and wingless Adults appear in the fall and produce eggs which hatch the following spring The spring cankerworm *Palaecrita vernata* is similar but smaller and paler in color Spring cankerworm



e fall cankerworm *Alsophila pometaria* wing span male 1–1½ in (*From E L Palmer Fieldbook of atural History* McGraw-Hill 1949)

cur over the eastern two-thirds of the United tates and Canada and in California They over inter as pupae emerging in the early spring The arvae of the fall species have three pairs of ab lominal prolegs the spring species only two airs Both are similar to other measuring worms f the family Geometridae in that the reduced number of prolegs causes them to move in the characteristic looping or measuring manner so well known *See* LEPIDOPTERA [J D B]

Canonical transformations

Transformations among the coordinates and momenta describing the state of a classical dynamical system which leave the canonical or Hamiltonian form of the equations of motion unchanged *See* HAMILTON'S EQUATIONS OF MOTION HAMILTON'S PRINCIPLE

General principles The equations of motion of the system are derivable from Hamilton's principle once the Lagrangian of the system is given Thus the statement

$$\Delta \int_{t_1}^{t_2} L[q(t)\ q(t)\ t]\ dt = 0 \qquad (1)$$

where Δ is the variation in the integral produced by a variation in the dependence of the q_i on t without varying the endpoints implies Lagrange's equations of motion and hence also Hamilton's equations of motion (*see* LAGRANGE'S EQUATIONS LAGRANGIAN FUNCTION) This statement can also be written as

$$\Delta \int_{t_1}^{t_2} \left(\sum_{i=1}^{f} p_i \dot{q}_i - H \right) dt = 0 \qquad (2)$$

where H is the Hamiltonian function The content of Hamilton's principle is not changed if a total time derivative is added to the Lagrangian since the variation of the integral of a total derivative vanishes identically Thus Eq (2) is equivalent to

$$\Delta \int_{t_1}^{t_2} \left[\sum_{i=1}^{f} p_i \dot{q}_i - H - \frac{d}{dt}\phi(q_1 \quad q_f\ q'_1 \quad q'_f\ t) \right] dt = 0 \qquad (3)$$

where ϕ is any differentiable function of the time and the old and new coordinates

Equation (3) can be written as

$$\Delta \int_{t_1}^{t_2} \left[\sum_{i=1}^{f} (p_i q_i) - H \right] dt \qquad (4)$$

provided that

$$d\phi = \sum_{i=1}^{f} (p\ dq_i - p_i\ dq_i) - (H - H')\ dt \qquad (5)$$

Now Eq (4) is of the same form as Eq (2) but contains only primed variables whereas Eq (2) contains only unprimed variables From (4) therefore follow all the consequences that follow from (2) or from (1) but expressed in primed variables The connection between the unprimed and the primed variables is given by Eq (5) or equivalently by

$$p_i = \frac{\partial \phi}{\partial q} \qquad p'_i = -\frac{\partial \phi}{\partial q_i}, \qquad H = H + \frac{\partial \phi}{\partial t} \qquad (6)$$

Equations (6) define a canonical transformation In order to obtain the transformation explicitly the first two sets of Eqs (6) must be solved for q' p in terms of q p t The quantity H must be expressed as a function of primed variables before can be used to get the equations of motion

The function $\phi(q\ q\ t)$ is called the generator the canonical transformation The variables appearing in ϕ are the old and new coordinates and the time The generator can be expressed as a function of any combination of old coordinates or momenta and of new coordinates or momenta Thus with

$$\psi(p\ q\ t) = \phi(q\ q\ t) - \sum_{i=1}^{f} p\ q_i$$

it follows from Eq (5) that

$$q = -\frac{\partial \psi}{\partial p_i} \qquad p_i = -\frac{\partial \psi}{\partial q_i} \qquad H = H + \frac{\partial \psi}{\partial t}$$

Similarly with

$$\psi\ (q\ p\ t) = \phi(q\ q\ t) + \sum_{i=1}^{f} p'_i q_i$$

and with

$$\phi\ (p\ p'\ t) = \phi(q\ q'\ t) + \sum_{i=1}^{f} (p'_i q'_i - p_i q_i)$$

There are thus four forms of generation for same canonical transformation

Canonical transformations constitute an Abel group the generator of the resultant of two successive canonical transformations is the sum of

generators of the separate transformations (*see* NUMBER THEORY) Thus, if

$$d\phi_1 = \sum_{j=1}^{f} (p_j\, dq_j - p'_j\, dq'_j) - (H - H')\, dt$$

and $$d\phi_2 = \sum_{j=1}^{f} (p'_j\, dq'_j - p''_j\, dq''_j) - (H' - H'')\, dt$$

it follows that

$$d(\phi_1 + \phi_2) = \sum_{j=1}^{f} (p_j\, dq_j - p''_j\, dq''_j) - (H - H'')\, dt$$

Applications Canonical transformations have a number of important applications of which the more important are briefly described in the remainder of this article

Hamilton Jacobi equation A time dependent canonical transformation changes the value of the Hamiltonian If the transformation is properly chosen the new Hamiltonian can be made to vanish rendering the equations of motion trivial A transformation which accomplishes this is generated by a complete integral of the equation

$$H\left(q, \frac{\partial \phi}{\partial q}, t\right) + \frac{\partial \phi}{\partial t} = 0 \qquad (9)$$

which comes from Eq (6) by setting $H' = 0$ Equation (9) is the Hamilton Jacobi equation A complete integral is a solution depending upon f constants in a nonadditive way *See* HAMILTON JACOBI THEORY

Infinitesimal canonical transformations If the new coordinates and momenta differ from the old only by small quantities, the transformation is called infinitesimal Such a transformation is most easily described by a generator of the form (7) with

$$\psi(p\, q'\, t) = -\sum_{j=1}^{f} p_j q'_j + \epsilon Y(q'\, p\, t) \qquad (10)$$

where ϵ is an infinitesimal parameter Since ϵ^2 is regarded as negligible this leads to

$$q_k = q'_k - \epsilon \frac{\partial X}{\partial p_k} \qquad p'_k = p_k - \epsilon \frac{\partial X}{\partial q'_k} \qquad (11)$$

It is immaterial in Eqs (11) whether X is regarded as a function of q' p t or of q p, t because X appears only in small terms, and q' differs from q by a small amount so that to first order in smallness there is no difference The quantity X is written now as $X(q\, p\, t)$ In this form it is a function of the state of the system and is therefore a dynamical variable

Let $q'_k - q_k = \delta q_k$, $p'_k - p_k = \delta p_k$ Then from Eqs (11)

$$\delta q_k = \epsilon \frac{\partial X}{\partial p_k} \qquad \delta p_k = -\epsilon \frac{\partial X}{\partial q_k} \qquad (12)$$

Thus if X is the z component of linear momentum of a particle, it generates an infinitesimal displacement in the z direction A component of angular momentum generates an infinitesimal rotation The Hamiltonian generates the changes corresponding to a time displacement, ϵ

If $Y(q\, p\, t)$ is a second dynamical variable the form of Y will change if its arguments are changed according to Eq (12) Let

$$Y'(q',p',t) = Y(q\, p,t) = Y(q',p',t) - \delta Y(q',p'\, t) \qquad (13)$$

Then

$$\delta Y = Y(q',p',t) - Y(q\, p,t) = \sum_{j=1}^{f} \left(+ \frac{\partial Y}{\partial q_j} \delta q_j + \frac{\partial Y}{\partial p_j} \delta p_j \right) = \sum_{j=1}^{f} \epsilon \left(\frac{\partial Y}{\partial q_j} \frac{\partial X}{\partial p_j} - \frac{\partial Y}{\partial p_j} \frac{\partial X}{\partial q_j} \right) = \epsilon(Y,X) \qquad (14)$$

Here (Y,X) is known as the Poisson bracket of two dynamical variables Y and X Clearly

$$(Y,X) = -(X,Y) \qquad (15)$$

If Y is the Hamiltonian H, then

$$(X,Y) = (X,H) = \sum_{j=1}^{f} \left(\frac{\partial Y}{\partial q_j} \frac{\partial H}{\partial p_j} - \frac{\partial Y}{\partial p_j} \frac{\partial H}{\partial q_j} \right) = \frac{dX}{dt} - \frac{\partial Y}{\partial t}$$

Let $\partial X/\partial t = 0$ Equation (14) now reads

$$\delta H = \epsilon(H,Y) = -\epsilon(X,H)$$

If the Hamiltonian is invariant under the infinitesimal canonical transformation generated by Y X is a constant of the motion This theorem connects the symmetry of a system directly with constants of motion

Quantum mechanics is related to classical mechanics by defining a quantum mechanical commutator as $ih/2\pi$ times the Poisson bracket of classically analogous dynamical variables Thus classically, the angular momentum components J_x etc, satisfy the relation

$$(J_x,J_y) = J_z$$

The corresponding operators in quantum mechanics do not commute, but satisfy

$$J_x J_y - J_y J_x = \frac{ih}{2\pi} J_z$$

See QUANTUM THEORY, NONRELATIVISTIC

Perturbation theory Let the Hamiltonian of a classical dynamical system be

$$H = H_0 + V$$

where H_0 is simple and V is small If $\phi_0(q$ is a complete integral of the Hamilton Jacobi equation

$$H_0\left(q, \frac{\partial \phi_0}{\partial q}, t\right) + \frac{\partial \phi_0}{\partial t} = 0$$

formed with H_0 and $\phi(q,q',t)$ is a complete integral of the Hamilton Jacobi equation with H, then

$$\phi = \phi_0 + \phi_1$$

where ϕ_1 is small

The exact Hamilton Jacobi equation may be expanded in powers of ϕ_1 and in the first approximation only linear terms in ϕ_1 and V retained

$$H_0\left(q\frac{\partial\phi}{\partial q},t\right)+V\left(q\frac{\partial\phi}{\partial q},t\right)$$
$$=H_0\left(q\frac{\partial\phi_0}{\partial q},t\right)+\left(\frac{\partial H_0}{\partial p}\right)_0\left(\frac{\partial\phi_1}{\partial q}\right)_0+V\left(q\frac{\partial\phi_0}{\partial q},t\right)$$
$$=-\frac{\partial\phi_0}{\partial t}-\frac{\partial\phi_1}{\partial t} \qquad (20)$$

From Eq (18) and using Hamilton's equations of motion

$$\left(\frac{\partial\phi_1}{\partial q}\right)_0\dot{q}_0+\frac{\partial\phi_1}{\partial t}=-V\left(q\frac{\partial\phi_0}{\partial q},t\right) \qquad (21)$$

The left side of Eq (21) is the total time derivative of ϕ_1 calculated on the unperturbed trajectory To first order

$$\phi_1=-\int_{C_0}V\left(q\frac{\partial\phi_0}{\partial q},t\right)dt \qquad (22)$$

with the integral taken along the unperturbed trajectory Then ϕ given by Eq (19) is the generator of the canonical transformation correct to first order in V or is the first approximation to the solution of the exact Hamilton Jacobi equation *See* PERTURBATION (MATHEMATICS) PERTURBATION (QUANTUM MECHANICS) [P M S]

Bibliography *See* LAGRANGE'S EQUATIONS

Cantaloupe

A name referring in America to a small to medium sized round to oval distinctly netted highly perishable muskmelon *Cucumis melo* of the plant order Campanulales The name cantaloupe evidently associated with the variety name *cantalupensis* originated by C. Naudin is a misnomer Naudin's designation referred to the rock melons of France which have hard rinds and no netting but scaly or warty surfaces, they are not grown in America Often loosely used in reference to any variety of muskmelon the name cantaloupe applies to those melons which weigh 2–4 lb are round to oval heavily netted with or without sutures show distinct separation of the fruit from the stem at maturity and have flesh that is sweet and of very distinct aroma and flavor Cantaloupe growing is commercially important in about 25 states of the United States However California Texas Arizona and Colorado produce about 80% of the total The average annual farm value in the United States for the period 1949–1957 was about $43 000 000 *See* CAMPANULALES MELON GROWING MUSKMELON [V R B]



Cantaloupe *Cucumis melo* fruits nearing maturity

Cantilever

A beam or truss supported at one end only or a section of a beam or truss overhanging a support The biggest cantilevers are in bridges, but some spectacular examples in both concrete and steel have been used to roof hangars Extending in one or both directions in the range of 120–160 ft from a central supporting section they permit unobstructed entry to planes through the open sides. Rolling doors may provide closure for the building

A common purely structural use of cantilevers in buildings is in so-called suspended beam framing Alternate beams in a line of beams running across several bays cantilever a fraction of a span beyond their supports The overhanging ends support shorter beams Required cross sections are reduced by the structural continuity of the overhanging beams over the supports and by the shorter spans of the suspended beams

Some designers use cantilevers to avoid columns in exterior walls of buildings From columns set back in the interior floor and roof beams cantilever to the exterior and support the walls which are often of lightweight materials

Cantilevers are used in many special cases where they appeal esthetically to the designer or where it is not convenient or possible to support both ends of a member Vertical members such as towers poles or entire buildings are often considered cantilevers for structural purposes in designing against wind or other lateral loads *See* BRIDGE ROOF CONSTRUCTION

Canvas

A fabric woven from hemp flax jute or cotton In its stronger coarser forms canvas is used for tents awnings sails webbing and belting sport shoes and luggage When waterproofed by tarring canvas can be made into tarpaulins for protecting materials Finer grades are used as tapestry and embroidery bases (art canvas) and for painting in oils (artist's canvas) Cotton flax and jute are used widely in art canvas flax being the usual fiber for artist's canvas and hemp or jute for the rougher sturdier canvases Canvas duck is a lightweight cotton or linen cloth used in making trousers although the term is occasionally used for heavier canvases as well *See* COTTON FLAX, HEMP JUTE. [C C6]

apacitance

he ratio of the charge q on one of the plates of capacitor (there being an equal and opposite harge on the other plate) to the potential differ nce v between the plates that is capacitance formerly called capacity) is $C = q/v$

In general a capacitor often called a con denser consists of two metal plates insulated from each other by a dielectric The capacitance of a capacitor depends on the geometry of the plates and the kind of dielectric used since these factors determine the charge which can be put on the plates by a unit potential difference existing between the plates

For a capacitor of fixed geometry and with con stant properties of the dielectric between its plates C is a constant independent of q or v since as v changes q changes with it in the same proportion This statement assumes that the di electric strength is not exceeded and thus that dielectric breakdown does not occur (If it does occur the device is no longer a capacitor) If either the geometry or dielectric properties or both of a capacitor change with time C will change with time

In an ideal capacitor no conduction current flows between the plates A real capacitor of good quality is the circuit equivalent of an ideal ca pacitor with a very high resistance in parallel or in alternating current (ac) circuits of an ideal capacitor with a low resistance in series

Properties of capacitors One classification sys tem for capacitors follows from the physical state of their dielectrics For a discussion based on this classification *see* CAPACITOR

Charging and discharging These processes can occur for capacitors while the potential difference across the capacitor is changing if C is fixed that is q increases if v increases and q decreases if v decreases If C and v both change with time the rate of change of q with time is given by

$$\frac{dq}{dt} = C\frac{dv}{dt} + v\frac{dC}{dt} \qquad (1)$$

Since the current i flowing in the wires leading to the capacitor plates is equal to dq/dt Eq (1) *gives i in the wires In many cases C is constant so $i = C\,dv/dt$*

Energy of charged capacitor This energy W_c is given by the formula $W_c = vq/2$ and is equal to the work the source must do in placing the charge on the capacitor It is in turn the work the capacitor will do when it discharges

Geometrical types The geometry of a capacitor may take any one of several forms The most com mon type is the parallel plate capacitor whose capacitance C in farads is given in the ideal case by

$$C = \frac{A k \epsilon_0}{d} \qquad (2)$$

where A is the area in square meters of one of the plates d is the distance in meters between the plates ϵ_0 is the permittivity of empty space with the numerical value 8.85×10^{-12} coul/ newton m^2, and k is the relative dielectric con stant of the dielectric between the plates The value of k is unity for empty space and almost unity for gases For other dielectrics k ranges in value from one to several hundred (*see* DIELEC TRICS, DIELECTRIC CONSTANT) In order that Eq (2) shall give a good value of C for an actual capacitor, d must be very small compared to the linear dimensions of either plate

Each plate of a parallel plate capacitor may be made up of many thin sheets of metal connected electrically with a corresponding number of thin sheets of metal making up the other plate The sheets of metal and their intervening layers of di electric are chosen and stacked in such a way that A will be large and d small without making the whole capacitor too bulky The result is ap preciable capacitance in a reasonable volume

The spherical capacitor is made of two concen tric metal spheres with a dielectric of relative dielectric constant k filling the space between the plates The capacitance in farads of such a ca pacitor is given by

$$C = 4\pi k \epsilon_0 \frac{r_1 r_2}{r_2 - r_1} \qquad (3)$$

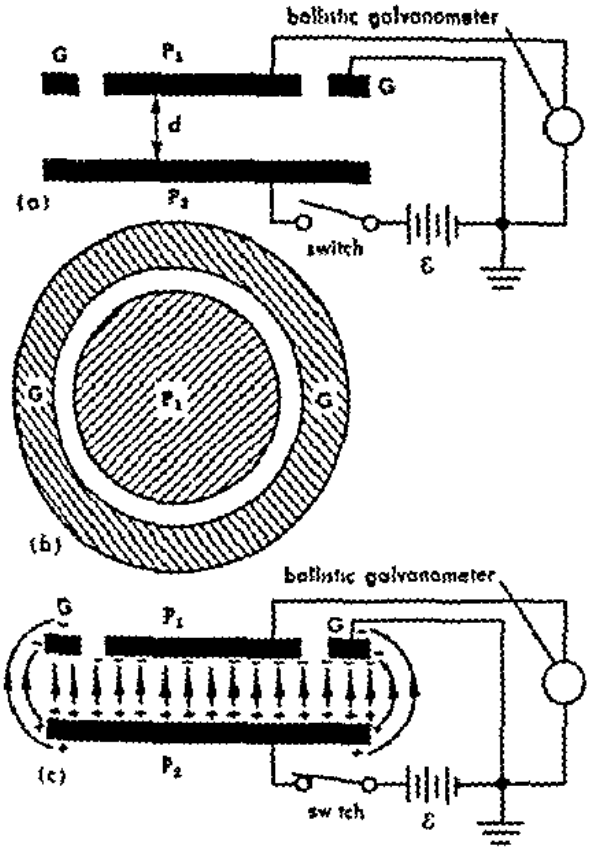
where r_2 is the radius in meters of the outer sphere and r_1 that of the inner sphere

The cylindrical capacitor as the name implies, is made of two concentric metal cylinders each of length l in meters with a dielectric filling the space between the cylinders If r_2 and r_1 are the radii in meters of the outer and inner cylinders respec tively and l is very large compared to $r_2 - r_1$ the capacitance C in farads is given by

$$C = \frac{2\pi k \epsilon_0 l}{\ln (r_2/r_1)} \qquad (4)$$

where k is the relative dielectric constant of the dielectric and $\ln (r_2/r_1)$ indicates the natural logarithm of the ratio r_2/r_1

Guard ring This is often used with a standard parallel plate capacitor as shown in the diagram in order that Eq (2) shall more accurately rep resent its capacitance It is the fringing of the electric lines of force which makes Eq (2) in accurate for an actual capacitor and as shown in the figure the fringing is nearly all at the outside edge of the guard ring and thus is not associated with the charge Q which is put onto plate P_2 while the capacitor is being charged It is the charge Q that determines the deflection of the ballistic galvanometer during the charging process Then Eq (2) gives the correct value of C that is needed to relate Q to the potential difference $\mathcal{E}$ across the plates by the equation $Q = C\mathcal{E}$ Thus with C known from Eq (2) and $\mathcal{E}$ known from a potentiometer measurement Q may be computed and the ballistic galvanometer calibrated This is



Parallel plate capacitor P_1, P_2 with guard ring GG. The spacing between guard ring and plate is grossly exaggerated. (a) Cross section with all parts of capacitor at ground potential. (b) Top view showing plate P_1 surrounded by guard ring. (c) Cross section of capacitor after it has been charged from the battery whose electromotive force is $\mathcal{E}$.

lustrates one use of a standard capacitor with a guard ring.

Body capacitance When a part of the human body, say the hand, is brought near a high impedance network, the body serves as one plate of a capacitor and the adjacent part of the network as the other plate. This situation is the equivalent of a capacitor of very low capacitance in parallel between that part of the network and ground, since the human body can usually be considered as being a grounded conductor. This capacitance is known as body capacitance and enters as a part of the distributed capacitance of the network. A high impedance network must be well shielded in order to eliminate the variable and undesirable effects of body capacitance.

[R P W]

Bibliography: R. P. Winch, *Electricity and Magnetism*, 1955.

Capacitance box

An assembly of capacitors and switches which permits adjustment of the capacitance existing at the terminals in nominally uniform steps from a minimum value near zero to the maximum which exists when all the capacitors are connected in parallel. Several arrangements are possible, the most common are those in which each decade consists of four capacitors in the ratios 1, 2, 2, 5 or 1, 2, 3, 4. The switch connects successively the combinations of these four capacitors necessary to provide increasing capacitance at the terminals in uniform steps. The term capacitance decade box is sometimes used. *See* CAPACITANCE MEASUREMENT.

[F R K]

Capacitance measurement

In a multiconductor system the capacitances between each of the conductors may be defined. In general these capacitances are functions of the *total geometry*, that is, the location of each and every conducting and dielectric body. When as is usually true one is interested in the capacitance between two conductors only, the presence of other conductors is an undesirable complication. It is then customary to distinguish between two terminal and three terminal capacitors and capacitance measurements. In the case of a two terminal capacitor either one of the conductors of primary interest essentially surrounds the other, in which case the capacitance between them is independent of the location of other bodies except in the vicinity of the terminals, or one accepts the somewhat indefinite contributions of the other conductors to the capacitance of interest.

A three terminal capacitor consists of two active electrodes surrounded by a third or shield conductor. The direct capacitance between the two active electrodes is the capacitance of interest and when shielded leads are used it is independent of the location of all other conductors except the shield. Only certain of the methods described are suitable for the measurement of three-terminal capacitors.

Every physically realizable capacitor has associated loss in the dielectric and in the metal electrodes. At a single frequency these are indistinguishable and the capacitor may be represented by either a parallel or series combination of pure capacitance and pure resistance. The measurement of capacitance then in general involves the simultaneous measurement of or allowance for an associated resistive element.

Most capacitance measurements involve simply a comparison of the capacitor to be measured with a capacitor of known value. Methods which permit comparison of essentially equal capacitors by simple substitution of one for the other at the same point in a circuit are frequently possible and almost always preferable.

Resonance method This method is suitable for two terminal capacitance measurements when only moderate accuracy is required. The resonance method involves resonating an inductor with a calibrated variable capacitor which has a range of variation larger than the value of any capacitor to be measured. The parallel or series LC circuit is tuned to resonance by adjustment of the variable capacitor. The capacitor to be measured is then connected in parallel with the variable unit and the

latter readjusted until resonance at the same frequency is again achieved The value of the capacitor being measured is equal to the change in the variable capacitance standard

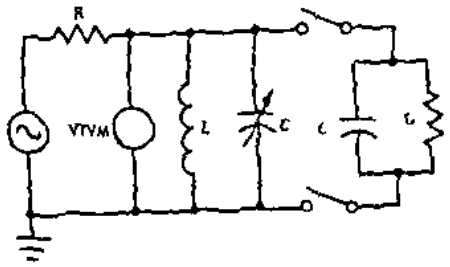


Fig 1 Susceptance variation method

A variety of techniques is available for determining when the resonance condition is achieved some using series and some parallel resonance but they differ significantly only in the way in which the source and detector are connected

Susceptance variation This method is a resonance technique capable of yielding both the effective parallel capacitance and conductance components of a capacitor (see Fig 1) The calibrated variable capacitor C is first adjusted to the value C_1 for which the vacuum tube voltmeter (VTVM) indicates a maximum V_m C is then increased to a new value C_2 for which the VTVM reads $V_m/\sqrt{2}$ Simple network theory shows that the equivalent parallel conductance of the LC network is given by

$$G_{eq} = \omega(C_2 - C_1)$$

If now the capacitor to be measured represented by the parallel combination C_x and G is connected across C and the process repeated yielding values C_1 and G_{eq} then

$$C_x = C_1 - C_1$$

and

$$G_x = G_{eq} - G_{eq}$$

Alternate resonance techniques include use of a parallel LC circuit as the frequency determining element in an oscillator or as one arm of a Wheatstone bridge whose other three arms are resistors In the latter case balance of the bridge defines the resonant condition and also provides a measure of the equivalent resistive component

Bridge methods When high accuracies are required bridge methods must be adopted See BRIDGE CIRCUIT, WHEATSTONE BRIDGE.

Resistance ratio bridges These are Wheatstone bridge configurations in which two adjacent arms are resistors as indicated in Fig 2 Application of the generalized Wheatstone bridge equation

$$Z_1Z_x = Z_2Z_s \quad \text{or} \quad Y_1Y_x = Y_2Y_s$$

leads to

$$C_x = C_s\frac{R_1}{R_2} \qquad G_x = G_s\frac{R_1}{R_2}$$

for the parallel arrangement and to

$$C_x = C_s\frac{R_1}{R_2} \qquad R_x = R_s\frac{R_2}{R_1}$$

for the series arrangement These are the conditions for bridge balance as indicated by zero voltage across the detector terminals

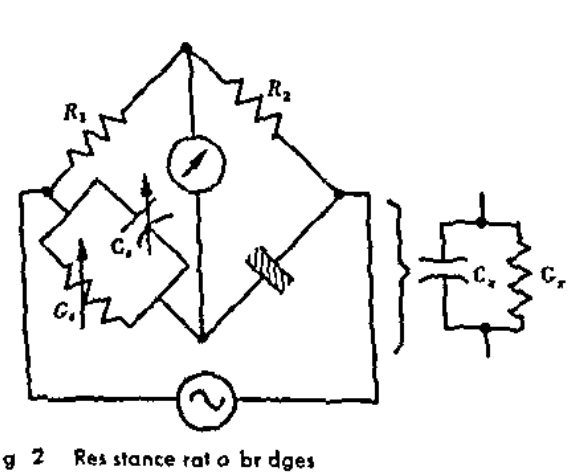
Schering bridge This bridge yields a measurement of the equivalent series circuit representation of a capacitor (see Fig 3) The equations of balance are

$$C_x = C_s\frac{R_1}{R_2} \qquad R_x = R_2\frac{C_1}{C_s}$$

The arrangement shown is used when it is desirable for high voltages to be applied to the capacitor under test The relative impedances are usually such that most of the applied voltage appears across the capacitors and if balance is effected by varying C_1 and R_1 or R_2 the operator need not approach the high voltage elements

In general with a given applied voltage higher sensitivity is obtained if the source and detector connections are interchanged this so-called conjugate bridge is more frequently used for measurements of high precision Because variable capacitors are less subject to errors from associated residuals than variable resistors balance is then usually effected by varying C_s and C_1 the standard capacitor C_s is assumed to be free from loss

Wagner branch The resistance ratio and Schering bridges shown in Fig 4 are useful for two-ter



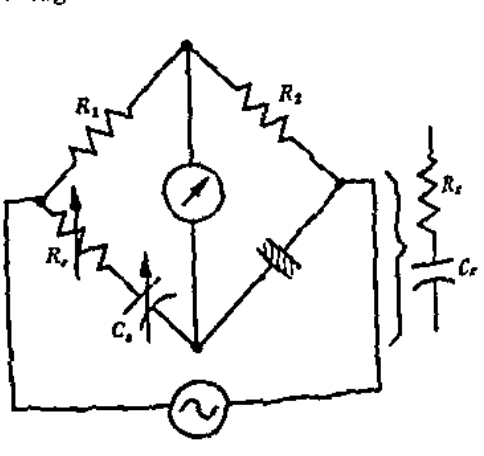


Fig 2 Resistance ratio bridges

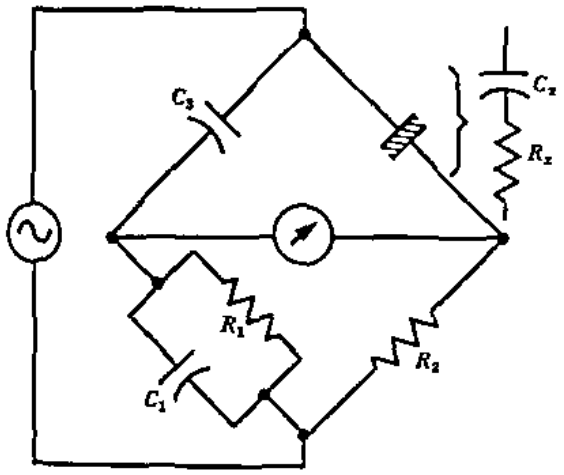


Fig 3 The Schering bridge

minal capacitance measurements Their use may be extended to three terminal measurements and extended in accuracy and range by the introduction of shielding and the addition of the Wagner branch

Balance is effected alternately by adjustment of the main bridge arms with the switch open and by adjustment of the Wagner branch elements with the switch closed The final balance may be considered to be that with the switch open and capacitances to ground at both the A and C corners of the bridge shunt the Wagner arms and do not affect the balance of the main bridge Capacitances to ground at the B and D corners carry no current at balance and therefore cannot introduce error

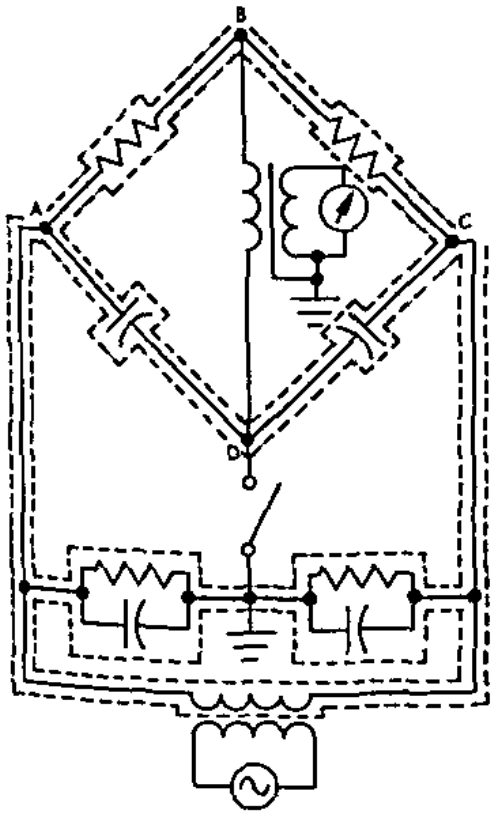


Fig 4 Shielded resistance ratio-arm bridge with Wagner branch

Transformer ratio bridges These are particularly suitable for three terminal capacitance measurements Of the variety of inductive and transformer ratio arm bridges that have been developed the one shown in Fig 5 seems most suitable for capacitance measurements of high accuracy

Capacitance to ground from b reduces sensitivity but does not affect the condition of balance Capacitances to ground from a and c introduce loads on the transformer secondaries but with proper transformer design the errors introduced may be kept negligible

Audio-frequency three-winding transformers with secondary open circuit voltage ratios equal to the turns ratios within 10 parts in 1 000 000 are quite readily constructed With care in design 1 1 and 10 1 transformers with ratio errors of the order of 1 part in 10^7 are entirely feasible The secondary

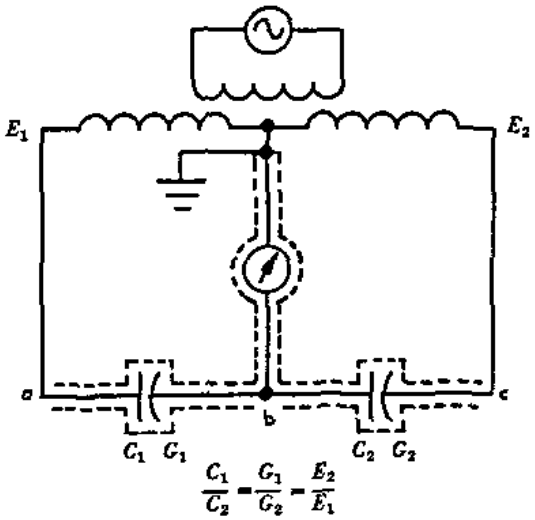


Fig 5 Transformer ratio bridge

winding resistances and leakage inductances under conditions of use introduce departures from the open circuit voltage ratio and therefore this bridge circuit is most useful for the measurement of capacitors less than 1 μf at audio frequencies Transformer design for radio frequency use is more difficult However the bridge circuit is used with reduced accuracy at capacitance levels of the order of 100 $\mu\mu$f and below at frequencies up to 10 Mc

Bridged T and parallel T networks These complex bridges possess a significant advantage over four arm bridges for medium accuracy radio frequency measurements of capacitance the source and detector have a common point of connection which may be grounded (Fig 6)

Use of the Y delta network transformation permits reduction of either the bridged T or the parallel T to the equivalent circuit shown Balance or null indication of the detector, is achieved by variation of the network components until the equivalent impedance Z_e is infinite In the application of the parallel T network to capacitance measurements as shown in Fig 7 two balances are required, one with and the other without the unknown

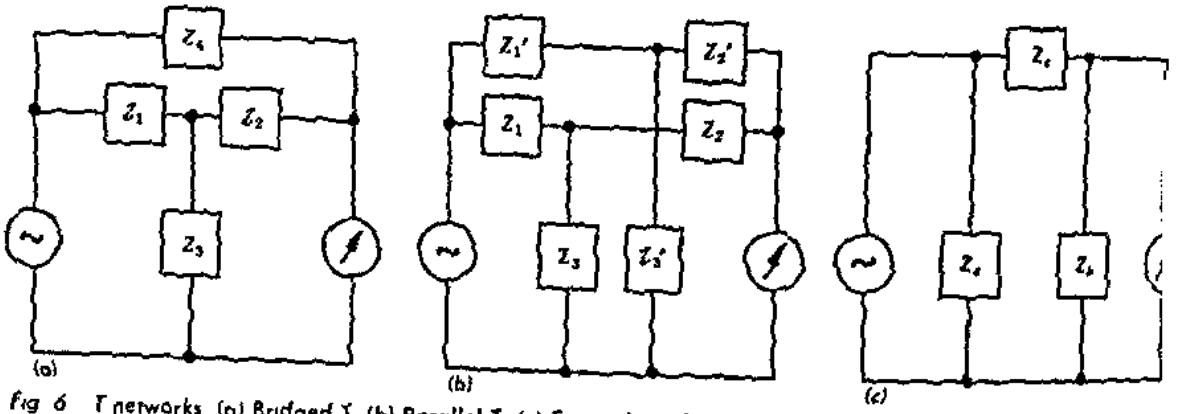


Fig 6 T networks (a) Bridged T (b) Parallel T (c) Equivalent circuit

The equivalent parallel components of the unknown admittance are obtained by adjusting the variable

suddenly applied to the series combination of a resistor and an initially discharged capacitor the charge and the voltage on the capacitor increase exponentially toward their full magnitudes with a time constant equal in seconds to the product of the resistance in ohms and the capacitance in farads Similarly when a charged capacitor is discharged through a resistor the charge and the voltage decay with the same time constant (*see* TIME CONSTANT) Various methods are available for the measurement of capacitance by measurement of the time constant of charge or discharge through a known resistor

Ballistic galvanometer method This method (Fig 8) compares the charge lost by the capacitor in a known time interval to the total charge With the capacitor completely discharged the switch is closed and the product of the galvanometer deflection and the multiplying factor of the shunt is proportional to the total charge Q_T The switch is opened for a measured time interval Δt and again closed The product of the galvanometer deflection and the shunt factor is then proportional to the charge Q_0 lost by the capacitor Because

$$Q_T - Q_0 = Q_T e^{-\Delta t/RC}$$

then

$$C = \frac{-\Delta t}{R \ln [(Q_T - Q_0)/Q_T]}$$

Integrating operational amplifier In this method the time required for the output voltage of an amplifier to increase to a value equal to the step function input voltage is determined by an electronic voltage-comparison circuit and timer (Fig 9) With the assumption of ideal characteristics for the amplifier such as infinite gain without feedback infinite input impedance and zero output impedance the measured time interval is equal to the product of the values of the known resistance and the capacitance being measured

Distributed capacitance An inductor is a particularly impure circuit component In addition to the series resistance of the winding, distributed capacitance is always present from turn to turn and layer to layer, making the effective inductance a function of frequency It is customary to assume that the effect of the distributed capacitance in an inductance coil may be represented by a single capacitor connected between the coil terminal In some cases the value of this equivalent capacitor may be obtained by a determination of the self resonant frequency of the coil, however, as a result of the distributed nature of both the inductance and the capacitance the coil may exhibit several resonance modes and a self resonance determination is then ambiguous

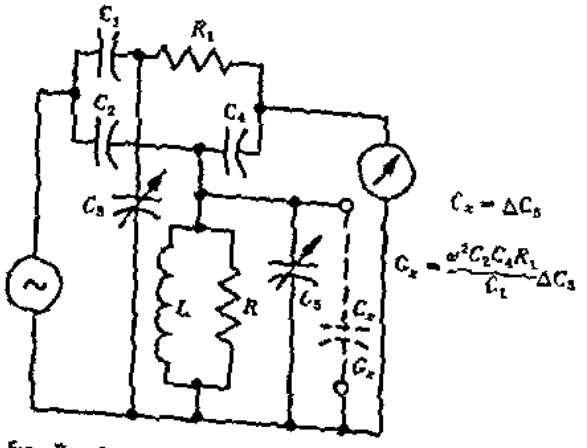


Fig 7 Parallel T network to measure capacitance

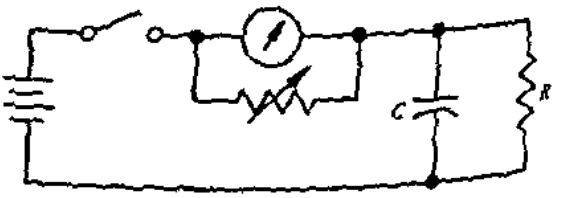


Fig 8 Ballistic galvanometer method

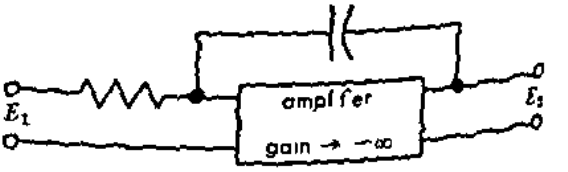


Fig 9 Integrating operational amplifier

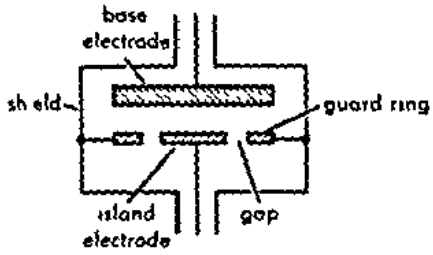


Fig 10 Kelvin guard-ring capacitor

A procedure that usually surmounts this difficulty is that of determining the resonant frequency for several settings of a variable capacitor connected in parallel with the coil A plot of the capacitance of the observed auxiliary capacitor against the reciprocal of the square of the corresponding resonant frequency and extrapolated to infinite frequency then gives a value for the lumped equivalent of the distributed capacitance

Capacitance standards These are high quality stable capacitors of known capacitance against which other capacitors may be compared A computable capacitance standard is a capacitor of such design and construction that its capacitance can be calculated from measured dimensions Simple geometries such as concentric spheres parallel circular plates and coaxial circular cylinders have been used successfully With the two latter types guard sections (which make the capacitors three terminal) are required to define the edge effects sufficiently well for precise calculation In the Kelvin guard ring capacitor the island electrode is insulated from the guard ring by a very narrow gap (Fig 10) If for purposes of calculation the guard ring and island are assumed to be at the same potential which is different from that of the base the field is everywhere normal to the plates except in the immediate vicinity of the gap It may be shown that to a first-order approximation the existence of a narrow gap increases the effective diameter of the island electrode by the width of the gap If A is the effective area d the plate separation and ϵ the permittivity of the dielectric the capacitance in rationalized mks units, is $C = \epsilon A/d$

The design of the Thompson Lampard cylindrical cross-capacitor is such that the capacitance may be calculated from one length measurement only One form consists of four insulated circularly cylindrical bars in a suitable shield (Fig 11) Bar a has end sections insulated from the central section The direct capacitance between bar b and the central section of bar a is a function only of the length L of that central section and has the value in rationalized mks units

$$C = \frac{\epsilon \ln 2}{\pi} L$$

Laboratory capacitance standards of the order of 0 001 μf and lower in nominal value are usually parallel plate air dielectric capacitors Capacitors from 0 001 to 1 μf in value are usually mica dielectric The common construction is a stack of flat parallel conductors separated by thin mica sheets The conducting plates may be evaporated films of silver on the faces of the mica sheets or sheets of metal foil clamped between the mica sheets

[F R K]

Bibliography B Hague *Alternating Current Bridge Methods* 5th ed 1957 F K Harris *Electrical Measurements* 1952 L Hartshorn *Radio Frequency Measurements by Bridge and Resonance Methods* 1947 M C McGregor J F Hersh et al New apparatus at National Bureau of Standards for absolute capacitance measurement *IRE Trans on Instrumentation* 1-7 253-261, 1958 M Wind (ed) *Handbook of Electronic Measurement* 2 vols 1956

Capacitor

A device for introducing capacitance into a circuit In general a capacitor consists of two metal plates insulated from each other by a dielectric The capacitance of a capacitor depends primarily upon the shape and size of the capacitor and upon the relative dielectric constant of the medium between the plates In vacuum and approximately so in air and most gases, k the dielectric constant is unity For other dielectrics k ranges from one to several hundred *See* CAPACITANCE DIELECTRIC CONSTANT

Classification One classification of capacitors comes from the physical state of their dielectrics The dielectric may be a gas (or vacuum) a liquid a solid or a combination of these Each of these classifications may be subdivided according to the specific dielectric used Capacitors are also classified as fixed adjustable or variable

Fixed capacitors The capacitance of fixed capacitors remains unchanged except for small variations (caused by temperature fluctuations or vibration for example)

Adjustable capacitors The capacitance of adjustable capacitors may be set at any one of several discrete values

Variable capacitors The capacitance of variable capacitors may be adjusted continuously and set at any value between minimum and maximum limits fixed by construction

Trimmer capacitors These are relatively small variable capacitors used in parallel with larger variable or fixed capacitors to permit exact adju t

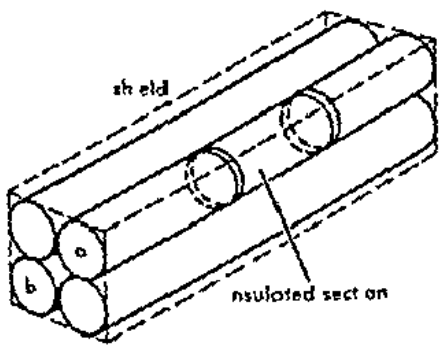


Fig 11 Thompson Lampard capac tor

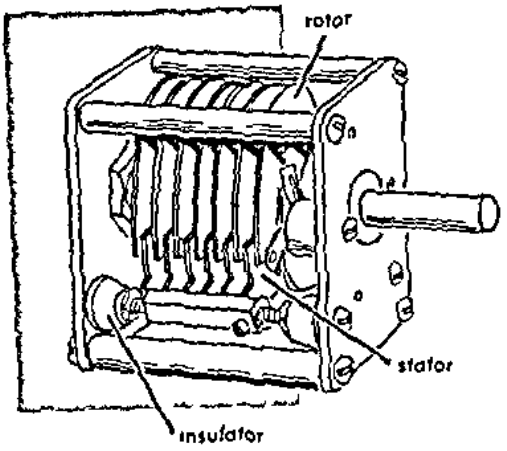


Fig 1 Variable air capacitor

ment of the capacitance of the parallel combination

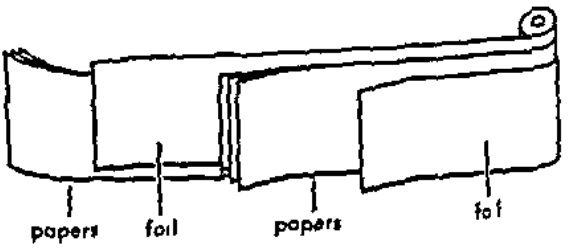
Air, gas, and vacuum capacitors. Made in both the fixed and variable types these are constructed with flat parallel metallic plates (or cylindrical concentric metallic plates) with air gas or vacuum as the dielectric between plates Alternate plates are connected together, and one set, or sometimes both is supported by means of a solid insulating material such as glass quartz, ceramic, or plastic Figure 1 shows a common type of variable air capacitor Gas capacitors are similarly built but are enclosed in a leakproof case If the gas capacitor is variable, the shaft supporting the movable plates or rotor is brought out through a pressure tight insulated seal Vacuum capacitors are of concentric cylindrical construction, enclosed in highly evacuated glass envelopes

The purpose of a high vacuum, or a gas under pressure is to increase the voltage breakdown value for a given plate spacing For high voltage applications when increasing the spacing between

used in high frequency circuits Fixed and variable air capacitors of special design are used as standards in electrical measurements

Solid dielectric capacitors. These use one of several dielectrics such as a ceramic, mica, glass or plastic film Alternate plates of metal or metallic foil, are stacked with the dielectric, or the dielectric may be metal plated on both sides The dielectric of the ceramic capacitor is a mixture of titanium oxide with other titanates The dielectric constant may range from about 6 to several hundred, depending upon the composition of the mixture Ceramic capacitors have a high capacitance to volume or mass ratio and a stable temperature capacitance characteristic, but are adversely affected by vibration, aging and overvoltage

Mica capacitors. These use thin rectangular sheets of mica as the dielectric The dielectric constant of mica is in the range of 6–8 The electrodes are either thin sheets of metal foil stacked alternately with the mica sheets or thin deposits of silver applied directly to the surface of the mica sheets Mica capacitors are used chiefly in radio-



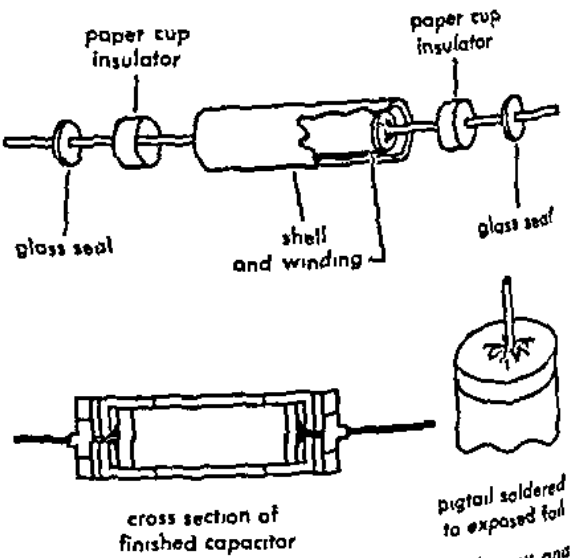


Fig 3 Extended foil paper capacitor (K Henney and C Walsh, eds, Electronic Components Handbook McGraw Hill, 1957)

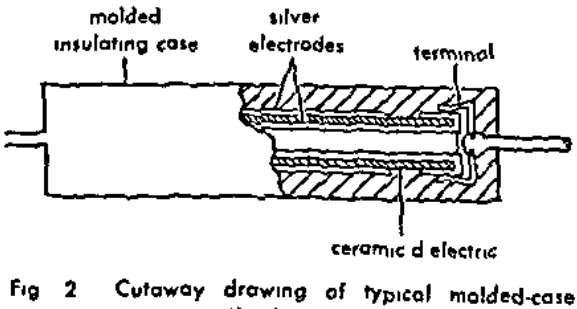
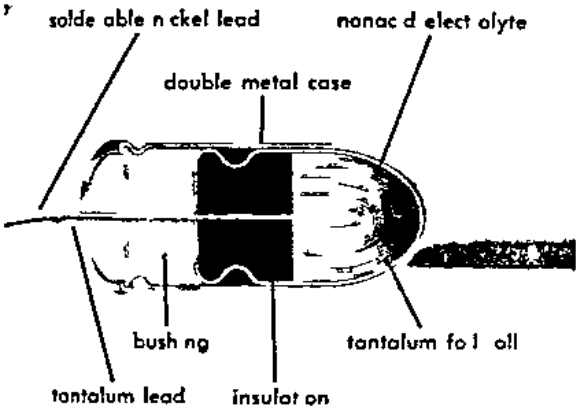


Fig 2 Cutaway drawing of typical molded-case ceramic capacitor (K Henney and C Walsh, eds, Electronic Components Handbook McGraw Hill, 1957)

frequency applications They have a low dielectric loss at very high frequencies good temperature frequency, and aging characteristics and low power factor, but have a low capacitance to volume or mass ratio They are made with dc voltage ratings from a few hundred to many thousand volts and with radio frequency current ratings up to about 50 amperes

Plastic film capacitors. These use dielectrics such as polystyrene or mylar with dielectric constants in the range of 2–6 These plastics may be used alone or as a laminate with paper Construc-



F g 4 Tantalum electrolytic capac tor (*General Elec tr c Company*)

tion is similar to paper capacitors These capaci tors are used for dc voltages up to about 2000 volts and where very low dc leakage current is required

Paper capacitors A dielectric of kraft paper usually impregnated with mineral oil chlorinated naphthalene or chlorinated diphenyl is used in pa per capacitors Both paper and plastic film capaci tors are constructed by stacking or forming into a roll alternate layers of foil and the dielectric Pa per capacitors have low cost per unit capacitance and moderate capacitance to volume ratio but are pervious to moisture unless hermetically sealed and change capacitance with temperature

Liquid-dielectric capacitors The plate as semblies of these are mounted in a tank filled with a suitable oil or liquid dielectric. External connec tion is through insulators or bushings and provi sion is made for expansion and contraction of the liquid during temperature changes They have high capacity and low losses

Electrolytic capacitors A large capacitance to volume ratio and a low cost per microforad of capacitance are chief advantages of electrolytic capac tors These use aluminum or tantalum plates on which an oxide film forms and acts as the d electric The characteristics of the oxide film de- pend on the polarity of the applied voltage Such a device is said to be polarized

Polarized electrolytic capacitors must be con nected to the circuit correctly They can be used only in circuits in which the dc component of voltage across the capacitor exceeds the crest value of the ac ripple

Nonpolarized electrolytic capacitors can be con structed for use in ac circuits In effect they are two polarized capacitors placed in series with their polarities reversed Nonpolarized capacitors have only one-half the capacitance of polarized capaci tors for a given dc voltage and foil area

Two important types of electrolytic capacitors are (1) the dry type aluminum oxide film and (2) the solid electrolyte tantalum capacitor Type (1) is used widely as a filter and bypass capacitor in rad o and television rece vers other electronic devices, and instruments Type (2) is useful over a fairly wide range of temperature is not affected by idleness as is type (1) can withstand vibration and shock and affords greater capacitance for a given volume Its maximum voltage rating is low but it has application in electronic circuits with low voltage devices such as transistors

[BLR WSP]

Bibliography K. Henney and C. Walsh (eds) *Electronic Components Handbook* 1957 A E Knowlton (ed) *Standard Handbook for Electrical Engineers* 9th ed 1957

Capillary (anatomical)

The smallest vessel of either the cardiovascular or lymphatic system The cap llary wall is composed of a single layer of flat endothelial cells The in side diameter of a capillary is about 8 μ which varies in different tissues and organs Extensive capillary beds result from the anastomoses of branching capillaries These capillary networks are denser and more extensive in those tissues in which there is a high metabolic activity

Capillaries represent the functional unit of the circulatory systems where passage of materials to and from the vessels occurs under the influence of osmosis diffusion hydrostatic pressure and other factors which alter permeability or rate of flow

Normally most capillaries in a given region re- main closed or open only sporadically In fact if all the capillaries in the body were to open at one time circulatory collapse would quickly follow *See* CIRCULATORY SYSTEM [E G ST]

Caprellidea

An arthropod suborder of the Amphipoda These crustaceans are restricted to marine and brackish water and are unknown as fossils Two families the Caprellidae or skeleton shrimps and Cyamidae or whale lice comprise this suborder

Caprellids and cyamids are strikingly different The former are relat vely slender with approxi mately cylindrical bodies the latter stubby and dorsoventrally compressed Both groups differ from other amphipods such as the Gammaridea and Hyperiidea in having a vestigial abdomen whose appendages are reduced to tiny stumps and lappets or are even entirely lost

Caprellidae Caprellids are the marine analogs of the terrestrial praying mantids The smallest

tertidal zones Some species occur at abyssal depths

In the typical caprellid stance the terminal two or three pairs of thoracic appendages grasp the substrate The more anterior part of the body rears up and the two pairs of clawed appendages or gnathopods are outstretched The remaining ap- pendages are not equally robust in caprellids At best the first two or three after the second gna thopods are more slender than the remaining ones A remarkable series which shows reduction of

these appendages occurs The two or three anterior pairs may be small stumps but in *Caprella* a genus of over a hundred described species which contains almost half of the known suborder appendages are completely lacking on the first two postgnathopod segments This is followed by three well developed pairs adapted for clinging Caprellids move on surfaces like inchworms and swim poorly

Caprellids eat ambient micrometazoa and protists which are caught with their gnathopods and may graze on sessile substrate organisms Two pairs of gills looking like partly inflated balloons are always borne on the two postgnathopod segments Some species have a third pair on the second gnathopod segment Females are marsupial the two regular gill segments bear the brood pouch from which the tiny young escape and cling to their mother giving her a coarse hairy appearance

Cyamidae Cyamids are remarkably modified caprellas having a striking superficial resemblance to insect lice but as befits the lice of whales they are much larger up to 15 mm in length than any terrestrial counterpart They cling caprellid like to the leathery skin about body orifices and at the bases of the walled and gooseneck barnacles of toothed and baleen whales One may reasonably assume that since whales evolved in the past 50 000 000 years a new ecological niche became available to enterprising caprellas A would be cyamid had then to mutate to the broad flattened form found in lice Cyamid feeding has not been adequately investigated Their presence in wounds on whales suggests that they may feed on superficial tissues *See* AMPHIPODA [E C DO]

Capricornus

The Sea Goat in astronomy an inconspicuous zodiacal constellation [illegible]

[illegible] stars the remainder being of fourth magnitude or fainter The constellation has been described from the earliest times as a goat or as a figure that is part goat with the tail of a fish Together with the neighboring zodiacal constellations Aquarius and Pisces Capricornus forms the great heavenly sea all the names are related to water The Tropic of Capricorn originates from this constellation which marked the southern limit of the ecliptic in ancient times *See* CONSTELLATION [C S Y]

Caprimulgiformes

An order of birds containing five families of nocturnal birds The best known and only widely distributed family is the Caprimulgidae the nightjars or goatsuckers These are highly vocal birds several such as the whippoorwill (*Caprimulgus vociferus*) are named for their call notes A hibernationlike torpidity previously unknown in birds was first demonstrated in the poor will (*Phalaenoptilus nuttallii*) and is now known to occur in other nightjars as well as in some hummingbirds Although they are small billed nightjars have huge gapes and feed primarily on insects captured in flight Larger relatives are the neotropical potoos (Nyctibiidae) and the Asiatic and Australian frogmouths (Podargidae) The small Australian owlet nightjars (Aegothelidae) suggest a link between this order and the owls The oilbird (*Steatornis caripensis*) sole member of the South American family Steatornithidae nests in caves in total darkness It navigates by echo location somewhat as bats do Feeding primarily on oily palm nuts these birds become very fat and Indians have long used oil from *Steatornis* for light and cooking *See* AVES [K C P]

Capybara

A grotesque tailless semiaquatic piglike mammal *Hydrochoerus capybara* also called water pig and cavy It is the largest of all rodents and lives in the waterways of eastern South America It is said to attain a length of 4 ft and a weight of 100 lb or more The capybara is sometimes used for food Although generally found in water this animal is frequently found in wet woodlands It



The capybara *Hydrochoerus capybara* length to 4 ft (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

feeds on plants and requires large quantities of food It has long coarse hair which is reddish brown above and paler below The toes are partially webbed There are four toes on the front feet three on the hind feet Although generally sluggish in habits it can dive and swim with speed and agility *See* MAMMALIA [J D B]

Carat

The unit of weight now used for all gemstones except pearls is the carat or metric carat (m c) By international agreement the carat weight was set at 200 milligrams (mg) Pearls are weighed in grains a unit of weight equal to 50 mg or ¼ carat

Despite the great value of many of the gemstones weighed against a unit called the carat the weight differed from country to country until early in the twentieth century Although most of the weights to which the name was applied were near 205 mg the range was from less than 190 to over 210 mg The 200 mg carat was proposed in 1907 in Paris This weight slowly gained acceptance

and by 1914 most of the important nations in the gem trade had accepted the metric carat as the legal standard for gemstones

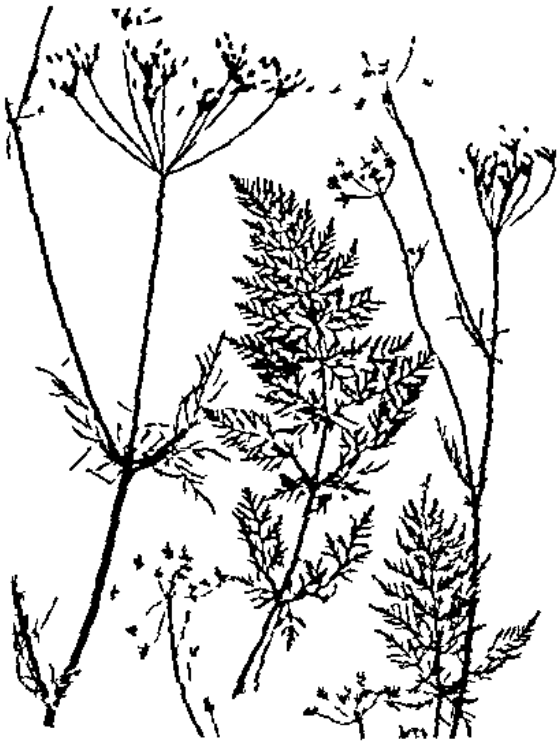
The origin of the gem weight standard and the term carat is interesting The locust tree that is common in the Mediterranean area produces seeds that are fairly uniform in weight averaging about 205 mg each As a result locust seeds came to be used for gem weight comparisons The word carat comes from the Greek word for the locust tree

The application of the term carat as a unit of weight must not be confused with the term karat used to indicate fineness or purity of the gold in which gems are mounted *See* GEM MOUNTING

[R T L]

Caraway

This is the most important of the umbelliferous fruits The plant, *Carum carvi*, is a perennial herb A native of Europe and western Asia, it is now cul *tivated in many temperate areas of both hemi*



Caraway Carum carvi (USDA)

spheres The small, brown slightly curved fruits are used in perfumery cookery confectionery in medicine and for flavoring beverages *See* SPICE AND FLAVORING, UMBELLALES

[P D S]

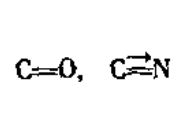
Carbanion

One of the charged fragments which arise on heterolytic cleavage of a covalent bond involving carbon In the generalized equation

$$:\ddot{A}:\ddot{B}: \rightarrow :\ddot{A}^{+} + :\ddot{B}:^{-}$$

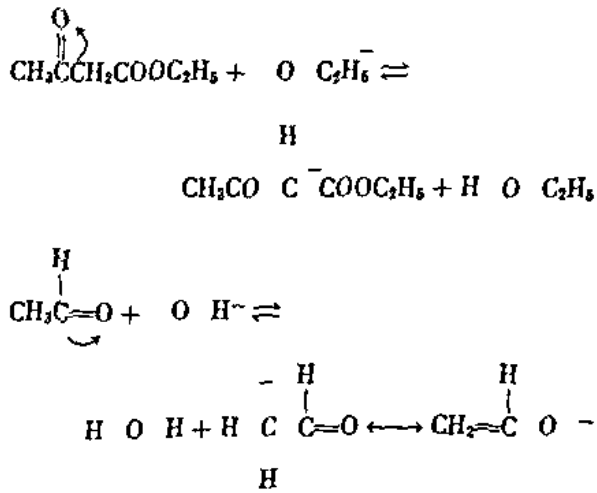
the atom B *acquires* the electron contributed by A in the formation of the covalent bond B is carbon, the fragment B carries an unshared pair of electrons and thus bears a negative charge In contrast to carbonium ions many instances of carbanions of relatively great stability are known

Carbanions can be formed by abstraction of a proton attached to a carbon atom by the action of a strong Lewis base Ease of carbanion formation in general depends on two factors strength of the base employed and stabilization of the resulting carbanion by means of resonance effects Further, carbanions are formed only from those compounds in which a functional group capable of weakening an adjoining carbon hydrogen bond is present The latter effect is due to permanent polarization and is most frequently encountered with compounds containing



functions In many instances carbanions formed originally by abstraction of a proton from carbon may carry the negative charge on oxygen or other atoms by virtue of resonance

Examples of carbanion formation are

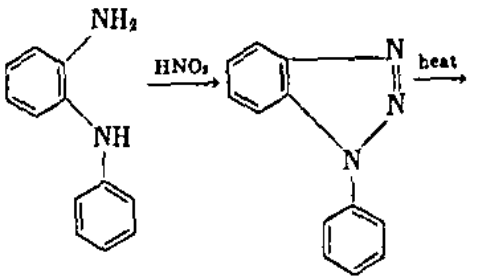


See CARBONIUM ION, ORGANIC REACTION MECHANISM RESONANCE (MOLECULAR STRUCTURE)

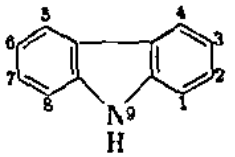
[R C E]

Carbazole

One of a group of organic heterocyclic compounds *(also called 9-azafluorenes) containing a dibenzo-*pyrrole system as in the parent compound carbazole (III) *See* HETEROCYCLIC COMPOUNDS The carbazole skeleton occurs in certain dyes and in the *Strychnos* alkaloids The parent compound was first found in coal tar Carbazoles can be synthesized by the Graebe-Ullmann reaction By this method an *o* aminodiphenylamine (I) is transformed to a 1 phenylbenzotriazole (II), which on heating loses nitrogen and gives a carbazole (III)



(I) (II)



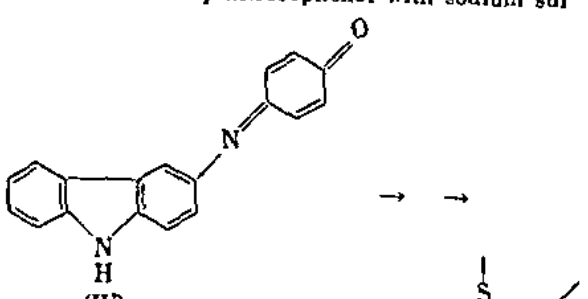
(III)

Another general scheme an adaptation of the Fischer indole synthesis converts cyclohexanone phenylhydrazones to 1 2 3 4-tetrahydrocarbazoles which can then be dehydrogenated Carbazoles can be obtained also by cyclizing *o* aminobiphenyls as well as *o o* diaminobiphenyls

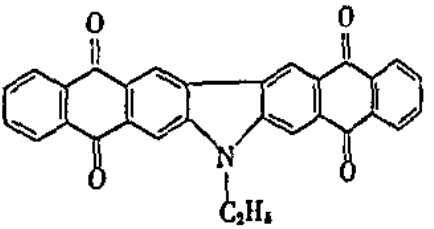
Carbazole (III) is a colorless water insoluble solid mp 246°C Substitution occurs at the 3 and 6 positions on nitration sulfonation halogenation and Friedel Crafts acylation Carbazole although sensitive to oxidation is markedly resistant to heat acid or alkali

The hydrogen at the 9 position is very weakly acidic but it can be replaced with metals under proper conditions The 9 position may be substituted with the help of familiar reagents to give 9-acyl or 9 alkylcarbazoles 9 Hydroxyethyl 9 nitroso and 9 vinylcarbazole are formed by reaction of carbazole with ethylene oxide nitrous acid and acetylene respectively 9 Vinylcarbazole is formed also by pyrolyzing the acetate of 9 hydroxyethyl carbazole The polymer obtained by peroxidic emulsion polymerization or solvent polymerization of 9 vinylcarbazole has useful electrical insulation properties similar to those of mica

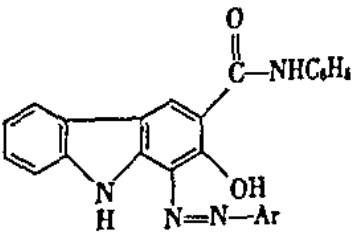
Hydron Blue R (V) a blue cotton dye is produced by treating the condensation product (IV) of carbazole and *p* nitrosophenol with sodium sulfide and sodium hydrosulfite Hydron Yellow (VI)



(IV) (V)



(VI)



(VII)

is representative of a number of carbazole vat dyes Compound (VII) is a carbazole azo dye *See* Dye. [W J GE]

Bibliography R C. Elderfield (ed) *Heterocyclic Compounds* vol 3 1952 W C Sumpter and F M Miller *Heterocyclic Compounds with Indole and Carbazole Systems* 1954

Carbide

A binary compound of carbon with an element less electronegative than carbon Carbon hydrogen compounds are excluded Effectively then carbides are comprised of metal carbon compounds if boron and silicon are included among the normal metals Essentially no volatile compounds (except AlC or its dimer) are known because decomposition sets in at higher temperatures before volatilization of the carbide as such

Most carbides can be prepared by heating a mixture of the powdered metal and carbon usually to high temperatures but not necessarily as high as the melting point Generally the same result is possible by heating a mixture of the oxide of the metal with carbon ($CaO + 3C \rightarrow CaC_2 + CO$) Some may be prepared by passing a hydrocarbon vapor over the hot metal in the form of an electrically heated filament The alkali metal carbides (Li_2C_2 Na_2C_2 K_2C_2 Rb_2C_2 and Cs_2C_2) are best prepared by passing acetylene (C_2H_2) into solutions of the metals in liquid ammonia ($2Na + 2C_2H_2 \rightarrow 2NaHC_2 + H_2$) followed by heating ($2NaHC_2 \rightarrow Na_2C_2 + C_2H_2$) The very unstable carbides Cu_2C_2 Ag C_2 Au_2C_2 ZnC_2 CdC_2 and HgC_2 are prepared by passing acetylene into solutions of the metal salts ($2CuCl + C_2H_2 \rightarrow Cu_2C_2 + 2HCl$) The carbides of these two series of elements are often regarded as acetylides partly in view of the preparative method but primarily because they react with water to give off acetylene gas ($Na_2C_2 + 2H_2O \rightarrow C_2H_2 + 2NaOH$)

It is useful to classify carbides as ionic (salt like) metallic (interstitial) and covalent The more electropositive elements (groups I II and III

and to some extent, members of the lanthanide and actinide series of the periodic system) form ionic carbides with transparent (or saltlike) crystals Belonging to this class are the acetylides listed above and BeC_2, MgC_2, CaC_2, SrC_2, BaC_2, Al_2C_6, and Ce_2C_6 Others yielding predominantly acetylene on reaction with water, but also producing additional hydrocarbons are YC_2, LaC_2, CeC_2, PrC_2, NdC_2 SmC_2 ThC_2, UC_2, and NpC_2 The acetylides contain pairs of carbon atoms in ion units C_2^{--} Other ionic carbides (methanides) which yield with water primarily methane but also other hydrocarbons and hydrogen, for example,

$$Al_4C_3 + 12H_2O \rightarrow 4Al(OH)_3 + 3CH_4$$

are Be_2C and Al_4C_3, and probably also Sc_4C_3 The action of water on ScC is not known

The carbide Mg_2C_3 yields allylene (propyne) on treatment with water

Highly refractory covalent carbides are formed with Si and B In the electric arc furnace SiC (diamond structure) is formed from a mixture of SiO_2 and coke The very hard B_4C can be made similarly from its oxide; it is unusual both structurally and in having a fairly high electrical conductivity

The group TiC, ZrC, HfC, V_2C, VC, Cb_2C, CbC Ta_2C, TaC, Mo_2C, MoC, W_2C, and WC has exceedingly high melting temperatures, is very hard, is metallic in appearance and in electrical conductivity, and is classified as metallic Important refractory units can be prepared by mixing the metal powder with carbon and sintering under pressure These carbides are reactive neither toward water nor in general toward acids or other chemicals The relatively smaller carbon atoms fit into the interstices between the metal atoms, and the compounds are therefore sometimes classified as interstitial Compositions may vary over a considerable range from the simple formulas given Probably ThC U_2C_3 UC, CeC, NpC, PuC, and possibly Ce_2C_3 Np_2C_3, and Pu_2C_3 should be included with the metall

but are much nearer the former in properties Cr_2C_6, Cr_7C_3, Cr_3C_2 $Mn_{23}C_6$, Mn_7C_3, Mn_3C_2, Fe_3C Fe_2C Co_3C, Co_2C, and Ni_3C react with water or acids to give either simple hydrocarbons or mixtures of hydrocarbon gases The presence of F_3C in iron is an important factor in the properties of steel *See* ABRASIVE, BORIDE, CARBON, CERMET, HYDRIDE, NITRIDE, OXIDE [R K E]

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Carbohydrate

A term applied to a group of related substances which include the sugars, starches, and cellulose, along with many other related substances This group of compounds plays a vitally important part in the lives of plants and animals both as structural elements and in the maintenance of functional activity Plants are unique in that they alone in nature have the power to synthesize carbohydrates from carbon dioxide and water in the presence of the green plant chlorophyll through the energy derived from sunlight, by the process of photosynthesis This process is responsible not only for the existence of plants but for the maintenance of animal life as well, since animals obtain their entire food supply directly or indirectly from the carbohydrates of plants *See* PHOTOSYNTHESIS

The carbohydrates as a group are comparable in importance with the proteins and fats Cane or beet sugar, D glucose, D fructose, starch, and cellulose may be cited as typical representatives A number of members of this group are of great industrial importance Among the undertakings dependent on carbohydrate materials are the cotton industry, certain branches of explosives, brewing, and the manufacture of alcohol

The term carbohydrate originated in the belief that naturally occurring compounds of this class, for example D-glucose ($C_6H_{12}O_6$), sucrose, ($C_{12}H_{22}O_{11}$), and cellulose $(C_6H_{10}O_5)_n$, could be represented formally as hydrates of carbon, that is $C_x(H_2O)_y$ Later it became evident that this definition for carbohydrates was not a satisfactory one New substances were discovered whose properties clearly indicated that they had the characteristics of sugars and belonged in the carbohydrate class but which nevertheless showed a deviation from the required hydrogen to oxygen ratio Examples of these are the important deoxy sugars, D deoxyribose, L fucose, and L rhamnose, the uronic acids, and such compounds as ascorbic acid (vitamin C) The retention of the term carbohydrate is therefore a matter of convenience rather than of exact definition A carbohydrate is usually defined as either a polyhydroxy aldehyde (aldose) or ketone (ketose), or as a substance which yields one of these compounds on hydrolysis However, included within this class of compounds are substances also containing nitrogen and sulfur

The properties of many carbohydrates differ enormously from one substance to another The sugars such as D glucose or sucrose, are easily soluble, sweet tasting and crystalline, the starches are colloidal and paste forming, and cellulose is completely insoluble Yet chemical analysis shows that they have a common basis, the starches and cellulose may be degraded by different methods to the same crystalline sugar, D glucose

Classification The carbohydrates usually are classified into three main groups according to complexity monosaccharides, oligosaccharides and polysaccharides

Monosaccharides These simple sugars consist of a single carbohydrate unit which cannot be hydrolyzed into simpler substances These are characterized, according to their length of carbon chain as trioses ($C_3H_6O_3$), tetroses ($C_4H_8O_4$), pentoses ($C_5H_{10}O_5$), hexoses ($C_6H_{12}O_6$), heptoses ($C_7H_{14}O_7$), and so on A monosaccharide may be an aldose or a ketose, depending on the type

carbonyl group (C=O) present This system gives rise to such names as aldotriose aldotetrose aldopentose and aldohexose The presence of a ketone group has been indicated by names such as ketopentoses and ketohexoses More recently the tendency is to indicate the presence of a ketone group by the ending "ulose in names such as pentuloses hexuloses and heptuloses *See* Monosaccharide

Oligosaccharides These compound sugars are condensation products of 2 3 4 or 5 molecules of [illegible] disaccharide penta monosaccharide molecules yielded upon hydrolysis

The sugars which include the monosaccharides and oligosaccharides are mostly crystalline compounds The monosaccharides and disaccharides have a sweet taste Products obtained from hydrolysis of high molecular weight polysaccharides and consisting of compound sugars that contain as *many as* nine monosaccharide units are also termed oligosaccharides However these higher members are not crystalline compounds The disaccharides and other groups of oligosaccharides are subclassified into reducing and nonreducing sugars depending on whether or not the sugar has a functional carbonyl group In a nonreducing oligosaccharide the carbonyl groups of the constituent monosaccharide units are involved in glycosidic linkage The compound sugars are in reality sugarlike polysaccharides but the prefix "poly is reserved for carbohydrates which consist of large aggregates of *monosaccharide units* *See* Oligosaccharide

Polysaccharides These comprise a heterogeneous group of compounds which represent large aggregates of monosaccharide units joined through *glycosidic* bonds They are tasteless nonreducing *amorphous* substances that yield a large and indefinite number of *monosaccharide* units on hydrolysis Their molecular weight is usually very high *and many of* them like starch or glycogen have *molecular* weights of several million They form colloidal solutions, but *some* polysaccharides of which cellulose is an *example* are completely insoluble in water On *account of their* heterogeneity they are difficult to classify One common system of classification *is based* primarily upon the class of monosaccharide yielded *on* hydrolysis Thus a polysaccharide that *yields* hexose monosaccharides on hydrolysis *is called* hexoglycan $(C_6H_{10}O_5)_n$ where *n* represents the number of monosaccharide units present A polysaccharide yielding a pentose sugar *is called* pentoglycan $(C_5H_8O_4)_n$ Each major class is further subdivided according to the particular *hexose* or pentose produced Thus a polysaccharide *composed* of the hexose sugar D glucose is referred to as glucan those composed *of the* pentose sugars D-xylose and L arabinose are called xylan and araban respectively

Some polysaccharides however yield *both* hexose and pentose sugars on hydrolysis and are classed as mixed hexosans and *pentosans*, others in addition to hexoses and pentoses frequently on acid hydrolysis yield the uronic acids D glucuronic D galacturonic, or D-mannuronic acid Such polysaccharides are frequently referred to as polyuronides *See* Polysaccharide

Reducing and nonreducing sugars The sugars are also classified into two general groups the reducing and nonreducing The reducing sugars are distinguished by the fact that because of their free, or potentially free, aldehyde or ketone groups they possess the property of readily reducing alkaline solutions of many metallic salts, such as those of copper silver, bismuth mercury, and iron The most widely used reagent for this purpose is Fehling's solution in which the oxidizing agent is the cupric tartrate ion, formed in a strongly alkaline solution of copper sulfate and a salt of tartaric acid The nonreducing sugars do not exhibit this property The reducing sugars constitute by far the larger group The monosaccharides and many of their derivatives reduce Fehling's solution Most of the disaccharides, including maltose lactose, and the rarer sugars cellobiose gentiobiose melibiose and turanose, are also reducing sugars The best known nonreducing sugar is the disaccharide sucrose Among other nonreducing sugars are the disaccharide trehalose the trisaccharides raffinose and melezitose the tetrasaccharide stachyose *and* the pentasaccharide verbascose

The alkali in the Fehling solution or other such reagents used for the determination of reducing sugars, causes considerable decomposition of the sugar molecule into reactive fragments which may also reduce the metal ions Thus while the *total reduction for a given sugar may* be constant under carefully controlled conditions and can therefore be used for quantitative purposes it is impossible to write a balanced equation for the reaction *in* terms of the simple oxidation of the sugar and reduction of the metal ion

Analysis. Carbohydrate analysis involves separation of the carbohydrate mixtures identification of the individual carbohydrates and estimation of their quantities

Separation and identification Sugars in most cases occur in living tissues as mixtures *Before* a sugar can be identified it must be isolated in pure form, preferably as a crystalline substance The pure crystalline compound is readily *identified* by its melting point, optical rotation and by *its* x ray diffraction pattern Preparation of certain crystalline derivatives facilitates *isolation and* identification of reducing sugars The phenylhydrazone and phenylosazone derivatives of these sugars *are* especially useful chiefly because of their ease of preparation The phenylosatriazoles benzimidazoles and diothioacetal acetates are *more* advantageous for the purpose of identification

Application of chromatographic technique provides a useful and rapid method for the *separation* and identification of sugars (*See* Chromatography) The great advantage of this *process* lies in the fact that it can be applied to minute amounts as well as to relatively large quantities *For* micro

amounts chromatography on filter paper is used The mixed sugar solution is applied as a spot on the narrow edge of a strip of filter paper The sugars are then separated by using a mixture of water and a partially immiscible organic solvent such as *n* butanol or phenol The paper is then dried and sprayed with coloring reagents such as *p* anisidine hydrochloride or aniline hydrogen phthalate which show the location of the individual sugars For separation of larger quantities of material column chromatography is used In this method the proper choice of solvents and absorbents is important The solvent is passed through a column *containing powdered cellulose silicic acid alumina* clay carbon or other adsorbent by gravity suction or pressure After sufficient development to form the different zones the products may be eluted from the column in successive batches

Color tests There are a number of color tests which are helpful in the identification of carbohydrates These tests are based on the condensation of various aromatic amines or phenolic substances with the degradation products of sugars The Molisch test is used for the general detection of carbohydrates In this test a purple color is produced when the solution containing carbohydrate is treated with strong sulfuric acid in the presence of α-naphthol In the Tauber test pentose sugars produce a cherry red color when heated with a solution of benzidine in glacial acetic acid Another test for pentoses and uronic acids is based on the fact that a violet red color develops when these sugars are treated with hydrochloric acid and phloroglucinol Seliwanoff's test is used for ketoses which give a red color with resorcinol in hydrochloric acid The Tollens naphthoresorcinol *and the Dische* carbazole tests are used for the detection of the uronic acids D glucuronic acid D galacturonic acid and D mannuronic acid The polysaccharide starch produces a blue color when treated with a dilute solution of iodine in potassium iodide while glycogen gives a reddish brown color with this reagent

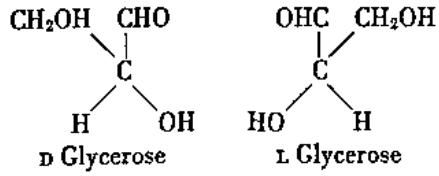
Paper chromatography and color tests only indicate the probable presence of a particular carbohydrate For unequivocal proof it is necessary to resort to isolation procedures

Estimation The reducing properties of aldoses and ketoses are most frequently utilized for the quantitative analysis of these sugars A nonreducing sugar such as sucrose or raffinose or a polysaccharide such as starch must be first hydrolyzed with acid or with an appropriate enzyme to its constituent reducing monosaccharide units before it is analyzed Upon heating the reducing sugars with Fehling's solution containing copper sulfate tartrate ion and sodium hydroxide a brick red color develops due to the formation and precipitation of cuprous oxide

The quantity of *the cuprous oxide precipitate* is a measure of the amount of reducing sugar present Several modifications of this reaction have been used for the quantitative determination of reducing sugars The estimation of sugar by the Benedict method involves the determination of the reduced cuprous ions colorimetrically after treatment with phosphomolybdic acid (*see* ALDEHYDE) In the Somogyi Shaffer Hartmann method the sugar is estimated by iodometric titration of reduced copper (*see* TITRATION) Several other quantitative methods for the determination of sugars are based on the reduction of ferricyanide ions in an alkaline solution These reactions can be applied to micro quantities of sugars There are also spectrophotometric methods devised by Dische which are based on light absorption by the reaction products resulting from treatment of sugars with carbazole or cysteine carbazole in sulfuric acid (*see* SPECTROPHOTOMETRIC ANALYSIS) Sugars can be accurately identified and determined by their specific optical rotations provided they are available in sufficient quantities and that no other interfering optically active materials are present

Stereoisomerism The sugars consist of chains of carbon atoms which are united to one another at a tetrahedral angle of 109°28 A carbon atom to which are attached four different groups is called asymmetric A sugar or any other compound containing one or more asymmetric carbon atoms possesses optical activity that is it rotates the plane of polarized light to the right or left The specific rotation of a substance possessing optical activity is the rotation expressed in angular degrees which is afforded by 1 g of substance dissolved in 1 ml of water in a tube 1 decimeter in length It is usually given at a definite temperature for example 20°C and sodium D line and is designated by $[\alpha]_D^{20}$ *See* OPTICAL ACTIVITY

The triose glycerose or glyceraldehyde has one asymmetric carbon atom and therefore exists in two optically active forms one dextrorotatory and the other levorotatory The spatial arrangement of the groups around the asymmetric carbons of the two isomers can be depicted as follows



D Glycerose L Glycerose

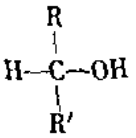
The D and L forms of glycerose are related to each other as the right hand is to the left hand being similar but not identical One may not be superposed upon the other If one model is held before a mirror the image in the mirror corresponds to the arrangement of the other model The two compounds whose molecules are mirror images of each other are called optical antipodes or enantiomorphs

It is difficult to represent stereochemically the more complex sugars having several asymmetric carbon atoms An examination of the formula for an aldohexose shown below reveals that it contains four different asymmetric carbon atoms that is each of the atoms marked with an asterisk at positions 2 3 4 and 5 carries four different groups or

toms The ketohexose contains three asymmetric arbon atoms at 3, 4 and 5

Position	Aldohexose	Position	Ketohexose
1	CHO	1	CH_2OH
2	*CHOH	2	C=O
3	*CHOH	3	*CHOH
4	*CHOH	4	*CHOH
5	*CHOH	5	*CHOH
6	CH_2OH	6	CH_2OH

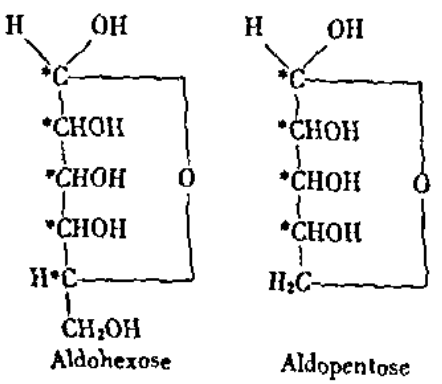
For example the carbon at position 2 in the aldohexose may be shown thus



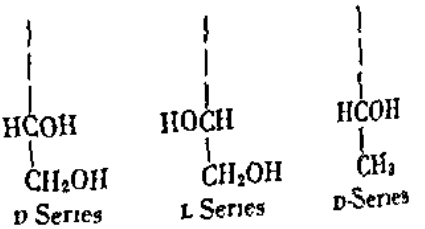
where R stands for the CHO group and R′ for everything below carbon atom 2

As the number of asymmetric carbon atoms in the sugar molecule increases *from the trioses to* the higher monosaccharides the number of stereoisomers increases in accordance with *the van't* Hoff formula 2^n where *n* represents the number of asymmetric carbon atoms (*see* DIASTEREOISOMER)

Thus the possible number of stereoisomers of an aldohexose such as glucose or galactose *when* written in open chain form, is 2^4 or 16 (eight enantiomorphous *pairs*) *In the* ketose sugars, there is one less asymmetric center than in the aldoses of equal chain length, therefore the number of isomers is reduced by a *factor of* 2 The possible number of stereoisomers of a ketohexose exemplified by fructose or sorbose, is 2^3 *or* 8 *(four* enantiomorphous pairs) Six stereoisomers consisting of three pairs of enantiomorphs, *are possible* for an aldopentose like xylose or arabinose If, as will be seen below the formulas of *these sugars* are represented in ring form, the first carbon atom in the monosaccharide chain *becomes asymmetric* because of formation of a cyclic hemiacetal with a new OH group and *another center* of asymmetry at carbon atom 1 The possible isomers for a cyclic aldohexose therefore become 2^5 or 32 and for an aldopentose 2^4 or 16



The spatial arrangement of the groups around the asymmetric carbon atom of the dextrorotatory form of glyceraldehyde (glycerose) is arbitrarily called the D configuration, while that of the levorotatory form is called the L configuration This connotation of the D and L refers to spatial configuration only and is not an indication of the direction of rotation of the plane of polarized light by the sugar The reference carbon atom regarding D or L configuration is for sugars containing more than one asymmetric carbon atom, the asymmetric carbon atom furthest removed from the active that is the aldehyde or ketone, end of the molecule and adjacent to the terminal group



Rosanoff, who introduced this criterion for designating the D and L form of sugars, regarded all sugars of the D series as built up, in theory from D glycerose, and those of the L series from L *glycerose* Although not accomplished in practice throughout the series, such a process is rendered possible without interfering with the original asymmetric carbon atom, by the stepwise addition of the repeating unit CHOH through the Kiliani cyanohydrin synthesis It must be emphasized that Rosanoff's representation of the D and L forms of sugar is merely a convention and has no relation to their direction of rotation *If it is desired to* indicate the direction of rotation of the compound the symbols (+), meaning dextrorotatory, and (−) meaning levorotatory, are used Thus a dextrorotatory sugar with the D configuration is *indicated* by the symbol D(+), while a levorotatory sugar of the same configuration is represented by D(−) Figure 1 shows the relationship of D glycerose to the D trioses, D tetroses, D pentoses, and D-hexose

Formulation Thus far the monosaccharides have been considered as open chain compounds designated by projection formulas The projection formula, introduced by Emil Fischer, is based on the convention that tetrahedrons representing individual asymmetric carbons of a sugar, viewed though supported by their carbon to carbon bonds with the hydrogen and hydroxyl groups extending outward are projected upon the depicting plane This formula is quite convenient, because the relationship between various sugars is easily demonstrated Its numbering begins at the terminal position associated with the carbonyl group, *in ketoses* the carbonyl group is in carbon *atom 2* position When Greek letters are used as in the older literature the carbon next to the —CHO group is called the α carbon atom

Although an aldohexose such as D-glucose or aldopentose such as D-xylose, exhibits many of the properties of common aldehydes, its reactivi

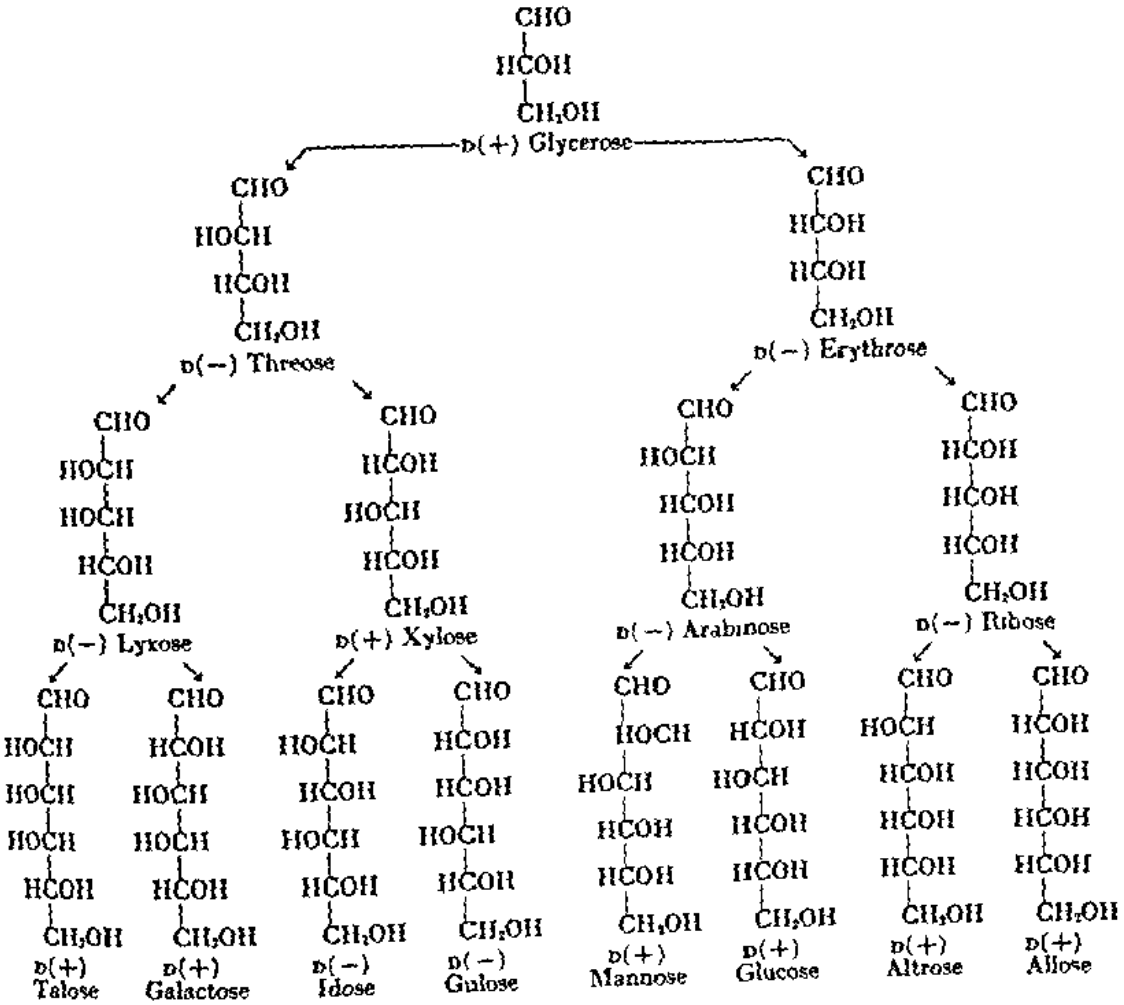
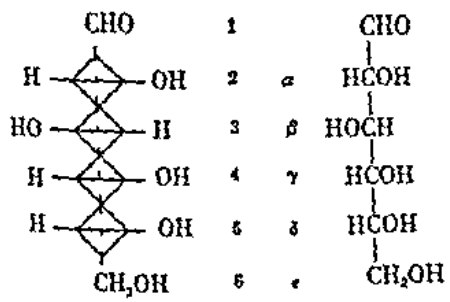


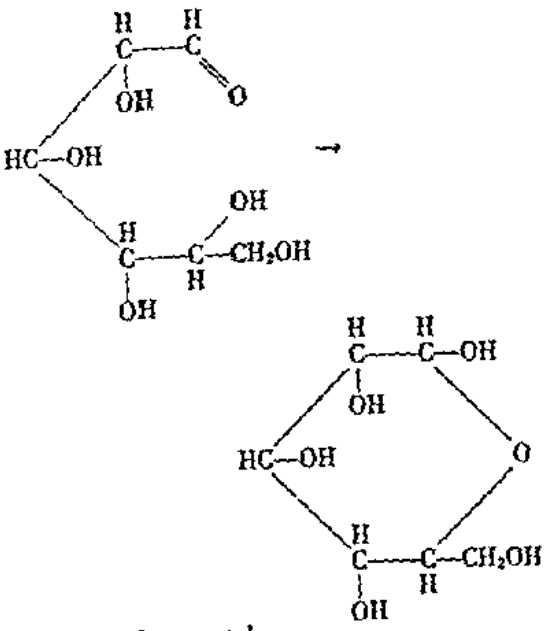
Fig 1 The D-series of aldose sugars

when compared with acyclic hydroxyaldehydes such as glycolic aldehyde or glyceraldehyde is not as great as would be expected if the sugar possessed the simple aldehydic projection formula



D Glucose

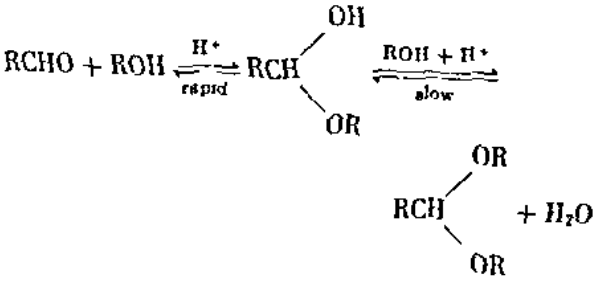
Furthermore the cyanohydrin reaction proceeds with difficulty and sugars fail to give the Schiff test for aldehydes Thus the straight-chain aldehydic projection formula does not represent the essential features of the sugar molecules particularly their tendency to form five and six membered rings In reality because of the tetrahedral angles between bonds of the carbon atoms the chain tends to form a ring Thus the ends of a six carbon chain approach each other as shown below permitting a reaction between the carbonyl group a hydroxyl on the fourth or fifth carbon atom and forming a hemiacetal



Formation of hemiacetal

The reaction is analogous to the formation of hemiacetals from simple aldehydes and alcohols

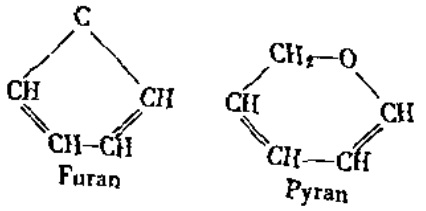
Admixture of an aldehyde and an alcohol in the presence of an acid catalyst produces first a hemiacetal Long standing in an excess of alcohol converts the hemiacetal into a complete acetal



Such a reaction occurs not only with aldose but also with ketose sugars Formation of a hemiacetal in a hexose monosaccharide from a reaction between carbon atom 1 and the OH group of carbon atom 6 is not likely because this would produce a strained seven membered ring Six and five membered rings are more easily formed because there is very little distortion of the bond angles Rings of four carbon atoms or less do not form easily

There is abundant evidence that sugars actually exist as cyclic compounds Most decisive proof is furnished by the phenomenon of mutarotation by the existence of two isomeric methylglycosides and by Haworth s methylation experiments in which he was unable to demonstrate open chain structure

In the older literature the six membered ring structure of the aldohexoses in which the first carbon atom is linked to the fifth carbon atom through an oxygen atom had been named amylene oxide or δ oxide configuration The five-membered rings in which carbon atom 1 is linked to carbon atom 4 had been termed butylene oxide or γ oxide configuration In 1927 W N Haworth suggested that the five-atom ring sugars should be regarded as derived from furan and the six atom ring configuration from pyran



Thus a sugar containing a γ oxide or 1 4-oxide ring is called a furanose sugar and if it is present as a glycoside it is described as a furanoside (see GLYCOSIDE) It must be noted however that unsubstituted furanose sugars have never been isolated although they do exist in small proportion in solution Although the 1 4 ring is stable and the 1 5 ring is relatively unstable in the sugar lactones the reverse is true for the sugars and glycosides Furanose structures are therefore found either in substituted sugars such as 2 3 5 6 O methyl D glucose where there is no free hydroxyl on carbon atom 5 or more commonly when the monosaccharide (D-fructose or L arabinose) is a constituent of complex sugars the oligosaccharides or polysaccharides

Similarly the names pyranose and pyranoside are applied to the sugars and sugar derivatives possessing the six membered δ oxide or 1 5 rings

In the Haworth perspective formulas carbon atoms 1–5 and the ring oxygen are represented in a single plane projecting from the plane of the paper on which it is written The valences of the carbon atoms not involved in ring formation are situated above or below the plane of the ring The thickened lines at the bottom of the ring formulas represent the sides of the hexagon nearest to the observer

When the carbon atoms in the ring are numbered clockwise, as in α D-glucopyranose the groups that are written on the right hand side in the projection formula are represented as projecting below the plane of the ring and the corresponding groups on the left hand side are projecting above However there is a discrepancy in the relative positions of the substituent groups on carbon atom 5 in that the H atom appears in the perspective formula below instead of above the plane of the ring This apparent anomaly is the result of torsion required to effect ring closure In forming a ring from the straight chain aldehyde form the fifth carbon atom must be rotated so that the oxygen atom in the OH group on this carbon atom is brought into the plane of the first five carbon atoms Consequently, the H atom attached to carbon atom 5 is now shifted to the other side of the chain because this carbon atom has been rotated through more than a 90° angle

The projection and perspective formulas for the α and β isomers of D glucose D xylose L arabinose and D fructose are shown in Fig 2

Since free D fructose primarily exists in the pyranose configuration the furanose ring structure of this sugar is shown with the active hydrogen of the [illegible] The substituents in the [illegible] ucto- furanosyl units as in the polysaccharide inulin

Mutarotation Two forms of glucose are known The α form is obtained by dissolving the sugar D-glucose in water and allowing it to crystallize through evaporation of the solvent The β form is obtained by crystallizing D-glucose from pyridine or acetic acid The products are not merely different crystallographic forms of the same substance for they have different properties when dissolved At 20°C a freshly prepared solution of α D glucose has a specific rotation $[\alpha]_D^{20}$ of +113° and a freshly prepared aqueous solution of β D-glucose at the same temperature has a specific rotation of +19° Upon standing both solutions gradually change in rotatory power The optical rotation of the α D form decreases and that of the β D-form increases until they reach the same equilibrium value of $[\alpha]_D$ +52 5°, which corresponds to a mixture of 37% α and 63% β This phenomenon of change in its optical property is called mutarotation It is displayed not only with glucose but with all crystalline sugars that have a free or potentially free aldehyde or ketone group in the molecule To

FISCHER PROJECTION FORMULAS

HAWORTH PERSPECTIVE FORMULAS

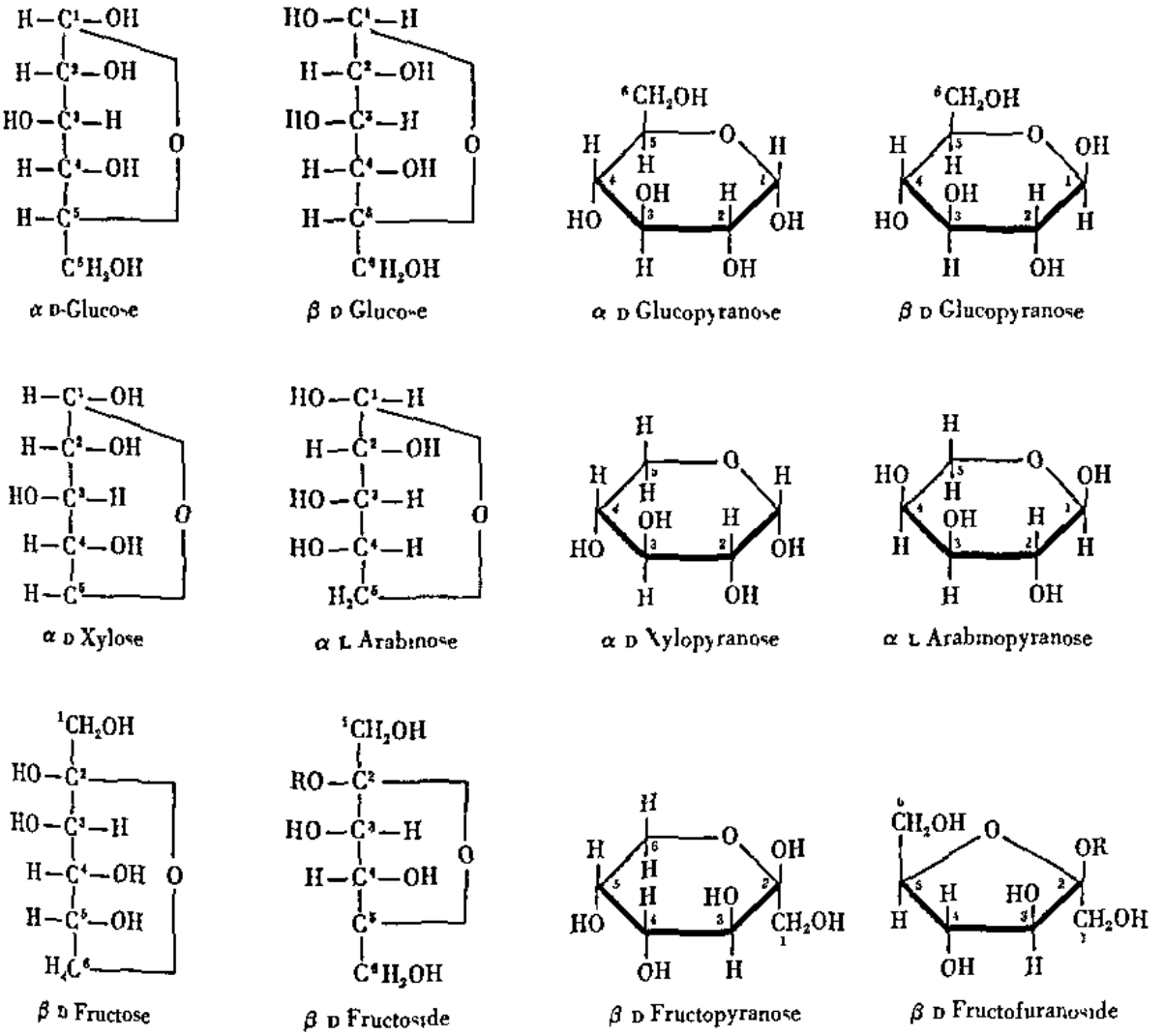
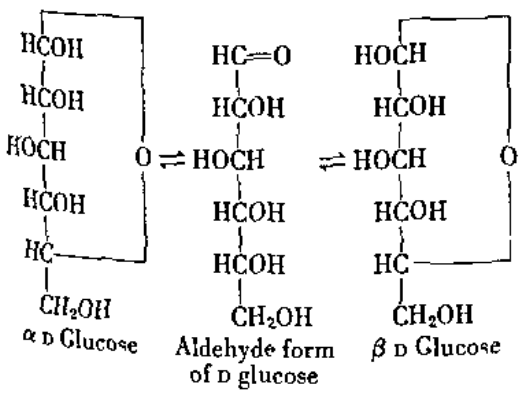


Fig 2 Fischer projection formulas with perspective formulas

account for the existence of two structures it is assumed that the monosaccharides exist in the form of cyclic hemiacetals rather than in open chain form Using the formula for D glucose as an example the following possible structures result

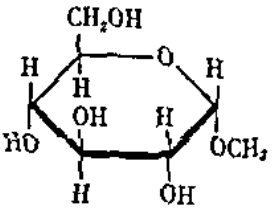


The process of mutarotation is due to the labile nature of the hemiacetal linkage and the interconversion of the α and β forms through the acyclic aldehyde form which exists in solution to a very small extent (about 0 1%) Mutarotation is catalyzed by both acid and base with the base being by far more effective

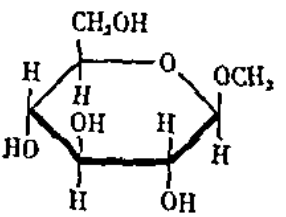
The α and β sugars are stereoisomeric but they are not mirror images They are known as anomers differing from each other only in the positions of the atoms or groups attached to the terminal asymmetric carbon atom

with the higher rotation in the positive sense shall be called the α form whereas the isomer with the lower rotation is designated as β The reverse holds good for the L series the enantiomorph of α D glucose being α L glucose with a lower specific rotation of $[\alpha]_D$ −113° than β L glucose $[\alpha]_D$ −19° In the α anomer of D-glucose the OH group attached to the aldehydic carbon atom and the OH group on the adjacent carbon atom are on the same side of the ring (*cis* position) In the β form these hydroxyl groups are on opposite sides of the hemiacetal ring (trans position)

Methyl glucosides When a solution of glucose in cold methanol is treated with dry hydrogen chloride as catalyst an acetal is formed Such a compound formed from glucose is called a glucoside if the sugar galactose were used the acetal would be called a galactoside Methyl glucoside is perhaps the simplest example of a large group of substances in which the hydroxyl of the hemiacetal group at carbon atom 1 of an aldose monosaccharide has been condensed with the hydroxyl group of an alcohol



Methyl α D glucose



Methyl β D glucose

In aqueous solution D glucose exists chiefly as D glucopyranose However a small proportion of this sugar exists in the furanose as well as in the open chain aldehyde forms the last in a minute amount Since the furanose structure reacts more rapidly to form the glucoside than does the pyranose configuration of the sugar a considerable amount of labile methylglucofuranoside is formed in the first few hours On prolonged standing or heating the more stable methyl α D glucopyranoside and methyl β D glucopyranoside appear It is therefore evident that when glucose is treated with methanolic hydrochloric acid, the yield of methylglucoside of a particular configuration has little bearing on the structure of the original sugar that is the structure of the glucoside may or may not correspond to the structure of the crystalline sugar However a relationship in this case can be established through hydrolysis of a methylglucoside When pure methyl α D glucoside is hydrolyzed the subsequent mutarotation of the hydrolysis product is found to be in the same direction as that of pure α D glucopyranose It is therefore concluded that α D-glucose and α D-glucoside have the same configuration about the first carbon atom

The α and β methylglucosides are crystalline compounds They may be separated by fractional crystallization or through the agency of enzymes The enzymes maltase and emulsin act selectively upon the two glucosides the former hydrolyzing the α-form only and the latter acting upon the anomeric β compound The specific rotation of methyl α D-glucopyranoside is +159° while that of methyl β D glucopyranoside is −33° *See* Biochemistry Carbohydrate metabolism

[W Z H]

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Carbohydrate metabolism

The fields of biochemistry and physiology deal with the breakdown and synthesis of simple sugars oligosaccharides and polysaccharides and with the transport of sugars across cell membranes and tissues The breakdown or dissimilation of simple sugars particularly glucose is one of the principal sources of energy for living organisms The dissimilation may be anaerobic as in fermentations or aerobic that is respiratory In both types of metabolism the breakdown is accompanied by the formation of energy rich bonds, chiefly the pyrophosphate bond of the coenzyme adenosine triphosphate (ATP) which serves as a coupling agent between different metabolic processes In higher animals glucose is the carbohydrate constituent of blood which carries it to the tissues of the body In higher plants the disaccharide sucrose is often stored and transported by the tissues Certain polysaccharides especially starch and glycogen are stored as endogenous food reserves in the cells of plants animals and microorganisms Others such as cellulose chitin and bacterial polysaccharides serve as structural components of cell walls As constituents of plant and animal tissues various carbohydrates become available to those organisms which depend on other living or dead organisms for their source of nutrients Hence all naturally occurring carbohydrates can be dissimilated by some animals or microorganisms *See* Adenosinetriphosphate (ATP) Carbohydrate Cellulose Chitin Glycogen Starch

Dietary carbohydrates Certain carbohydrates cannot be used as nutrients by man For example the polysaccharide cellulose which is one of the main constituents of plants cannot be digested by man or other mammals and is a useful food only for those such as the ruminants that harbor cellulose-decomposing microorganisms in their digestive tracts The principal dietary carbohydrates available to man are the simple sugars glucose and fructose the disaccharides sucrose and lactose and the polysaccharides glycogen and starch Lactose is the carbohydrate constituent of milk and hence one of the main sources of food during infancy The disaccharides and polysaccharides that cannot be absorbed directly from the intestine are first digested or hydrolyzed by enzymes secreted into the alimentary canal The nature of these enzymes known as glycosidases will be discussed later in this article *See* Fructose Lactose

Intestinal absorption and transport The simple sugars of which glucose is the major component reach the intestine or are produced there through the digestion of oligosaccharides They are absorbed by the intestinal mucosa and transported across the tissue into the blood stream This process involves the accumulation of sugar against a concentration gradient and requires active metabolism of the mucosal tissue as a source

of energy The sugars are absorbed from the blood by the liver and are stored there as glycogen The liver glycogen serves as a constant source of glucose in the blood stream The mechanisms of transport of sugars across cell membranes and tissues are not yet understood but appear to be highly specific for different sugars and to depend on enzymelike components of the cells

Dissimilation of simple sugars The degradation of monosaccharides may follow one of several types of metabolic pathways In the phosphorylative pathways the sugar is first converted to a phosphate ester (phosphorylated) in a reaction with ATP The phosphorylated sugar is then split into smaller units either before or after oxidation In the nonphosphorylative pathways the sugar is usually oxidized to the corresponding aldonic acid This may subsequently be broken down either with or without phosphorylation of the intermediate products Among the principal intermediates in carbohydrate metabolism are glyceraldehyde-3-phosphate and pyruvic acid The end products of metabolism depend on the organism and to some extent on the environmental conditions Besides cell material that is formed through various biosynthetic reactions the products may include carbon dioxide (CO_2) alcohols organic acids and hydrogen gas In the so called complete oxidations, CO_2 is the only excreted end product. In incomplete oxidations characteristic of the vinegar bacteria and of certain fungi oxidized end products such as gluconic ketogluconic citric or fumaric acids may accumulate Organic end products are invariably found in fermentations, since fermentative metabolism requires the reduction as well as the oxidation of some of the products of intermediary metabolism (*see* FERMENTATION) The energy available from the complete oxidation of 1 mole of glucose with molecular oxygen is approximately 688 000 cal while that which can be derived from fermentation is very much less for example alcoholic fermentation yields about 58 000 cal In aerobic metabolism a great deal of the available energy is harnessed for the needs of the organism as energy rich bonds primarily in ATP through the process known as oxidative phosphorylation In fermentation a much smaller amount of ATP is produced Hence the amount of biosynthesis and mechanical work that an organism can do at the expense of a given amount of sugar is many times greater in respiration than in fermentation

Glycolysis The principal phosphorylative pathway involved in fermentations is known as the glycolytic hexose diphosphate or Embden Meyerhof pathway This sequence of enzymatic reactions is the basis of the lactic acid fermentation of mammalian muscle and of the alcoholic fermentation of yeast Its main features may be summarized as follows

1 Glucose is phosphorylated to yield glucose-6-phosphate by the enzyme hexokinase with the conversion of a molecule of ATP to adenosinediphosphate (ADP)

2 Glucose-6-phosphate is epimerized to fructose 6 phosphate by phosphoglucoisomerase

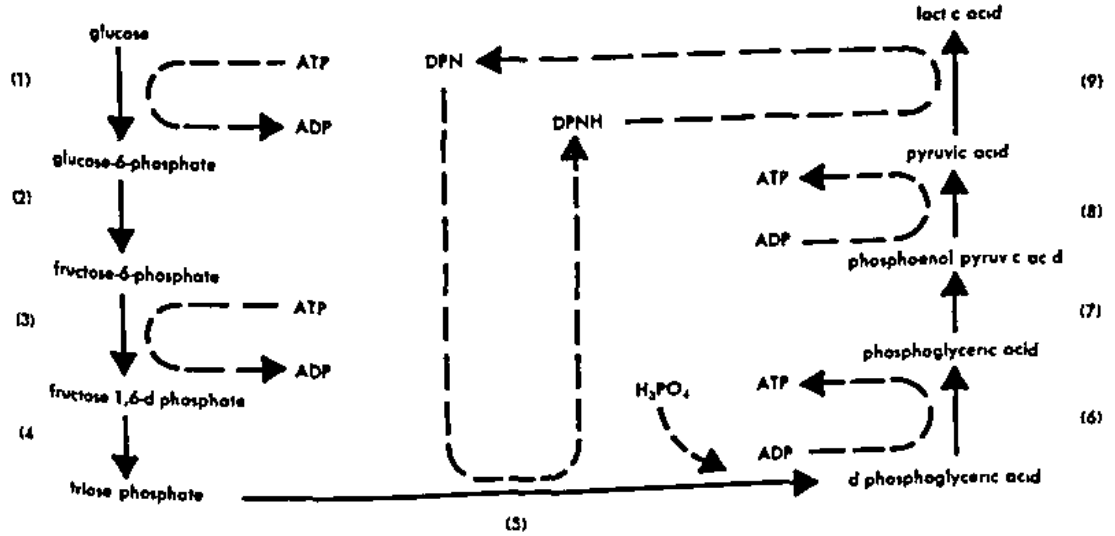
3 Fructose 6-phosphate is phosphorylated with ATP to yield fructose-1 6 diphosphate This reaction is catalyzed by phosphofructokinase

4 Fructose 1 6 diphosphate is split to two molecules of triose phosphate (dihydroxyacetone phosphate and glyceraldehyde phosphate) by aldolase

5 Both molecules of triose phosphate which are interconverted by triose phosphate isomerase are oxidized to 1 3 diphosphoglyceric acid by triose phosphate dehydrogenase Inorganic phosphate is esterified in this reaction and the coenzyme diphosphopyridine nucleotide (DPN) becomes reduced to DPNH

6 1 3 Diphosphoglyceric acid reacts with ADP to yield ATP and 3-phosphoglyceric acid in the presence of phosphoglycerate kinase

7 3-Phosphoglyceric acid is converted to 2 phosphoglyceric acid by phosphoglyceric acid



D agram of glycolys s in lact c ac d fermentat on

mutase and the product is dehydrated to phosphoenolpyruvic acid by enolase

8 In a reaction catalyzed by pyruvic kinase phosphoenolpyruvic acid reacts with ADP to give pyruvic acid and ATP

9 Pyruvic acid is converted to the various end products of metabolism In the lactic acid fermentation it is reduced to lactic acid with the simultaneous reoxidation of DPNH which had been formed in step 5 to DPN In alcoholic fermentation pyruvic acid is decarboxylated to yield CO_2 and acetaldehyde and the latter compound is reduced to alcohol with DPNH

For every molecule of glucose fermented through the glycolytic sequence two molecules of ATP are used for phosphorylation (Steps 1 and 3) while four are produced (steps 6 and 8) Thus fermentation results in the net gain of two energy rich phosphate bonds as ATP at the expense of inorganic phosphate esterified in step 5 The excess ATP is converted back to ADP and inorganic phosphate through coupled reactions useful to the organism such as the mechanical work done by the contraction of muscle or biosynthetic reactions associated with growth *See* ADENOSINEDIPHOSPHATE (ADP) DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN) GLUCOSE 1 PHOSPHATE GLUCOSE 6 PHOSPHATE

Oxidative mechanisms The oxidative or respiratory metabolism of sugars differs in several respects from fermentative dissimilation First the oxidative steps that is the reoxidation of DPNH are linked to the reduction of molecular oxygen Second the pyruvic acid produced through glycolytic or other mechanisms is further oxidized usually to CO_2 Third in most aerobic organisms alternative pathways either supplement or completely replace the glycolytic sequence of reactions for the oxidation of sugars Where pyruvic acid appears as a metabolic intermediate it is generally oxidatively decarboxylated to yield CO_2 and the two carbon acetyl fragment which combines with coenzyme A The acetyl group is then further oxidized via the Krebs cycle *See* KREBS CYCLE

The principal alternative pathways by which sugars are dissimilated involve the oxidation of glucose-6 phosphate to the lactone of 6 phosphogluconic acid and are known as the hexose monophosphate pathways In the best known hexose monophosphate pathway 6 phosphogluconic acid is formed from its lactone by hydrolysis and is oxidatively decarboxylated to yield CO_2 and the five carbon sugar ribulose 5 phosphate Ribulose 5 phosphate is then converted to glucose 6 phosphate through a series of reactions in which phosphorylated sugars containing three four five six and seven carbon atoms are formed as intermediates The principal enzymes involved in these transformations are transaldolase transketolase and epimerases Since the glucose 6-phosphate that is produced from ribulose-5 phosphate is oxidized by the same sequence of reactions the cyclic operation of this mechanism results in the complete oxidation of glucose Some of the enzymatic steps involved in this pathway provide the pentoses necessary for the synthesis of nucleotides and participate in the photosynthesis of green plants

Simple sugars other than glucose The metabolism of simple sugars other than glucose usually involves the conversion of the sugar to one of the intermediates of the phosphorylative pathways described for glucose metabolism For example fructose may be phosphorylated to fructose 6-phosphate which can then be degraded via the glycolytic pathway or converted to glucose-6-phosphate and oxidized through the hexose monophosphate pathway Similarly mannose may be phosphorylated to mannose 6-phosphate which is then transformed to fructose 6 phosphate by phosphomannose isomerase Alternatively in some bacteria mannose is epimerized to fructose before phosphorylation The principal mechanism for galactose metabolism requires the phosphorylation of the sugar to galactose-1 phosphate and the conversion of this ester to glucose 1 phosphate through the mediation of uridine diphosphoglucose Glucose 1 phosphate is then converted to glucose 6 phosphate by phosphoglucomutase *See* URIDINE DIPHOSPHOGLUCOSE (UDPG) The pentoses may be metabolized via their phosphate esters which are converted to glucose 6-phosphate as described in the discussion of the hexose monophosphate pathway

Disaccharides and polysaccharides The dissimilation and biosynthesis of the oligosaccharides are effected through the enzymatic cleavage or formation of glycosidic bonds between simple monosaccharide constituents of the complex carbohydrates The principal types of enzyme which split or synthesize glycosidic bonds are the hydrolases or glycosidases phosphorylases and transglycosylases The enzymes are generally highly specific with respect to the glycosidic portion or moiety and the type of linkage of the substrates which they attack For example the glycosidic moiety may be glucosidic or galactosidic and the linkage may be α or β The essential function of all three types of enzymes is the transfer of the glycosyl moiety of the substrate which may be designated as the glycosyl donor to an appropriate glycosyl acceptor with the liberation of the aglycone The different types of enzymes generally require different types of acceptors for the transfer reactions but some enzymes can use a variety of acceptors and can act in more than one capacity For example an enzyme can act as a phosphorylase transglycosylase or hydrolase for the same substrate

Hydrolytic cleavage is an essentially irreversible process and hence is used mostly in dissimilative metabolism Phosphorylases and transglycosylases on the other hand may function in biosynthesis as well as the degradation of oligosaccharides

The glycosidases or hydrolytic enzymes use preferentially the hydroxyl ion of water as the

glycosyl acceptor The aglycone is liberated after combining with the remaining hydrogen ion

Lactases for example are β galactosidases and they combine the β galactosyl portion of the disaccharide lactose with hydroxyl ion of water to yield galactose liberating glucose These enzymes can also hydrolyze methyl or phenyl β galactosides with the formation of galactose and methanol or phenol respectively

Maltases are α glucosidases which can hydrolyze maltose to two molecules of glucose

Sucrases or invertases are enzymes which hydrolyze sucrose to yield glucose and fructose The typical yeast invertase is a β fructosidase specific for the β fructosyl portion of sucrose The sucrase found in the human intestinal mucosa on the other hand is an α glucosidase

Amylases or diastases are enzymes which hydrolyze (digest) starch The α amylases such as the human salivary and pancreatic amylases split starch to smaller polysaccharide units known as dextrins and the disaccharide maltose The β amylase of malt on the other hand produces maltose as the main product of hydrolysis *See* DEXTRIN

The phosphorylases catalyze the reversible phosphorolysis of certain disaccharides polysaccharides and nucleosides by transferring the glycosyl moieties to inorganic phosphate The breakdown of glycogen and starch by the enzymes known as amylophosphorylases is an example of biologically important phosphorolytic reactions α D Glucose 1 phosphate which is the product of this process can be metabolized after conversion to glucose 6-phosphate Starch and glycogen can be synthesized from glycose 1 phosphate by the reverse reaction The polysaccharide chain acts as either donor or acceptor for glycosyl groups in organic phosphate being the alternative acceptor The reversible synthesis of sucrose sucrose phosphate and cellulose from uridine diphosphoglucose is similar to the phosphorolytic reactions with the uridine compound serving as glucosyl donor

The transglycosylases interconvert various disaccharides and polysaccharides by the transfer of glycosyl groups For instance dextrins can be synthesized from maltose in a reversible reaction catalyzed by the bacterial enzyme amylomaltase

$$n\underset{\text{Maltose}}{C_{12}H_{22}O_{11}} \rightleftharpoons \underset{\text{Dextrin}}{(C_6H_{10}O_5)_n} + n\underset{\text{Glucose}}{C_6H_{12}O_6}$$

Many glycosidases have marked transglycosylase activity *See* BIOCHEMISTRY [M D]

Carbomycin

A macrolide antibiotic isolated from fermentation broths of strains of *Streptomyces halstedii S hygroscopicus* and perhaps other species Macrolide antibiotics are basic antibiotics characterized by a macrocyclic ring structure Not infrequently small amounts of a second closely related antibiotic carbomycin B occur in the broth Carbomycin is known commercially as Magnamycin

Isolation and general properties The carbomycins are monobasic relatively high molecular weight substances Isolation from broth is readily accomplished by solvent extraction of the base re extraction of the acid form into water, and solvent extraction of the base Concentration in vacuo of the purified solvent extract yields white needle-shaped crystals of the base melting point 199 5–200 5°C The compound is optically active A 1% solution in chloroform is levorotatory

$$[\alpha]_D^{25} = -58\,6°$$

Acid salts are highly water soluble the base is only partially water soluble

Antimicrobial activity The antibacterial spectrum of carbomycin is very similar to that of penicillin for example it is principally active against gram positive bacteria with little or no activity against gram negative types with the exception of the *Neisseriae* Unlike penicillin carbomycin is also active against various rickettsiae such as those responsible for Rocky Mountain spotted fever and psittacosis (*see* RICKETTSIOSES) In general it does not cross resist that is organisms resistant to penicillin or streptomycin are not resistant to carbomycin with other nonmacrolide antibiotics such as erythromycin and oleandomycin

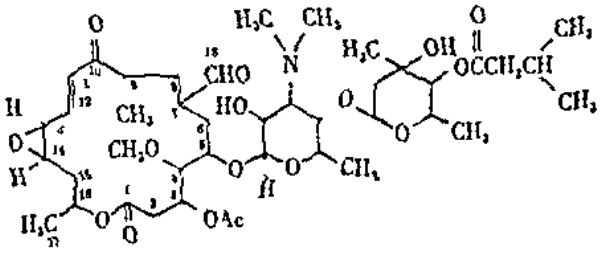
Typical antibacterial activity of carbomycin

Bacteria	Minimum inhibiting concentration μg/ml
Bacillus subtilis	0 3
Clostridium telani	0 3
Clostridium botulinum	1 5
Micrococcus flavus	0 15
Micrococcus pyogenes var *aureus*	0 15–1 5
Streptococcus pyogenes	0 03 2 5
Streptococcus fecalis	0 4 1 5
Diplococcus pneumoniae	03– 15
Haemophilus influenzae	1 5–6 2
Bordetella (Hemophilus) pertussis	3 1
Erysipelothrix rhusiopathiae	0 25
Neisseria gonorrhoeae	0 1–0 5
Neisseria meningitidis	0 2 1 5

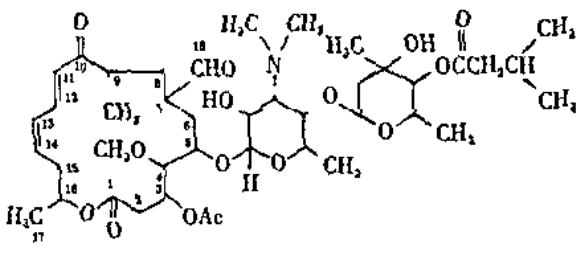
Carbomycin B exhibits the same spectrum of activity but is 40–60% less active

Chemistry The empirical formulas of carbomycin $C_{45}H_{67}NO_{16}$ (mol wt 842) and carbomycin B $C_{45}H_{67}NO_{15}$ (mol wt 826) are illustrative of the close relationship between the two compounds The structural formulas of both compounds have

[illegible] comprises three principal units (1) the isovaleryl ester of a C_6 deoxy sugar mycarose, linked to (2) a second C_6 deoxy sugar containing dimeth[illegible]



Carbomycin $C_{42}H_{69}NO_{16}$



Carbomycin B $C_{42}H_{67}NO_{15}$

ylamine, mycaminose, which in turn is linked to (3) a 17 member lactone (lactone + mycaminose = carimbose)

Pharmacology. Carbomycin has a low degree of toxicity in experimental animals Toxicity is expressed as LD_{50} or the dose which kills 50% of the animals tested (*see* LETHAL DOSE 50) The intravenous LD_{50} in mice is 550 mg/kg Daily oral or intramuscular administration, 200 mg/kg, in dogs for 20 weeks produced no untoward systemic symptoms Cats receiving 200 mg/kg intramuscularly for 9 weeks exhibited no evidence of eighth cranial nerve damage The eighth cranial nerve functions in hearing and balance [F W T]

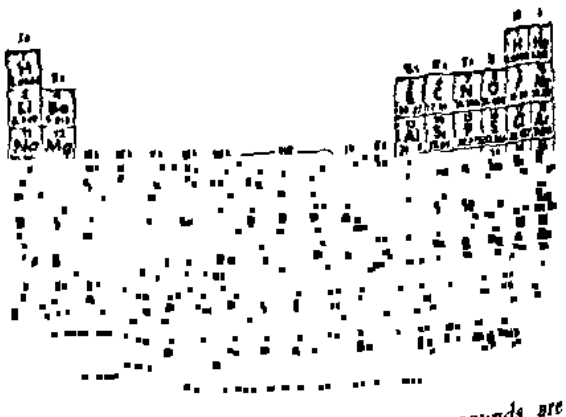
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Carbon

Chemical element number 6, carbon C, has an atomic weight of 12 011 The element is unique in chemistry because it forms a vast number of compounds, larger than the sum total of all other elements combined By far the largest group of these carbon compounds are those composed of carbon and hydrogen (*see* ORGANIC CHEMISTRY) It has been estimated that there are at least 1 000,000 known organic compounds, and this number is increasing rapidly each year Although the classification is not rigorous, carbon forms another series of compounds which are classified as inorganic compounds This group comprises a much smaller number than the organic compounds

Uses of the element and its compounds. The free element has many uses, ranging from ornamental applications of the diamond in jewelry to the black colored pigment of carbon black in automobile tires and printing inks. Another form of carbon, graphite, is used for high temperature crucibles, arc light and dry cell electrodes, lead pencils, and as a lubricant. Charcoal, an amorphous form of carbon, is used as an absorbent for gases and as a decolorizing agent. *See* CARBON BLACK; CHARCOAL; DIAMOND; GRAPHITE

The compounds of carbon find many uses Carbon dioxide is used for the carbonation of beverages, for fire extinguishers, and in the solid state as a refrigerant Another oxide of carbon, carbon monoxide, finds use as a reducing agent for many metallurgical processes Carbon tetrachloride and carbon disulfide are important solvents for industrial uses Gaseous dichlorodifluoromethane commonly known as Freon, is used in refrigeration devices Calcium carbide is used to prepare acetylene which is used for the welding and cutting of metals as well as for the preparation of other organic compounds Other metal carbides find important uses as refractories and metal-cutting tools



Occurrence. Carbon and its compounds are found widely distributed in nature It is estimated that carbon makes up 0 032% of the earth's crust. Free carbon is found in large deposits as coal an amorphous form of the element which contains additional complex carbon hydrogen nitrogen compounds Pure crystalline carbon is found as graphite and in small amounts as diamonds

Extensive amounts of carbon are found in the form of its compounds In the atmosphere, carbon is present in amounts up to 0 03% by volume as carbon dioxide Various minerals such as limestone, dolomite, marble and chalk all contain carbon in the form of carbonate All plant and animal life is composed of complex organic compounds containing carbon combined with hydrogen oxygen, nitrogen, and several other elements The remains of past plant and animal life are found as deposits of petroleum, asphalt, and bitumen Vast deposits of natural gas contain compounds composed of carbon and hydrogen

Physical and chemical properties. Elemental carbon exists in two well defined crystalline allotropic forms, diamond and graphite Other forms which are poorly developed in crystallinity are charcoal, coke, and carbon black

Charcoal is prepared by the ignition of wood sugar blood and other carbon containing compounds in the absence of air X ray diffraction studies reveal that it has a graphite structure but is not very well developed in crystallinity The lack of crystallinity is the result of defects in the crystal structure and the high surface area In the activated state charcoal adsorbs gases liquids and solids Activation of the charcoal is accomplished by treatment of the substance with steam this tends to remove the adsorbed hydrocarbons from the surface The adsorbing property of charcoal is related to the large surface area present It is stated that one cm^3 of charcoal has a surface area of 1000 m^2 *See* ADSORPTION

Coke another form of amorphous carbon is prepared by heating coal in the absence of air It is used primarily for the reduction of metal oxides to the free metals *See* COKE

Chemically pure carbon is prepared by the thermal decomposition of sugar (sucrose) in the absence of air Impurities in the carbon are removed by treatment with chlorine gas at red heat The substance is then washed with water and the residual chlorine is removed by heating in an atmosphere of hydrogen gas

The physical and chemical properties of carbon are dependent on the crystal structure of the element The density varies from 2 25 g/cm^3 for graphite to 3 51 g/cm^3 for diamond For graphite the melting point is 3500°C and the extrapolated boiling point is 4830°C. This is abnormally high because a large amount of energy is required to break the three dimensional covalent bonding in the crystal

Elemental carbon is a fairly inert substance It is insoluble in water dilute acids and bases and organic solvents At elevated temperatures it combines with oxygen to form carbon monoxide or carbon dioxide With hot oxidizing agents such as nitric acid and potassium nitrate mellitic acid $C_6(CO_2H)_6$ is obtained Of the halogens only fluorine reacts with elemental carbon A number of metals combine with the element at elevated temperatures to form carbides

Principal compounds Carbon forms three compounds with oxygen carbon monoxide CO carbon dioxide CO_2, and carbon suboxide C_3O_2 The first two oxides are the more important from an industrial standpoint

Oxides of carbon Carbon monoxide is prepared in the laboratory by the dehydration of formic acid with concentrated sulfuric acid

$$HCOOH + H_2SO_4 \rightarrow CO + H_2SO_4 \cdot H_2O$$

Similarly other organic acids can be used for example oxalic acid $H_2C_2O_4$ However in this case carbon dioxide is obtained along with the carbon monoxide The highest purity carbon monoxide is prepared by the thermal decomposition of nickel carbonyl at 200°C

$$Ni(CO)_4 \rightarrow Ni + 4CO$$

The industrial preparation of carbon monoxide is by the water gas reaction Water in the form of steam is passed over hot coke or coal at 600°–1000°C

$$C + H_2O(g) \rightleftharpoons CO + H_2$$

The temperature of the reaction must be carefully controlled because at 500°C carbon dioxide is obtained instead of carbon monoxide Also because the reaction is endothermic air must be passed over the heated coke or coal at regular intervals to maintain the minimum 600°C temperature *See* FUEL GAS

Carbon monoxide is a highly poisonous colorless odorless tasteless gas having a melting point of −205 1°C and a boiling point of −190°C The gas is stable at room temperature but at elevated temperatures it disproportionates into carbon and carbon dioxide

$$2CO \rightleftharpoons C + CO_2$$

This reaction is accelerated by the presence of certain metal catalysts At elevated temperatures the gas is an excellent reducing agent With metal oxides such as copper(II) oxide it gives copper metal and carbon dioxide

$$CuO + CO \rightarrow Cu + CO_2$$

Many other applications of this reducing property are known and perhaps the most important is the blast furnace reduction of iron(III) oxide to pig iron *See* IRON (EXTRACTION FROM ORE)

Carbon monoxide combines with many metals and nonmetals With chlorine in the presence of sunlight it forms highly poisonous phosgene $COCl_2$ with sulfur carbonyl sulfide COS is obtained A number of other carbonyl compounds are known such as carbonyl fluoride COF_2 carbonyl bromide $COBr_2$ and carbonyl selenide COSe

With metals a class of compounds known as metal carbonyls are formed These metals are from groups Ib IIb VIa VIIa and VIII of the periodic table The metal carbonyls can be prepared by the direct combination of the metal with carbon monoxide although several of the compounds require fairly high pressures With finely divided nickel the compound $Ni(CO)_4$ is formed at 50°C and normal atmospheric pressure

$$Ni + 4CO \rightarrow Ni(CO)_4$$

With others such as iron cobalt molybdenum and tungsten pressures of 200–450 atm and temperatures above 200°C are necessary to prepare $Fe(CO)_5$ $Co_2(CO)_8$ $Mo(CO)_5$ and $W(CO)_6$ respectively

The metal carbonyls react with the halogens to produce metal carbonyl halides With hydrogen a similar reaction takes place to form metal carbonyl hydrides

Nickel carbonyl finds application in the purification and separation of nickel from other metals (*see* NICKEL) Iron carbonyl has been used in antiknock gasoline preparations It is also used to pre-

Carbon monoxide may be considered to be the anhydride of formic acid It does not react with water however to form an acid solution It reacts with a sodium hydroxide solution at 140°C and under pressure to give sodium formate $NaCO_2H$ This solution on acidification gives formic acid

Carbon monoxide has assumed great importance in the field of synthetic organic chemistry By use of pressures of 100–200 atm temperatures of 300–600°C, and various mixed metal oxide catalysts direct combination reactions with hydrogen can be carried out to produce methyl alcohol and benzene

$$CO + 2H_2 \rightarrow CH_3OH$$
$$12CO + 3H_2 \rightarrow C_6H_6 + 6CO_2$$

Many other similar reactions utilize carbon monoxide

As stated previously carbon monoxide is extremely poisonous As little as 9 parts of the gas in 10,000 *parts of air will* cause nausea and headache and *slightly larger* amounts will cause death The physiological action of carbon monoxide poisoning is based *upon the formation* of a stable compound with the hemoglobin of the blood This compound is more *stable than oxyhemoglobin* thus body tissues are prevented from receiving the necessary oxygen *Caution should* be exercised in handling carbon monoxide at all times Automobile exhaust gas is a common *source of* carbon monoxide poisoning

Carbon monoxide can be detected by the green

absorbed in an aqueous solution of copper(I) chloride containing hydrochloric acid

Carbon dioxide is prepared by the combustion of *carbon* in air or by the *decomposition* of a metal carbonate with an acid or by heat *(see* CARBON DIOXIDE)

Carbon *suboxide* C_3O_2 is a lesser known oxide of carbon It *is prepared* by the dehydration of *malonic* acid HOOCCH COOH with phosphorus(V) oxide in a vacuum at 140–150°C

$$HOOCCH_2COOH \xrightarrow{P_2O_5} C_3O_2 + 2H_2O$$

Carbon suboxide is a gas with a
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Carbon tetrahalides Carbon forms compounds with the halogens which have the general formula CX_4 where X is fluorine *chlorine* bromine or iodine At room temperature carbon tetrafluoride is a gas carbon *tetrachloride is a liquid* and the other two compounds are solids All are covalent compounds with the *usual tetrahedral* structure

By far the most important carbon halide is car

$$CS_2 + 3Cl_2 \rightarrow CCl_4 + S_2Cl_2$$

The carbon tetrachloride is separated from the reaction mixture by fractional distillation Carbon tetrachloride is a colorless pleasant smelling nonflammable liquid with a melting point of −22.9 C a boiling point of 76.4°C, and a density of 1.595 g/ml at 20°C. The compound is an excellent solvent and finds much use as a solvent for fats greases waxes and many other organic compounds It is commonly used as a dry cleaning fluid and also as a spot remover for clothing

The heavy nonflammable vapor finds use in fire extinguishers The dense vapors exclude air and oxygen from the combustion area It should not be used to extinguish fires where hot metal surfaces are present In the presence of hot metals as catalysts water vapor reacts with carbon tetrachloride to produce among other products poisonous phosgene

Carbon tetrabromide and tetraiodide are prepared from the tetrachloride by reaction with aluminum bromide and aluminum iodide respectively Both of these substances are thermally unstable at elevated temperatures

Mixed carbon tetrahalides are also known Perhaps the most important of them is dichlorodifluoromethane CCl_2F_2 commonly called Freon It is prepared by the reaction of hydrogen *fluoride* with carbon tetrachloride in the presence of *antimony(III)* chloride Freon is used as a refrigerant *See* FREON HALOGENATED HYDROCARBON

Metal carbides Metal carbides are prepared by heating the metal metal oxide or metal *hydride* with carbon or other carbon compounds *The most* important of these carbides is calcium carbide CaC_2 This compound is prepared by heating calcium oxide CaO and coke in an electric arc *furnace* The most important use for calcium carbide is in the preparation of acetylene C_2H_2 *(see* ACETYLENE) Acetylene is obtained by the reaction of calcium carbide with water

$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$$

Many other metals react to form carbides for example titanium hafnium tantalum and tungsten This latter group of metals forms *refractory* type carbides they are noted for their extreme hardness (almost equal to that of diamond) and have very high melting points For example tantalum carbide TaC, has a melting point of about 3900°C All of these refractory carbides are chemically inert and are important for use as cutting tools in industry *See* CARBIDE

Analytical methods Carbon is usually determined as carbon dioxide The free element can be burned in air metal carbonates can be decomposed by acids or heat carbon monoxide can be burned in air and organic compounds contain carbon can be oxidized to give carbon dioxide The evolved carbon dioxide is weighed directly by absorption in a mixture of sodium hydroxide and calcium hydroxide contained in a glass tube *A* qualitative test for carbon dioxide is to pass the

through limewater a $Ca(OH)_2$ solution and observe the presence of a white precipitate of calcium carbonate $CaCO_3$ *See* ACTIVATED CARBON GERMANIUM SILICON [W W W E]

Carbon black

An amorphous form of carbon produced commercially by thermal or oxidative decomposition of hydrocarbons It is used principally in rubber goods pigments and printer's ink

Because of the irregular arrangement of its carbon atoms the physical properties of carbon black differ from the graphite and diamond forms of carbon The surface area of blacks used for rubber reinforcement ranges from 10 to 150 square meters per gram (m^2/g) when determined by nitrogen adsorption and the ultimate black particle has an average diameter of 20 to 300 millimicrons Pigment grade blacks have surface areas of 300–500 m^2/g Loose carbon black has a density of 2 3 lb/ft^3 but it is usually compressed for bag shipment or pelleted for bulk shipment in hopper cars

Principal noncarbon components of carbon black are oxygen hydrogen and sulfur Oxygen and hydrogen are combined chemically with carbon on the surface of the particle The ratio of hydrogen to oxygen varies with the manufacturing process In contact (channel) blacks oxygen content is 2 5% while hydrogen amounts to about 0 5% in furnace blacks the oxygen content is usually under 1% The amount of sulfur in the black depends on the sulfur content of the hydrocarbon feed

Manufacturing processes may be classed as contact furnace or thermal In the channel (contact) process natural gas is burned with insufficient air for complete combustion The smoky flame from individual burners impinges on a cool channel iron and carbon black deposited on the channel is removed by a scraper blade The yield of channel black is dependent upon the composition of the gas and the grade of black produced Yield of black decreases as the heating value of the natural gas decreases Of the three grades of black produced—Easy (EPC) Medium (MPC) or Hard (HPC) Processing Channel—the yield of EPC is lowest and averages about 1 3 $lb/1000\ ft^3$ of natural gas

In the furnace process the hydrocarbon and air are fed into a reactor Combustion of part of the hydrocarbon raises the temperature to 2000–3000°F causing decomposition of the unburned hydrocarbon to carbon black A water spray quickly cools the hot reaction products and the finely divided black is recovered by cyclones and bag filters Natural gas was the principal feed to the furnace process until 1943 when a furnace process utilizing heavy petroleum oils was introduced The oil black produced was superior for reinforcing synthetic rubber and oil furnace blacks now constitute the major type of carbon black produced The oil process can produce a variety of blacks designed for specific uses in rubber goods and tire manufacture Yield of carbon black from the furnace process depends on feed stock used and type of black produced ranging from 2 to 16 $lb/1000\ ft^3$ of natural gas and 2 5 to 6 lb/gal of oil

In the thermal process natural gas is decomposed to carbon and hydrogen by heated refractories Because this decomposition cools the refractories rapidly it must be periodically interrupted to reheat the refractories In one variant of this process employing acetylene as the feed heat is liberated during the decomposition of acetylene Acetylene black is distinguished by unusually high electric conductivity and it is used in the manufacture of dry cells

Over 90% of the production of carbon black in the United States is used by the rubber industry hence carbon black and rubber technology are interrelated Carbon black accounts for one fourth the weight of a tire It is not an inert filler but enhances and reinforces various properties of rubber Carbon black may be dispersed in rubber latex (masterbatch process) to produce after coagulation an intimate solid mixture of black and rubber ready for fabrication of rubber goods

Prior to 1940 channel black accounted for nearly 90% of domestic carbon black production In 1957 channel black accounted for less than 20% of the 1 800 000 000 pounds of black produced in the United States This dramatic shift from contact to oil furnace processes is the result of the rapid price increase of natural gas along with the superior performance of oil blacks in tire manufacture *See* DIAMOND DUST AND MIST COLLECTION GRAPHITE RUBBER [C J H]

Carbon dioxide

A colorless odorless tasteless gas about 1 5 times as dense as air The specific volume at atmospheric pressure and 60°F is 8 6 ft^3/lb It is a very stable compound composed of 1 atom of carbon and 2 atoms of oxygen and abbreviated by the chemist with the formula CO

The decay (slow oxidation) of all organic materials gives off carbon dioxide Fresh air contains approximately 0 03% carbon dioxide by volume In the respiratory action (breathing) of all animals and humans carbon dioxide is exhaled *See* RESPIRATORY SYSTEM

Under certain conditions carbon dioxide gas may be liquefied or even solidified If the gas at a pressure of 300 pounds per square inch gage (psig) is chilled to 0°F it will become a liquid However if it is not practical to chill the gas below 60°F it can still be liquefied by compressing [illegible] to 730 psig and chilling to [illegible] applied

If liquid CO_2 is chilled to −70°F the pressure will drop to 60 psig and carbonic snow will be formed This pressure and temperature of CO is known as the triple point at which all three phases [illegible] liquid and gaseous exist in equilibrium with

each other Further drop in pressure to atmospheric conditions will reduce the temperature of this snow to −110°F If this snow is compressed under a pressure of 1200 psig a block of carbonic ice (dry ice) will be obtained This ice is sold in 10 in cubes weighing approximately 50 lb

Carbon dioxide is obtained commercially from three sources natural wells by products from chemical processing and direct manufacture High purity CO_2 is found in natural wells located principally in the southwestern United States and in Mexico By product CO_2 gas is available from distillers in the fermentation of grain and from plants that burn limestone to make lime

Applications The uses of carbon dioxide may be classified into refrigeration inert gas chemical reaction and pressure medium groups

Refrigeration Solid carbon dioxide has a greater refrigerating effect than ice made from water because it evaporates directly as a gas and because it has an extremely low temperature It is particularly useful for preserving perishables in transit A small block of ice may be inserted in a package for self contained refrigeration or multiple blocks may be charged controlled ift parts to military specifications at −65°F and below either dry ice or low pressure (300 psig) liquid CO_2 may be used effectively Test cells may be refrigerated directly or a secondary fluid may be chilled and circulated through refrigerant coils in a closed circuit air stream Because of the low use factor of these test cells a CO_2 system is less costly and much more simple than a multi stage mechanical refrigeration system

Carbon dioxide liquid or ice may be used to advantage for embrittling the flash or rind of molded rubber parts This excess material is then easily removed by tumbling in an insulated barrel Liquid CO_2 is adaptable to an automatic barrel cycle a more economical process than hand trimming

Other uses of CO_2 for refrigeration include the chilling of shortening for homogeneous blending with dry ingredients by makers of pie crust mixes for mixing with hamburger and sausage meats prior to grinding for maintaining natural color and to avoid softening of spices chemicals and thermoplastic materials as well as increasing output during pulverizing

The refrigerating effect of CO_2 is dependent not only upon its physical state but also upon its pressure and temperature If one pound of solid CO_2 sublimes at atmospheric pressure a refrigerating effect of 246 Btu will be obtained This is 70% larger than that obtainable from an equal amount of water ice If it is possible to capture the refrigerating effect of the gas as it warms up from −110°F to 40°F an additional refr gera [illegible] F

[illegible] olatiles at higher temperatures (about 1% at 2800°F)

Liquid CO_2 discharged upon a fire can put it out quickly because of the blanketing effect of the inert gas and because it reduces the temperature below the ignition point

In the automatic electric arc welding of steel using a filler wire CO_2 may be used to prevent oxidation of the molten metal at a lower cost than with the use of argon gas

In paint manufacture CO_2 gas is bubbled through cooking vessels to provide agitation moisture removal and fire protection as well as to prevent skin formation on the surface of fluids in storage tanks

The shelf life of coffee and other foods may be increased when packaged in a CO_2 atmosphere by reducing oxidation from the air

Chemical applications The largest single market for CO_2 for chemical purposes is the carbonation of beverages in which the 'bite' is given to the drink by weak carbonic acid

Other uses include hardening of foundry cores in the core box by gassing a sodium silicate binder anesthetizing hogs to permit their easy shackling prior to slaughtering neutralization of water in municipal water softening plants manufacture of basic lead carbonate for paint and in the preparation of salicylic acid for aspirin

Pressure medium Because CO_2 is charged into cylinders in the liquid state one third more gas is available than from nonliquefied gases such as nitrogen

Life rafts and preservers are packaged to include small CO_2 cartridges which permit instantaneous inflation upon operation of a quick-opening valve Manufacturers of toy and target practice pistols use small CO_2 capsules to impart velocity to the bullet

Because of its inert characteristics CO_2 is an inexpensive safe gas used to force flammable fluids through pipelines

Manufacture Carbon dioxide is manufactured by the burning of high purity fuels such as hard coal coke fuel oil or natural gas The fuel must be burned efficiently with a minimum of excess air in the furnace of a water tube steam generator The flue gas is removed from the furnace and forced through one or more absorbing towers by means of a blower The CO_2 is selectively absorbed by a solution flowing countercurrent to the gas flow through the towers and the residual gas is finally discharged to the atmosphere

The concentrated solution is then pumped to the [illegible] ab- sorbing solution is returned to the absorb ers to repeat its cycle

The wet CO_2 gas from the plate tower is dried by condensing the moisture in a cold water heat exchanger The gas is then compressed in several stages by a steam driven reciprocating machine to a pressure which will condense the CO_2 gas with the coldest water available

Distribution Carbon dioxide is distributed in three different ways as high pressure liquid in steel cylinders as low pressure liquid in insulated truck trailers or insulated rail tank cars and as ice in insulated trailers or rail cars

If the temperature of liquid CO_2 is maintained at 0°F the vapor pressure will not exceed 300 psig thus permitting much lighter vessel construction This allows the shipper to transport 9 tons or more of liquid in an insulated truck trailer Suppliers of CO_2 provide their customers with 4- 6 or 12 ton insulated and refrigerated vessels for storage of the liquid under low pressure

If CO_2 is transported as ice no heavy pressure vessel is required However, part of the ice will be lost as it sublimes During sublimation the ice changes to a gas without going through the liquid phase By transporting the solid in a well insulated container sublimation losses may be kept within economical limits *See* SUBLIMATION

If the customer receives CO_2 in the solid form but requires it in the liquid or gaseous form he may liquefy the ice in a heavy steel vessel known as a converter A converter has an opening through which the ice may be inserted and then sealed with a pressure tight cover The ice will be converted to a liquid by the heat transferred from the atmosphere through the vessel wall *See* ATMOSPHERIC CHEMISTRY CARBON PHOTOSYNTHESIS [F C S]

Carbon star

A class of stars with an apparently high abundance ratio of carbon (C) to hydrogen (H) In normal stars, also oxygen (O) is in greater abundance than C C and nitrogen (N) are about equal In carbon stars C is more abundant than O The majority of the carbon rich stars are low temperature red giants of the C class showing bands of C_2 CN CH (the older designation of this type is R or N) A few hot carbon rich stars are also known An excess abundance of carbon is also found in the S (zirconium oxide stars) and the barium (heavy element stars) The C stars have surface temperatures in the range 5500–2500°K The degree of enhancement of C is variable from star to star An outstanding peculiarity is the presence of the carbon isotope C^{13} in some of these stars as shown by the presence of $C^{12}C^{13}$ and $C^{13}C^{13}$ bands with an abnormally high C^{13}/C^{12} ratio between 1 to 4 and 1 to 10 In some other C stars the $C^{12}C^{13}$ bands are absent indicating a low C^{13}/C^{12} ratio possibly near the terrestrial value of 1 to 90 *See* STAR [J L GR]

Carbon tetrachloride

A colorless dense liquid (specific gravity 1 595) of formula CCl_4 made by treating carbon disulfide with dry chlorine gas in the presence of a catalyst such as iron and also by chlorinating natural gas It is widely used in dry cleaning, as a solvent for various oils and greases as a fire extinguisher (particularly for oil and electrical fires), and in the manufacture of Freon refrigerants Carbon tetrachloride fumes may form phosgene gas a deadly poison It once was common as an insecticide and in the treatment of hookworm but because it irritates the skin and depresses the central nervous system it has been supplanted by other chemicals in these applications *See* HALOGENATED HYDROCARBON [G CO]

Carbonate

The CO_3 ion derived from carbonic acid H_2CO_3 which is a solution of carbon dioxide CO in water Because there are two replaceable hydrogen ions in carbonic acid the salts obtained by neutralizing only one hydrogen are called bicarbonates, for example sodium bicarbonate $NaHCO_3$

Carbonates can be converted into bicarbonates by adding excess carbon dioxide Eq (1) The re

$$Na_2CO_3 + CO_2 + H_2O \rightleftharpoons 2NaHCO_3 \qquad (1)$$

action can be reversed by heating At even higher temperatures a second reaction takes place for example limestone is converted to lime

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2 \qquad (2)$$

This reaction is commercially important in the production of lime and portland cement

Reaction (1) is the mechanism whereby the ground water in limestone areas dissolves $CaHCO_3$ to give hard water $CaHCO_3$ and bicarbonates in general are more soluble than carbonates All the carbonates except those of the alkali metals are insoluble

Sodium carbonate is produced by the Solvay process from the raw materials ammonia carbon dioxide and sodium chloride Sodium carbonate is used in the manufacture of glass paper and textiles *See* CARBON LIMESTONE [E E WR]

Carbonate minerals

Mineral species containing CO_3 groups as fundamental anionic units in the structure Mild treatment of carbonate minerals with acid will normally liberate carbon dioxide They may be divided into the following classes (1) anhydrous normal carbonates (2) acid carbonates or bicarbonates (3) hydrated carbonates and (4) complex carbonates which contain other anionic units in addition to the CO_3 groups

Common carbonate minerals The more common carbonates are of class 1 which includes calcite $CaCO_3$ magnesite $MgCO_3$, siderite, $FeCO_3$ rhodochrosite $MnCO_3$ smithsonite $ZnCO_3$ dolomite $CaMg(CO_3)_2$ ankerite $Ca(Fe\ Mg)(CO_3)_2$ and kutnahorite $CaMn(CO_3)_2$ These minerals all have hexagonal (rhombohedral) symmetry and structures similar to that of calcite The cationic radii are approximately 1 angstrom (A) or less Layers of cations alternate with layers of CO_3 groups the layers being stacked to lie at right angles to the main axis of symmetry In the last three minerals alternate cationic layers are of calcium *See* ANKERITE CALCITE DOLOMITE

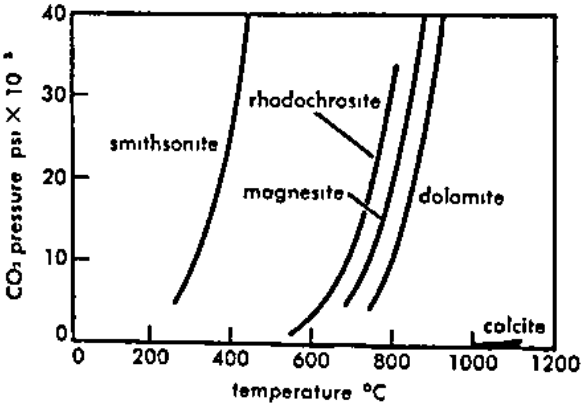


Fig 1 $P_{CO_2} - T$ diagram showing the upper limits of stability of several carbonates

KUTNAHORITE MAGNESITE, RHODOCHROSITE, SIDERITE SMITHSONITE

Other members of the same class are aragonite $CaCO_3$ witherite $BaCO_3$ strontianite $SrCO_3$ and cerussite $PbCO_3$ These are orthorhombic and have structures similar to that of aragonite in which the cations are approximately arranged as in hexagonal close packing The cationic radii are approximately 1 A or more Calcium with an ionic radius of about 1 A forms carbonates in both groups *See* ARAGONITE, CERUSSITE, STRONTIANITE, WITHERITE

Dissociation products On heating these carbonates break down to their oxides and carbon dioxide Dolomite ankerite and kutnahorite first dissociate to give oxides carbon dioxide and calcitic phases When heated in air the carbonates dissociate in the following order cerussite smithsonite siderite rhodochrosite magnesite dolomite and calcite At elevated pressures of carbon dioxide the equilibrium dissociation temperatures have been determined for several carbonates as indicated in Fig 1

All these carbonates may take various amounts of foreign cations into solid solution The equilibrium amounts of substitution as a function of temperature are indicated in Fig 2 for some rhombohedral carbonates *See* AZURITE, HUNTITE MALACHITE, *see also* ROCK, SEDIMENTARY ROCKS [R I H]

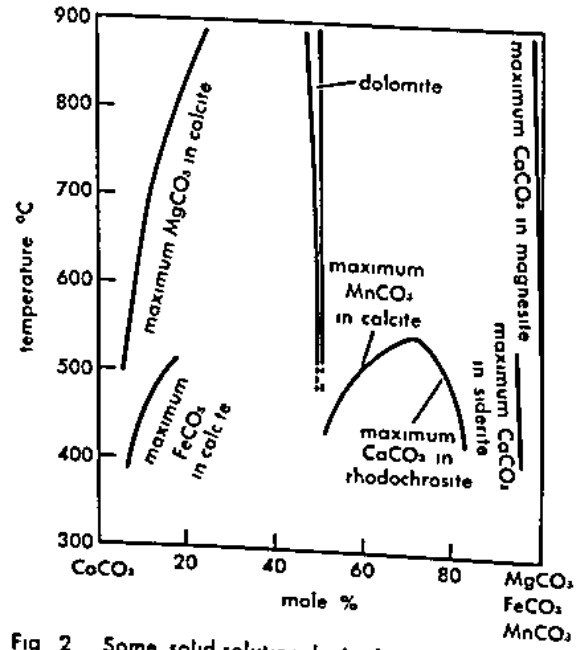
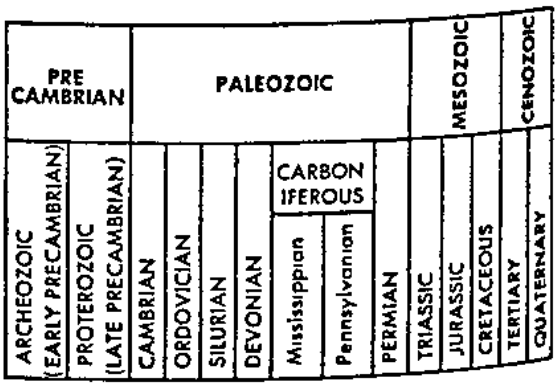


Fig 2 Some solid solution limits between anhydrous normal carbonates

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Carboniferous

A main division of late Paleozoic time following Devonian and preceding Permian The name Carboniferous Period introduced (1822) in England, refers to the prevailing prominence of carbon (coal) in sedimentary deposits formed at this time, especially in younger strata of the division called Coal Measures Black oil shale deposits of the Lower Carboniferous in Scotland also are rich in carbon content



Structural relations of the Carboniferous System to contiguous older and younger systems vary from place to place but in the type region of northern England the boundaries are well defined by angular unconformities In this area pre Carboniferous strata were considerably folded locally faulted and then beveled by erosion before sedimentation of the Carboniferous Period began Similarly the Coal Measures and underlying beds are found to be folded and truncated by erosion beneath Permian deposits Thus, separateness of the system is indicated in the rock succession Elsewhere in the world however determination of lower and upper boundaries of deposits classed as Carboniferous is not so simple for older and younger strata may lack discordant structure or any evidence of interruption in sedimentation Consequently, such terms as Devono Carboniferous and Permo Carboniferous are employed in places where classification is doubtful *See* UNCONFORMITY

Nature of deposits and their divisions Every continent contains important deposits of Carboniferous age and broadly these exhibit similar characters

Lower Carboniferous Lower Carboniferous formations called Mississippian in North America and in some other areas prevailingly consist of marine limestones rich in organic remains they furnish records of extensive submergences by shallow seas into which only small quantities of sand clay or other clastic (fragmental) detritus were brought from adjacent low lying lands Large amounts of dissolved silica were precipitated chemically or organically in many deposits along with calcium carbonate These Lower Carboniferous rocks are collectively known as Dinantian in Europe (or Avonian in the British Isles) they contain two main divisions (Tournaisian below Visean above) that commonly are separated by an unconformity denoting interruption in sedimentation and more or less erosion Total thickness ranges from 2000 to 3500 ft in Great Britain and 4500 ft in eastern Russia Especially in central Europe dark siliceous limestone (Kohlenkalk) interbedded with black shale replaces light colored limestone and this dark siliceous type of deposit is known as the Culm facies Rocks of Culm type are reported to be 40 000 ft thick in Czechoslovakia

Upper Carboniferous Upper Carboniferous formations which in North America are known as the Pennsylvanian System generally are much more varied [illegible]

few inches to a few feet but laterally they are very persistent This indicates geologically rapid changes in conditions of deposition that rather uniformly affected large areas with near or precise simultaneity Coal making conditions on an unprecedented scale distinguish the Upper Carboniferous they are not duplicated in any other part of earth history to such extent aggregate duration or quantity and quality of coal formed

In Europe a threefold major partition of Upper Carboniferous strata has been adopted Namurian at the base Westphalian in the middle and Stephanian at the top These are by no means equally distributed or closely comparable in average thickness and economic importance The Namurian named from Namur in southern Belgium and known as the Millstone Grit in England comprises 1000–5000 ft of alternating shale and sandstone mostly marine with minor coal beds locally it occurs chiefly in northwestern Europe The Westphalian typically defined in the Ruhr coal basin of Western Germany attains a thickness of several thousand feet (12 000 in Ruhr 8000 in northern England) it consists mainly of nonmarine shale sandstone and coal and is the most important coal bearing division The Stephanian is spotty in distribution generally less than 4000 ft thick and coal poor or barren in most places this division is named from a small basin in the eastern part of the Massif Central of France that as an exception to the rule yields considerable tonnage of coal

In the United States at least some deposits of Namurian age are classed definitely as Upper Mississippian (Chesteran) on reliable evidence furnished by marine fossils therefore the Pennsylvanian System is not precisely equivalent to Upper Carboniferous of European usage The Pennsylvanian which is richly coal bearing especially in states east of the Mississippi River is divisible into three main parts classed as series which are conveniently and simply referred to as Lower Middle and Upper Pennsylvanian Each contains important coal seams

Environments of sedimentation Important generalizations with respect to the conditions of origin of sedimentary rocks of Carboniferous age in most parts of the world are (1) persistence and very great geographic spread of shallow seas on continents in the early half of the period (2) abundance of marine transgressions and regressions in Late Carboniferous time combined with relatively brief duration and extraordinary extent of the submergences and (3) prevalence areally of coal swamp conditions associated with frequency in repetition of their establishment especially throughout the latter half of the period

The first mentioned feature of environment matched in several other parts of the geologic record favors intermigrations of bottom dwelling invertebrates and largely accounts for the cosmopolitan nature of Lower Carboniferous marine faunas facilitating interregional correlation of deposits The other characters cited are unique They indicate that in areas measuring many thousands of square miles on different continents surfaces of [illegible]

narily extensive coal swamps were formed again and again Meanwhile the areas receiving loads of sediment gradually sank The total amount of subsidence was measured by the aggregate thickness of accumulated deposits

The conditions just described are expressed by a widespread cyclic arrangement of alternating marine and nonmarine sedimentary layers of several sorts many times repeated in constant order of vertical succession (Fig 1) Such characters are seen in the upper part of the Lower Carboniferous (Yoredale beds) and throughout most of the Millstone Grit and Coal Measures of England in Namurian and Westphalian deposits of continental Europe and in Upper Mississippian (Chesteran) and Pennsylvanian strata of the United States A typical cyclic succession contains (in upward order) marine shale and limestone with fossils of nearshore type followed by offshore and then near

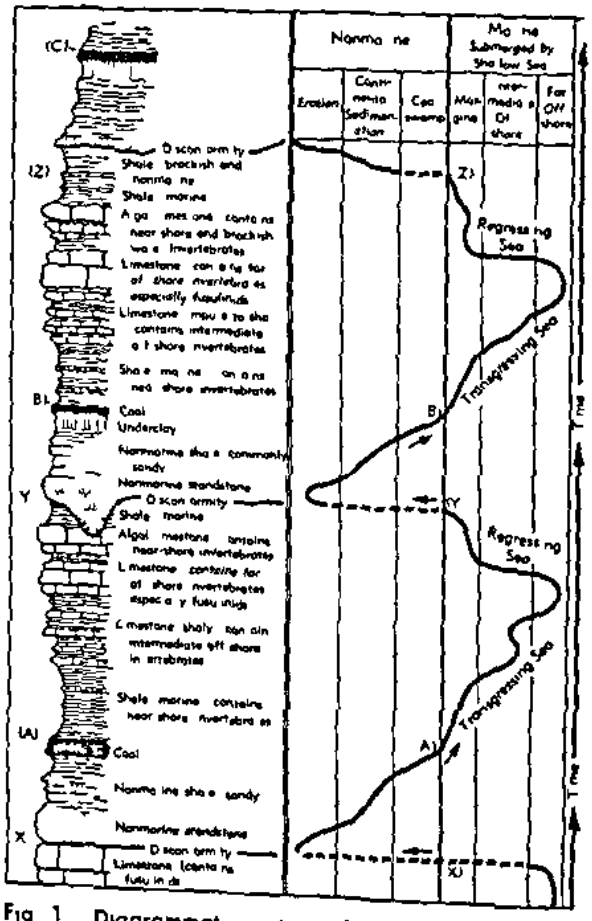


Fig 1 Diagrammat c section of Upper Carboniferous (Pennsylvanian) rocks in Kansas showing cyclic sedi mentation Repeated near ident cal sequences of ma r ne and nonmarine strata prove repeated submergence and emergence of cont nental interior regions The boundaries between successive cycles may be inter preted variously accord ng to one method by the ho rizon of change from nonmarine to marine cond tions (A B C on left on diagram) and according to another method by the horizon of change from marine to non mar ne cond t ons (X Y Z on diagram) Utility favors the latter method with boundar es at top of coals (From R C Moore Introduct on to Historical Geology, 2d ed McGraw-Hill 1958)

shore assemblages above the marine strata are subaerially deposited sandy and shaly beds that may contain remains of land plants and traces of land vertebrates these are succeeded by a layer of plastic clay (underclay) and a coal bed Overlying strata repeat this succession Each cycle furnishes record of the several differing sedimentary environ ments that followed one another at a given place during inundation by shallow sea water and later disappearance of the sea when sedimentation by streams and in fresh water lakes prevailed and coal swamp conditions eventually were established Drowning of the swamp by readvance of the sea in troduced a new cycle The upper part of the Car boniferous System contains scores of [illegible]

of mean sea level rather than only by period c slight crustal movements of the continents See CYCLOTHEM

Great lateral extent of many thin layers espe cially marine limestones and shales and numerous coal beds is observed in Upper Carboniferous de posits of central and eastern United States and of northwestern Europe The known distribution of some such individual units exceeds 10 000 square miles and it is very likely that many were originally at least ten times larger

Coal making The coal beds that especially char acterize the Carboniferous System almost invari ably lie on clay (underclay), clayey to silty or sandy shale, or shaly sandstone of subaerial origin They may be overlain by marine or nonmarine de posits The coal is a moderately hard black rock that leaves a residue of ash when burned Some coals ignite easily and burn with a yellowish flame [illegible]

of coal ranging from lignite through sub-bitumi nous and bituminous coal to anthracite All coal is composed mainly of carbon but low grade varie ties contain much more volatile matter (chiefly hydrogen and oxygen) than high grade types Mi croscopic study of coal proves that it is made up mostly of plant remains, among which identifiable elements include leaves flattened twigs or branches, and isolated cell structures of several sorts See COAL

The preservation of coal making plant remains from complete decay is attributable to the protect ing cover of water in the marshes or swamps where the plants of Carboniferous time grew Even under water there is partial decomposition through the agency of bacteria When the more or less altered plant material is compacted together peat is formed The conversion of peat to coal is accom [illegible] pro- less fer

ous coals are high grade because of the cons der able compression which they have undergone and their geologic age Anthracite coal occurs where the strata have been strongly folded and com pressed In coal basins such as the Ruhr where mining of different beds extends to depths of [illegible] ncrease ilt of vary

BOTANY

North America in Carboniferous time Evidence concerning conditions and events in North America during the Carboniferous Period is found not only in the very large areas where sedimentary deposits formed at this time are now exposed but also in a still larger territory mainly in western United States and Canada where these rocks are con cealed by younger formations (Fig 2) Subsurface

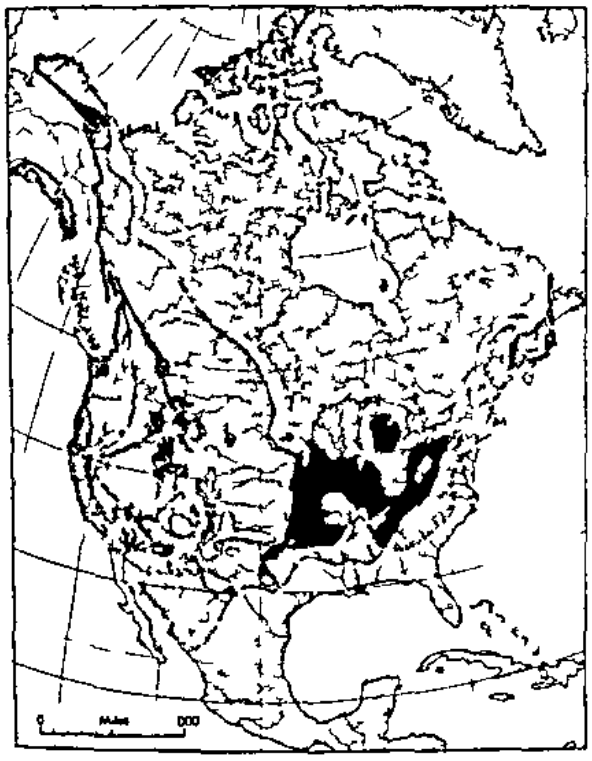


Fig 2 Distribution of Carboniferous rocks in North America Outcrops are shown in solid black and known or inferred subsurface occurrence by oblique ruling stippled areas indicate exposed pre-Carboniferous formations and blank areas occurrence of post-Carboniferous not underlain by Carboniferous.

information now is available from many thousand deep wells In addition fairly reliable inferences can be made concerning once-present deposits of Carboniferous age that have been eroded away for example in the Ozark region of Missouri and the Cincinnati Nashville upwarp extending from Tennessee across central Kentucky to Ohio Indiana and beyond

At the beginning of Carboniferous time a mountainous highland extended along the eastern border of the continent from Nova Scotia to Virginia from this area of erosion large quantities of detritus were carried westward and deposited partly as fluviatile sands and muds on a sloping plain and partly as near shore marine sediment Both types rested evenly on Upper Devonian strata with bedding planes parallel to them Farther west throughout the Mississippi Valley Great Plains and Rocky Mountains region basal Mississippian black marine shale similarly follows Devonian black shale or limestone with little or no interruption Therefore an initial submergence affected most of the continent probably excepting only border highlands and the very broad old rock lowland in central Canada known as the Canadian Shield. Continuation of submergence is recorded by the widespread nearly uniform limestone deposits that generally comprise the Mississippian formations, with thickness in places ranging to 1500 ft Limestone is prominent in Upper Mississippian deposits as far east as the border of the Appalachians although subaerially formed redbeds occur in Pennsylvania and West Virginia Relatively minor marine oscillations are indicated by unconformities observed in parts of the rock succession in some regions Interruptions of this sort accompanied by change in the fossil content of strata contiguous to the breaks serve to define divisions classed as series or stages in upward order called Kinderhookian Osagian Meramecian and Chesteran All are named from localities near the Mississippi River

Considerable difference in conditions of sedimentation was introduced in North America near the middle of Carboniferous time as shown by the strong contrast between Pennsylvanian and Mississippian formations almost everywhere Mainly the change reflects crustal movements that produced moderately to strongly elevated land masses especially along the eastern and southeastern margins of the continent and in parts of the Rocky Mountain region Mississippian rocks were eroded away partly or entirely in various places and enormous quantities of noncalcareous rock waste were spread out as layers of gravel sand silt and clay This denotes the exposure of source rocks other

ported and deposited mostly by subaerial agencies attained thicknesses ranging to 25 000 ft In the continental interior fine-grained clastic sediment partly marine and partly nonmarine occurs in extremely widespread sheets alternating with thin marine limestones Coal beds are numerous and also widely distributed In some places especially toward the top of the succession redbeds become prominent and marine layers disappear remains of land plants and vertebrates may be common The Pennsylvanian was a time of very frequently repeated shallow submergences and emergences that affected many hundred thousand square miles coincidently *See* GEOSYNCLINE REDBED

Mountain building More or less pronounced folding and faulting of rock formations produced mountain chains in various regions throughout the 55 000 000 year span of the Carboniferous Period

east to west trend in northern France Belgium and northwestern Spain and various other directions in central Europe Mountain building (called Bretonian) occurred near the close of Devonian time and very early in the Carboniferous especially in Brittany The so called Sudetian mountain building which chiefly affected central and southern Europe and northern Asia is dated as belong ing near the boundary between Early and Late

America there is evidence of mountain building in the Appalachian and Ouachita regions very early in the Carboniferous in the Arbuckle region of southern Oklahoma in the middle part of Late Pennsylvanian time and in western Texas near the close of the Carboniferous

Life of Carboniferous time. On land the Carboniferous Period is distinguished by richness of its lush vegetation and by presence of a considerable variety of spiders and primitive insects many amphibians the oldest known reptiles and fresh water fishes Ferns were a prominent element of the flora and ranged from delicate small plants to tropical tree terns 50 ft or more in height some 6000 species have been described Seed ferns are a special type that mark an advance in mode of plant reproduction Giant lycopods or scale trees which are relatives of modern club mosses many of them more than 100 ft tall were especially abundant in the Carboniferous coal swamp forests Associated with them were bamboolike horsetail rushes that grew to an equal height Large cockroaches and dragonflies with wingspreads of 30 in are among the types of insects well preserved as Carboniferous fossils The amphibians of this time were mostly diminutive creatures but some attained the size of crocodiles Conquest of the land by vertebrate animals is credited to Carboniferous reptiles which first became free of the necessity to begin life in an aquatic environment

Marine life of Carboniferous time was very abundant and varied It included nearly all known kinds of invertebrates and numerous sorts of sharks and other fishes Many Lower Carboniferous formations are characterized by the extraordinary abundance of sea lily (crinoid) remains to such an extent that culmination in development of these echinoderms is reckoned to have been reached at this time Among shelled invertebrates brachiopods were very numerous The most common and widely distributed forms were concavoconvex shells known as chonetids and productids Their occurrence is world wide Relatively giant spindle shaped protozoans (termed fusulinids) are characteristic fossils of Upper Carboniferous marine formations and are very useful for correlations See PALEOBOTANY, PALEONTOLOGY

Climate The prevailing climate in most of the world during Carboniferous time evidently was warm and humid as indicated by the nature of land floras and most shallow water marine fossil assemblages Parts of the Southern Hemisphere contain record of glacial conditions however and desert climate is indicated by some Carboniferous redbeds containing evaporite deposits

Economic resources The most important substances useful to man that are derived from Carboniferous formations are fuels These are solids (coals of several grades) liquids (petroleum) and gases (natural gas) The worth of their annual production is more than $1 000 000 000 Other important resources include clay stone lead zinc salt and gypsum [R C M]

Carbonium ion

One of the charged fragments which arise on heterolytic cleavage of a covalent bond involving carbon In the generalized equation

$$:\ddot{A}:\ddot{B}: \rightarrow :\ddot{A}^{+} + :\ddot{B}:^{-}$$

the atom, A loses the electron which it contributed in the formation of the covalent bond with B When A is carbon the fragment A^+ is electron deficient and acquires a positive charge Simultaneously the fragment, B, becomes negatively charged Although the existence of carbonium ions can be demonstrated in certain instances the concept of such a species as a reaction intermediate of extremely short life is a valuable tool in consideration of organic reaction mechanisms

As a rule formation of carbonium ions may be expected whenever an acid (in the Lewis sense) approaches a molecule capable of furnishing a pair of electrons This pair of electrons may be unshared as in oxygen compounds or may be those involved in a multiple covalent bond as in an alkene The acid may be a proton or other electron acceptor such as aluminum or boron halides which carry only 6 electrons in the valence shell

Examples of the formation of carbonium ions are the following:

$$R_2C{=}CH_2 + H^+ \rightleftharpoons R_2\overset{+}{C}{-}\overset{H}{\overset{|}{C}}{:}H$$

$$R_2C{=}\ddot{O}: + H^+ \rightleftharpoons R_2\overset{+}{C}{-}\ddot{O}{:}H$$

$$R_2C{=}\ddot{O}: + \ddot{Al}{:}Cl \rightleftharpoons R_2\overset{+}{C}{-}\ddot{O}{:}\ddot{Al}{:}Cl^-$$

$$R{:}\ddot{O}{:}H + H^+ \rightleftharpoons R{:}\overset{H}{\ddot{O}}{:}H \rightleftharpoons R^+ + :\ddot{O}{:}H$$

See CARBANION, ORGANIC REACTION MECHANISM [R L E]

Carbon-nitrogen cycle

The name applied to a theoretically deduced chain of thermonuclear reactions which appears to be important as an energy producing process in certain types of stars The cycle has the property that C^{12} (carbon) nuclei act as "catalysts" for a chain of nuclear reactions which finally converts four protons into one He^4 (helium) nucleus with a release of energy *See* NUCLEAR REACTION THERMONUCLEAR REACTION

The predicted sequence of reactions is as follows Collision of a proton with a C^{12} nucleus results in a p,γ reaction which yields N^{13} The N^{13} rapidly undergoes β^+ decay to C^{13} releasing about 1 Mev of energy Stable C^{13} undergoes another p,γ

reaction releasing 8 Mev and producing N^{14}. The N^{14} undergoes another $p\gamma$ reaction yielding 7 Mev. The resulting O^{15} nucleus undergoes β decay to N^{15} (releasing 1.7 Mev in positron and neutrino energy). At this point a $p\alpha$ reaction occurs producing a He^4 nucleus, a C^{12} nucleus, and 5 Mev of energy. Thus the chain is completed and a new C^{12} catalyst nucleus is created so that the reaction can continue.

The over-all rate of this cycle is essentially determined by the smallest cross section of the chain. These cross sections are not yet well enough known to determine the basic rates with precision so that the role of the carbon-nitrogen cycle relative to others such as the proton-proton chain is not accurately known (*see* PROTON-PROTON CHAIN). Published calculations predict that the C-N cycle rate exceeds the p-p chain rate only in stars with central temperatures $> 18 \times 10^6$ °K and is important only in particular evolutionary phases of certain types of stars. *See* STELLAR EVOLUTION.

[R. F. P.]

Bibliography: E. M. Burbridge, G. R. Burbridge, W. A. Fowler, and F. Hoyle, *Rev. Mod. Phys.* 29(4):547–650, 1957; A. G. W. Cameron, *Nuclear astrophysics*, *Ann. Rev. Nuclear Science*, 8:299, 1958; E. E. Salpeter, *Ann. Rev. Nuclear Science*, 2, 1953.

Carboxylic acid

One of a large family of organic substances widely distributed in nature and characterized by the presence of one or more carboxyl groups (—COOH). These groups typically yield protons in aqueous solution. *See* ACID AND BASE.

In the type formula $R(CXY)_nCOOH$ the symbols R, X, and Y can be hydrogen, saturated or unsaturated groups, carboxyl, alicyclic or aromatic groups, halogens, or other substituents, and n may vary from zero (formic acid, HCOOH) to more than 100, provided that the normal carbon covalence of four is maintained.

Nomenclature and general properties. According to the International Union of Chemistry an acid is named by its relation to the parent hydrocarbon, but in common practice trivial names are used often to indicate the origin of the substance. Thus HCOOH, formic acid (from Latin *formica*, ant), is properly methanoic acid, and $CH_3(CH_2)_7COOH$, pelargonic acid, from the leaves of *Pelargonium roseum*, is nonanoic acid. Substituents are located numerically on the carbon chain, counting the carboxylic carbon as 1, but an older common method uses Greek letters beginning with the carbon adjacent to the carboxyl. The following exemplifies both systems.

$$\overset{\varepsilon}{CH_2}\overset{\delta}{OH}\overset{\gamma}{CH_2}\overset{\beta}{CHBr}\overset{\alpha}{CHBr}CH_2COOH$$
$$6 \quad 5 \quad 4 \quad 3 \quad 2 \quad 1$$

is 3,4-dibromo-6-hydroxyhexanoic acid, or $\beta\gamma$-dibromo-ε-hydroxycaproic acid. *See* ORGANIC CHEMISTRY.

Physical and chemical properties of carboxylic acids are represented grossly by the resultant of the various chemical groupings present in the molecule. A short-chain aliphatic acid wherein the carboxyl is dominant is a pungent corrosive water-soluble liquid of abnormally high boiling point (because of molecular association) with specific gravity close to 1 (higher for formic and acetic acids). With increasing molecular weight the hydrocarbon grouping overbalances the carboxyl, sharpness of odor diminishes, boiling and melting points rise, the specific gravity falls toward that of the parent hydrocarbon, and the water solubility decreases. Thus the typical high-molecular-weight saturated acid is a bland waxlike solid.

Ionization and acidity. Ionization occurs on exposure to a proton acceptor (base in the Brønsted-Lowry sense) in water the opposing equations

$$R(CXY)_nCOOH + H_2O \rightleftharpoons R(CXY)_nCOO^- + H_3O^+$$

describe the fundamental equilibrium encountered with any feebly ionized or weak acid. Hydration of the proton to form H_3O^+ is virtually complete; thus the process of ionization is analogous to that of neutralization; the degree to which ionization proceeds varying directly with the basicity of the solvent (proton acceptor) and inversely with the O–H bond strength of the carboxylic hydroxyl group.

The above equilibrium leads to the dissociation constant K_a defined as

$$K_a = \frac{[H_3O^+][R(CXY)_nCOO^-]}{[R(CXY)_nCOOH]}$$

[illegible]

1.75×10^{-5}) which means that simple organic acids are only slightly ionized in aqueous solution. However, the degree of dissociation is sensitive to electronegative (electron-attracting) substituents, particularly when located on the α or 2-carbon (K_a for trichloroacetic acid 1.3×10^{-1}). *See* EQUILIBRIUM, IONIC.

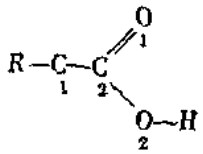
Table 1 presents a list of 30 saturated monocarboxylic acids together with their important constants. Also indicated is the main source of each acid; the letter S stands for synthetic, meaning that the acid is manufactured commercially by one or more of the methods described under synthesis. The fatty acids comprise a group of carboxylic acids both saturated and unsaturated, obtainable by hydrolysis of animal or vegetable fats and oils; these are indicated in the table by the letter F. Acids produced by fermentation processes are designated Ferm.

Structure and properties. The unionized carboxyl group has been shown via many classical studies to have the structure

Table 1 Saturated monocarboxylic acids*

Name	Formula	Main source	Melting point, °C	Boiling point °C
Formic	$HCOOH$	S	8 4	100 5
Acetic	CH_3COOH	S and Ferm	16 7	118 1
Propionic	CH_3CH_2COOH	S	−22 0	141 0
Butyric	$CH_3(CH_2)_2COOH$	F S and Ferm	−4 7	164 1
Valeric	$CH_3(CH_2)_3COOH$	S and *Valeriana officinalis*	−34 5	186 4
Isovaleric	$(CH_3)_2CHCH_2COOH$	F and S	−29 3	176 5
Caproic	$CH_3(CH_2)_4COOH$	F and S and by product in butyric Ferm	−1 5	205 8
Heptanoic	$CH_3(CH_2)_5COOH$	S from heptaldehyde	−7 5	223 0
Caprylic	$CH_3(CH_2)_6COOH$	F and S Goat's butter	16 3	239 7
Pelargonic	$CH_3(CH_2)_7COOH$	S Oxidation of oleic and *Pelargonium roseum*	12 5	255 6
Capric	$CH_3(CH_2)_8COOH$	F Coconut palm kernel oils	31 5	268 7
Undecylic	$CH_3(CH_2)_9COOH$	S Reduction of undecenoic acid	29 3	228/160 mm
Lauric	$CH_3(CH_2)_{10}COOH$	F Coconut and laurel oils	44 1	225/100 mm
Tridecylic	$CH_3(CH_2)_{11}COOH$	S	41 0	236/100 mm
Myristic	$CH_3(CH_2)_{12}COOH$	F Nutmeg oil	58 0	250/100 mm
Pentadecylic	$CH_3(CH_2)_{13}COOH$	S	51 0	257/100 mm
Palmitic	$CH_3(CH_2)_{14}COOH$	F Palm and olive oils	62 8	271 5/100 mm
Margaric	$CH_3(CH_2)_{15}COOH$	S	59 9	227/100 mm
Stearic	$CH_3(CH_2)_{16}COOH$	F Tallow and reduction of oleic acid	69 9	291/110 mm
Nonadecylic	$CH_3(CH_2)_{17}COOH$	S	66 5	298/100 mm
Arachidic	$CH_3(CH_2)_{18}COOH$	F Peanut oil	77 0	305/1 mm
Heneicosanoic	$CH_3(CH_2)_{19}COOH$	S	75 2	
Behenic	$CH_3(CH_2)_{20}COOH$	F Reduction of erucic acid	80 2	306/60 mm
Tricosanoic	$CH_3(CH_2)_{21}COOH$	S	79 1	
Lignoceric	$CH_3(CH_2)_{22}COOH$	F *Adenanthera pavonina* seed beechwood tar, rotten oak	84 2	
Pentacosanoic	$CH_3(CH_2)_{23}COOH$	S	83 0	
Cerotic	$CH_3(CH_2)_{24}COOH$	Beeswax carnauba wax	87 7	
Heptacosanoic	$CH_3(CH_2)_{25}COOH$	S	87 6	
Montanic	$CH_3(CH_2)_{26}COOH$	Montan wax from lignite	90 9	
Nonacosanoic	$CH_3(CH_2)_{27}COOH$	S	90 3	
Melissic	$CH_3(CH_2)_{28}COOH$	Beeswax	93 6	

* Based on A N Lange *Handbook of Chemistry* 9th ed McGraw-Hill 1956



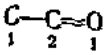
in which carbon 2 is doubly bonded to oxygen 1 and singly bonded to oxygen 2 Geometrical considerations lead to the conclusions that distance



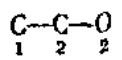
should be shorter than



and the angle



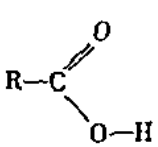
should be greater than angle



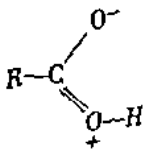
This is confirmed by measurements on crystalline acids, although the fact that the single bond



never reaches the normal length (about 1 44 Å) means that some resonance is involved between the two forms



and



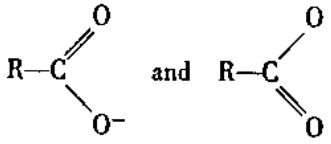
In the ionized state, however, the two resonating

Table 2. Dicarboxylic, aromatic, and unsaturated acids*

Name	Formula	Melting point °C	Boiling point °C
Dicarboxylic acids			
Oxalic	HOOC—COOH	189.5 (dec)	
Malonic	$CH_2(COOH)_2$	135 (dec)	
Succinic	$(CH_2)_2(COOH)_2$	185–187	235
Glutaric	$(CH_2)_3(COOH)_2$	98.0	302–304
Adipic	$(CH_2)_4(COOH)_2$	152	337.5
Pimelic	$(CH_2)_5(COOH)_2$	105–107 (Subl.)	272/100 mm
Suberic	$(CH_2)_6(COOH)_2$	142	279/100 mm
Azelaic	$(CH_2)_7(COOH)_2$	106.5	286/100 mm
Sebacic	$(CH_2)_8(COOH)_2$	134	295/100 mm
Aromatic acids			
Benzoic	C_6H_5COOH	121.7	249
o-Toluic	*o*-$CH_3C_6H_4COOH$	104	259/751 mm
m Toluic	*m* $CH_3C_6H_4COOH$	111	263
p-Toluic	*p*-$CH_3C_6H_4COOH$	180	275
o-Ethylbenzoic	*o*-$C_2H_5C_6H_4COOH$	68	259
m Ethylbenzoic	*m* $C_2H_5C_6H_4COOH$	47	
p-Ethylbenzoic	*p* $C_2H_5C_6H_4COOH$	113	
o-Fluorobenzoic	*o*-FC_6H_4COOH	122	
m Fluorobenzoic	*m* FC_6H_4COOH	124	
p-Fluorobenzoic	*p*-FC_6H_4COOH	182–184	
o-Chlorobenzoic	*o*-ClC_6H_4COOH	140.2	
m Chlorobenzoic	*m* ClC_6H_4COOH	154.3	
p-Chlorobenzoic	*p*-ClC_6H_4COOH	239.7	Subl.
o-Bromobenzoic	*o*-BrC_6H_4COOH	148–150	Subl.
m Bromobenzoic	*m* BrC_6H_4COOH	154–155	
p-Bromobenzoic	*p*-BrC_6H_4COOH	251–253	
o-Iodobenzoic	*o*-IC_6H_4COOH	162	
m Iodobenzoic	*m* C_6H_4COOH	187	Subl.
p-Iodobenzoic	*p*-IC_6H_4COOH	270	Subl.
Salicylic	*o*-HOC_6H_4COOH	158.3	211/20 mm
m Hydroxybenzoic	*m* HOC_6H_4COOH	201	
p-Hydroxybenzoic	*p*-HOC_6H_4COOH	215	
Gallic	3,4,5 $(HO)_3C_6H_2COOH$	235 (dec)	
Anthranilic	*o*-$H_2NC_6H_4COOH$	144–145	Subl.
m Anthranilic	*m* $H_2NC_6H_4COOH$	173–174	
p-Anthranilic	*p*-$H_2NC_6H_4COOH$	187–188	
α Naphthoic	α $C_{10}H_7COOH$	160–161	300
β Naphthoic	β $C_{10}H_7COOH$	184	>300
Unsaturated acids			
Acrylic	CH_2=CH—COOH	14	141
Crotonic (trans)	CH_3CH=$CHCOOH$	71.6	185
ι Crotonic (cis)		15.5	
Mesaconic (trans) / Citraconic (cis)	$HOOCC(CH_3)$=$CHCOOH$	202 / 91	250 (dec)
Tiglic (trans) / Angelic (cis)	CH_3CH=$C(CH_3)COOH$	64 / 45	198 / 185
Cinnamic (trans) / Allocinnamic (cis)	C_6H_5CH=$CHCOOH$	133 / 68	300 / 125/18 mm
Fumaric (trans) / Maleic (cis)	$HOOCCH$=$CHCOOH$	287 / 130	
Elaidic (trans)	$CH_3(CH_2)_7CH$‖$HOOC(CH_2)_7CH$	44	288/100 mm
Oleic (cis)		13	288/100 mm

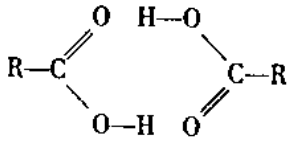
* Based on N. A. Lange (ed.) *Handbook of Chemistry*, 9th ed. McGraw-Hill, 1956.

forms of the anion are electronically equivalent



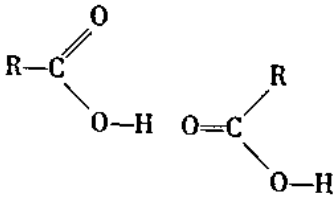
and the actual structure of the carboxylate ion is a stable hybrid of these *See* RESONANCE (MOLECULAR STRUCTURE)

In the free state (solid liquid or gas) the lower acids tend to exist as dimers in which two molecules are associated through relatively weak hydrogen bonds (energy about 5 kcal/mole)



[illegible]

(C8) there is a tendency toward polymorphism ascribable to hydrogen bonding of the following type

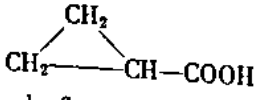


See MOLECULAR ASSOCIATION

As determined by x ray diffraction studies, the carboxyl and terminal methyl groups of acids containing an odd number of carbons are on the same side of the molecule with acids containing an even number of carbons these groups are on opposite sides permitting closer packing in the crystal lattice and consequent increased Van der Waals forces Thus the melting point of any even numbered acid lies above that of the preceding and following odd numbered acid

Structural variations These are of two types (1) variations not involving the carboxyl group and (2) variations involving the carboxyl leading to the acid derivatives

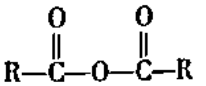
In the first type are such distinctive classes [illegible]



halogenated acids fluoro chloro or bromo, rarely iodo (*see* TRICHLOROACETIC ACID), hydroxy acids (*see* LACTIC ACID LACTIDE AND LACTONE, TARTARIC ACID) dicarboxylic and polycarboxylic acids (*see* ETHYL MALONATE, OXALIC ACID), aromatic acids (*see* BENZOIC ACID PHTHALIC ACID), β keto acids (*see* ETHYL ACETOACETATE), or amino acids (*see* AMINO ACIDS LACTAM AND LACTIM, PROTEIN)

An important class of acids contains unsaturated groups for example acrylic acid (CH_2=CHCOOH) Acids of this type are unstable and polymerize readily, they and their esters have been much studied for this reason *See* POLYACRYLATE RESIN

Among the variations involving the carboxyl group are found many important classes of substances derived from acids by suitable substitution within the carboxylic group Thus replacement of the hydroxyl group with alkoxyl gives esters (*see* ESTER, FAT AND OIL, NONEDIBLE, WAX ANIMAL AND VEGETABLE), replacement of OH by halogen forms acid halides (*see* ACID HALIDE ACYLATION) substitution of OH by amino (NH_2) group gives amides (*see* AMIDE ACID, UREA, UREID), intermolecular dehydration of two acids generates the anhydride structure



(*see* ACID ANHYDRIDE), the hydrolysis of long chain esters by alkali hydroxides forms soaps *See* SOAP AND DETERGENT

Table 2 lists some important dicarboxylic acids aromatic acids and unsaturated acids together with their important physical constants

Reactions and uses Acids are used in large quantities in the production of esters acid halides, acid amides and acid anhydrides Decarboxylation of acids to form hydrocarbons containing one less carbon is accomplished by pyrolyzing the sodium or barium salt with soda lime If the potassium salt is electrolyzed at a platinum anode (Kolbe electrolysis) the hydrocarbon RCH_2CH_2R is produced by the acid $RCH_2COO\ K^+$ Ethylenic and acetylenic acids containing unsaturation $\alpha\beta$ to the carboxyl are easily decarboxylated by heat Aromatic acids such as benzoic and toluic are frequently used as sources of hydrocarbons, the decarboxylation is effected by treating the acid in boiling quinoline with a copper powder catalyst

Many acids obtained by acid hydrolysis of fats or waxes are reduced to the corresponding alcohols for example lauric acid to lauryl alcohol The reaction is carried out in the laboratory by means of lithium aluminum hydride the industrial procedure utilizes hydrogen at elevated temperatures over a mixed catalyst of the oxides of copper and chromium

Acids find wide use in the manufacture of soaps and detergents in thickening lubricating greases (stearate soaps), in modifying rigidity in plastics, in compounding buffing bricks and abrasives and in the manufacture of crayons dictaphone cylinders and phonograph records The solvent action of acids finds use in manufacture of carbon paper inks and in the compounding of synthetic and natural rubber Because of the stability of saturated fatty acids toward oxidation these are often used as solvents for carrying out oxidation reactions upon sensitive compounds [EBR]

Carbuncle

An infection of the subcutaneous tissues in which multiple sinuses are created by tissue destruction caused by the spreading microorganism

The most common agent responsible for carbuncles is *Staphylococcus aureus* although other microorganisms are sometimes responsible. *See* STAPHYLOCOCCUS

Like boils or furuncles most carbuncles begin with the spread of infection from an initial site in a hair follicle or other superficial structure. The invading organisms multiply and penetrate into the deeper regions of the dermis subcutaneous tissues and sometimes even below the deep fascia of the body layers. Although the boil is typically a single pocket of pus the carbuncle differs by being multiloculated and usually deeper in its location.

The burrowing of the progressive infection is accomplished by destruction and lysis of tissue by bacterial enzymes which cause necrosis and coagulation of breakdown materials thus causing the tendency for localization of foci. *See* BACTERIAL ENZYME.

Quite often tissue penetration produces several superficial openings into the carbuncle all of which may drain pus.

Regional tenderness pain and swelling are usual. In older or debilitated persons there is a greater chance of such infections becoming blood borne with resultant bacteremia spread of abscesses to distant sites and severe damage to such organs as the kidney brain and lungs. [E. C. ST.]

Carburetor

The device that controls the power output and fuel feed of internal combustion spark ignition engines generally used for automotive aircraft and auxiliary services. Its duties include (1) control of the engine power by the air throttle (2) metering delivery and diffusion of fuel in the air stream (3) graduating the fuel air ratio according to engine requirements in starting idling and load and altitude changes.

Engine air charge A simple updraft carburetor illustrates basic carburetor action (Fig. 1). Intake air charge, at full or reduced atmospheric pressure as controlled by the throttle is drawn into the cylinder by the downward motion of the piston to mix with the unscavenged exhaust remaining in the combustion chamber from the previous explosion. The total air charge weight per unit time is approximately proportional to the square root of its pressure drop in the carburetor venturi throat (with a square root correction direct for change in air pressure and inverse for change in air absolute temperature). Also each individual cylinder air charge volume follows the intake pressure minus about one sixth the exhaust pressure so that the intake manifold pressure and temperature are often taken as an approximate indication of the engine torque this factor times the engine speed is similarly taken as a measure of the engine

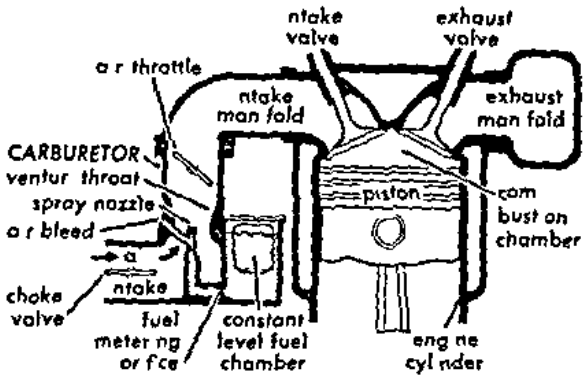


Fig. 1. Elements which basically determine the air and fuel charges received by the engine through the carburetor.

power output. Any given fixed part throttle opening gives higher intake manifold pressure increased individual cylinder air charge and greater engine torque as the engine speed is decreased.

A cylinder is most completely filled with the fuel air mixture when no other cylinder is drawing in through the same intake at the same time so that for high speed best power is usually obtained with multiple carburetor and intake duct units. However in practice it is more difficult to throttle all the cylinders equally when the multiple units are used.

Fuel charge The fuel is usually metered through a calibrated metering orifice at a differential pressure derived from the pressure drop in a venturi throat in the intake air passage. Since this fuel flow also follows the square root of its differential pressure the fuel and air rates tend to be accurately parallel particularly if a small bleed of air is fed into the fuel delivery or spray nozzle to overcome the retarding effect of surface tension.

Fuel air requirements For normal steady speed the limits of consistent ignition lie between 0.066 and 0.083 fuel air by weight (Fig. 2). Richer mixtures (more fuel) give higher power apparently cooler combustion and less detonation. The weaker mixtures give better fuel economy.

A narrowly controlled rich mixture is required for idling because low charge densities and relatively high contamination with residual exhaust

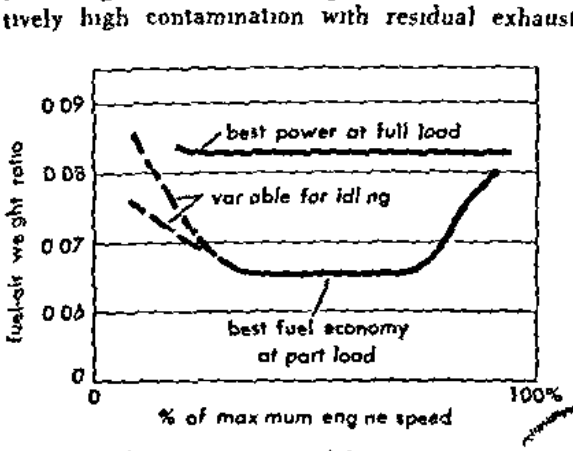


Fig. 2. Fuel-air ratios required for engine oper

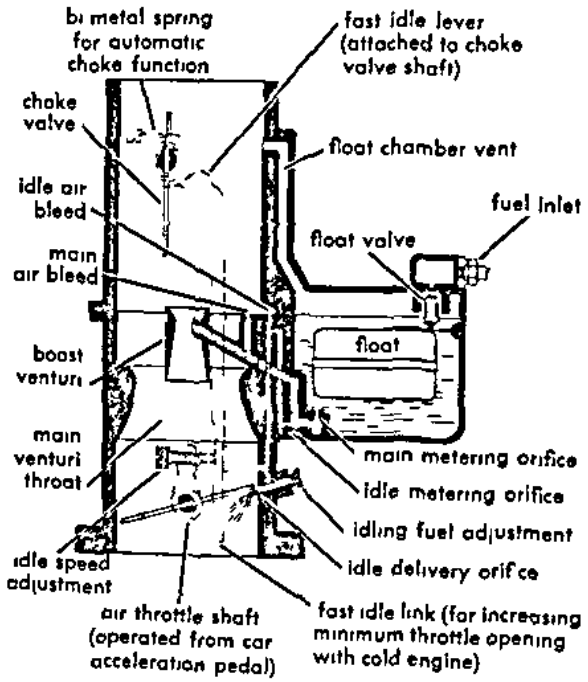


Fig 3 Idling fuel circuit and choke device for starting and warm up

make combustion conditions unfavorable Individual adjustments are required both for the idling fuel feed and for the throttle closure stop to keep the engine firing at minimum speed (Fig 3) Slight intake or exhaust valve leaks can make smooth idling impossible

Cold engine operation Motor fuels are a mixture of components varying in volatility usually selected so that they *evaporate* completely in the intake manifold at ordinary operating temperatures at the reduced pressures of part throttle but not at full throttle There is *a tendency* toward vapor saturation at full power and low engine speed so that richer fuel air ratios are required, especially with a cold engine For *starting at* low temperatures and for the first few ignitions with cylinder walls cold a great increase in fuel feed is momentarily required since only the most volatile part of the fuel can vaporize and burn

The higher metering suction necessary to give the excess fuel feed required for cold starting is usually supplied by a choke valve which may be manually or *automatically* operated Partial closure of this valve also yields the moderate enrichment needed during the warm up period While it is usually impossible to over choke a cold engine, an additional connection is generally supplied on passenger car carburetors *so* that pressing the accelerator pedal all the way down will open the choke valve and permit return to normal fuel feed

Automobile carburetion. An automobile engine performs through a *wider range* of loads and speeds than most prime movers Furthermore, its transient response to changes of load is highly important For these *reasons*, the functions of the automobile carburetor are complex Figure 3 is a section through one barrel of a typical down draft carburetor with the throttle closed to the idling position The multiple main and boost venturi structure is used to increase the fuel metering force for a given air delivery, also, it yields better metering regulation at the higher air velocities

Idling system To obtain adequate metering forces at low air speeds and small throttle openings, the fuel, after passing through the main metering orifice, is bypassed to an idle metering orifice, then to an idling delivery orifice located in the high suction at the edge of the throttle valve Some graduation of fuel feed from low to high idling speed is obtained as the throttle valve edge passes across the idling delivery holes

Because of increased piston and other friction with a cold engine, greater throttle opening as well as more fuel is required for idle at that time and it is common to interconnect the choke valve so that in its partly closed or cold engine position, the minimum throttle area is increased

Power enrichment The richer fuel feeds necessary for best power are customarily obtained by varying the area of the main metering orifice preferably by a valve responsive to intake manifold pressure beyond the throttle as shown on the right side of Fig 4 At light loads the lowered manifold pressure draws the enrichment valve down but a rise in manifold pressure resulting either from a drop in engine speed or added throttle opening will allow the plunger spring to open the metering orifice further An approximation of this function is obtained in some designs by a direct mechanical connection between the enrichment valve and the throttle

Transitional requirements Proper regulation under change of throttle is a major problem in obtaining what is commonly called good carburetor action Any lag in evaporation of the fuel when the throttle is opened tends to give a momentary delay in power response, which is usually compensated by an accelerating pump, shown on the left side of Fig 4 The pump gives a quick squirt of fuel as the throttle is opened The apparent willingness of the engine to respond to the accelerator

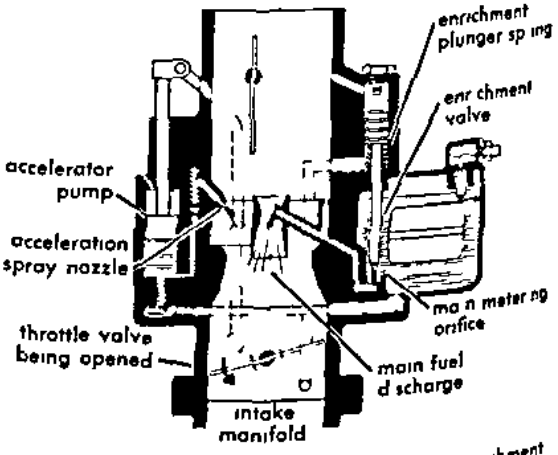


Fig 4 Special acceleration and power enrichment devices used on the automobile carburetor

pedal is largely determined by how accurately the accelerating pump discharge is proportioned to the existing engine temperature and to the volatility of the fuel in use

A converse transitional problem is associated with sudden closing of the throttle, when wet fuel is present on the intake manifold walls The sudden drop in pressure causes the liquid to flash into vapor, resulting in a temporarily over rich condition in the cylinder, with subsequent misfiring and incompletely burned combustion products in the exhaust Better manifold heating helps as does injection of fuel at cylinder intake ports

Aircraft carburetion Early aviation carburetors followed automobile carburetor practice, but in the 1940s the pressure or injection type came into use These incorporated the following advantages (1) The whole metering system is kept under pressure, to prevent formation of bubbles and disturbances to the metering under the reduced pressures at altitude (2) The fuel spray can be delivered into a heated part of the intake system so that ice formation resulting from fuel evaporation becomes impossible (3) Correction of the metering function under changes of altitude and temperature is automatically provided (4) The closed system permits a design that avoids disturbance of the fuel metering, or leakage from vents during vigorous maneuvers of the airplane

In the most commonly used form, the metering function of the automobile carburetor is retained in that the fuel metering differential, between chambers D and C of Fig 5 is derived from the multiple venturi air differential A minus B by the system of opposed synthetic rubber diaphragms as illustrated The idling spring adds a small positive increment to the A minus D force to provide the required rich idle fuel flow

The fuel pressure in chamber C is held to a desired value above the surrounding atmosphere by the fuel pressure valve and its regulating diaphragm and spring

Beyond the pressure valve the fuel may be led to a spinner ring which has multiple discharge orifices The ring is mounted on and rotates with the supercharger shaft On other common installations the fuel, after metering as here illustrated is taken to an injection pump which divides the charge equally and delivers a portion at much higher pressure to the interior of each engine cylinder on its intake stroke

The engine driven fuel pump pressure as regulated by its bypass valve, must be adequate to maintain flow through the system at the highest powers but beyond this it does not affect the fuel metering

Fuel air ratio as desired for light or full load or as selected by the pilot is controlled by one or more metering valves which collectively determine the flow area between pressures D and C A variety of combinations have been used but all are directed toward the regulation illustrated in Fig 2

Correction of the fuel air ratio at increased altitude or temperature is accomplished by bringing the pressure in chamber A down nearer to that in chamber B thus decreasing both the A minus B and the D minus C differentials A small fixed size depression vent V is provided between chamber A and the venturi communication channel, while a large pressure vent between the main air intake and chamber A is varied by the aneroid valve This valve is connected to the aneroid capsule a metallic bellows filled with inert gas and extended by a spring As the airplane gains altitude, or as the entering air temperature rises, the capsule extends to reduce the area of the entering air vent to cham

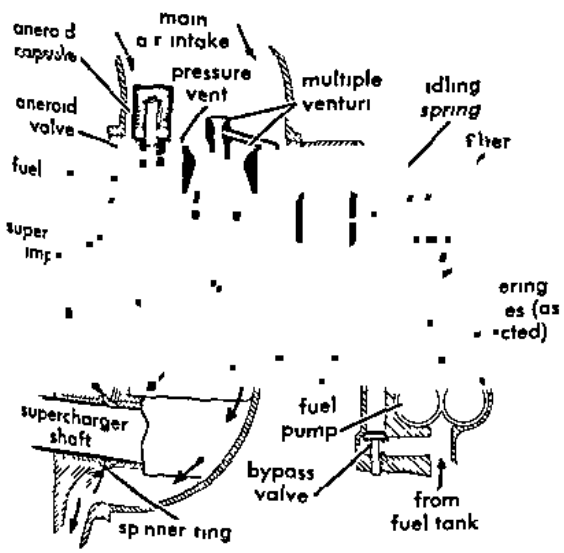


Fig 5 Schematic view of an aircraft injection or pressure-type carburetor

Deviations from the form of Fig 4 have been used on smaller American aircraft engines Occasionally in both England and the United States, similar construction has been used to regulate fuel feed by the parameters of engine speed and intake manifold pressure this is commonly called speed density metering

Carburetor icing There are two reasons for condensation of atmospheric moisture and formation of ice in the intake system First, at partly closed throttle the adiabatic pressure drop across the throttle orifice generates a temperature drop When

had time to build up With carburetors having a fuel discharge at the throttle edge (Fig 3), the addition of water soluble antifreeze to the fuel may reduce such icing tendency

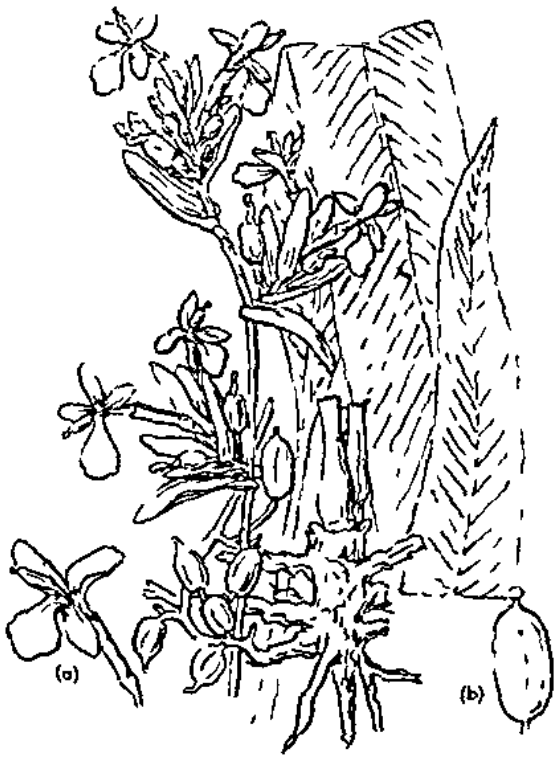
The other source of temperature drop in the intake system is the evaporation of fuel to form wherever fuel spray imp

heated surface Such icing was formerly encountered frequently in aircraft operation and was dealt with by heating the intake air which reduced the engine power and sometimes caused detonation Later the problem was largely eliminated either by use of the injection carburetor, which delivers fuel only in the warm parts of the intake system, or by direct injection into the engine cylinders [F C MO]

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Cardamon

For centuries this plant has been an important spice in the Orient The plant *Elettaria cardamomum*, a perennial herb 6–12 ft tall, is a native of India The small light colored seeds, borne in cap-



Cardamon (*Elettaria cardamomum*) (a) Flower (b) Fruit (From P DeJanville, Atlas de Poche des Plantes Utiles des Pays Chauds, Librairie des Sciences, 1902)

sules, have a delicate flavor They are used in curries, cakes, pickles, and in general cooking, as well as in medicine In India, the seeds are a favorite masticatory *See* SCITAMINALES, SPICE AND FLAVORING [P D S]

Cardinal

A brilliant, showy songbird, *Richmondena cardinalis*, of the family Thraupidae It is common throughout most of the United States and Canada east of the Great Plains, and southward into Central America Frequently it is called redbird The



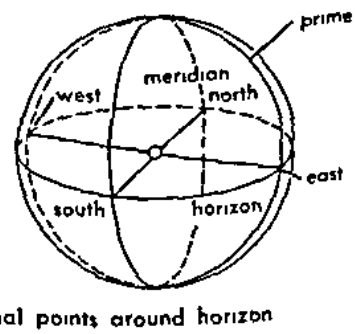
The cardinal, *Richmondena cardinalis*, length to 9½ in (From E L Palmer, Fieldbook of Natural History McGraw Hill, 1949)

cardinal male is 8–9 in long and solid red except for a black patch at the base of the bill The female and young birds are yellowish brown, suffused with varying degrees of red, depending upon age and sex The cardinal is the only red bird with a crest, and it has a short, stout, red bill It is nonmigratory The adults eat seeds; nestlings are fed insects There are several distinct subspecies In the arid Southwest of the United States there is a similar, related species, the pyrrhuloxia, *Pyrrhuloxia sinuata*, distinguished by its gray back

The cardinal is a friendly bird, welcomed as a yard and garden bird because of its brilliance and its assortment of loud, cheerful calls *See* PASSERIFORMES [J D B]

Cardinal points

The four intersections of the horizon with the meridian and with the prime vertical circle or simply prime vertical, the intersections with the meridian being designated north and south and the intersections with the prime vertical being designated east

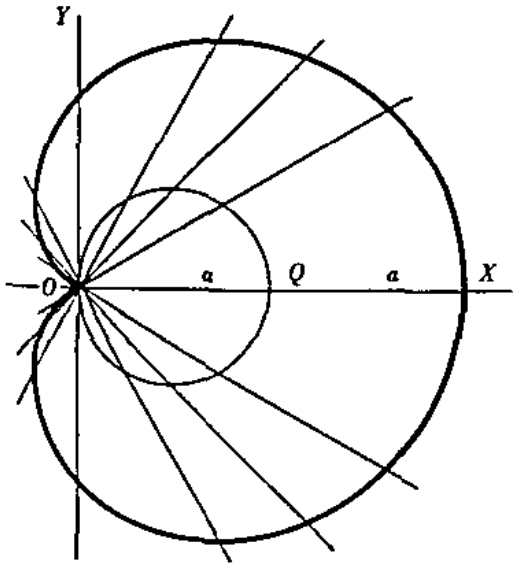


Cardinal points around horizon

and west The cardinal points are 90° apart, they lie in a plane with each other and correspond to the cardinal regions of the heavens The four intermediate points, northeast, southeast northwest and southwest, are the collateral points [F H R]

Cardioid

A heart shaped curve generated by a point of a circle that rolls (without slipping) on a fixed circle of the same diameter In point wise construction of the curve let O be a fixed point of a circle C of diameter a and Q a variable point of C Lay off distance a along the secant OQ in both directions from Q The locus of the two points thus obtained



Cord o d

is a cardioid If a rectangular coordinate system is chosen with O for origin initially and y axis tangent to C at O *the cardioid has equation* $(x + y^2 - ax)^2 = a^2(x + y^2)$ The equation in polar coordinates is $\rho = a(1 + \cos\theta)$ Its area is $\frac{3}{2}\pi a^2$ or six times the area of C and its length is $8a$ *See* Analytic geometry [L M BL]

Cardiovascular system

Those structures such as the heart or pumping mechanism and the arteries veins and capillaries which provide *channels for the flow of blood* The cardiovascular system is sometimes called the blood vascular system The circulatory system includes both the cardiovascular and lymphatic systems the latter consists of lymph channels (lymphatics) nodes and fluid lymph which finally empties into the blood stream This article discusses the cardiovascular system under the following major headings comparative embryology partition of embryonic heart functional development of the heart fetal circulation at term postnatal circulation comparative anatomy comparative physiology and congenital defects of the heart and of the great vessels *See* Blood Hematopoiesis Lymphatic system

COMPARATIVE EMBRYOLOGY

Heart The heart of each species attains its characteristic morphology through an orderly series of changes which begin in early embryonic life Although the details of development differ for different animals there are a number of basic principles which apply to all species Emphasis will be placed on the general principles first and species characteristics will be noted subsequently

The prospective heart rudiment that is the tissue which eventually differentiates into the heart can be located experimentally by explantation *transplantation and vital dyes before morphological* differentiation is observable The rudiment consists of bilateral areas of splanchnic mesoderm located near the blastopore in the early amphibian gastrulae and near the pharyngeal arches just prior to initial morphological differentiation

The heart field the mesoderm with potency for heart development is more extensive than the prospective rudiment which normally forms the organ For example a normal heart can develop in amphibians after complete removal of a visibly differentiated primordium This results from migration of mesoderm from the periphery of the field to *the region of extirpation*

The heart field like the prospective rudiment is bilateral The potency for cardiac development is greatest at the center of the field and least at the periphery The limits of the fields have been determined precisely in chick embryos by studies on the fates of small areas transplanted to the chorioal lantoic membrane *See* Fate maps embryonic

Induction The prospective rudiment in amphibian embryos becomes destined (determined) for heart development at the time of gastrulation through an inductive effect exerted by tissue adjacent to the blastopore Endoderm has a further *inductive* role on the heart forming mesoderm at the neurula stage as evidenced by lack of heart development following extirpation of the endoderm *See* Embryonic induction

Determination and self differentiation The prospective rudiment is determined early as outlined above This is tested by transplantation to abnormal environment

Polarity Polarity or axial determination occurs at different times for the different axes For example when the anteroposterior axis is changed by 180° in neurula stage amphibians the heart develops with reversed morphology and beat When the early rudiment is rotated around the long axis altering only the dorsoventral and ventrolateral axes the heart develops normally

Totipotency The ability of part of an organ rudiment *to develop* the whole organ is called totipotency Experiments on amphibians birds and mammals show that either of the bilateral rudiments is capable of developing a complete organ Furthermore a whole organ may form from less than one half that is several hearts can form from one rudiment

Tubular heart formation *The heart is usually* described as tubular during its early morphologi

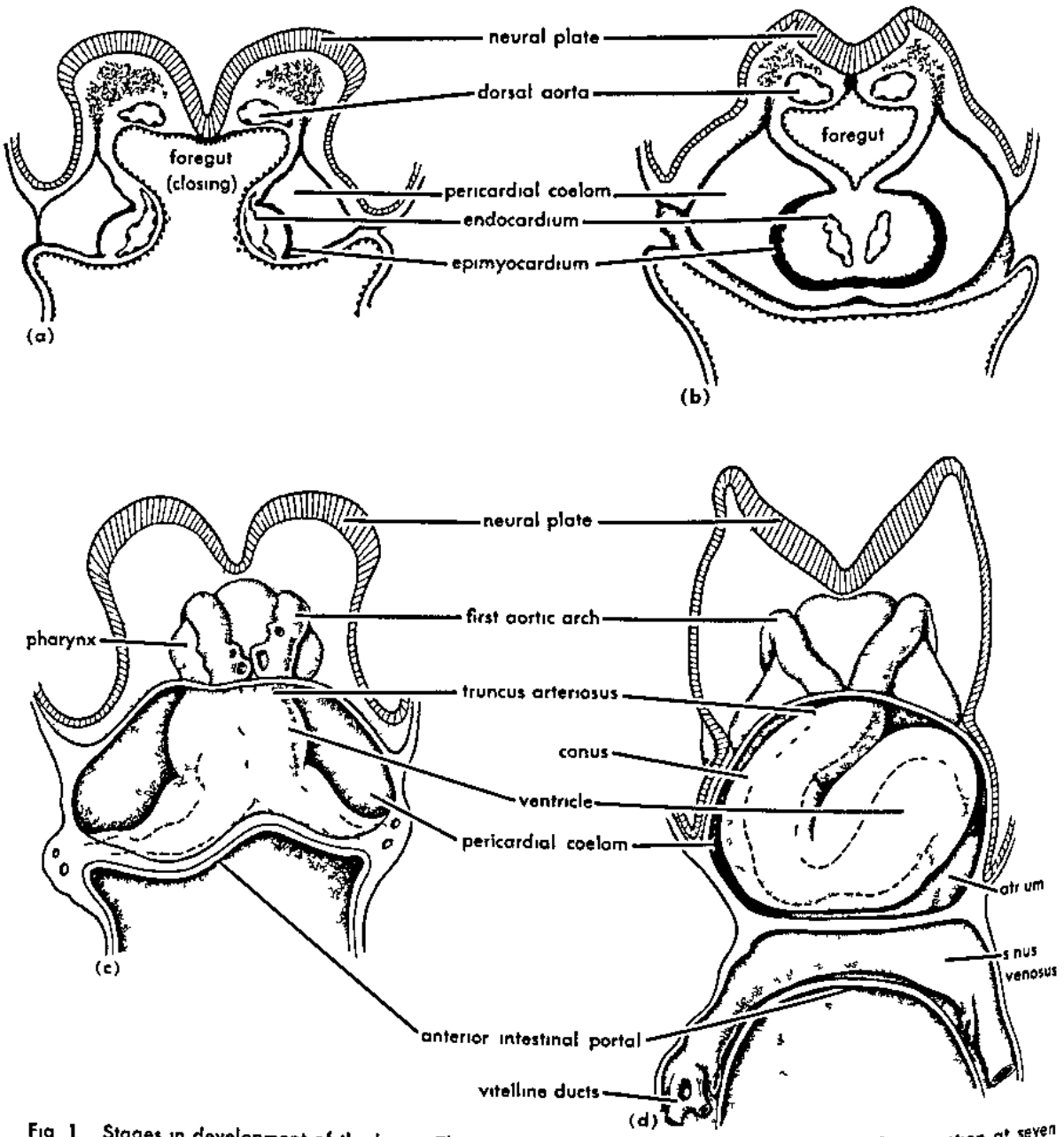


Fig 1 Stages in development of the heart The organ is depicted as translucent with the endocardium (broken lines) visible through the myocardium (a) Cross section from a four somite embryo (b) Cross section at seven somites (c) Ventral view at four somites (d) Ventral view at thirteen somites (*Modified after B M Patten*)

cal differentiation, although it is saccular in shape in most species

Mesenchymal cells arising from the splanchnic mesoderm of the heart rudiment differentiate into

The ventral portion of the splanchnic mesoderm of each bilateral heart rudiment thickens and differentiates into epimyocardium around the endocardium (Fig 1) A space between endocardium and myocardium during early development is filled with homogeneous material known as cardiac jelly It is eventually replaced by connective tissue uniting the endocardium and myocardium

The space between the splanchnic and somatic mesoderm of the heart rudiment becomes the pericardial cavity, and a part of the somatic mesoderm differentiates into parietal pericardium

Development of vertebrate heart The bilateral portions of the tubular heart approach the midline and unite to form a single tubular or saccular heart (Fig 1) Fusion progresses in a cephalocaudal direction Likewise, structural and functional differentiation of the chambers progresses cephalocaudally These chambers beginning with the most caudal one, are the sinus venosus atrium ventricle and bulbus cordis (conus) The sinus venosus receives the blood from the veins, the bulbus empties into the truncus arteriosus and thence into the aortic arches

The heart is attached not only by its vascular trunks but by a continuity of visceral pericardium with the serous portion of the parietal pericardium at its venous and arterial ends Attachment by a dorsal mesocardium persists for a brief period

During its growth the heart undergoes curvature which moves the venous end cephalically and the arterial end caudally until the entering and exiting vessels approximate the same level Curvature is the result of *differential* intrinsic growth and of mechanical factors (growth in length within the confines of the pericardial cavity)

Pulsations are initiated in advance of cardiac innervation this is one of the proofs of the myogenic origin of the beat Contraction also precedes the development of striations observable with the light microscope but this does not imply the absence of molecular orientation

Evidence from immunological techniques adapted for localizing myosin and actin in chick embryos indicates that contractile proteins are synthesized in the cardiac primordia before they are aggregated in the form of fibrils and before the initial stage of cardiac contractions

The first contractions begin in the ventriculobulbar area, and the rate is slow With further differentiation in a cephalocaudal direction the atrium and sinus venosus acquire the ability to contract each with a successively higher intrinsic rate which dominates its predecessors Early in embryonic life the sinus venosus becomes the pacemaker

Cardiac differentiation Cardiac differentiation follows a general plan in all vertebrate species during early development but varies for different classes and species in later development particularly in relation to partitioning into right and left chambers

In elasmobranch fishes the adult heart retains all the primitive chambers in an unpartitioned state

In amphibians the atrium acquires a partial division into right and left sides in salamanders and a complete division in frogs The other parts (sinus ventricle and conus) retain the primitive plan

In reptiles the atrium is divided completely and the ventricle partially

In birds the sinus venosus becomes largely incorporated in the right atrium which is divided completely from the left Likewise a septum completely separates the primitive ventricle into right and left sides The proximal portion of the conus becomes incorporated into the right ventricle and the distal portion of the conus and truncus arteriosus divide into right and left sides which constitute the pulmonary and aortic arches respectively

In mammals the incorporation of the sinus venosus into the right atrium becomes complete A specialized area within the primitive sinus known as the sinoatrial node serves as the cardiac pacemaker In mammals as in birds the primitive atrium and primitive ventricle are completely divided into right and left chambers

The interatrial partition arises through the development of two overlapping septa with the primary one serving as a valve for the foramen ovale in the secondary septum during fetal life

Complete division of the heart into right and left sides that is complete separation of respiratory and systemic circulations is achieved only in birds and mammals This supplies a higher arterial pressure on the systemic side and distributes materials to the tissues more rapidly than in animals with partial separation (reptiles) or those with no separation (fishes)

Embryogenesis of blood vessels The endothelial lining of the earliest embryonic vessels arises from mesenchyme with differentiation occurring first in the wall of the trophoblast and only slightly later in the body stalk and yolk sac The mesenchymal cells with potency to form endothelium are designated as *angioblasts*

According to one view (angioblastic theory) the vessels within the body of the embryo arise by migration of angioblasts from the body stalk and yolk sac According to the local origin theory the main intraembryonic vessels such as the aorta arise by in situ differentiation from vasoformative mesenchymal cells Most experimental evidence favors the latter view

After the main embryonic vessels have arisen new vessels arise by vascular sprouts from preexisting vessels Regeneration of endothelium of new vessels following injury in adult life is likewise dependent upon outgrowth from preexisting endothelium

Angiogenesis The earliest observable differentiation of endothelium occurs in blood islands of the trophoblast body stalk and yolk sac Each island consists of mesenchymal cell clusters in which the central cells differentiate into blood corpuscles and the peripheral cells elongate and transform into endothelium Growth and union of the isolated vascular spaces give a plexus of primitive vascular channels Endothelium of the main vessels of the body of the embryo differentiates also but without relationship to blood islands

Circulatory system morphogenesis The earliest vessels are anastomosing thin walled tubes (capillaries) lined only by endothelium In the course of differentiation some of the capillaries enlarge to form arteries and veins some remain as capillaries and some fall into disuse and atrophy It seems well established that the amount rather than the rate of blood flow through any given portion of a capillary plexus determines whether a vessel merely persists as a capillary or whether it enlarges to form an artery or vein In a similar manner alterations in vascular pathways occur after the capillary plexus stage of differentiation For example arteries atrophy when their blood flow is diverted to newly formed vessels

Formation of ventral aorta The aorta arises from bilateral primordia continuous with the bilateral cardiac primordia The bilateral [illegible] quickly fuse to form a common truncus

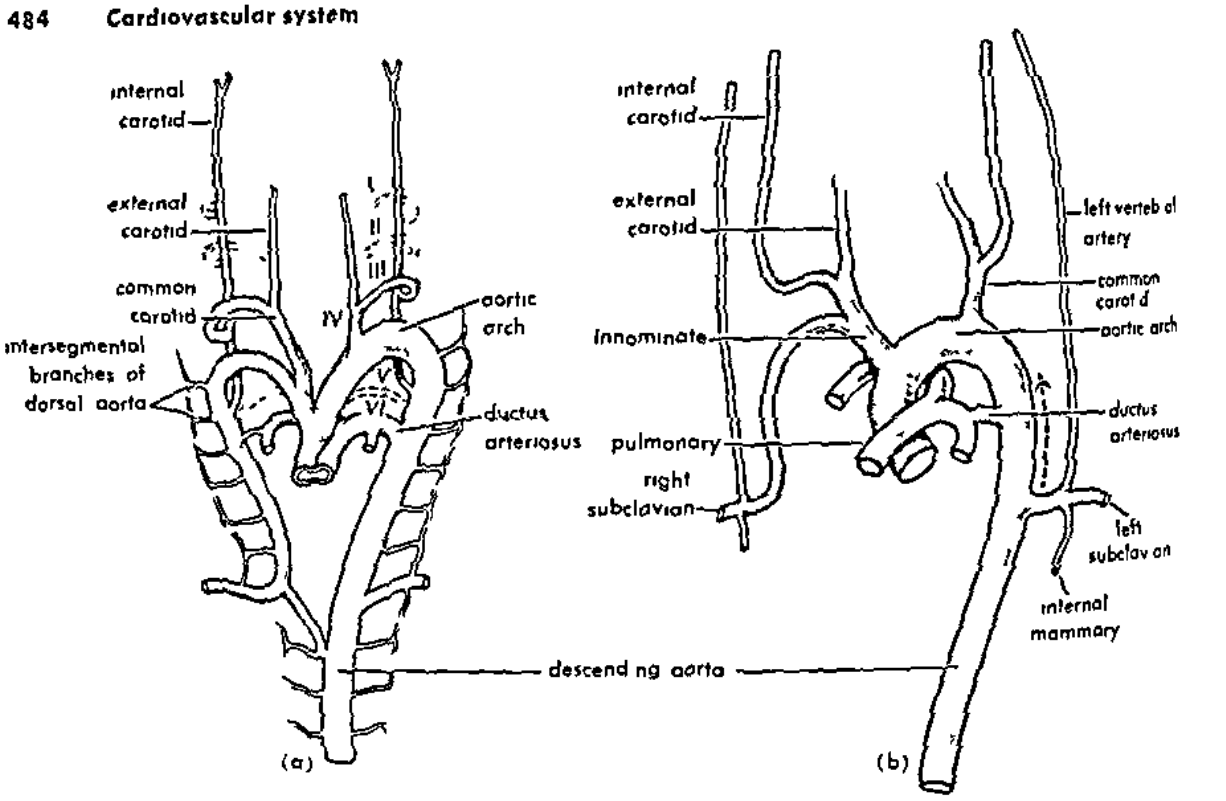


Fig 2 Transformations of human aortic arches ventral view (*a*) Diagram of early stage of transformation when the first *second and fifth* pairs of vessels (broken lines) have degenerated (*b*) *Adult* derivatives Diagram from a fetus shows the left subclavian arising from caudal part of the arch Left subclavian shifts to a higher position at a later stage, as indicated by the arrow Ductus arteriosus normally atrophies after birth (*Modified after B M Patten*)

continuous with the bulbus *cordis* By formation and fusion of two longitudinal ridges along the inner surface of the *distal* portion of the bulbus, the primitive aortic bulb is split into a pulmonary trunk and an ascending aorta The *latter* is relatively short in mammals It connects with the dorsal aorta by means of *aortic arches* which vary at different embryonic stages *and* the final pattern differs in different species

Formation of aortic arches In mammalian embryos there are usually *six* pairs of arches but these do not all function *simultaneously* Furthermore, the fifth pair is very rudimentary The arch *which* follows the questionable fifth one is usually called the pulmonary arch because it becomes a part of the pulmonary arterial system

The first pair of aortic arches forms in human embryos at the beginning of *the fourth* week and the remaining pairs develop in *sequence* during the fourth week Transformations (*Fig 2*) occupy *the fifth* to seventh weeks

The first and second pairs become *dysfunctional and* atrophy as the third and fourth *pairs* enlarge, and form more direct pathways from *the* ventral to the dorsal aortas Following atrophy of portions of the dorsal aortas between levels *of the third* and *fourth* arches the third arches and *cephalic* portions of the dorsal aortas remain as the paired primitive internal carotid arteries After the external carotid grows out from the third *arch*, the proximal portion is known as the common carotid

The fate of the fourth arches differs for *different* classes of vertebrates In mammals, the left fourth arch persists as the arch of the aorta, whereas the right fourth arch forms a portion of the innominate artery and the proximal portion of the subclavian artery (Fig 2) In birds the condition is the reverse of that in mammals with the arch of the aorta forming on the left In reptiles and amphibians, both fourth arches retain their connection with *the* dorsal aorta

Formation of dorsal aorta The dorsal aorta arises from bilateral primordia which persist as the paired internal carotid arteries cephalically (Fig. 2) and fuse caudally to form the unpaired descending aorta

The aorta has dorsal, lateral and ventral branches which are arranged serially There are about 30 pairs of dorsal branches which are also known as intersegmental arteries because they occur between successive body segments Each of *the* intersegmental arteries divides into dorsal and ventral rami, the dorsal rami give rise to the spinal and vertebral arteries and the ventral rami *form* the intercostals and lumbars

The lateral aortic branches are not segmentally arranged They form the renal, suprarenal *inferior* phrenic, and internal spermatic or ovarian *arteries*

The ventral aortic branches develop as paired vitelline arteries to the yolk sac They fuse *when* the paired aortas fuse Later, they are reduced *until* they occur only at three levels *forming the*

celiac, superior mesenteric and inferior mesenteric arteries

Arteries of the extremities Vascularization of the extremities illustrates the growth of given pathways within a plexus of vessels At first each extremity has a blood supply from several lateral aortic branches Then one lateral branch enlarges and the others fall into disuse In the arm the main stem is the brachial artery which is a continuation from the subclavian The extension of the brachial into the arm progresses by differential growth of pathways of a capillary plexus At one stage the brachial continues by the interosseous to the vessels of the hand Later when the median artery arises as a brachial branch and annexes the vessels of the hand the interosseous becomes less prominent At a still later stage the ulnar and radial arteries develop as brachial branches and become the main vessels of the forearm

The first axial vessel of the leg is known as the sciatic artery Later it is superseded by the femoral artery which is a continuation of the external iliac a branch of the common iliac After the femoral joins and annexes portions of the sciatic the proximal portion of the sciatic persists merely as the inferior gluteal whereas the distal part of the sciatic becomes the popliteal artery in continuity with the femoral

Primitive venous system In the early embryo there are three sets of paired veins of particular significance vitellines carrying blood from the yolk sac to the heart umbilicals from the placenta and cardinals from the head and body of the embryo

Changes in vitelline veins Changes in these vessels are correlated with the developing liver in the sense that there is a mutual intergrowth between cords of hepatic cells and endothelial sprouts from the vitelline veins Thus the vitelline veins are interrupted by liver sinusoids By enlargement of some of the sinusoids a direct channel is formed between the left umbilical vein and the proximal portion of the right vitelline (the future hepatic) the channel is known as the ductus venosus

Caudal to the liver the right and left vitelline veins become united by three cross anastomoses By growth of some parts and atrophy of other parts of this system the S shaped portal vein arises

The segment of the right vitelline between the liver and the heart becomes the hepatic vein the left vitelline of this level disappears

Changes in umbilical veins During its growth the [illegible] into the ductus venosus [illegible] umbilical vein and the ductus venosus persist as important vessels until birth then they atrophy and become the ligamentum teres and the ligamentum venosum respectively

Plan of the cardinal veins Paired precardinal veins from the head join paired postcardinals from the body at the level of the heart to form the common cardinals (ducts of Cuvier) During development parts of the postcardinals are replaced and superseded by subcardinals and supracardinals The major veins of the body arise through transformation [illegible] of the head vein drains anterior median and lateral plexuses over the brain The rostral portion of the head vein becomes the cavernous sinus portions of the anterior plexus enlarge to become the superior sagittal sinus and a dorsal connection between the middle and posterior plexuses becomes the transverse sinus

The main precardinal stem of each side becomes the internal jugular vein as far caudal as the level of a shunt from the left to the right precardinal (Fig 3) The shunt itself becomes the left innominate and the left precardinal caudal to the shunt remains as the relatively small first intercostal

The right common cardinal with the right precardinal up to the point of intercardinal anastomosis forms the superior vena cava The left common cardinal of man persists as the small oblique vein of the left atrium As a congenital anomaly it may remain as a left superior vena cava In some mammals and in the lower vertebrates two superior venae cavae (left and right) occur normally

Postcardinal system transformations The postcardinals develop primarily as vessels of the mesonephroi and their fate in different species varies with that of the mesonephroi In *Petromyzon* the postcardinal of each side remains as in the embryo in elasmobranchs the plan is modified by a renal portal system and in man and some other mammals the postcardinals become altered as shown in Fig 3 This transformation is related to the development of subcardinal veins ventral to the mesonephroi and supracardinals dorsomedial to the postcardinals Parts of each of these systems contribute to the formation of the inferior vena cava (Fig 3)

Veins of the extremities These develop by channels within capillary plexuses as already described for the arteries Each extremity of an early embryo develops a peripheral or border vein In the upper extremity the border vein persists on the ulnar side as the subclavian axillary and basilic veins in the lower extremity it persists on the fibular side

Pulmonary veins These develop from pulmonary plexuses At one stage of development all branches combine to open by a single stem into the left atrium By growth of the atrium more of the pulmonary vessel is drawn into the atrial wall until there are four pulmonary vein openings into the atrium two from each lung [W M C]

PARTITION OF EMBRYONIC HEART

The partitioning of the heart in the embryo involves far more than its str[illegible]

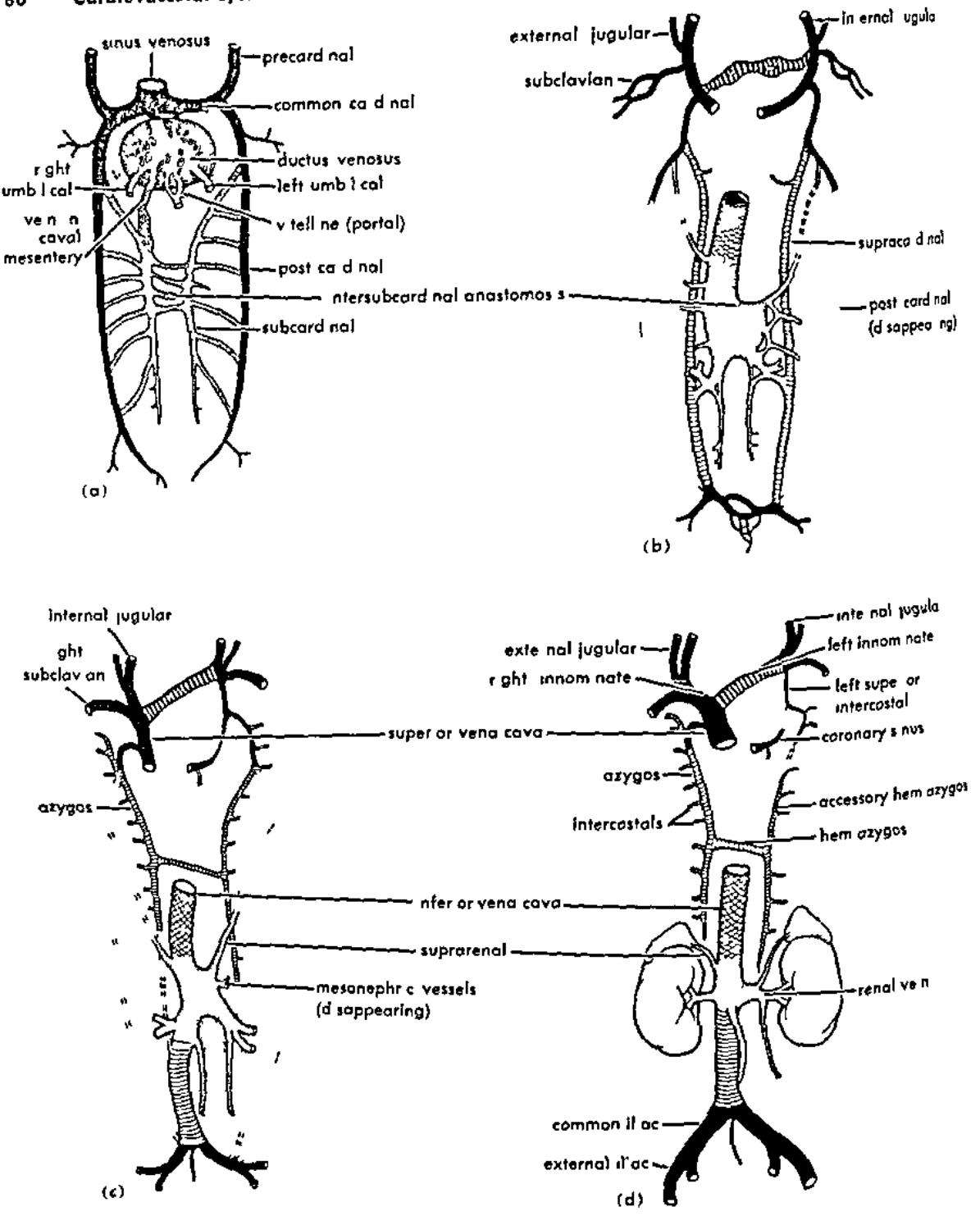


Fig 3 Transformat ons of pr mit ve ve ns of a human embryo ventral v ew (a) At 5½ weeks (b) At 7 weeks (c) At 8 weeks (d) At term In (a) prox mal port ons of the umb l cals (broken l nes) have atroph ed Rema nder of the right umb l cal atroph es later Vitell nes (am phalomesenterics) have been interrupted by l ver s nuso ds R ght prox mal v tell ne has enlarged and w ll become the hepat c Caudal portions of vitell nes are transform ng into the portal ve n A connect on from the hepat c to the subcard nals v a the ventral mesentery will form hepat c segment of nfer or vena cava Vessels associated w th the l ver are om tted f om (b) (c) and (d) (*Mod f ed after B M Patten and after C F W McClure and E G Butler*)

into chambers The process is beset by striking functional exigencies Starting in a young embryo as a simple valveless tube with the blood passing through it in an undivided stream the heart by the time of birth must become converted into an elaborately valved four chambered organ pump ing from its right side a pulmonary stream which is returned to its left side to be pumped out aga n over the aorta as the systemic blood stream During these changes there can be no interruption in the

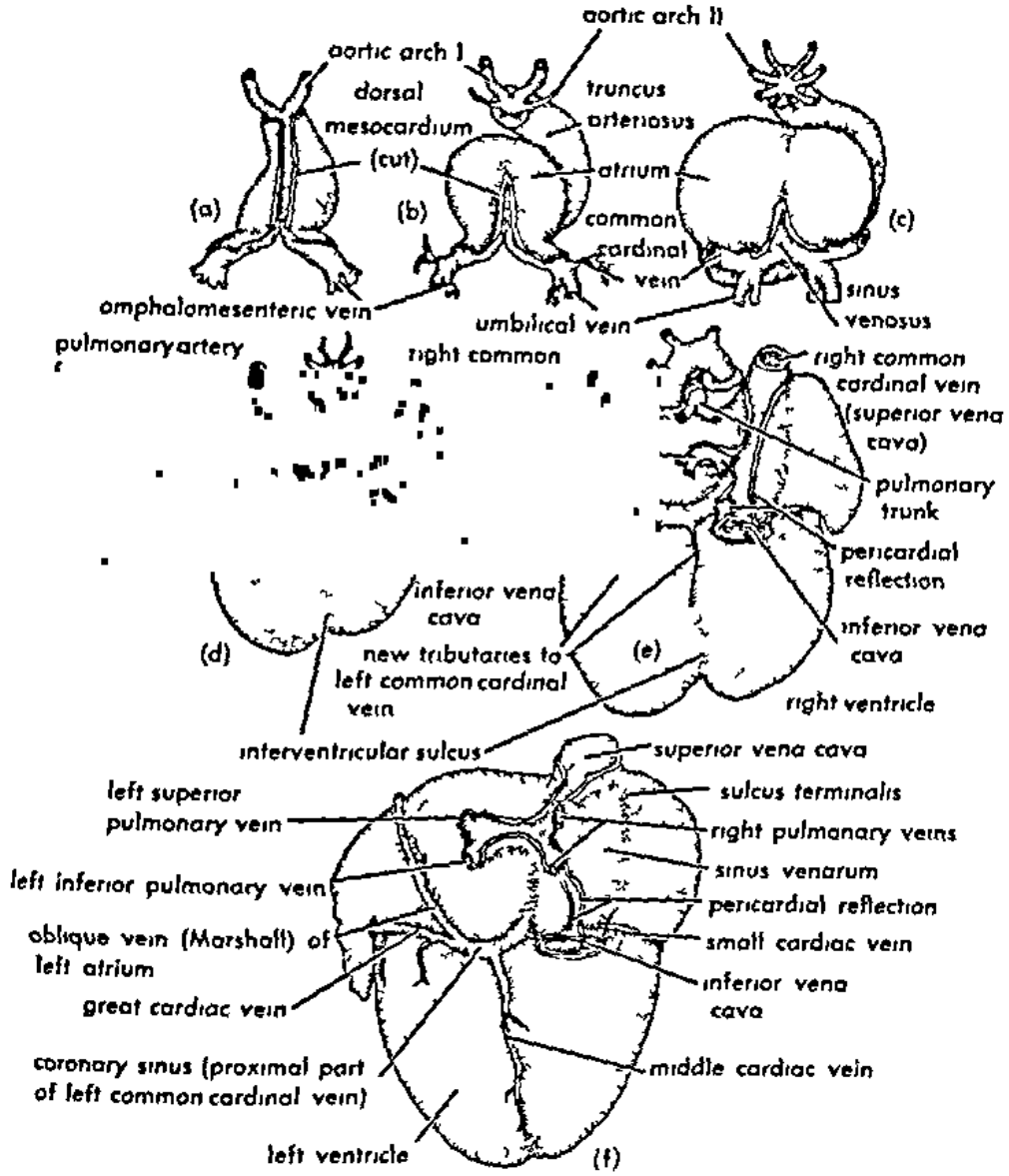


Fig 4 Six stages in development of the heart in dorsal aspect to show changing relations of the sinus venosus and great veins entering the heart (a) 2½ weeks (8–10 somites) (b) 3 weeks (12–14 somites) (c) 3½ weeks (17–19 somites) (d) 5 weeks (6–8 mm crown rump) (e) 8 weeks (about 25 mm) (f) 11 weeks (about 60 mm) (From B M Patten Human Embryology 2d ed Blakiston–McGraw Hill 1953)

blood supply to all parts of the growing embryo Moreover at the end of gestation, the vascular mechanism must be prepared for air breathing instead of the aquatic life of the embryo submerged in amniotic fluid The lungs their blood vessels and the right ventricle which pumps the pulmonary circuit must at the moment of birth be ready to take over from the placenta the entire responsibility of oxygenating the blood

The systemic part of the circulation must also be prepared Throughout intrauterine development the left side of the heart receives less blood by way of the pulmonary veins than the right side of the heart receives from the vena cava However after birth the left ventricle will be called on to do more work than the right ventricle It must pump sufficient blood through the myriad peripheral vessels of the systemic circulation to care for the active metabolism and continued growth of all parts of the body These are just some of the striking functional situations which the growing heart must encounter before it can attain its adult condition The manner in which they are met is doubly interesting because they seem at first sight to be insurmountable

Regional differentiation In the section on the establishment of the circulatory system in very young embryos the origin and structure of the tubular heart were discussed One of the primary factors which brings about the regional differentiation of this young tubular heart is its rapid elongation The heart increases in length so much faster than the chamber in which it lies that it first makes a U shaped bend to the right and is then twisted into a loop With the formation of the cardiac loop during the fifth week of gestation the primary regional divisions of the heart become clearly recognizable The sinus venosus is the thin walled

ber in which the great veins become confluent to enter the heart at its primary caudal end (Fig 4c) The atrial region is established by transverse dilation of the heart tube just cephalic to the sinus venosus and the ventricle is formed by the bent midportion of the original cardiac tube (Figs 4 and 5) Between the atrium and ventricle the heart remains relatively undilated This narrow connecting portion is the atrioventricular canal (Fig 7a) The most cephalic part of the cardiac tube undergoes the least change in appearance, persisting as the truncus arteriosus connecting the ventricle with the aortic arches (Fig 5)

Atrium and ventricle. Almost from their earliest appearance the atrium and the ventricle show external indications of their impending division into right and left sides A distinct median furrow ap

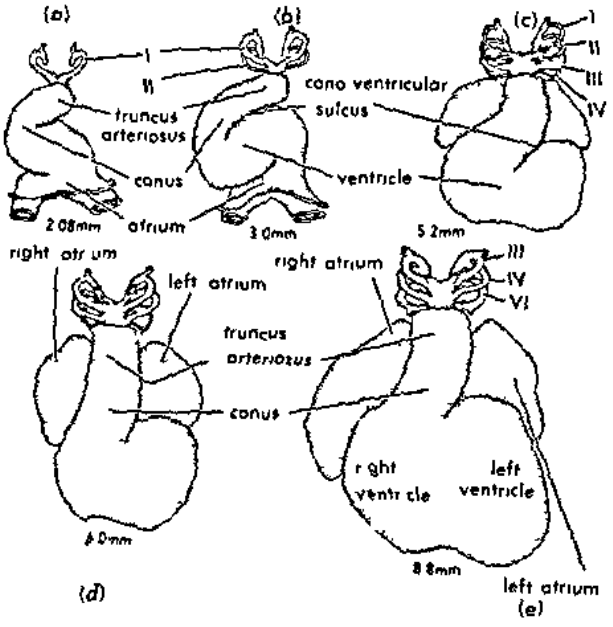


Fig 5 (a e) Ventral views of human embryonic heart show bending of the cardiac tube and the establishment of its regional divisions Roman numerals I to VI indicate aortic arches of corresponding numbers (After T C Kramer Am J Anat, 71(3) 343–370 1942)

pears at the apex of the ventricle (Figs 4d and e and 5c, d, and e) The atrium meanwhile bulges out on either side of the midline (Fig 4) Its bilobed configuration is emphasized by the manner in which the truncus arteriosus compresses it midventrally (Fig 5c d, and e) These superficial features suggest the

ne

ing muscular bands the trabeculae carneae Opposite the external furrow these muscular bands

Partition Meanwhile two conspicuous masses of the loosely organized mesenchyme called endocardial cushion tissue develop in the walls of the

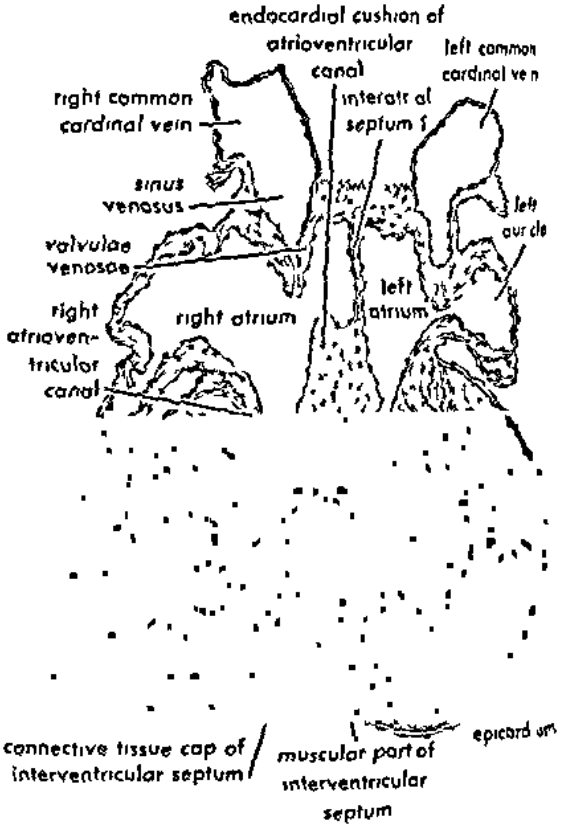


Fig 6 Section through heart of a 9 4-mm pig embryo Stage of development corresponds to that in a human embryo of the sixth week (From B M Patten, Foundations of Embryology, McGraw Hill, 1958)

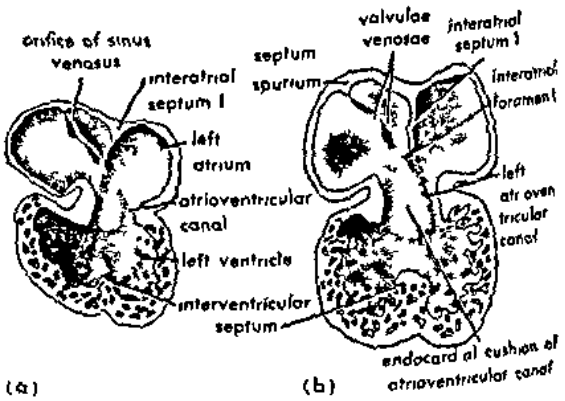


Fig 7 Semischematic drawings of interior of heart to show initial steps in its partitioning (a) Cardiac septa represented at the stage reached in human embryos early in the fifth week of development, showing primary relations of interatrial septum primum Based on original reconstructions of heart of a 3 7 mm pig embryo and on Tandler's reconstructions of corresponding stages of the human heart (b) Cardiac septa in human embryos of sixth week Note restriction of interatrial foramen primum by growth of interatrial septum primum Based on original reconstructions of the heart of a 6 mm pig embryo, on Born's reconstructions of rabbit heart, and Tandler's reconstructions of corresponding stages of the human heart (From B M Patten, Human Embryology, 2d ed, Blakiston–McGraw Hill 1953)

narrowed portion of the heart between the atrium and ventricle One of these endocardial cushions of the atrioventricular canal is formed in its dorsal wall (Fig 7*b*) A similar cushion is formed opposite it on the ventral wall When these two masses meet they divide the atrioventricular canal into right and left channels (Fig 8)

Septum primum Concurrently a median partition appears in the cephalic wall of the atrium Because another closely related partition will form adjacent to it later this is called the first interatrial septum or septum primum It is composed of a thin layer of young cardiac muscle covered by endothelium It is crescent shaped with its concavity directed toward the ventricle The apices of the crescent extend to the atrioventricular canal where they merge respectively with its dorsal and ventral endocardial cushions (Fig 7) This leaves the atria separated from each other except for a diminishing opening called the interatrial foramen primum (Fig 7*b*)

While these changes have been occurring the sinus venosus has been shifted out of the midline so that it opens into the atrium to the right of the interatrial septum (Fig 4) The heart is now in a critical stage of development Its original simple tubular form has been altered so that the four chambers characteristic of the adult heart are clearly suggested Partitioning of the heart into right and left sides is well under way but there are still open communications from the right to the left side in both atrium and ventricle If partitioning were completed now the left side of the heart would be left almost literally dry because the sinus venosus into which systemic portal and placental

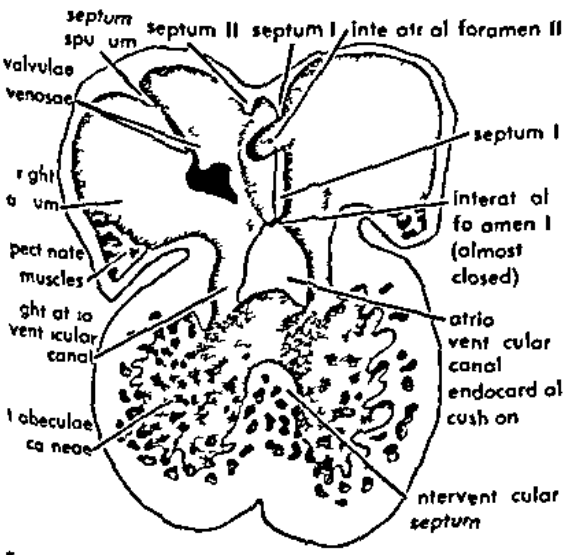


Fig 8 Semischematic drawing of interior of heart to show start of interatrial septum secundum and appearance of interatrial foramen secundum in septum primum Based on original reconstructions of the hearts of pig embryos and on Tandler's reconstructions of the heart of human embryos of the seventh week (*From B M Patten Human Embryology 2d ed Blakiston–McGraw Hill 1953*)

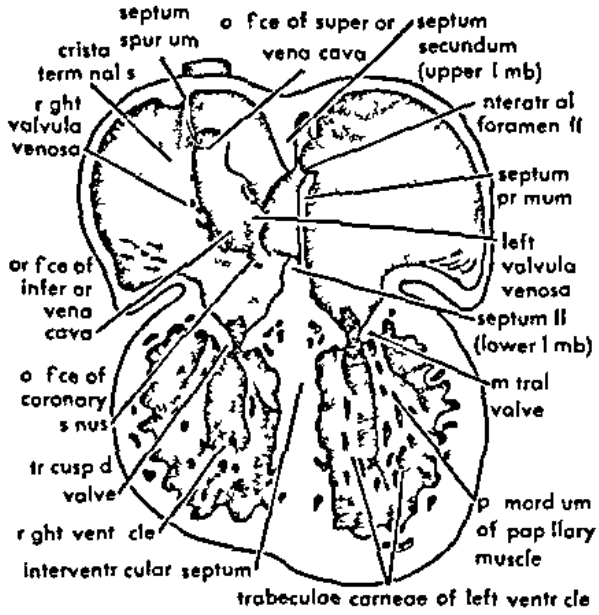


Fig 9 Schematic drawing of internal configuration of heart in human embryos of the third month Resorption has begun to involve valvulae venosae and septum spurium as indicated by the many small perforations in their margins Left venous valve is coming to lie against septum secundum with which it is already beginning to fuse it usually leaves no recognizable traces in the adult but occasionally delicate lacelike remains of it can be seen adhering to septum secundum and more rarely extending for a short distance onto the valvula foraminis ovalis (*From B M Patten Foundations of Embryology McGraw Hill 1958*)

currents all enter opens on the right of the interatrial septum Not until much later do the lungs and their vessels develop sufficiently to return any considerable volume of blood to the left atrium The partitions in the ventricle and in the atrioventricular canal do progress rapidly to completion (Figs 7 8 and 9) but an interesting series of events takes place in the interatrial septal complex which assures that an adequate supply of blood will reach the left atrium and thence the left ventricle

In the sixth week just when the septum primum is about to fuse with the endocardial cushions of the atrioventricular canal thus closing the interatrial foramen primum a new opening is established The more cephalic part of the septum primum becomes perforated at first by multiple small holes These soon coalesce to form the interatrial foramen secundum thus keeping a route open from the right to the left atrium (Fig 8)

Septum secundum During the seventh week the second interatrial partition makes its appearance just to the right of the first Like the septum primum the septum secundum is crescent shaped The concavity of its crescent is however differently oriented Whereas the open part of the septum primum is directed toward the atrioventricular canal the open part of the septum secundum i

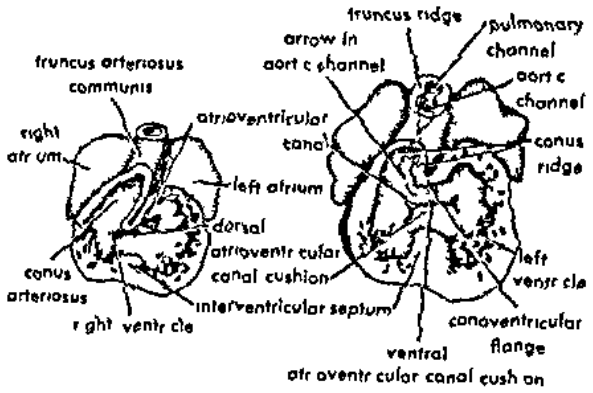


Fig 10 Semischematic drawings of dissections of developing hearts in frontal aspect to show relations of importance in establishing aortic and pulmonary outlets (After T C Kramer Am J Anat 71(3) 343–370 1942)

which later becomes the opening of the inferior vena cava into the right atrium (Figs 8 and 9) This difference in the direction of growth in the two interatrial septa is of vital functional significance because it means that as the septum secundum grows the opening remaining in it is carried out of line with the interatrial foramen secundum in the septum primum (Fig 9) The opening in the septum secundum although it becomes relatively smaller as development progresses will not be completely closed but will remain as the foramen ovale

The flaplike persisting portion of the septum primum overlying the foramen ovale constitutes an efficient valvular mechanism between the two atria When the atria are filling some of the blood returning by way of the great veins can pass freely through the foramen ovale merely by pushing aside the flap of the septum primum When the atria start to contract, pressure of the blood within the left atrium forces the septum primum against the

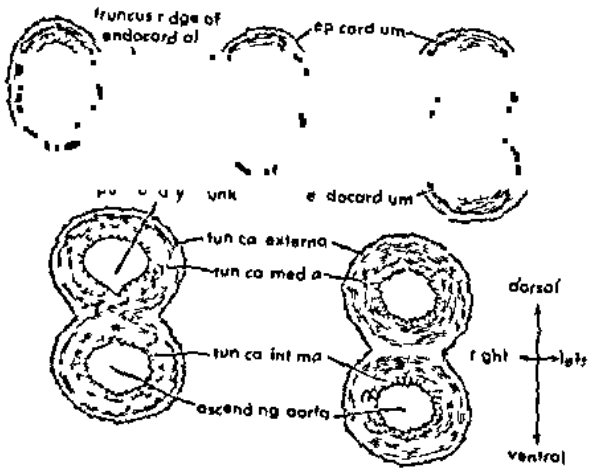


Fig 11 Schematic diagrams showing the partitioning of the truncus arteriosus to form the ascending aorta and the pulmonary trunk (From B M Patten, in S E Gould, Pathology of the Heart, Charles C Thomas 1953)

septum secundum, effectively closing the foramen ovale against return flow into the right atrium Without some such mechanism to afford a fair share of blood to the left atrium the fetal left ventricle would receive a low blood volume and as a result its muscular wall would not develop adequately to carry its postnatal pumping load The strength of cardiac muscle and other muscles in the body depends on the work the muscle is called upon to do

Division of the truncus. While these changes are going on in the main part of the heart the truncus arteriosus is being divided into two separate channels This process starts where the truncus joins the ventral roots of the aortic arches Continuing toward the ventricle, the division is effected by the formation of longitudinal ridges of plastic young connective tissue of the same type as that making up the endocardial cushions of the

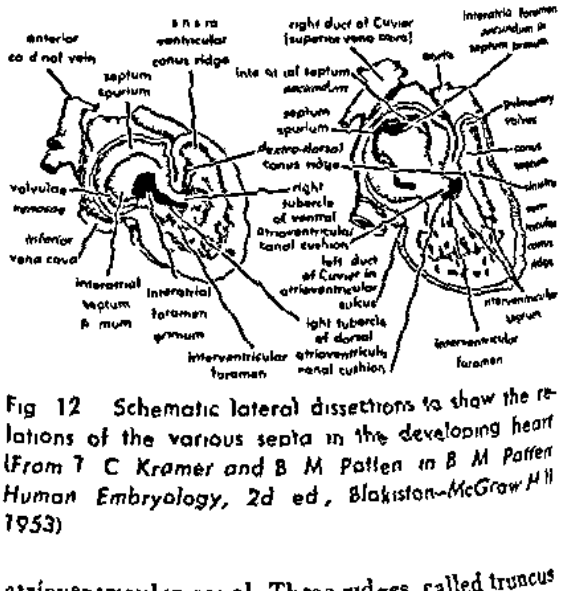


Fig 12 Schematic lateral dissections to show the relations of the various septa in the developing heart (From T C Kramer and B M Patten in B M Patten Human Embryology, 2d ed, Blakiston–McGraw-Hill 1953)

atrioventricular canal These ridges called truncus ridges, bulge progressively further into the lumen of the truncus arteriosus and finally meet to separate it into aortic and pulmonary channels (Figs 10 and 11) The semilunar valves of the aorta and the pulmonary trunk develop as local specializations of these truncus ridges Toward the ventricles from the site of formation of the semilunar valves the ridges are continued into the conus of the ventricles (Fig 12) The truncoconal ridges follow a spiral course through the truncus and extend down into the ventricles where they meet and become continuous with the margins of the interventricular septum This reduces the relative size of the interventricular foramen but does not close it completely Its final closure is brought about by a mass of endocardial cushion tissue from three sources Bordering the interventricular foramen ventrocaudally is the interventricular septum the crest of which above its main muscular portion is made up of endocardial cushion tissue (Fig 6) Toward the atrioventricular canal lie the masses of endocardial cushion tissue which were responsible for its partitioning (Fig 12) In the conus outlet are the ridges that were just considered From all

three of these adjacent areas endocardial cushion tissue encroaches on the opening About the end of the seventh week the interventricular foramen is completely plugged with a loose mass of this young readily molded connective tissue Later this mass differentiates into the membranous portion of the interventricular septum and the septal cusps of the atrioventricular valves When the interventricular septum has thus been completed the right ventricle leads into the pulmonary trunk and the left leads into the ascending aorta With this condition established the heart is completely divided into right and left sides except for the interatrial valve at the foramen ovale which must remain open throughout fetal life until after birth when the lungs attain their full functional capacity and the entire volume of the pulmonary stream passes through them to be returned to the left atrium

Ductus arteriosus This leaves only one of the functional exigencies of heart development still to be accounted for If during early fetal life and before the lungs are well developed the vessels to the lungs were the only exit from the right side of the heart, the right ventricle would not have an outlet adequate to develop its pumping power It is only late in fetal life that the lungs and their vessels develop to a degree which prepares them for assuming their postnatal activity and the power of the heart muscle can be built up only gradually by continued functional activity This situation is met by the ductus arteriosus leading from the pulmonary trunk to the aorta Throughout fetal life any blood from the right ventricle that cannot be accepted within the pulmonary circuit is shunted by way of the ductus into the descending aorta Thus the right ventricle is able to develop its muscular walls by pumping throughout prenatal life its full share of the cardiac load

In the foregoing account of the partitioning of the heart attention has been called to the functional changes correlated with the growth of the various septa Special emphasis was laid on the balancing of the pumping load on the right and left sides of the heart during its growth [B M P]

FUNCTIONAL DEVELOPMENT OF HEART

The heart begins to beat before all its parts have been formed The character of the heartbeat changes with the sequential formation of the regions of the heart The heart arises by the fusion of bilateral primordia which converge from positions on opposite sides of the embryo In the human embryo virtually the entire development of the heart and major blood vesesls occurs between the third and eighth weeks of embryonic life In the chick embryo one of the principal objects of experimental analysis the bilateral primordia begin to fuse in the 7 somite stage The first beats can be recorded in the embryo of 9 somites at which stage the first cross striations also are observed

Contractions of the heart The first contractions occur along the right side of the developing ventricle the first part of the heart to form The beat is at first slow but rhythmical and gradually

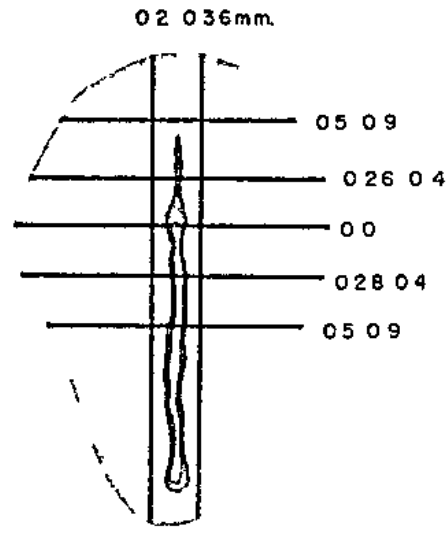


Fig 13 Heart forming areas of the chick embryo

involves the whole wall of the ventricle The first contractions may be described as rhythmic but intermittent that is rhythmic contractions interrupted by rest periods Next is added the atrium which begins to contract at a higher rate than that of the ventricle stepping up the rate of the entire heart because the part of the tube with the highest rate of contraction sets the pace for the heart as a whole At this time the blood is set in motion The sinus venosus begins to contract somewhat later, again its inclusion steps up the heartbeat Contractions begin before any of the nerve fibers which in their development grow out from the central nervous system reach the heart and before the specialized system for conducting impulses in the heart is established The nervous system secondarily assumes the regulation of the rate of the pulsations originating in the myocardium retarding and accelerating functions being established by the vagus and cervical sympathetic fibers respectively

Heart forming areas The first pulsations of the heart are foreshadowed by the localization of the heart forming cells to well demarcated regions of the embryo in the head process stage about 10 hours earlier Figure 13 shows the position of the heart forming areas as demonstrated by experimental tests of the histogenetic capacity of isolated fragments of the early embryo Although cardiac muscle arises from the mesoderm it is impossible to state whether it develops independently in the chick or whether interactions between the mesoderm and endoderm are required Such an inductive interaction appears to be required for normal development of the heart in the salamander embryo

Contractile proteins The question has been raised as to what extent the early localization of heart forming cells reflects the early differentiation of specificity in chemical composition or metabolism It has also been questioned whether the heart forming areas differ chemically from adjacent regions of the embryo Immunochemical techniques employing as tools specific antiheart sera reveal that the early embryo contains macromolecules

identical with or closely related to those of the adult heart a conclusion that is supported by the additional finding that when early embryos are cultured in a medium containing antiheart serum the development of the heart is differentially suppressed Similar techniques have revealed the time of origin and pattern of localization of the cardiac contractile proteins myosin and actin

Synthesis of contractile proteins The synthesis of cardiac myosin is initiated during the formation of the mesoderm the protein being detected first during the movement of prospective mesodermal cells through the primitive streak As these formative movements are terminated myosin is distributed widely in the ectoderm and mesoderm but cannot be detected in the endoderm At the head process stage cardiac myosin is restricted to the heart forming regions of the embryo where at the same time the synthesis of cardiac actin is initiated It is impossible at the present time to say whether the myosin first detected is adult myosin or a complete myosin molecule closely related to but not identical with the adult protein a situation that exists in the sequential formation of fetal and adult hemoglobin molecules (*see* HEMATOPOIESIS) It is postulated that in the formation of cardiac muscle the contractile proteins are synthesized and subsequently aggregated to form fibrils Although this hypothesis of stepwise organization agrees with the limited information available on the development of the fine structure of heart muscle a note of caution must be expressed because in skeletal muscle myosin has been detected simultaneously with the formation of the first simple muscle fibrils and not before

Action of inhibitors In further studies of the biochemical differentiation of the heart forming areas it has been found that the metabolic pathways operating in the development of the brain and heart differ markedly When early chick embryos are cultured in vitro on a medium containing traces of the metabolic inhibitor antimycin A the development of the regions destined to form muscle is inhibited almost completely whereas the developing brain and spinal cord remain intact The heart is more sensitive than other mesodermal tissues Another compound sodium fluoride also inhib

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are the heart forming regions At succeeding stages in the establishment of the heart the locations of the cells destroyed by sodium fluoride reflect the sites of highest ability to form pulsatile heart and the area of greatest capacity for the synthesis of actin and myosin Thus the primary forces operating in the formation of the heart must be sought at the very outset of development

[JDE]

FETAL CIRCULATION AT TERM

The circulation in the mammalian fetus at term must be thoroughly understood as a basis for the consideration of postnatal circulatory changes because the very mechanisms which ensure intracardiac balance during prenatal life maintain a balanced cardiac load during the changes to the postnatal basis In this discussion of the fetal circulation at term the basic conditions presented are essentially applicable to all the higher mammals Reference to ages and to other specific details are however, based on the conditions in man

Last trimester of pregnancy By the last trimester of pregnancy all the major blood vessels have been developed in essentially their adult pattern, and all the steps in the partitioning of the embryonic heart are leading progressively closer to the final adult condition in which the heart is a four chambered organ completely divided into right and left sides However from the nature of its living conditions it is not possible for the fetus in utero to attain fully the adult type of circulation The plan of the divided circulation of postnatal life is predicated on lung breathing After birth the right side of the heart receives the blood returning from a circuit of the body and pumps it to the lungs where it is relieved of carbon dioxide and acquires a fresh supply of oxygen The left side of the heart then receives the blood that has just been aerated in the lungs and pumps it through ramifying channels to all the tissues of the body In the last part of intrauterine life the lungs and their blood vessels are fully formed and ready to function but they cannot actually try out their functional competence until after birth However in the first minutes of its postnatal life a fetus must successfully change from an existence submerged in the amniotic fluid to air breathing with its hitherto untested lungs Moreover this abrupt change must be accomplished without the sudden overloading of any part of the cardiac pump

It is in the light of these functional exigencies that the fetal circulation at term must be considered It was to pave the way for such a consideration that in discussing the formation of the interatrial septal complex emphasis was laid on the fact that at no time during prenatal life were the atria completely separated from each other This permits the left atrium to receive a contribution of blood from the inferior vena cava by a transseptal flow which compensates for the relatively small amount of blood entering the left atrium directly by way of the pulmonary circuit The routes and the relative amounts of this interatrial shunt are different at different ages Very early in development before the lungs have grown to any great extent the pulmonary return is negligible and the flow from the right atrium through the interatrial ostium primum constitutes practically the entire intake of the left atrium (Fig 14*b*) After the ostium primum has been closed and while the lungs are but little developed flow through the interatrial ostium secundum must provide for the major part of the blood entering the left atrium (Fig 14*d*) During the latter part of fetal life the foramen ovale in the septum secundum becomes

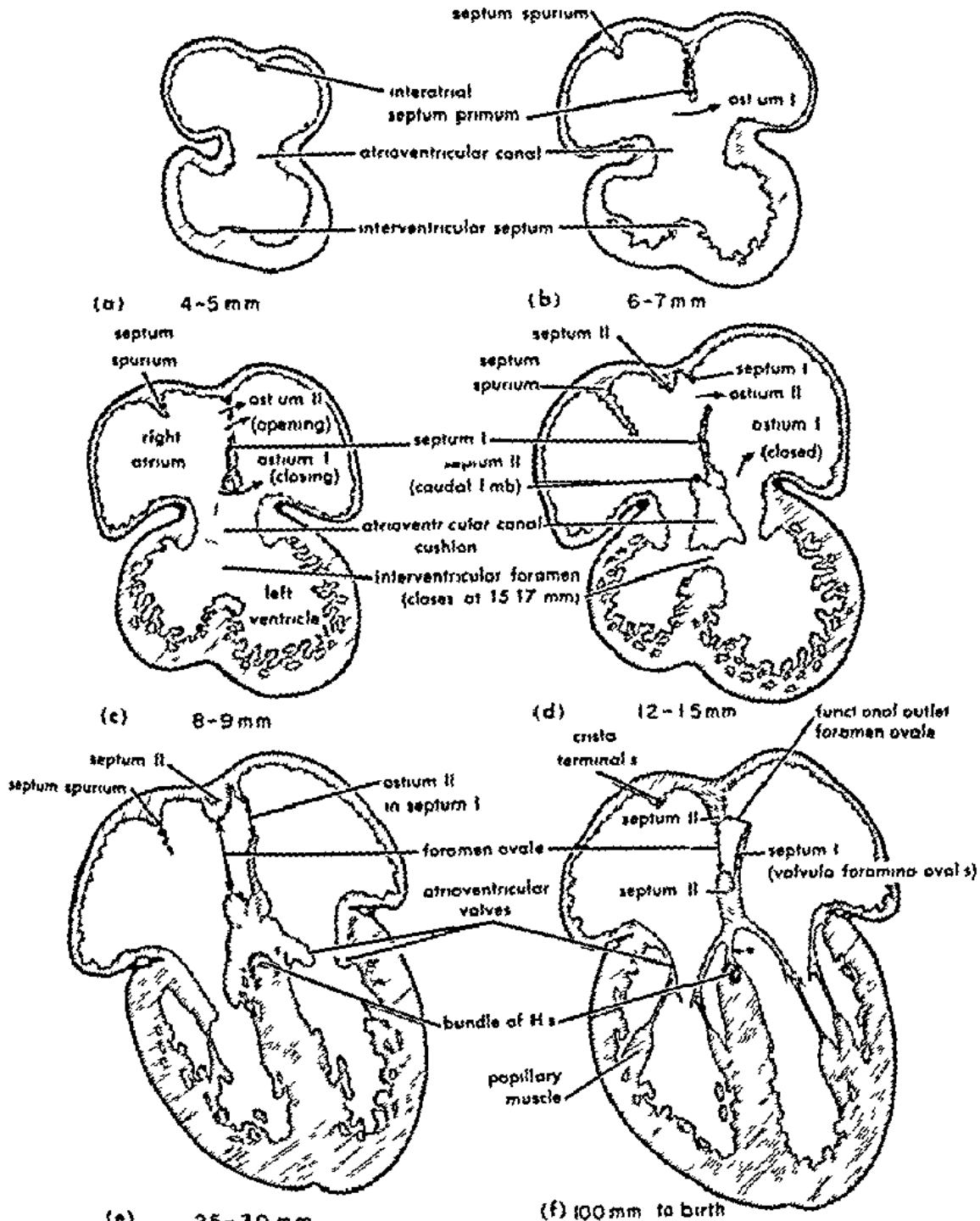
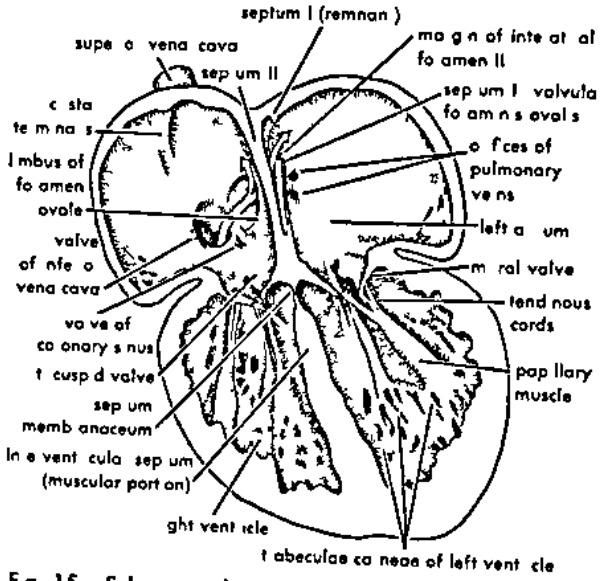


Fig 14 (a f) Sectional plan of embryonic heart in frontal plane giving a more precise picture of the rate of progress of partitioning in the human embryo. Endocardial cushion tissue is shown by stippled areas, muscle by diagonal hatching, and epicardium by solid black. Lightly stippled areas in the atrioventricular canal in (b) and (c) indicate location of endocardial cushions of atrioventricular canal before they have grown sufficiently to fuse in the plane of the diagram. (Slightly modified from B. M. Patten, Developmental defects of the foramen ovale, Am. J. Path., 14(2) 135–161, 1938)

the transseptal route for blood (Fig. 14*e* and *f*).

Transseptal flow balance. The precise manner in which this balancing transseptal flow occurs in a fetus at term and where and to what extent the various blood streams are mixed has long been a controversial subject. By a synthesis of the most significant of the anatomical e

newer experimental evidence, the course followed by the blood in passing through the heart may be summarized as follows. The inferior caval entrance is so directed with reference to the foramen ovale that a considerable portion of its stream passes directly into the left atrium (Figs. 15 and 16).



Fg 15 Schemat c draw ng of interrelat ons of septum pr mum and septum secundum during latter part of fetal l fe Lower part of septum primum is s tuated so that t acts as a one-way valve at the oval foramen n septum secundum Spl t arrow nd cates the way a cons derable part of the blood from the infer or vena cava passes through the foramen ovale to the left atr um wh le the rema nder edd es back into the r ght atr um to m ngle w th the blood being returned by way of the superior vena cava (*From B M Patten Founda t ons of Embryology McGraw H ll 1958*)

the interatrial communication through the foramen ovale is considerably smaller than the inferior caval inlet This implies that the portion of the in ferior caval stream which could not pass through this opening into the left atrium must eddy back and mix with the rest of the blood entering the right atrium Angiocardiographic studies confirm this inference

Pulmonary circulation As the lungs grow and the pulmon
atively
of the
vessels b l g lur gs However the circula tion of the lungs although increased as compared with earlier stages has been shown by angiocardio graphic studies to be much less in volume than the caliber of the pulmonary vessels would lead one to expect Until the lungs are inflated there are evi dently factors either vasomotor mechanical or both which restrict flow through the smaller pul monary vessels Therefore even in the terminal months of pregnancy a considerable right left flow must still be maintained through the foramen ovale in order to keep the left atrial intake equal to that of the right

Atrial ventricular balance The balanced atrial intake thus maintained impl es a balanced ventric ular intake and this in turn implies the necessity of a balanced ventricular output Although not in the heart itself there is in the closely associated great vessels a mechanism which affords an ade quate outlet from the right ventricle during the pe riod when the pulmonary circuit is develop ng When the pulmonary arteries are formed as out growths from the sixth pair of aortic arches the right sixth arch soon loses its original connection with the dorsal aorta On the left however a por tion of the sixth arch persists as the ductus arte riosus connecting the pulmonary artery with th dorsal aorta (Fig 16) This vessel remains ope throughout fetal life and acts as a shunt carryin over to the aorta whatever blood the pulmona vessels at any particular phase of their develo ment are not prepared to receive from the r gh ventricle The ductus arteriosus can therefore b called the exercising channel of the right ventricl because it makes it possible for the right ventr cle to carry its full share of work throughout de velopment and thus to be prepared for pumping it full quota of blood through the lungs at the t m of birth

Thus by means of intake and output shunts ther is maintained throughout prenatal development an effective right left balance in the pumping loa of the heart The importance of this for the attain ment of normal cardiac structure is forcefully shown by the abnormalities that appear when the balancing mechanisms are in any way disturbed The importance of these same mechanisms in ac complishing postnatal circulatory changes is d s cussed in the following section

POSTNATAL CIRCULATION

The changes in circulation following birth in volve some of the most dramatic and fascinat ng biological processes One of the most impressive phenomena in embryology is the perfect prepared ness for these changes which has been built into the very architecture of the circulatory system dur ing its development The shunt at the ductus arte riosus which has been one of the factors in balanc ing ventricular output throughout intrauter ne development and the valvular mechanism at the foramen ovale which has been balancing atr al intakes are perfectly adapted to prevent any abrupt unbalancing of cardiac load as a result of postnatal changes in circulatory routes

Pulmonary circuit and ductus In much of the older literature great emphasis was placed on what happened at the foramen ovale It is now known that these changes are secondary and that the events of primary significance occur in connec tion with the pulmonary circuit and the ductus ar teriosus In the section on fetal circulation at term the importance of the ductus arteriosus as an exer cising channel for the right ventricle was empha sized From the standpoint of postnatal circulatory changes the reciprocal relation between flow through the ductus and flow through the lungs be comes the center of interest As the lungs increase in size relatively more of the blood leaving the right ventricle by way of the pulmonary trunk goes to the lungs and relatively less goes through the ductus arteriosus to the dorsal aorta

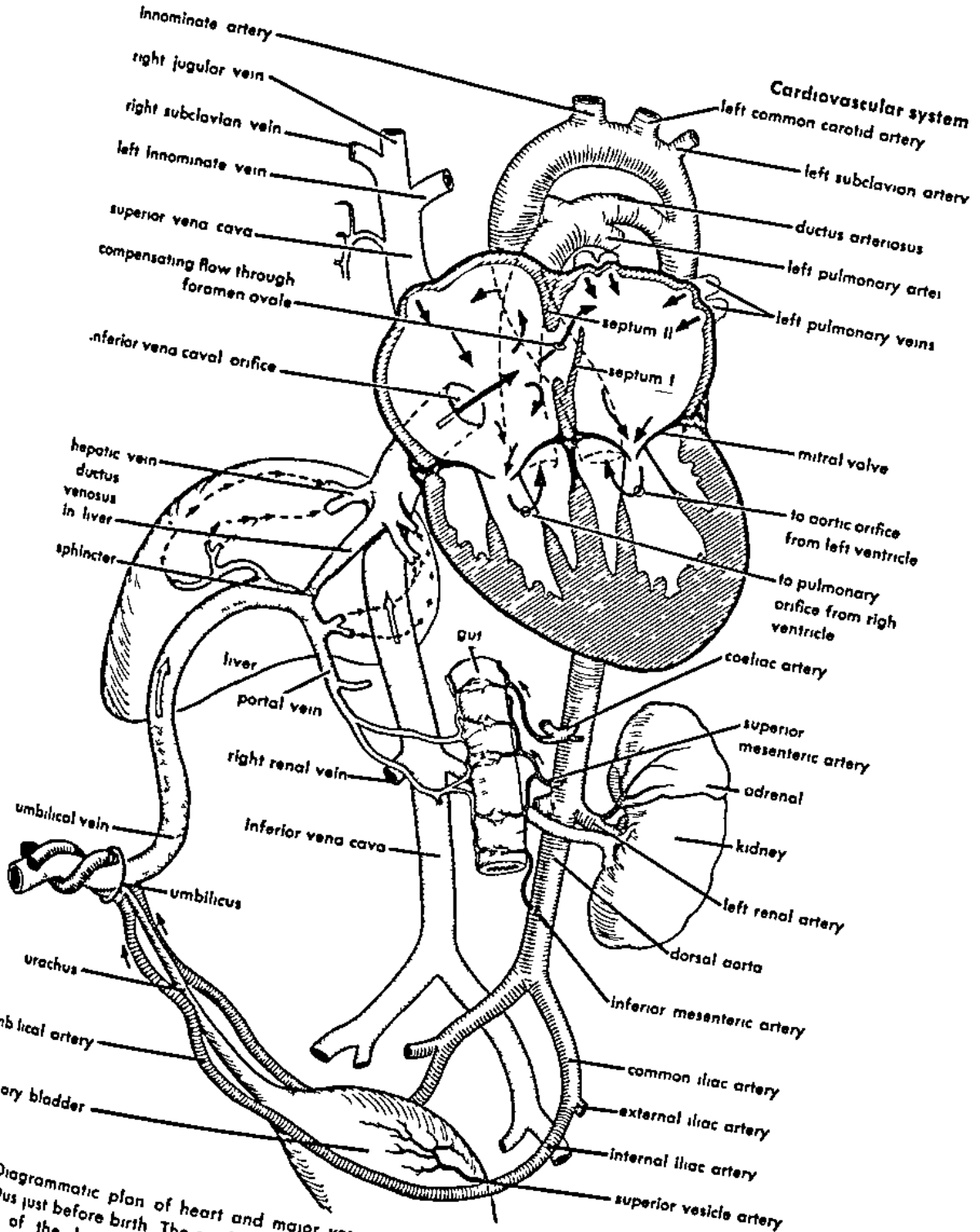
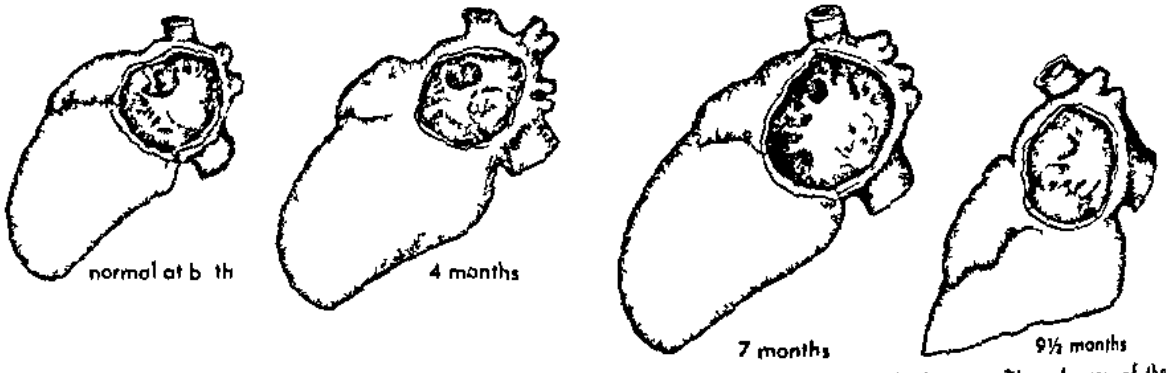


Fig 16 Diagrammatic plan of heart and major vessels of a fetus just before birth The small arrows within the outline of the liver indicate alternative blood routes by way of the hepatic sinusoids (*From B M Patten, Foundations of Embryology, McGraw Hill, 1958*)

By the end of gestation the pulmonary vessels must be large enough to handle a blood volume adequate to care for oxygenating the blood Injection preparations of fetuses clearly show that the vascular channels in the lungs are of generous size for this function well before birth However, such postmortem material does not show that before birth these large vessels are not carrying the blood volume their size would suggest

Pulmonary blood flow The brilliant work of C. Wegelius and J Lind, utilizing angiocardiographic methods on living fetuses, has shown that the flow of blood through the pulmonary circuit is actually restricted to a volume much below the potential capacity of the vessels How much of this is the result of mechanical factors such as the unexpanded condition of the lungs, and how much it depends upon differential vasoconstriction of the



Figs 17 and 18 Hearts w th left atr um opened to show gross changes in relat ons of valvula dur ng the per od in wh ch the foramen ovale is be ng closed anatomically (*From* B M Patten *The closure of the foramen ovale Am J Anat* 48 19–44 1931)

smaller vessels within the lungs remains to be determined It is clear however that pulmonary channels of the requisite size have been formed and are ready to increase their blood flow radically and promptly with the beginning of respiration Within a short time after birth under the stimulus of functional activity the lungs are able to take all the blood from the right side of the heart

Lung function When the lungs accept all the blood entering the pulmonary trunk blood flow through the ductus arteriosus ceases Following its functional abandonment the ductus arteriosus is gradually occluded by an overgrowth of its intimal tissue This process in the wall of the ductus is as characteristic and regular a feature of the development of the circulatory system as the formation of the cardiac septa Its earliest phases begin to be recognizable in the fetus as the time of birth approaches and postnatally the process continues at an accelerated rate to terminate in complete anatomical occlusion of the lumen of the ductus some 6–8 weeks after birth

Postnatal readjustment Postnatal readjustment of the circulation cannot however wait on this protracted structural closure Following birth there appears to be an immediate reduction in the bore of the ductus accompanied by a reduced flow of blood through it This reduction in the shunt from the pulmonary circuit to the aorta acting together with the lowering of resistance in the vascular bed of the lungs which accompanies their newly assumed respiratory activity aids in raising the pulmonary circulation promptly to full functional level At the same time the functional closure of the ductus arteriosus paves the way for the ultimate anatomical obliteration of its lumen by the active growth of its intimal connective tissue

The results of increased pulmonary circulation with the concomitant increase in the direct intake of the left atrium are manifested secondarily at the foramen ovale Following birth as the pulmonary return increases compensatory blood flow from the right atrium to the left decreases correspondingly and shortly ceases altogether In other words when equal zation of atrial intakes has occurred the compensating one way valve at the fora

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looseness of the valvula foraminis ovalis and the consequent diminution of the interatrial communication to a progressively narrower slit between the valvula and the septum

Obliteration of the foramen ovale Anatomical obliteration of the foramen ovale slowly follows its functional abandonment (Figs 17 18) There is a highly variable interval of 3–9 months following birth before the septum primum fuses with the septum secundum to seal the foramen ovale This delay is however of no functional import because as long as the pulmonary circuit is normal and pressure in the left atrium equals or exceeds that in the right the orifice between them is functionally inoperative It is not uncommon to find the fusion of these two septa incomplete in the hearts of individuals who have as far as circulatory disturbances are concerned lived uneventfully to maturity Such a condition can be characterized as probe patency of the foramen ovale When in such hearts a probe is inserted under the margin of the fossa ovalis and pushed toward the left atrium the probe is prying behind the no longer used but still unfastened interatrial door

Physiological aspects of transition Much yet remains to be learned concerning the more precise physiology of the fetal circulation and concerning the interaction of various factors during the transition from intrauterine to postnatal conditions Nevertheless it is quite apparent that the changes in the circulation which occur following birth involve no revolutionary disturbances of the load carried by different parts of the heart The fact that the pulmonary vessels are already so well developed before birth means that the changes which must occur following birth have been thoroughly prepared for and the compensatory mechanisms at the foramen ovale and the ductus arteriosus which have been functioning throughout fetal life are entirely competent to effect the final postnatal reroutings of the circulation with a minimum of functional disturbance The change from water living

to air living is crowded into a few crucial moments that in phylogeny must have been spread over eons of transitional amphibious existence [B M P]

COMPARATIVE ANATOMY

Heart The hearts of vertebrates differ from those of members in the lower phyla in their ventral rather than dorsal location Blood is pumped anteriorly through arteries and forced to the dorsal side The greater part then courses posteriorly through arteries which terminate in capillaries in various parts of the body The blood returns to the heart through veins

Phylogeny In lower vertebrates the heart is located far forward in the body but there is a gradual backward shifting as the vertebrate scale is ascended The heart lies in a pericardial cavity which is surrounded by an investing membrane the pericardium The pericardial cavity is a portion of the coelom which has been cut off from the remainder of the body cavity In elasmobranchs the separation is incomplete and the two portions of the coelom are connected by a pericardio-peritoneal canal A thin serous membrane the epicardium covers the surface of the heart It is continuous with the lining of the pericardial cavity

The heart is primarily a pulsating tube derived from fusion of two vitelline veins It becomes divided into chambers called atria and ventricles In addition two accessory chambers may be present called the sinus venosus and conus arteriosus respectively Cyclostomes and most fishes have 2-chambered hearts with one atrium and one ventricle A sinus venosus connects with the atrium and a conus arteriosus leads from the ventricle Dipnoans and amphibians with 3-chambered hearts have two atria and one ventricle The 3-chambered heart of most reptiles is similar to that of amphibians but an incomplete partition appears in the ventricle In crocodiles and alligators this becomes complete forming a 4-chambered heart with two atria and two ventricles Birds and mammals have 4-chambered hearts Valves are present to regulate the direction of blood flow

Circulation in the heart Vertebrates with 2-chambered hearts have the single type of circulation (Fig 19) in which only unoxygenated blood passes through the heart which pumps it to the

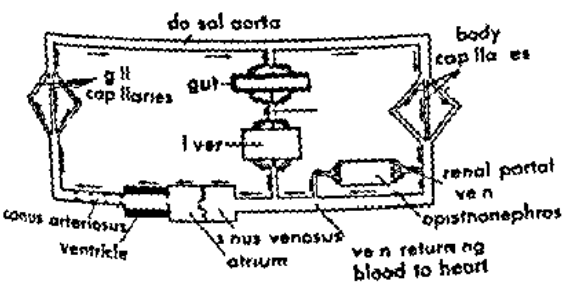


Fig 19 Diagram of single type of circulatory system (From C K Wichert *Anatomy of the Chordates* 2d ed McGraw-Hill 1958)

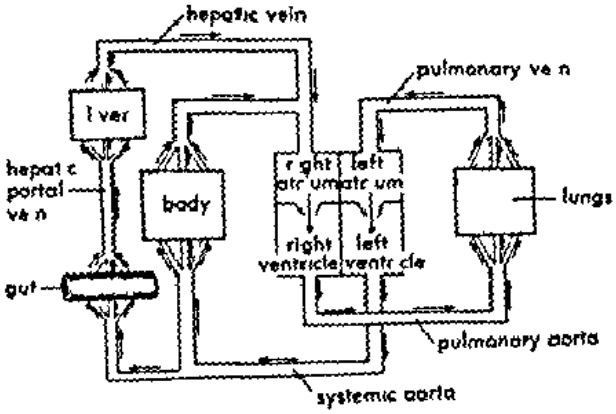


Fig 20 Diagram of double type of circulatory system in a vertebrate having a 4-chambered heart (From C K Wichert *Anatomy of the Chordates* 2d ed McGraw-Hill 1958)

gills for aeration The double type of circulation (Fig 20) exists in 3- and 4-chambered hearts through which pass two streams of blood one oxygenated and the other either unoxygenated or partly oxygenated Even in 3-chambered hearts these two streams do not mix to any appreciable extent Partitioning of the heart has been associated in evolution with development of a pulmonary circulation accompanying the appearance of lungs

The conus arteriosus no longer exists as such in adults of higher forms it is split into trunks leading to the aorta and lungs respectively

In those forms having 2 chambered hearts unoxygenated blood from all parts of the body is collected by the sinus venosus which joins the atrium In the 3-chambered hearts of dipnoans and amphibians the sinus venosus has shifted its position and joins the right atrium A large sinus venosus is present in certain reptiles but in most it is very small or is lacking Birds and mammals possess a sinus venosus only during early embryonic development In vertebrates having 3- or 4-chambered hearts unoxygenated blood is returned to the heart through the sinus venosus or directly to the right atrium as the case may be

Arterial system Although the arterial systems of various adult vertebrates appear to be very different in arrangement a study of development reveals that all are built upon the same fundamental plan

Ventral and dorsal aortas In lower vertebrates the conus arteriosus leads forward to a ventral aorta During early development this vessel divides anteriorly into two aortic arches which course dorsally in the mandibular region These continue posteriorly as the paired dorsal aortas Additional pairs of aortic arches then appear forming connections between ventral and dorsal aortas on each side They appear in sequence in an anteroposterior direction each coursing through the tissues between adjacent pharyngeal pouches. The typical number of aortic arches to form in vertebrates is six pairs (Fig 21*a*) although there are certain discrepancies among lower forms The paired dor-

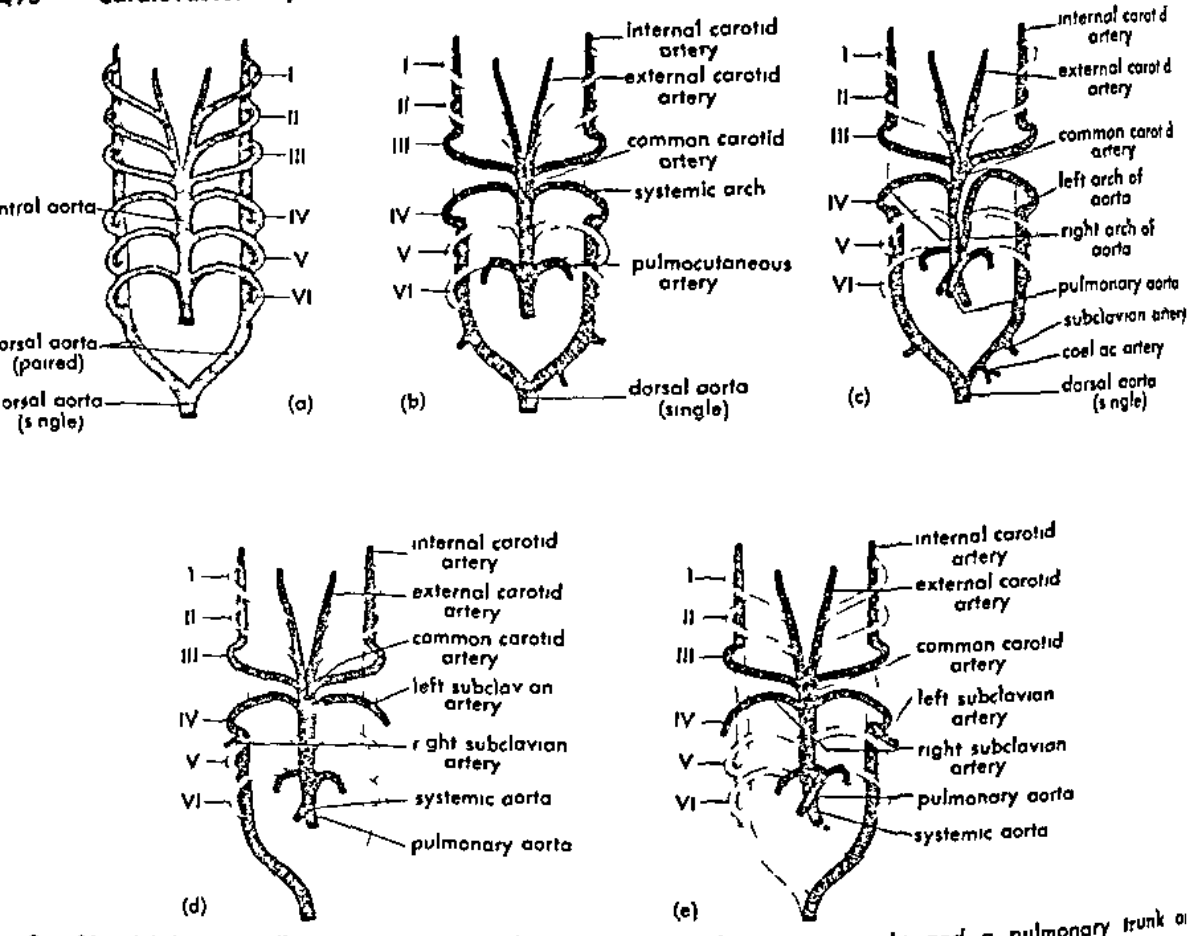


Fig 21 (a) Diagram illustrating typical condition of aortic arches in vertebrate embryos ventral view Six pairs of arches connect dorsal and ventral aortas (b) Diagram showing modification of aortic arches in salientian amphibians ventral view (c) Diagram showing modification of aortic arches in reptiles ventral view Ventral aorta has split into three vessels, right and left systemic trunks and a pulmonary trunk a aorta (d) Diagram showing modification of aortic arches as found in birds, ventral view (e) Diagram showing modification of aortic arches as found i mammals, ventral view (*From C K Weichert, Anatomy of the Chordates, 2d ed , McGraw Hill* 1958)

sal aortas unite posterior to the pharyngeal region to form a single vessel This single dorsal aorta continues posteriorly into the tail region as the caudal artery

Various paired and unpaired arteries arise along the length of the dorsal aorta to supply all structures of the body posterior to the pharyngeal region Anterior continuations of the ventral aorta and the anterior remnants of the paired dorsal aortas supply the head and anterior branchial regions Although the vessels arising from the dorsal aorta are fairly uniform throughout the vertebrate series the aortic arches undergo profound modifications The changes are similar in members of a given class

Blood pumped anteriorly by the heart, passes to the aortic arches These vessels then carry the blood to the dorsal aorta or aortas from which it goes either anteriorly to the head or posteriorly to the remainder of the body

Aortic arches Changes in the aortic arch region constitute the chief differences in the arterial systems of the separate vertebrate classes A progressive reduction in the number of aortic arches occurs as the evolutionary scale is ascended I cyclostomes and fishes, in which gills are used r respiration, the aortic arches break up into affer ent and efferent portions connected by numerou gill capillaries in which blood is oxygenated

The changes in this region involve primarily routing of the blood through certain aortic arche with a consequent atrophy or disappearance those which are no longer used and a splitting the conus arteriosus and ventral aorta, particularly in reptiles birds and mammals, in such manner that systemic and pulmonary trunks a established (Fig 21*b*, *c*, *d*, and *e*) The system trunk, coming from the left ventricle (or left si of the ventricle) distributes oxygenated (or pa tially oxygenated) blood to the body in gener The pulmonary trunk, coming from the right ve tricle (or right side of the ventricle) carries blo to the lungs Oxygenated blood returns throu veins from the lungs to the left atrium Vesse which carry blood from the heart to the lun and back comprise the pulmonary circulatio Branches of the sixth pair of aortic arches gi rise to the pulmonary arteries

Coronary arteries supplying the tissues of the heart itself arise as branches of certain aortic arches or of the systemic trunk near the point where it emerges from the heart

Somatic arteries The arteries supplying the body proper are usually paired structures which clearly show evidences of segmental arrangement (metamerism) They spring from the dorsolateral regions of the dorsal aorta Fusion of two or more segmental arteries may take place obscuring the fundamental metameric arrangement *See* METAMERISM

Visceral arteries Arteries supplying the viscera are of two kinds paired and unpaired The paired arteries usually restricted to certain regions are segmentally arranged They supply structures derived from the part of the embryo from which the urogenital organs and their ducts arise

Unpaired visceral arteries supply the spleen and digestive tract There are usually three such vessels in vertebrates The celiac artery supplies the stomach spleen pancreas liver and duodenum the superior mesenteric artery supplies most of the intestine and a portion of the pancreas and the inferior mesenteric artery goes to the posterior part of the large intestine and rectum Variations from this condition are accounted for by fusions or separations

Venous system A comparison of veins in the various vertebrate groups shows that they are arranged according to the same fundamental plan and that the variations encountered form a logical sequence as the vertebrate scale is ascended In its development the venous system of higher forms passes through certain stages common to the embryos of lower forms

Sinus venosus The accessory chamber present in the hearts of lower vertebrates through which blood from all over the body is returned to the heart is the sinus venosus

In cyclostomes and fishes the sinus venosus typically receives a pair of common cardinal veins or ducts of Cuvier formed by the union of anterior and posterior cardinals a pair of small inferior jugular veins from the ventrolateral part of the head and a pair of hepatic veins coming from the liver In lower fishes a lateral abdominal vein also joins each duct of Cuvier Each lateral abdominal vein receives a subclavian vein from the pectoral fin and an iliac vein from the pelvic appendage (Fig. 22) In some fishes the inferior jugular veins are lacking in others they have fused Teleost fishes lack lateral abdominal veins rather the subclavians enter the common cardinals In the dipnoan *Neoceratodus* the lateral abdominal veins fuse to form a single anterior abdominal vein which joins the sinus venosus directly

The sinus venosus in amphibians is conspicuous The ducts of Cuvier have consolidated to form two precaval veins each of which in addition to the usual vessels receives a large cutaneous vein from the skin before joining the sinus venosus A postcava derived partly from the sinus venosus and partly from the vitelline veins joins the sinus venosus posteriorly

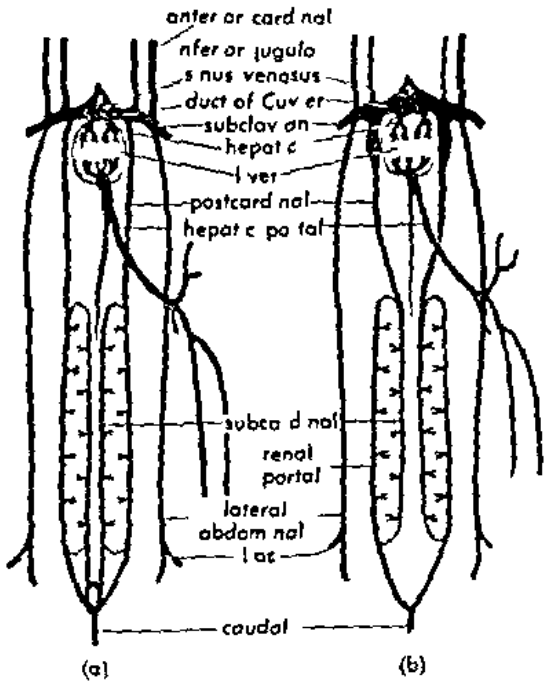


Fig. 22 Diagrams (a) and (b) illustrating the changes over the primitive condition which occur in the venous system of lower fishes ventral view (From C K Weichert *Anatomy of the Chordates* 2d ed McGraw Hill 1958)

A large sinus venosus is present in turtles in

birds and mammals which lack a sinus venosus precaval and postcaval veins enter the right atrium directly Valves present where veins enter the right atrium represent vestiges of the sinus venosus

Cardinal veins Anterior cardinal or jugular veins are prominent in cyclostomes and fishes In amphibians they receive internal and external tributaries before joining the precaval veins This condition persists in reptiles birds and mammals In some mammals a single precava is present an anastomosis having developed between the two original vessels

Postcardinal veins which course along the lateral borders of the kidneys at first carry blood away from the kidneys In fishes they separate into anterior and posterior portions The posterior sections terminate in the kidneys to become the renal portal veins The anterior sections connect with a new pair of vessels the subcardinals which appear

tions the anterior portions of the postcardinals disappear and the blood from the kidneys reaches the sinus venosus by way of the postcava In reptiles and birds the renal portal veins have lost most of their significance and in mammals they disap-

pear entirely A remnant of the anterior end of the right postcardinal of mammals becomes the azygos vein a branch of the right precava which drains the intercostal muscles

Abdominal veins The lateral abdominal veins of amphibians and reptiles like those of the lungfish *Neoceratodus* have fused to form a single anterior abdominal vein Instead of entering the sinus venosus however it joins the hepatic portal vein In reptiles birds and mammals the lateral abdominal veins are represented during embryonic life by allantoic or umbilical veins which lose their direct connections with the sinus venosus when the liver develops In adult birds the anterior abdominal vein may possibly be represented by the coccyge omesenteric vein or the epigastric vein It disappears entirely in all mammals with the exception of *Echidna*

Portal systems A portal system is a system of veins that breaks up into a capillary network before the blood which courses through it is returned to the heart All vertebrates have a hepatic portal system in which blood collected from the digestive tract and spleen passes through capillaries (sinusoids) in the liver before reaching the heart The embryonic vitelline (subintestinal) vessels are represented in adults by the hepatic portal vein and its tributaries The renal portal system of lower vertebrates has already been mentioned Another small but important portal system is found associated with the blood vessels draining the pituitary gland *See* LIVER

Miscellaneous Coronary veins draining the tissues of the heart enter the sinus venosus in lower forms or the right atrium in higher vertebrates Pulmonary veins found in amphibians reptiles birds and mammals first appear in the dipnoan fishes where they drain the swim bladder They enter the left atrium *See* RESPIRATORY SYSTEM SWIM BLADDER {C K W}

COMPARATIVE PHYSIOLOGY

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this tissue fluid envelops the individual cells and *acts as the medium* of exchange into which the products of metabolism enter and from *which the cells* of the tissues obtain the substances necessary for their activities The central feature *in the mechanism* for assuring a turnover of tissue fluid adequate to maintain a constant environment in regions of *active metabolism* is the fitness of the circulatory system to deliver a large amount of blood at *high pressure* In other words, the circulatory system is a mechanism on which each tissue may make *demands that will* be automatically met within the limitation of the system

Organization The *circulatory* system is composed of the heart and blood vessels and thus is frequently referred to as *the cardiovascular* system The mammalian heart is made up of four separate chambers or two *pumps each* consisting of a receiving chamber, the auricle (atrium) and a pumping chamber, the ventricle Blood passes from the right auricle to the right ventricle which pumps it through the pulmonary artery to the lungs and returns it by the pulmonary vein to the left auricle The blood passes from the left auricle to the left ventricle which pumps it into a large artery the aorta The aorta divides into arteries of smaller diameters and these in turn branch into still smaller arterioles which arborize into extensive networks of fine capillaries The capillaries form the bridges between the arteries and veins Blood leaving the capillaries enters small venules which converge into larger veins which in turn converge into still larger veins to form eventually the venae cavae leading into the right auricle The principal anatomical features of the circulatory system are shown diagrammatically in Fig 23.

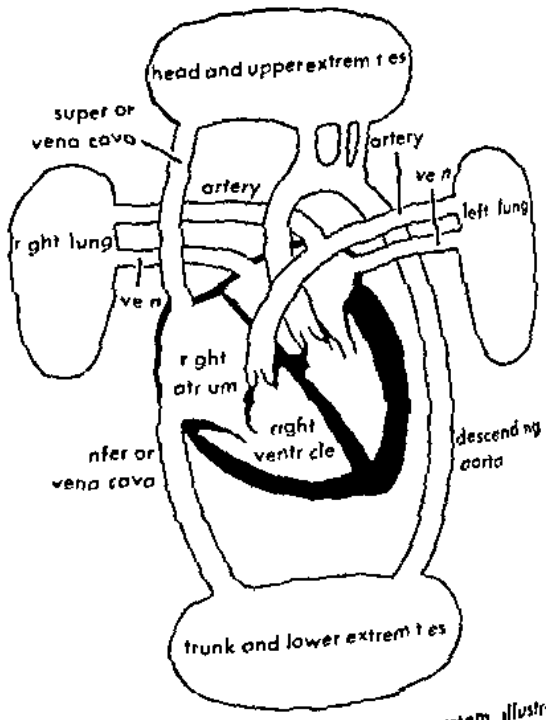


Fig 23 Diagram of the circulatory system illustrating major anatomical features (*From H B Taussig Congenital Malformations of the Heart* 1947)

The different types of blood vessels are admirably suited to their functions Thus the thick walled elastic aorta acts as a compression chamber to receive the blood from the left ventricle and to force it forward In this way it exerts a subsidiary pump action The arterioles on the other hand are distinguished by having muscular walls which permit these vessels to change their diameters readily Capillaries are extremely thin walled blood vessels that permit exchange of substances The capillaries are thus the true functional center of the circulatory system Veins are thin walled and distensible and can act as temporary reservoirs for large amounts of blood Valves in the veins prevent back flow and maintain the direction of flow toward the heart

Volume distribution. As an example of blood volume distribution, consider a hypothetical 20-year-old man who weighs 63 kg is 178 cm tall, and has a total blood volume of 5 2 liters in his case the blood might be expected to be distributed as shown in Table 1 With an additional 250 ml of blood contained in the heart this leaves about 550 ml of extra blood unaccounted for and which is probably in reservoir areas of the liver and spleen

Table 1 Typical blood volume distribution

Pulmonary system		Systemic vessels	
Area	Volume, ml	Area	Volume ml
Pulmonary arteries	400	Aorta	100
Pulmonary capillaries	60	Systemic arteries	450
Pulmonary venules	140	Systemic capillaries	300
Pulmonary veins	700	Venules	200
		Systemic veins	2050
Total	1300	Total	3100

The veins form not only a collecting system but also a very capacious reservoir This reservoir in cludes *the venae cavae with their main branches* and the great veins of the liver The vascular bed of the lungs stores blood under the same conditions as those which cause blood to be stored in systemic veins

Blood pressure. Four terms are used to charac terize the pressure in the circulatory system sys tolic diastolic, pulse pressure, and mean pressure The systolic pressure is the highest pressure devel oped during the systole or contraction phase of the heart The diastolic pressure is the pressure remaining at the end of the diastole or relaxation phase of the heart The pulse pressure is the dif ference between the systolic and diastolic pressures and can be considered as representing the live load on the heart that is the pressure which the heart must develop in order to overcome the resistance in the blood vessels and to empty itself The mean pressure is usually given as one half the sum of the values for the systolic and diastolic pressures al though the true or geometric mean is somewhat lower than this, lying nearer the diastolic than the systolic pressure

Variation in pressure The systolic pressure is subject to wider variations under ordinary condi tions of health than the diastolic pressure and par ticularly reflects changes in the output of the heart or distensibility of the walls of the aorta or large arteries Diastolic pressure, on the other hand is a reflection of the constant load which the vascular walls are carrying throughout the arterial system and is a reliable index of the state of the more peripheral vessels

Considerable individual differences are found in the values for blood pressures in man In groups of the same age body build and occupation one individual will be apparently normal with a sys tolic pressure *of 100 mm Hg and another equally* healthy individual will have a systolic pressure of 125 mm Hg or higher Highly individual patterns of blood pressure are frequently seen It should be emphasized that average figures have only a rela tive value, and statistical studies although of in terest in a general study of blood pressure, indi cate only that the blood pressure of an individual has a statistical probability of being normal

Age and sex variations Table 2 illustrates the mean and range in systolic and diastolic blood pressures at different ages and in the two sexes The data were collected from 15 706 persons and can be taken as representative of the results of many similar studies The mean systolic and dias tolic pressures increase with age in both sexes Av erage systolic pressure readings for men show a fairly smooth progression up to the age of 50, thereafter the increase accelerates For women the increase in the averages by age is somewhat less smooth than it is for men but it also is acceler ated after the age of 50 The average systolic pres sures no longer continue to rise with age in males after 65 or in females after 70–74 years of age They remain constant to age 85 and then decline Female pressures exceed male by 14 mm Hg at *age 70–74 but over the age of 90 the values ap* proach each other Diastolic pressures show no sex difference and decline slightly after 85 years of age The data indicate that 95% of apparently healthy males over 65 years of age will have sys

Table 2 Systolic and diastolic blood pressure readings by sex and age*

Sex and age	Systolic			Diastolic		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
Males						
16	118 4	12 17	10 28	72 9	10 33	14 17
17	121 0	12 88	10 64	74 4	9 36	12 58
18	119 8	11 95	9 97	71 4	10 03	13 48
19	121 8	14 99	12 31	74 6	10 29	13 79
20–24	122 9	13 74	11 18	76 0	9 93	13 07
25–29	125 1	12 58	10 06	77 8	8 98	11 54
30–34	126 1	13 61	10 79	78 5	9 68	12 33
35–39	127 1	14 20	11 17	80 4	10 42	12 96
40–44	129 0	15 07	11 68	81 2	9 53	11 74
45–49	130 0	16 93	13 02	82 0	10 81	13 18
50–54	134 5	19 21	14 28	83 4	11 31	13 56
55 59	137 8	18 80	13 64	84 0	11 40	13 57
60–64	141 8	21 11	14 89	84 5	12 36	14 63
Females						
16	116 1	12 10	10 42	72 3	9 55	13 21
17	116 0	11 51	9 92	72 0	9 16	12 72
18	116 3	11 42	9 82	71 8	8 60	11 98
19	115 1	11 87	10 31	71 1	8 93	12 56
20–24	115 7	11 83	10 22	71 7	9 67	13 49
25–29	116 8	11 43	9 79	73 7	9 05	12 28
30–34	119 8	13 97	11 66	74 9	10 78	14 39
35–39	123 9	13 85	11 18	78 0	10 01	12 83
40–44	127 0	17 07	13 44	79 5	10 60	13 33
45–49	130 6	19 47	14 91	81 5	11 63	14 27
50–54	137 3	21 29	15 51	83 5	12 36	14 80
55–59	138 5	21 40	15 45	83 5	11 72	14 04
60–64	144 0	22 33	15 51	85 0	12 95	15 24

* From A *M* Master *L. I Dublin and H H Marks* The normal blood pressure range and its clinical impli tions *J Am Med Assoc* 143 1462 1950

tolic pressures ranging from 100 to 190 mm Hg and diastolic pressures of 62–102 mm Hg (mean = 145 and 82 mm respectively) Values for females were computed as 100–212 mm Hg for the range of systolic pressure (mean = 156 mm Hg) and 55–112 mm Hg for diastolic pressure (mean = 84 mm Hg)

The beginning of menstruation does not seem to influence the levels of blood pressure of young girls Nonmenstruating adolescents may have relatively higher pressures but this is probably caused by their usual gain in weight Pregnancy when uncomplicated does not produce significant changes in either systolic or diastolic pressures Most available evidence indicates that Negroes of the United States have a higher incidence of hypertension (high blood pressure) than white persons of the same age groups In general however climate and environment seem to be more important than racial origin in determining blood pressure levels Thus Americans living in China have lower pressures as the Chinese do whereas Chinese living in this country for any length of time have pressures within the same (higher) range as Americans *See* HYPERTENSION

Regulation of mean blood pressure The mean blood pressure is the resultant of the heart output and the amount let out by the arterioles If the heart output increases the arteries stretch and the blood pressure rises If the arteriolar drainage increases the elastic arteries empty and the arterial pressure falls The regulation of the mean blood pressure levels thus involves the maintenance of a balance between these two quantities so that pressure in the arteries stays within physiological limits

Poiseuille's law The blood leaving the larger vessels and coming to the arterioles encounters considerable resistance to flow in these vessels This is usually referred to as peripheral resistance It is due mainly to the small caliber of arterioles the resistance to flow is inversely proportional to the fourth power of the radius of the tube The resistance to flow of simple viscous fluids such as water through fine glass tubes can easily be evaluated from a knowledge of the dimensions of the tube The fundamental equation is that of Poiseuille

$$F = P_1 - P_2 = \frac{8\eta VL}{r^2} = \frac{8\eta Vl}{\pi r^2}$$

This indicates that flow F is directly proportional to the difference in pressure at the two ends of a tube $(P_1 - P_2)$ and that the pressure drop is directly proportional to viscosity η the flow velocity V, or the flow F in ml/sec and inversely proportional to a power of the radius r of the tube Poiseuille's law does not hold however for flow of blood through vascular beds This is caused in part by the anomalous viscosity of blood and in part perhaps by the fact that at higher pressures the arterioles are distended by the pressure so that the blood may flow more freely It is therefore difficult to arrive at a quantitative knowledge of the activity of arterioles (vasomotor activity)

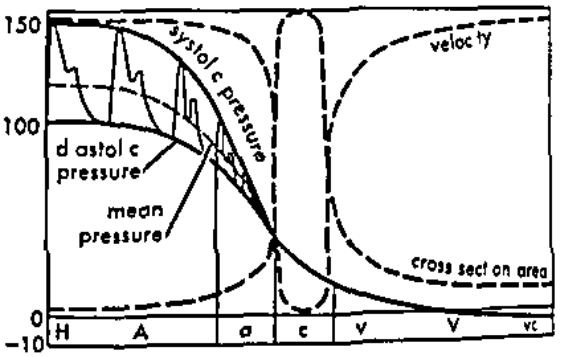


Fig 24 Relationships of pressure cross sectional area and velocity of blood flow in blood vessels

Pressure, flow, and cross sectional area The relationships between pressure, flow velocity and cross sectional area are shown in Fig 24 From Poiseuille's law it is clear that the resistance to flow is greatest in small vessels This is true even though the linear velocity of blood flow in the smaller vessels is much less than it is in the larger vessels If the mean aortic pressure is approximately 100 mm Hg it will have fallen little until it has reached the arterioles in which the pressure will have dropped to about 75 mm Hg By the time blood has reached the capillaries the pressure of the blood entering will be about 40 mm Hg and it will continue to fall so that at the venous end it will be only 15–20 mm Hg The pressure on the venous side of the circulation is thus relatively low In fact it is so low that it is not convenient to measure it in terms of millimeters of mercury venous pressures are usually stated in terms of centimeters of water Thus the pressure in the veins at the level of the elbow is within the range of 7 12 cm of water The pressures in the hands and feet are about 1–3 cm higher whereas the mean pressure in the right auricle is near the zero (atmospheric) level or slightly below because of the negative pressure in the thorax The relatively small pressure gradient from the veins in the periphery to the right auricle is adequate to cause flow of blood back to the heart when the individual is in the prone or supine position because relatively little resistance to flow is encountered in the venous system

Blood flows fastest where the stream bed is narrowest in the arteries near the heart As the larger arteries divide, the cross section of the bed increases so that the aggregate cross section of the peripheral arterial branches is always greater than the cross section of the trunk from which the branches derive The increase in total cross-sectional area of the peripheral bed means that the velocity of flow gradually decreases as the arteries branch toward the periphery, and it is less in the small arteries than in the large arteries As the arterioles open out into the capillaries the aggregate cross section of the vascular bed is greatly increased It is estimated that all the capillaries of the body have a cross section that is more than 800 times the cross section of the aorta The velocity of the blood in the capillaries is therefore very slow

indeed that is soon that in the aorta *This slow* flow is of advantage because it is in the capillary that exchange of materials takes place between the tissues and blood a process which needs a certain amount of time to be accomplished *effectively* As the capillaries come together in veins the vascular bed begins to narrow again and the velocity of *blood flow* increases As the veins combine into the vena cava the *blood flow becomes more and* more rapid until it reaches its greatest velocity *at the portals* of the heart where the aggregate cross section of the venous bed is smallest The velocity of *blood through any part of the* vascular tree is in no way related to the pressure in that *part but is directly related* to its aggregate cross section The pressure as previously discussed becomes *progressively less* as the blood passes from artery *to capillary and vein*

Control of peripheral resistance Because the *peripheral resistance* measures the pressure drop concerned with the flow of blood through the arterioles, *it varies with the caliber* of these vessels Vasodilatation (increase in caliber) reduces and *vasoconstriction* (decrease in caliber) increases the peripheral resistance Physiological adjustments *are made by* increasing and decreasing the caliber of arterioles thus lowering or raising the *peripheral resistance* and mean blood pressure Viscosity of the blood also influences resistance to flow *Thus a* decrease in blood viscosity will result in a decrease in peripheral resistance even though *there is no* dilation of arterioles

Three major mechanisms serve to control the caliber of arterioles and thus influence the level *of the mean blood* pressure (1) nervous (2) hemodynamic and (3) chemical or hormonal These *mechanisms* serve to minimize fluctuations in blood pressure under changing physiological or normal *conditions* such as posture exercise and sleep as well as under temporary pathological or abnormal *conditions* such as blood loss trauma or other similar conditions *See* CARDIOVASCULAR SYSTEM DISORDERS CIRCULATION DISORDERS HEMORRHAGE

Nervous (vasomotor) mechanisms The ability of arterioles to change their calibers is referred to as tone *Vasomotor* tone is the result of a constant stream of impulses coming chiefly from the medulla *any part* of the brain These tend to keep the arterioles in a partially constricted state A decrease in

through the

the brain

terioles usually occurs because of diminished vasoconstriction Vasoconstrictor (pressor) impulses are mediated by the sympathetic nervous system fibers Receptors which when stimulated will modify the *blood* pressure have been located in many parts of the body particularly in the walls of the large *arteries* Most information is known about those located in the arch of the aorta and in the *carotid sinus* The latter bulging structure occurs on the internal carotid artery just as it branches from the common carotid and enters the skull at the angle of the jaw These receptors respond to *stretch* Thus an increased pressure of the blood *in the carotid* sinus or in the aortic arch stimulates the

serves to diminish peripheral resistance and mean blood pressure Likewise *a fall in pressure will* result in a reflex increase in vasoconstriction and rise in *blood* pressure because fewer inhibitory impulses will arise *See* AORTIC BODY

Hemodynamic control Blood volume is an important factor in the control of *blood pressure* The circulatory system is a closed system so that the blood volume and the capacity of the vascular bed must always be the same The elastic bed may be distended at a greater or less pressure but empty spaces are inconceivable and any change in the size of the blood vessels must be associated with a corresponding change in blood volume otherwise it must be assumed that any enlargement of one set of vessels is exactly balanced by an equal reduction in the size of other vessels Although nervous reflex control probably plays the major role in rapid adjustments alteration in blood volume is part of the usual mechanism Capillary and osmotic pressure relationships determinants of blood vol

pressure in the capillaries resulting in a transudation of dilute plasma (the liquid portion of blood) to the extravascular system so that arterial pres

forth from the extravascular system acts as an effective control of mean blood pressure supplementing nervous control

Chemical control It has generally been assumed although never definitely proved that chemical substances (hormones) secreted by the medulla of the adrenal gland markedly contribute to the vasomotor control of blood vessels and thus serve to regulate the level of blood pressure The adrenal medulla is known to secrete epinephrine and norepinephrine but the injection of small amounts of these substances in doses which might be assumed to be similar to amounts elaborated by the adrenal produces equivocal results on blood pressure

Considerable interest has been shown in the presence of various chemical (humoral) substances in the brain circulation and their possible effects on control of blood pressure The roles of acetylcholine serotonin cerebrotonin and substance P (a

teraction of a variety of mechanisms The composition of the blood hormonal or humoral mechanisms and reflexes and impulses from higher brain levels influence the vasoconstrictor areas and so modulate the resistance of blood vessels Equally

important are the amount of blood actively circulating in the blood stream and the levels of venous return and output of the heart In this respect the heart occupies a key position As servant of the circulation the heart must accept an adequate amount of blood from the veins and eject an adequate amount of blood into the aorta to meet the particular demands of the organism

Pulmonary circulation This circulation is often referred to as the lesser circulation Its function is to carry blood from the right to the left heart through the lungs It is made up of short circuits with little resistance to flow Because the output of the right heart moves through the lungs the stream of blood in the pulmonary artery from the right heart to the lungs is the same size as that in the aorta which receives the left heart output for distribution to the body The main pulmonary artery and its branches have great distensibility and consequently large capacity It has been estimated that the volume of blood in the lungs is three times that in the heart This constitutes a reserve supply of blood which can be drawn upon to meet rapid circulatory readjustments such as are needed for producing the larger heart outputs which occur during physical work Although the stroke output of each ventricle is approximately the same except for temporary differences the pressures in the pulmonary artery are only about ⅙–⅒ of those in the aorta (systolic is 22 27 mm Hg vs 120–125 mm Hg diastolic is 8–12 mm Hg vs 65–72 mm Hg)

lar wall as compared with arterioles in other regions S Rodbard and his coworkers from a study in the turtle dog and chicken suggest that the pulmonary arterial pressure remains low in the higher vertebrates probably as a result of factors which act to increase the rate of exchange of blood gases with those of the environment These factors include (1) the enormous pulmonary vascular bed (2) the absence of tissue support of the pulmonary capillaries which are exposed over nearly their entire surface to the environment resulting in (3) the great distensibility of the capillaries which permits little increment in pressure with

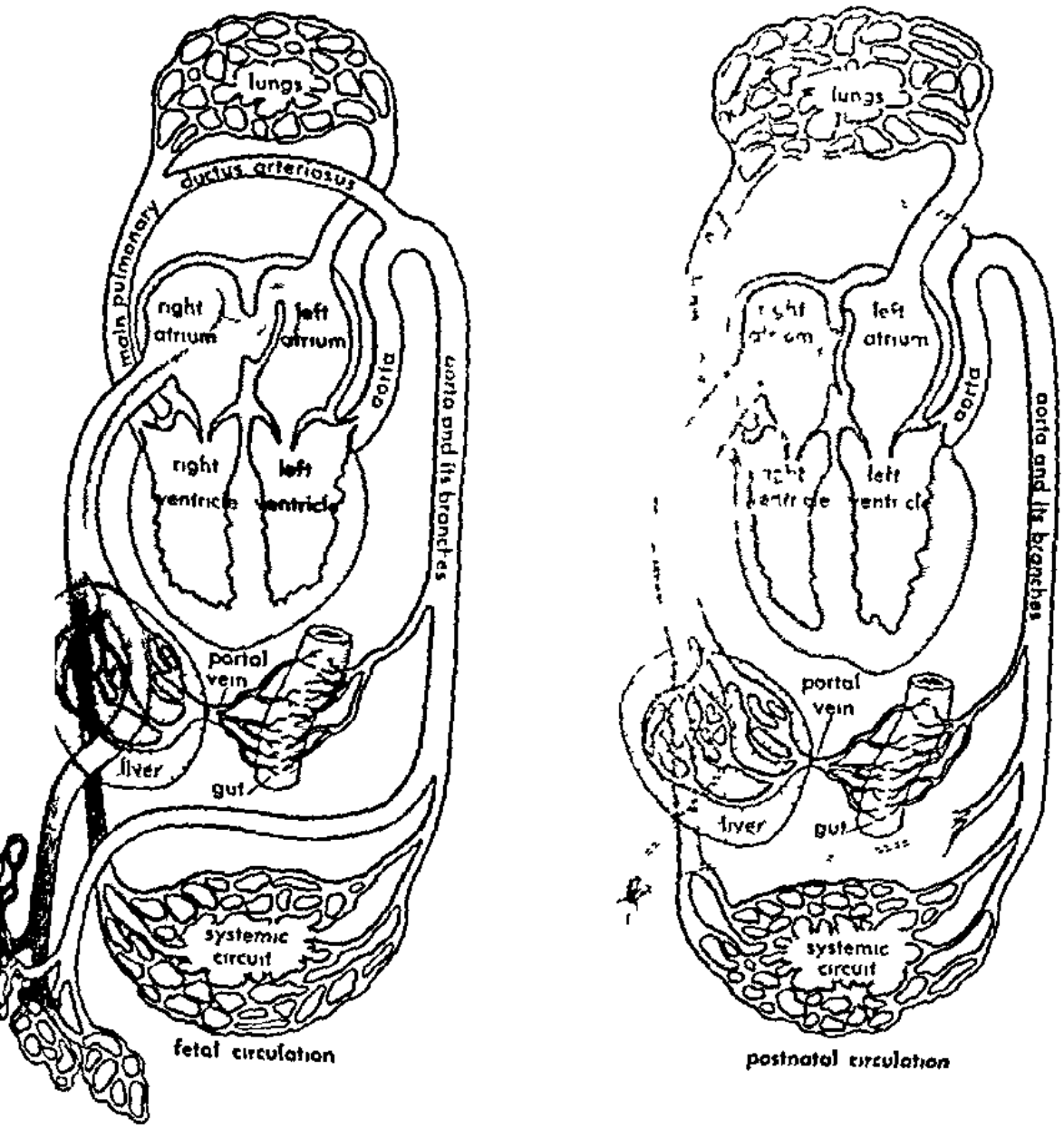
division of the primitive ventricle into two chambers results not only in the separation of arterial from venous blood but also provides conditions in which the systemic pressure can be raised without directly affecting the pulmonary blood pressure and blood flow

Cerebral circulation The brain is a highly metabolizing organ and consequently has a high oxygen consumption This necessitates the maintenance of a blood flow adequate to meet the demands of metabolic activity at all times Indeed the availability of adequate amounts of blood (and oxygen) is one of the factors which limit the functional capacity of the individual to withstand stresses such as high altitudes The brain is in a peculiar situation in that it is enclosed in a bony box the skull which limits its maximum volume Even if the bone were removed its volume would be limited by the inelastic envelope the dura which covers the brain

Regulation Two mechanisms regulate the blood flow to the brain (1) an intrinsic or intracerebral mechanism and (2) an extrinsic or extracerebral mechanism The brain does not function as a unit and blood is shifted from one part to another These shifts are compensated for by shifts in cerebrospinal fluid or blood from one area to another No general dilatation of the brain vessels can occur because of the limitation of the brain volume by the dura and skull The intrinsic mechanism by which these shifts are mediated is made up of two sets of control nervous and chemical Stimulation of the cervical sympathetic nerves will produce constriction whereas stimulation of the facial nerve will produce dilatation of blood vessels in the pia mater Section of the sympathetic nervous system results in a dilatation of cerebral vessels and a decrease in resistance to flow Although this nervous control of the tone of blood vessels is important in regulating blood flow in the brain its role is probably masked by the changes produced by variations in the blood carbon dioxide tension Carbon dioxide acts as a powerful dilator of cerebral vessels and changes in tension of 4 5 mm Hg or greater will produce significant alterations in blood flow *See* NERVOUS SYSTEM

The extrinsic control is by means of the systemic blood pressure If the mean blood pressure rises the flow of blood to the brain is increased if it falls the flow is diminished The critical pressure below which normal cerebral function cannot be maintained appears to be about 40 mm Hg On the other hand any significant rise in blood pressure will increase the brain volume and consequently the pressure within the skull (intracranial pressure) As the intracranial pressure rises the thin walled cerebral veins are apt to be compressed and normal blood flow to important areas will be disturbed Thus the vasomotor areas in the brain which control the tone or caliber of arterioles will be stimulated by a diminished blood flow (an oxygen lack) to cause a widespread arteriolar constriction This will increase the blood pressure still further and create a vicious cycle which can be broken only by lowering of the blood pressure or relief of the high intracranial pressure Teleol gically speaking the carotid sinus stretch receptor mechanism is in a strategic position to guard against abnormal variations in cerebral blood flow because the carotid artery is the main source of supply to the brain and a rise in pressure in the carotid sinus will cause a reflex vasodilatation and conversely

Blood flow values Various methods some involving the use of isotopes have been used to measure cerebral blood flow The results obtained under a



Schematic diagrams showing the changes occurring in the circulation at the time of birth (*From B. M. Patten Foundations of Embryology, McGraw Hill* 1958)

Table 3 Physiological and pathological states involving alterations in cerebrovascular resistance and blood flow

Condition	Mean arterial blood pressure mm Hg	Cerebral blood flow ml/(100 g)(min)	Cerebral oxygen consumption, ml/(100 g)(min)	Cerebrovascular resistance mm Hg / ml/(100 g)(min)
Normal	85	54	3 3	1 6
Fatigue	91	61	3 7	1 5
Mental arithmetic	93	67	4 0	1 5
Sleep	90	6›	3 4	1 5
Hyperventilation	98	34	3 7	2 9
CO_2 (5 7%)	93	93	3 3	1 1
O_2 (85 100%)	98	4›	3 2	2 2
Increased intracranial pressure	118	34	2 8	3 5
Cerebral ischemia (tilting)	48	31	2 9	1 5
O_2 (10%)	78	73	3 2	1 1
Primary polycythemia	108	25	3 0	4 3
Hypothermia (83°F)	82	12	0 9	7 4
Anemia	78	79	3 3	1 0
Cerebral arteriosclerosis	121	41	2 8	3 0
Cerebral hemangioma	75	161	3 3	0 5
Essential hypertension	159	54	3 4	3 0
Hyperthyroid	83	67	3 6	1 4

variety of conditions are given in Table 3 The normal blood flow range is 45–65 ml/100 g of brain per minute The average weight of the human brain is about 1400 g The blood flow for the average whole brain therefore would be between 615 and 930 ml/min This represents approximately 15% of the output per min of the heart Of particular interest is the marked increase in blood flow resulting from the inhalation of 5–7% carbon dioxide (CO_2) and the equally significant reduction in blood flow with hyperventilation which decreases blood carbon dioxide tension These changes reflect the strong dilator effect of CO_2 previously discussed It is also evident that changes in flow in all situations are intimately related to the state of the blood vessels and the resistance to flow which they offer

Hepatic circulation The vascular system of the liver in higher species is unique in that the blood is received from two separate sources the portal vein and the hepatic artery

The portal venous system drains most of the blood from the gastrointestinal tract spleen and pancreas This portal system is supplied by large arteries with extensive capillary beds and a highly developed system of vasomotor control The portal vein interposed between the liver capillaries (sinusoids) and the capillary bed of the digestive tract and other abdominal viscera carries blood that is highly enriched with freshly absorbed nutritive materials to the liver Most of the food is brought to the liver by the portal vein

The hepatic artery is not large but the pressure in it is the same as that in any systemic artery of its size normally about 120 mm Hg This is in contrast to the pressure in the portal vein which is about 7 cm H_2O The hepatic artery brings about one third of the blood supply to the liver at high pressure whereas the portal vein carries about two thirds of the supply at relatively low pressure There is evidence of a reciprocal relationship in these two sources of supply so that a reduction in portal venous flow may lead to an increase in hepatic arterial flow

In the liver the blood from both sources becomes mixed in the large spaces or sinusoids found in this tissue although a whole sector of a liver lobule may be supplied by purely arterial or purely venous (portal) blood Anastamoses or connections between the two vessels are also present The si

varies within wide limits Estimates vary between 1000 and 2500 ml/min or a daily flow of about 2000 liters of this total an average of 1200 liters

a large amount of tissue and thus has a low oxygen content when it reaches the liver Because of its large size and its position close to the right heart the liver is perhaps the most important blood reservoir in the body The venous blood channels or sinuses are capable of increasing tremendously in volume If an animal is given a large transfusion one of the first structures of the animal's body to enlarge is the liver On the other hand after hemorrhage the liver sinuses are capable of contracting considerably and sending a large amount of blood to the right side of the heart [H S M]

HEART PHYSIOLOGY

The vertebrate heart functions as a pump which propels blood through the circulatory system and

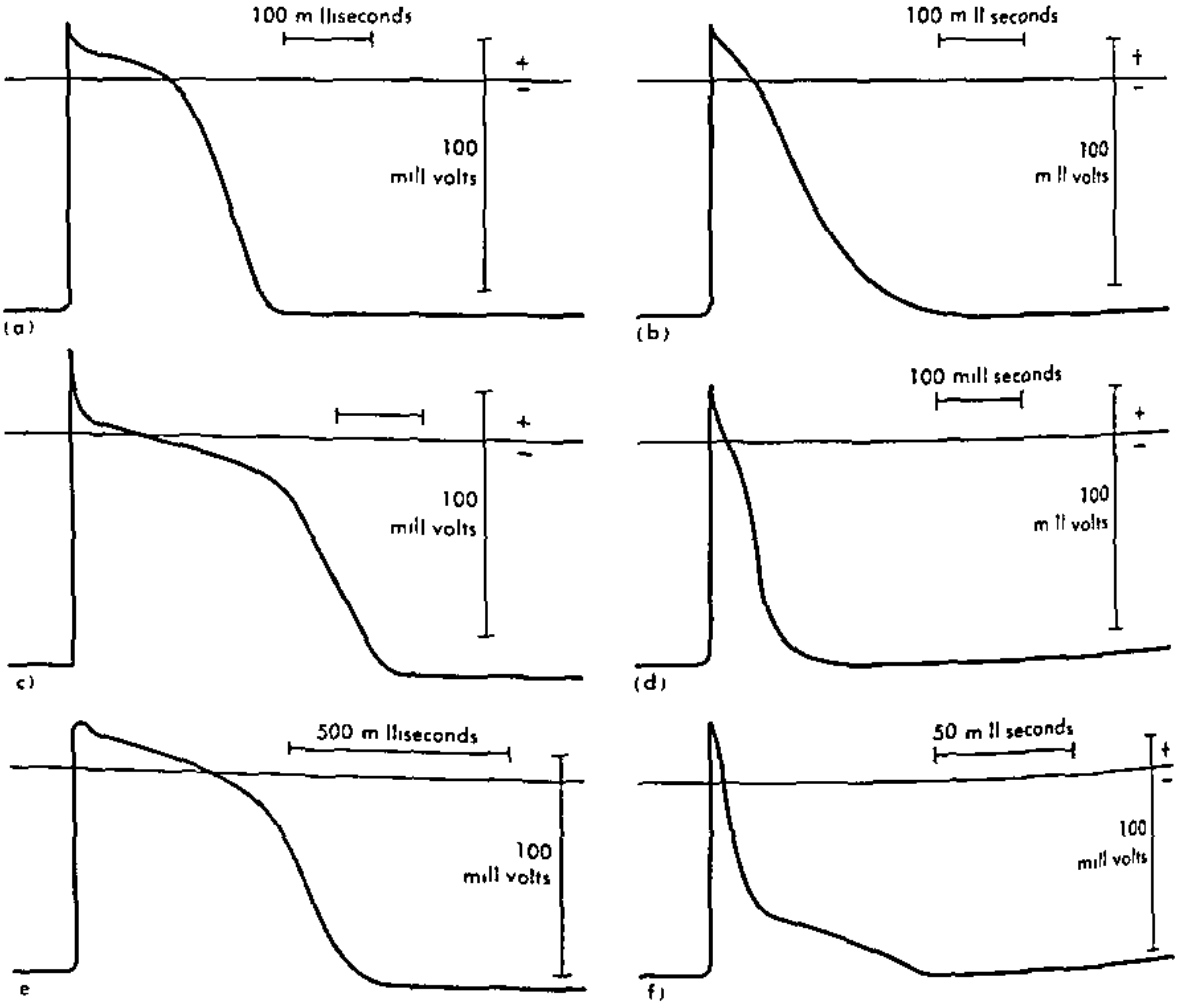


Fig 25 Transmembrane resting and action potentials recorded at usual body temperature from single fibers of (a) dog ventricle (b) dog atrium (c) dog Purkinje fiber (d) rat ventricle (e) frog ventricle (20°C) (f) canary ventricle Ordinate scale in millivolts is the same for all records abscissa, showing time in milliseconds, indicated in each record

cytial striated muscle which comprises the walls of its chambers and which by contraction supplies a propulsive force to the blood Unidirectional blood flow results because the various chambers of the heart are separated *from* each other and from the arterial tree by one way valves which are closed by a pressure drop across the valve orifice by muscular action or by a combination of these forces

The number *and* arrangement of chambers in the heart vary In lower forms ( ) eost fishes) arranged in tially from the sinus venosus to the atrium, ventricle, conus arteriosus and arteries In lungfishes the atrium is *partially* divided by a septum into right and left sides blood from the systemic veins enters the right side and blood from the lungs the left side In amphibians separation of the two atria is complete and the ventricle is partially divided by a septum In this *heart* the systemic venous blood passes from the sinus venosus to the right atrium and oxygenated pulmonary venous blood to the left atrium, blood from the right and left atria is only partially *mixed* in the ventricle, and thus right atrial blood is pumped to the lungs and oxygenated left atrial blood is pumped to the systemic arteries In higher forms such as birds and mammals the sinus venosus and conus arteriosus have disappeared and separation of the ventricle into right and left sides is complete The heart thus consists of four chambers with the right and left atria and right and left ventricles arranged in parallel The flow of systemic venous blood is from the venae cavae to the right atrium right *ventricle* and pulmonary artery, oxygenated pulmonary venous blood flows to the left atrium, left ventricle and aorta

Electrical activity. The membrane surrounding myocardial fibers is called an excitable membrane because it responds to appropriate stimuli *by* developing an electrical response the action potential which is regenerative and which propagates over the entire syncytium At rest there is a steady potential difference across the cardiac membrane the inside being negative with respect *to* the outside This resting potential amounts to 80–90 millivolts (mv) in all vertebrate hearts where accurate measurements have been made During activity the transmembrane potential changes (Fig 25) the inside becoming positive with respect to the

outside by 10–40 mv for a variable period of time (depolarization) and then returning more slowly to the resting potential (repolarization) This change in potential the transmembrane action potential varies in shape and duration in different vertebrates and in different chambers of the same heart *Two major forms are noted In one depolarization* and repolarization are separated by an interval during which the transmembrane potential remains almost constant and thus forms a plateau in the other repolarization commences immediately after depolarization In frogs and turtles the transmembrane action potentials recorded from all chambers show a plateau In dogs cats and ungulates ventricular fibers show a plateau but atrial fibers do not in rats and mice in contrast neither atrial nor ventricular action potentials show plateaus

Action potential duration Action potential duration varies with heart rate body temperature and species In turtle or frog at 20°C the ventricular action potential lasts 0 5–1 5 sec in the dog at 38°C the duration is 0 25–0 3 sec and in the rat at 40°C, 0 08–0 1 sec *In all vertebrate hearts the* transmembrane potentials depend upon the partition of ions by the selectively permeable fiber membrane Excess extracellular K^+ (potassium ions) decreases the resting potential in all hearts A low concentration of extracellular Na (sodium ions) decreases the amplitude of the action potential of some hearts (dog, turtle calf) more than others (guinea pig) however in all hearts excitability is lost in media free of Na^+ All vertebrate hearts fail to respond to stimuli applied shortly after the onset of electrical activity The duration of this period of refractoriness varies in direct proportion to the duration of the action potential and normal excitability is restored after completion of repolarization *See* BIOPOTENTIALS AND ELECTROPHYSIOLOGY

Electrocardiogram The electrocardiogram recorded from vertebrates varies mainly in the presence or absence of a potential due to electrical activity of the sinus venosus and in the presence or absence of a clearly demarcated indication of ventricular repolarization the T wave The latter is present when the ventricular action potential shows a plateau The electrocardiogram of frogs and turtles shows both these potentials whereas the electrocardiogram of rats and mice shows neither Other differences in electrocardiograms from different vertebrate hearts depend mainly upon differences in heart rate body temperature conduction velocity and the presence or absence of a well developed specialized conducting system

Origin and control of heartbeat The vertebrate heart has an intrinsic rhythmicity if the heart is removed from the body and if the sinus venosus atria, ventricles and conus arteriosus are separated from each other each chamber continues to contract rhythmically Frequency is highest in the sinus venosus and lowest in the ventricles or conus arteriosus When the heart is intact that part contracting at the highest rate acts as pacemaker for the entire organ In hearts of lower forms (fish amphibians) the pacemaker is located in the sinus venosus in birds and mammals the normal pacemaker is in the sinoatrial node a mass of histologically distinct fibers located in the wall of the right atrium close to the entry of the superior vena cava

Cause of rhythmicity The cause of intrinsic rhythmicity is similar in all vertebrates and is best understood in terms of changes in the potential difference across the membrane of the pacemaker fiber In contrast to muscle fibers of atria and ventricles pacemaker fibers do not maintain a steady resting potential After completion of repolarization the transmembrane potential slowly decreases When as a result of this slow depolarization the membrane potential reaches a critical value (the threshold potential) excitation occurs This potential change causes the intrinsic rhythmicity of all normal vertebrate pacemakers (Fig 26)

Control of rate The frequency of the pacemaker is determined largely by the slope of the slow depolarization and the level of the threshold potential Changes in heart rate result largely from reflex autonomic nervous control *In all vertebrates activity* of the vagus nerve causes slowing and (except in certain fishes) activity in sympathetic nerves causes acceleration These effects are brought about by decreasing or increasing the slope of slow depolarization Lowered temperature has an effect similar to that of the vagus excess Ca (calcium ions) causes slowing by altering the threshold potential The average heart rate of quiescent vertebrates varies greatly two major determinants are body size and basal metabolic rate In poikilotherms and in hibernators changes in body temperature produce marked rate changes At similar temperatures rates are highest in small mammals and birds *See* HEART (GANGLIONIC PACEMAKER) HIBERNATION

Spread of excitation In the vertebrate heart conduction is partly through specialized paths and partly through muscle fibers of the atria and ventricles Although there is some evidence for the existence of specialized conducting fibers in the atria of mammals their importance in atrial activation has been demonstrated only in birds In fish and amphibians there is a radial spread of electrical

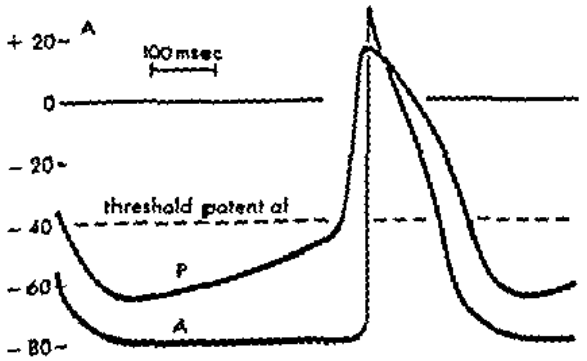


Fig 26 Tracings of transmembrane action potentials of rabbit heart at 33°C recorded from a single fiber of the sinoatrial node (P) and a single atrial muscle fiber (A) Ordinate in millivolts

Table 4 Heart rate of various species

Species	Rate beats/min	Weight grams	Energy expenditure cal (kg)(24 hrs)
Mouse	500	20	170
Frog	30	25	15
Tortoise	20	130	85
Hen	300–350	1 000–2 000	80–110
Rabbit	200	2 000	50
Cat	100–150	2 500	80
Dog	70–90	9 500	40
Man	60–80	66 000	25
Pig	70–85	130 000	20
Ox	25	500 000	45
Elephant	20–50	36 000 000	15
Frog 4°C	6–8		
20°C	35–45		
Hedgehog 6°C	3–6		
32°C	250–300		

activity from the sinus venosus over the atrial muscle in mammals spread from the sinoatrial node similarly takes place in atrial muscle fibers In all vertebrate hearts the spread of activity from atrial to ventricular muscle is delayed because of conduction at a low velocity through specialized fibers at the atrioventricular junction In higher forms this specialized tissue is aggregated in a histologically distinct structure called the atrioventricular node in lower forms the slowly conducting tissue partly or completely surrounds the atrioventricular canal In mammals and birds the wave of excitation spreads to the ventricles over bundles of large diameter specialized fibers which conduct at high velocity and which make up the bundle of His and the ventricular Purkinje system Through this system the ventricles are activated almost simultaneously at many points and synchronous contraction is assured Although the existence in lower forms of a similar specialized conducting system is doubted fibers similar to Purkinje fibers have been demonstrated in the interventricular septum of turtle and frog hearts and their presence in other forms should be expected

Conduction velocity varies with the species fiber type and temperature At average body temperature in mammals conduction velocity in atrial and ventricular muscle is 0 6–1 0 meters per second (m/sec) and in frogs at 18°C 0 1–0 2 m/sec In the mammalian atrioventricular node velocity is 0 05–0 02 m/sec and in the ventricular Purkinje system velocities as high as 2–3 m/sec (dog) or 3–4 m/sec (ox) have been recorded Conduction velocity is strongly dependent upon the amplitude and rising velocity of the transmembrane action potential and on the level of the threshold potential

Contractility Excitation of cardiac muscle is followed by contraction the rate of change of tension varies widely between different species and is most strongly influenced by temperature and heart rate In general the duration of the contraction parallels the action potential duration but exceptions are noted as in the ventricles of the rat and mouse where repolarization is largely completed during the early stages of contraction The contractile unit in vertebrate hearts is a complex protein arranged in longitudinal fibrils and composed largely of actin and myosin The force of contraction is influenced strongly by the resting length of the fiber and by the rate and rhythm of contraction The composition of the extracellular fluid also regulates contractile force excess calcium increases and low concentrations of K^+ or Na^+ decrease force of contraction of heart muscle In mammals birds reptiles and amphibia Pressures developed within the chambers of the vertebrate heart vary widely In most reptiles and amphibians the peak pressure during contraction of the ventricle ranges from 25 to 35 mm Hg in fishes the pressures range from 35 to 85 mm Hg In mammalian and bird hearts the pressures in the right and left ventricles differ, right ventricular pressure ranges from 10 to 40 mm Hg and left ventricular pressure from 100 to 150 mm Hg In certain species cases such as the giraffe the peak pressure appears to increase with the length of the neck The volume of blood pumped by the heart per unit time varies from several milliliters to several many liters per minute, the major determinants of the volume per minute are the body weight and metabolic rate The output of all vertebrate hearts increases in response to bodily activity and increased body temperature Pharmacological agents also influence contractility and output marked differences in the sensitivity of different species are noted as in a comparison of the action of digitalis on cat and rat heart or of sympathomimetic amines on rat cat rabbit and guinea pig [B F H

CONGENITAL DEFECTS

Both the heart and major blood vessels show an almost infinite variety of malformations

Heart It is possible to deal with only a few of the basic types of congenital heart defects pointing out the great differences in the gravity of the outlook they entail and indicating some of the different ways in which they may arise No blanket statements concerning either clinical seriousness or the origin of congenital cardiac defects as a group can possibly be valid Each condition must be assessed on an individual basis

functional disturbances involved it is necessary to have a sound knowledge of the normal circulatory dynamics of the fetus It is for example necessary to know the extent to which a particular type of septal defect disturbs the right left balance of cardiac pumping load in the fetal heart and thereby leads to abnormal muscular development of one or the other of the ventricles It is necessary to determine whether or not the pulmonary circuit has been interfered with in a manner which will lessen the efficiency of the oxygenation of the blood when postnatal living conditions are faced It must be ascertained whether there is any interference with

the charging of the left ventricle through the mitral valve or any obstruction in its outflow tract either at or below the level of the aortic valves or in the aorta itself Accurate diagnosis is necessary for intelligent treatment of any kind and of paramount importance if surgery is being considered Complicated cases may need the aid of cardiac catheterization blood chemistry studies and angiocardiography *in addition to the more routine x ray* and electrocardiographic studies

One of the highly significant conditions that emerges from studies of the functional balance of

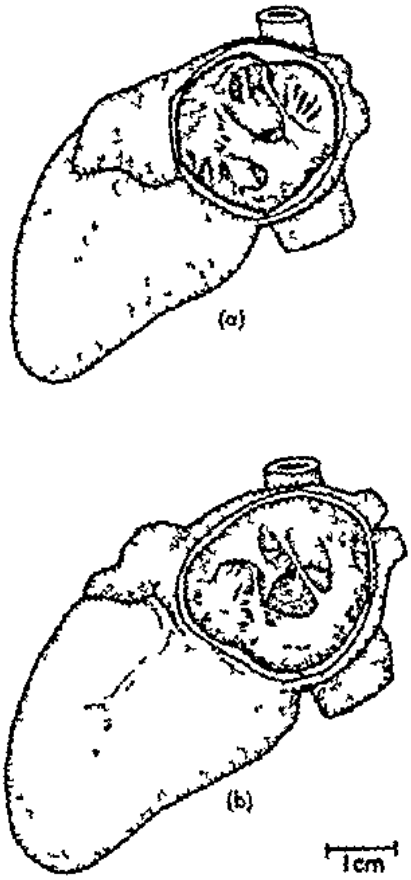


Fig 27 Incompetent valve of foramen ovale resulting from excessive resorption of septum primum associated with the formation of ostium secundum (a) Male still born at term (b) Female 6 weeks old (*From B M Patten Developmental defects of the foramen ovale Am J Path 14(2) 135–161 1938*)

the circulation in individuals with congenitally defective hearts is the presence or absence of cyanosis This is so striking that it is quite usual for clinicians to group congenital defects into two main categories those involving cyanosis and those which are acyanotic This has certain advantages from the diagnostic standpoint but leaves very heterogeneous groups from both the structural and the developmental standpoint In this account written primarily from an embryological viewpoint it has seemed simpler to group the defects according to the regions involved *See* ELECTROCARDIOGRAPHY VECTORCARDIOGRAPHY

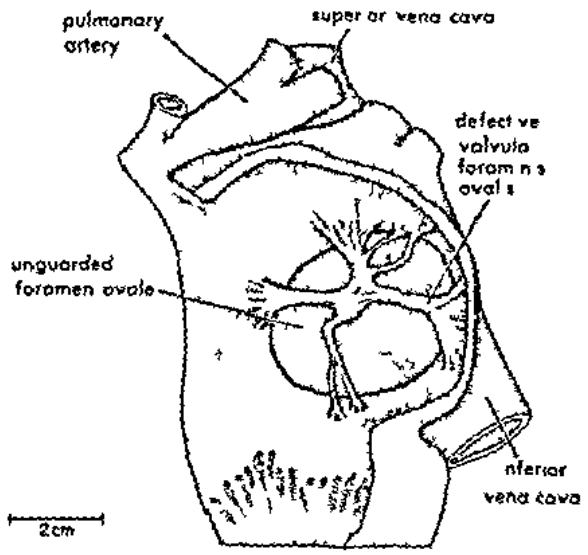


Fig 28 Unclosed foramen ovale in adult resulting from extensive secondary resorption of septum primum and less than normal growth of septum secundum Male day laborer age 21 years (*From B M Patten Developmental defects of the foramen ovale Am J Path 14(2) 135–161 1938*)

Interatrial septal defects The most common site of interatrial defects is the foramen ovale The defects occurring here differ widely in both type and manner of origin For example abnormally extensive resorption of the septum primum at the time the interatrial foramen secundum (ostium II) is formed may leave a valvula foraminis ovalis which is inadequate to guard the foramen ovale (Figs 27 and 28) When as happens sometimes

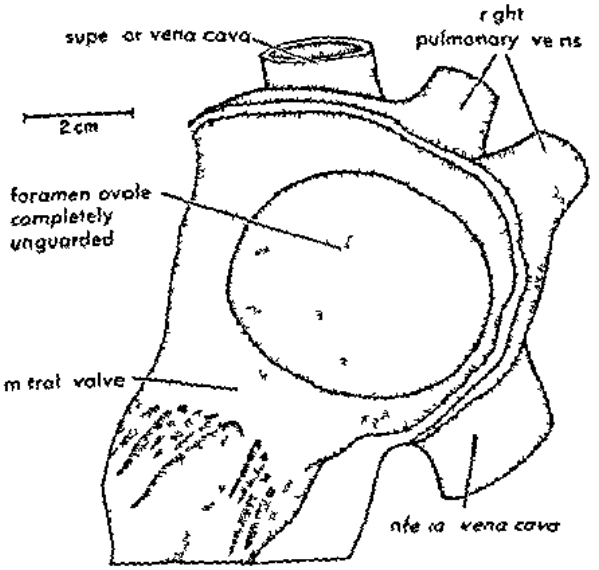


Fig 29 Extremely large unguarded foramen ovale resulting from complete secondary resorption of septum primum Male laborer age 44 years (*From B M Patten Developmental defects of the foramen ovale Am J Path 14(2) 135–161 1938*)

an extensively or completely resorbed valvula occurs concurrently with less than normal growth of septum secundum the foramen ovale itself remains excessively large and the unguarded interatrial communication may be of huge proportions (Fig 29)

Destruction of the valvula The excessive secondary destruction of the valvula foraminis ovalis such as that illustrated in Figs 27 and 28 appears to have arisen essentially as an extension beyond its usual limits of the resorptive process normally involved in the formation of ostium II Another related but developmentally different defect occurs not infrequently instead of progressing too far from a start in the area normally involved resorption may occur in regions in which it does not normally appear at all Such a case is illustrated in Fig 30 The configuration of the attached margin of the valvula clearly indicates that the resorption directly involved in the formation of ostium II ceased within normal limits There are however multiple perforations in the valvula directly over the foramen ovale where no resorption normally occurs This is clearly a disturbance in the positional regulation of a developmental process rather than mere retardation or acceleration of its rate

Premature closure of the foramen One of the rare anomalies of the foramen ovale is its premature closure (Fig 31) In spite of its uncommon occurrence this malformation is worth emphasizing for two reasons First it is not the result of a growth arrest of the type so much emphasized in the older discussions of congenital defects On the contrary it is the result of the continuation of a normal growth process beyond the point specified in the plans The septum secundum fails to cease growing when its margins have reached the usual boundaries of the foramen ovale This condition resulting from overgrowth and the defects of the valve of the foramen ovale produced by too much resorption or by resorption in abnormal locations are clear warnings that the search for causative factors in the genesis of abnormalities must not be limited to the scrutiny of possible growth inhibiting factors

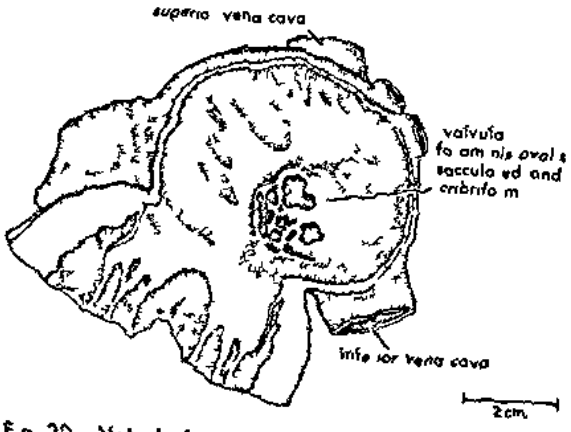


Fig 30 Valvula foramin*is* oval*is* with multiple perforations in an area not normally involved by resorption From B M Patten *Developmental defects of the foramen ovale* Am J Path 14(2) 135–161 1938)

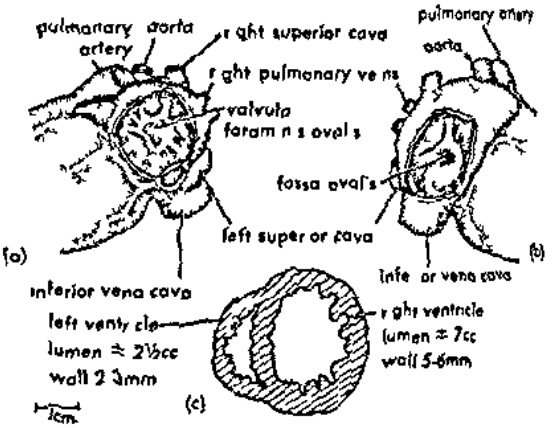


Fig 31 Case of premature closure of the foramen ovale (a) Tightly adherent valvula (b) Fossa ovalis has been reduced to a small slit (c) Section across the ventricles shows the small lumen and poor muscular development of the left ventricle (From B M Patten *Developmental defects of the foramen ovale* Am J Path 14(2) 135–161, 1938)

The second reason for emphasizing premature closure of the foramen ovale is the striking evidence such cases afford concerning the importance of the shunt at the foramen ovale during fetal life In the section on fetal circulation at term emphasis was laid on this mechanism which brings the intake of the left side of the heart to approximate equality with that of the right. When the foramen ovale is unduly restricted during fetal life the intake of the left atrium and thereby the intake of the left ventricle is curtailed The resultant lack of growth of the left ventricular chamber in hearts with this defect is clearly shown in sections cut transversely through the ventricular region (Fig 31c) Not having carried its full pumping load prenatally the left ventricle has not developed adequate size or muscular power to handle the systemic circuit postnatally and early death ensues.

Septal defects Defects may also appear low in the interatrial septum altogether independently of the foramen ovale Such defects (Figs 32 and 33) are attributable primarily to the persistence of interatrial foramen primum In other words the septum primum never grew all the way down to meet and fuse with the atrioventricular canal cushions When this occurs the septum secundum being without the scaffolding normally furnished for it by septum primum fails to grow into the unclosed area Such a defect although properly designated as a persistent interatrial foramen primum involves the abnormal development of both the septum primum and septum secundum

In rare cases a developmental disturbance in this territory also extends to involve the atrioventricular canal cushions (Fig 34) Embryologically there are really three regions involved in such defects the interatrial septal complex the endocardial cushions of the atrioventricular canal and the

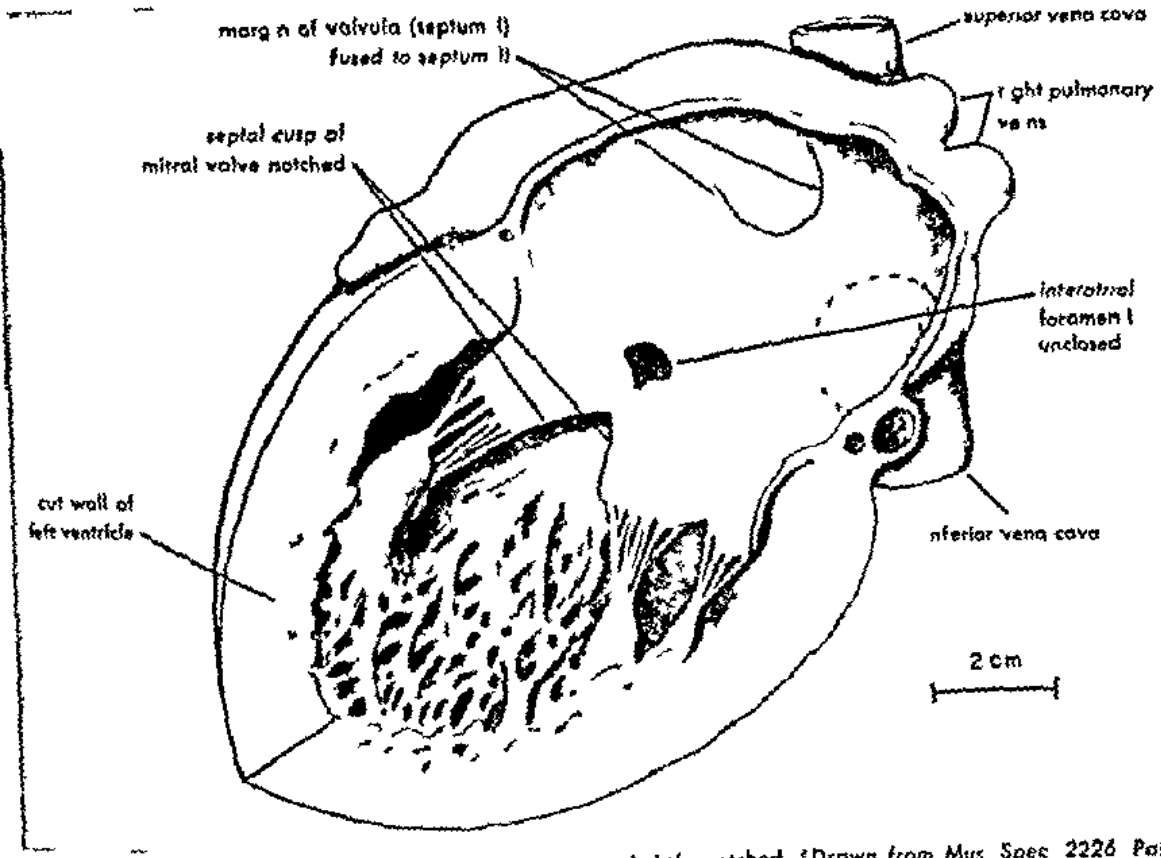


Fig 32 Unclosed interatrial foramen *primum* In this case the defect is small and the mitral valve is only slightly notched (Drawn from Mus Spec 2226 Pathologische Anatomische Inst tut Vienna)

composite primordia of the membranous portion of the interventricular septum

In general interatrial septal defects either at the foramen ovale or at the level of ostium *primum* provided they do not extend to involve the atrioventricular partition or valves are compatible with life They, of course cause a distinct lowering of the margin of safety in the cardiovascular system and make individuals possessing them more vulnerable to intercurrent pulmonary disturbances Very striking in such hearts is their generally increased size the dilation and hypertrophy being particularly marked in the *right* chambers The reason for this is that postnatally left atrial pressure becomes slightly higher than right atrial pressure This means that with each cardiac cycle a little blood passes back from *left to right* through the septal defect and must be pumped as an extra load by the right side of the heart Cardiac muscle like any other muscle develops in proportion to the work it is made to do *and this* accounts for the characteristic enlargement of the right side of the heart seen in these cases Except with intercurrent disturbance or terminally such patients do not show any cyanosis because there is an adequate volume of blood passing through the lungs and returning to the left atrium and there is no shunt of unoxygenated blood into the systemic side of the heart *In the absence of any* complicating factors as for example pulmonary di which they are highly vulnerable individuals with large interatrial septal defects may live a long and relatively active life

Interventricular septal defects Defects of the interventricular septum occur most frequently at its membranous portion This is natural in view of the fact that in its normal development three independently growing structures the connective-tissue crest of the muscular part of the interventricular septum the tubercles of the atrioventricular canal cushions and the conus ridges must all meet at the right time and in the right place to complete this part of the septum Defects at this point although they sometimes occur *in an otherwise* normal heart (Fig 35) are much more likely to occur in conjunction with disturbances in the division of the truncus arteriosus

Anomalies of truncus partitioning There are four *basic* anomalous conditions in which the primary disturbance involves the partitioning of the truncus arteriosus (1) undivided truncus (2) transposition of arterial stems, (3) aortic stenosis and (4) pulmonary stenosis The division of the originally common outlet of the heart commences in the sixth week of development with the fusion of the *truncus ridges* If these ridges for any reason fail to develop an undivided or persistent truncus results These ridges which start in the truncus are normally continued down into the conus where they will contribute to the formation of

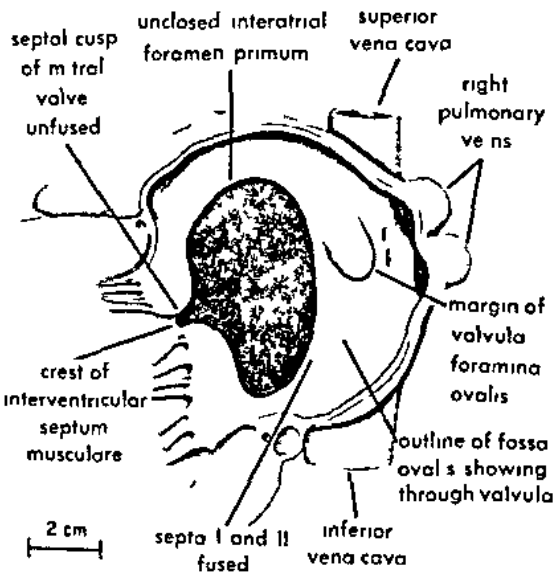


Fig 33 Unclosed interatrial foramen primum In this case defect is exceptionally large and septal cusps of the atrioventricular valves are completely divided exposing the crest of the muscular portion of the interventricular septum (*Drawn from Mus Spec 3236 Pathologische Anatomische Institut Vienna*)

septum membranaceum It is therefore inevitable that an undivided truncus should be accompanied by a defective septum membranaceum Thus both ventricles pump into a common outflow channel with free mingling of the blood from the two sides of the heart The inefficiency of such a circulation is obvious, and individuals with this defect usually survive only briefly postnatally

Arterial stem transposition Another anomaly involving truncus partitioning is known as transposition of arterial stems or simply transposition In this condition the ascending aorta arises from the right ventricle instead of from the left and the malplaced pulmonary trunk arises from the left ventricle Underlying this condition is the failure of the truncoconal ridges to follow their usual spiral course as they develop In such cases the malposition of the conus ridges means that they do not meet normally with the other structures which contribute to the closing of the interventricular foramen, hence, there is almost always a concomitant defect of the septum membranaceum Obviously the presence of such an interventricular defect offers some possibility of survival after birth If present, an unguarded foramen ovale would be a further help in bringing blood from the lungs to the misplaced aortic outlet Even with mixture of blood

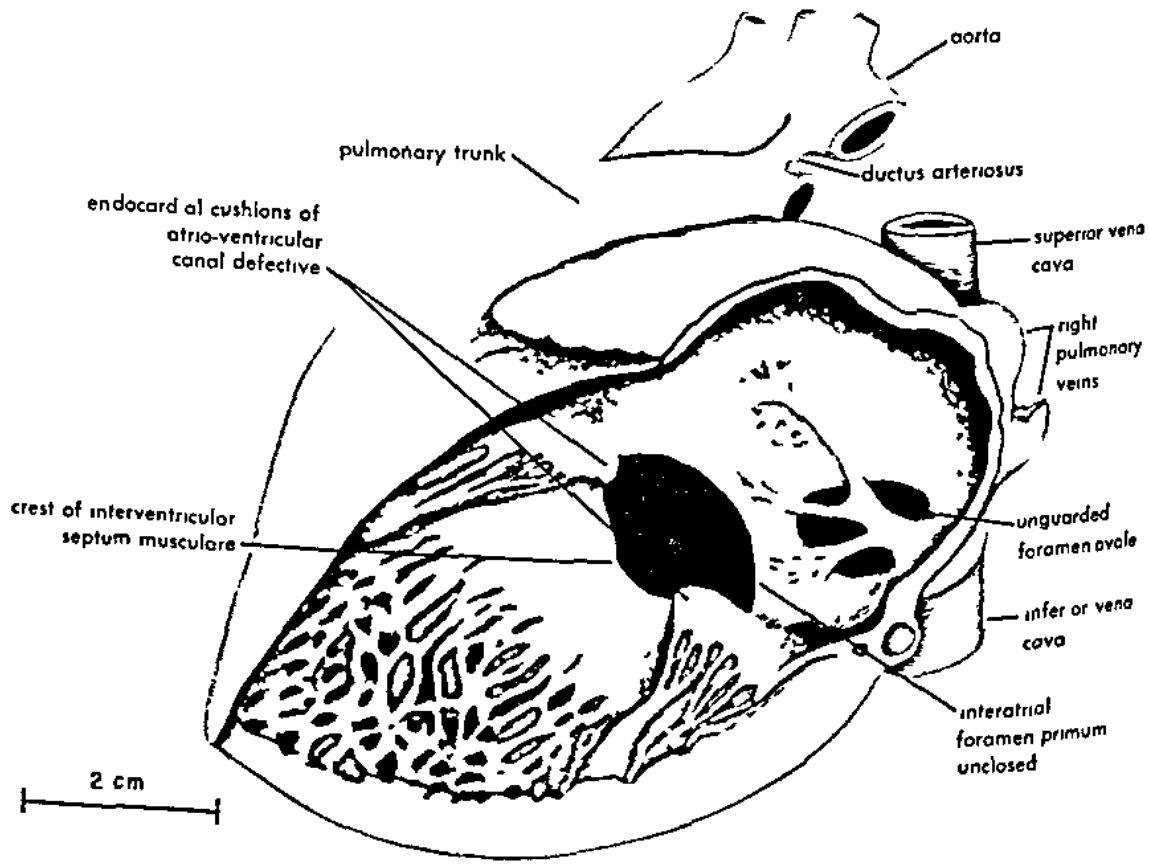


Fig 34 Unclosed interatrial foramen primum combined with markedly deficient growth of atrioventricular canal cushions This leaves all four chambers of the heart in open communication with each other (*Drawn from Mus Spec 4502, Pathologische Anatomische Institut Vienna*)

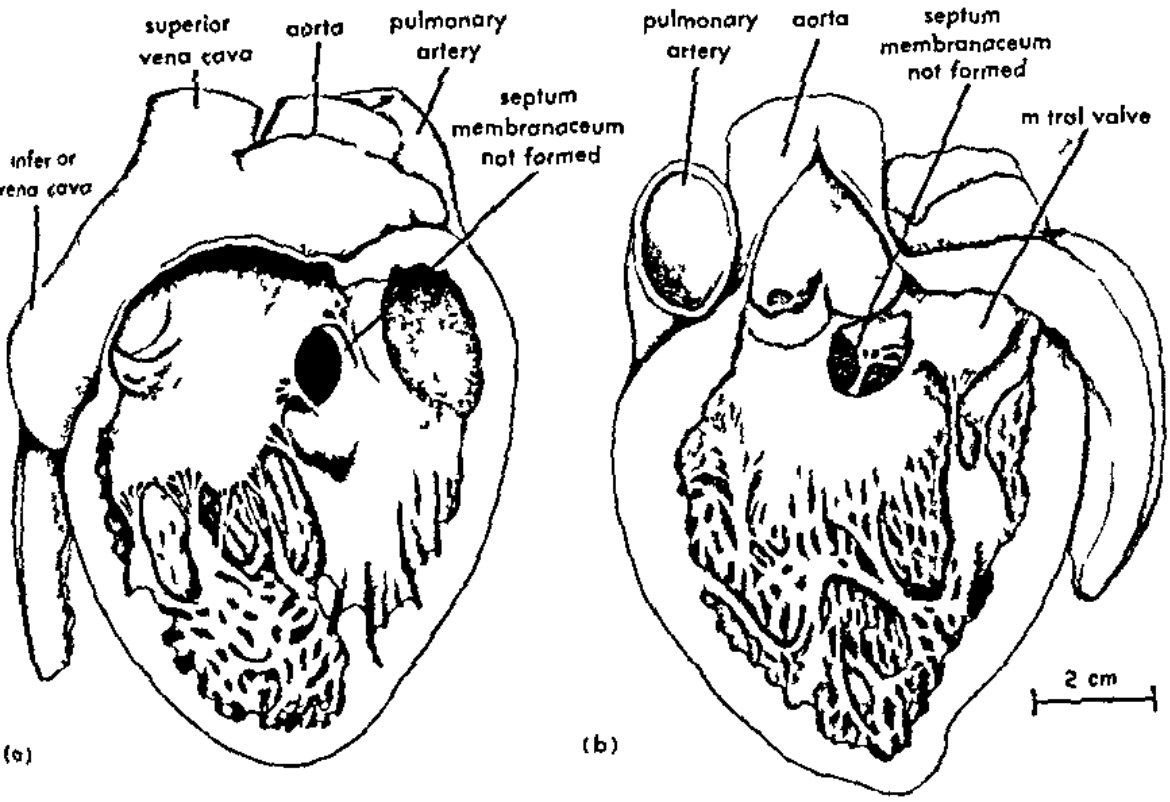


Fig 35 Defect of interventricular septum membranaceum unaccompanied by other anomalies (a) Viewed from right (b) Viewed from left (*Drawn from Mus Spec 4933 Patholog sche Anatom sche Inst tut V enna*)

from the two sides of the heart bringing about some oxygenation of the blood in the systemic circuit the hold on life of an individual with this condition is tenuous The boy whose heart is illustrated in Fig 36 lived to be 17 years old but that is an unusually long survival for a case of transposition

Truncus arteriosus displacement If instead of effecting an even division of the truncus arteriosus the truncus ridges arise off center one or another of two serious anomalies results There will be according to the direction of the displacement either a large pulmonary trunk with a small aorta or a small pulmonary trunk with a large aorta In either case the concomitant malposition of the conal portion of the septal complex almost invariably brings a defect of the septum membranaceum as a sequel If the aorta is markedly narrowed the condition is called aortic stenosis (Fig. 37*a*) In such cases during intrauterine life some of the blood flows back into the arch of the aorta from the ductus arteriosus instead of going entirely into the descending aorta as it does in a normal individual This compensates to a certain extent for the low blood volume coming in from the small ascending aorta and is apparently adequate to take care of the needs of the cephalic region as long as the blood is being oxygenated in the placenta When lung breathing replaces placental interchange as a source of oxygen the open septum membranaceum permits some oxygenated blood to enter the pulmonary trunk and to pass on into the aorta by way of the ductus arteriosus This frequently is enough to permit a brief postnatal survival but if the ductus closes the major compensating mechanism is gone and the systemic circuit is hopelessly inadequate It is striking that in both pulmonary and aortic stenosis the ductus arteriosus tends to close at about the usual time

the truncus leaves a narrowed pulmonary trunk and a large aorta the condition is known as pulmonary stenosis (Fig 37*b*) In rare instances a pulmonary stenosis may develop unaccompanied by other defects The great majority of cases will however be combined with other correlated abnormalities As in other disturbances involving the truncoconal ridges there is almost always an interventricular defect at the site of the septum membranaceum (Fig 38) The aorta tends to be large in proportion to the pulmonary trunk and its great size makes it crowd over to the right so that it arises astride the interventricular defect (Fig 39*d*) As a result of equal pressures because of their intercommunication the right ventricular wall instead of being thin is of the same thickness as the left These four associated conditions (1) pulmonary

abnormally thick right ventricular wall (2) what is called the tetralogy of Fallot Patients with this complex of conditions are likely to give the

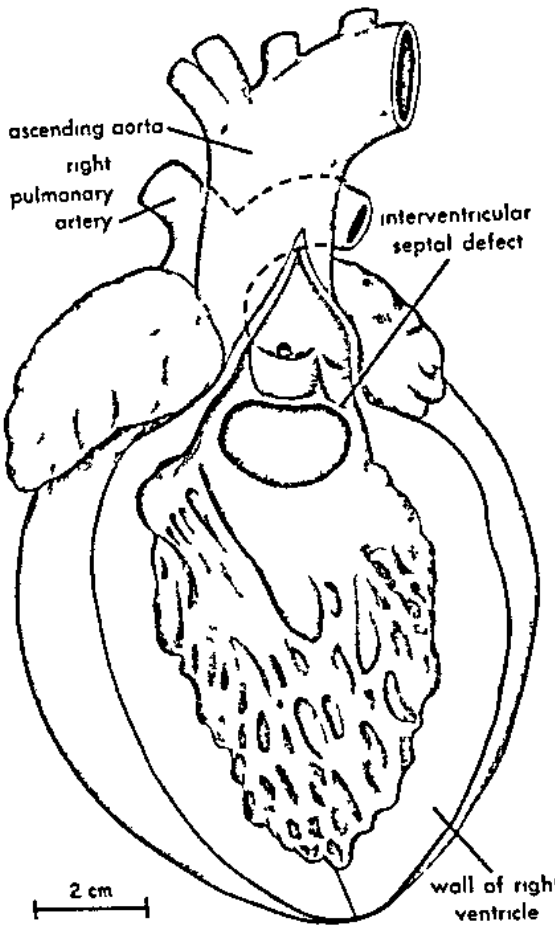


Fig 36 Transposition of aorta and pulmonary trunk There was also an unclosed foramen ovale not shown in the illustration (Drawn from Mus Spec 3118 Pathologische Anatomische Institut Vienna)

history of having been cyanotic since birth The critical factor in their situation is whether they can maintain a volume of blood flow through the lungs for sufficient oxygenation to support life As long as the ductus arteriosus remains unclosed there will be compensatory flow through it from the aorta to the pulmonary arteries (Fig 38) When the ductus closes the deficit in pulmonary circulation is of course increased The extent of collateral circulation that has been developed by way of the bronchial arteries is crucial at this time Even when collateral circulation helps tide an individual through the period of closure of the ductus arteriosus it is rarely more than an alleviation of a still serious lack of pulmonary circulation The brilliant surgical handling of such cases developed by A Blalock and H Taussig consists of cutting one of the major arteries above its origin from the arch of the aorta freeing the stump and suturing it into one of the pulmonary arteries In this procedure the innominate artery may be anastomosed to the right pulmonary artery (Fig 39*f*), or the left subclavian may be anastomosed to the left pulmonary artery (Fig 39*g*) Essentially this operation amounts to reestablishing a shunt to replace the closed ductus arteriosus It is not a cure for pulmonary stenosis because the basic abnormalities still remain uncorrected Nevertheless, in properly selected cases, it greatly lessens the handicaps and brings about an amazing increase in the amount of activity that can be tolerated

In pulmonary stenosis either uncomplicated or as the primary factor in the tetralogy of Fallot the narrowing of the pulmonary outlet is by no means always in the same location or of the same developmental origin In many cases it is of the type described as being the result of unequal truncus division (Fig 39) In other instances the narrowing is the result of encroachment of abnormal muscle bands on the pulmonary conus so that the narrowing of the outlet is below valve level The most common sites of such constricting muscle bands are indicated by the asterisks in Fig 38

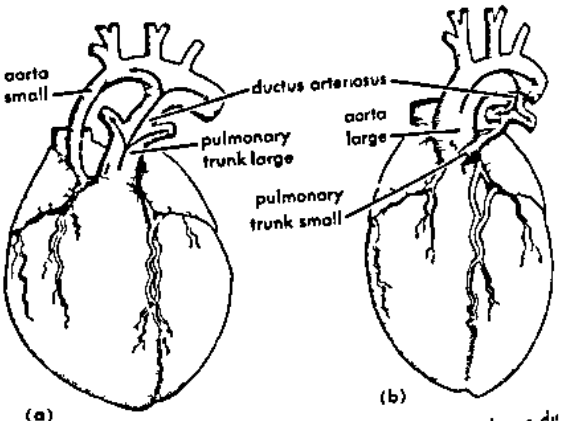


Fig 37 Two anomalous hearts in which the basic disturbance was unequal partitioning of the truncus arteriosus (a) Heart of infant with aortic stenosis Schematic drawing from case coming to autopsy at Maternity Hospital, Cleveland, Ohio (b) Heart of infant with pulmonary stenosis Schematic drawing of Specimen 2269, Rokitansky Museum, Vienna (From B M Patten *Human Embryology* 2d ed , *Blakiston–McGraw Hill, 1953*)

Valvular stenosis Still another type of stenosis is that in which the valve leaflets are thickened and partially fused with one another, so that the orifice leading into the pulmonary trunk is seriously restricted The developmental processes disturbed in each of these types of stenosis are obviously different in nature and operative at different phases of development A stenosis from unequal truncus division is probably the earliest to become established because the truncus ridges appear about the end of the fifth week and show their most rapid progress during the sixth Certainly a stenosis at valve level must be established definitely later in development The primordial mounds of endocardial cushion tissue from which the aortic and pulmonary semilunar valves are derived appear about the beginning of the seventh week and undergo their primary histological differentiation during the eighth, ninth and tenth weeks The em

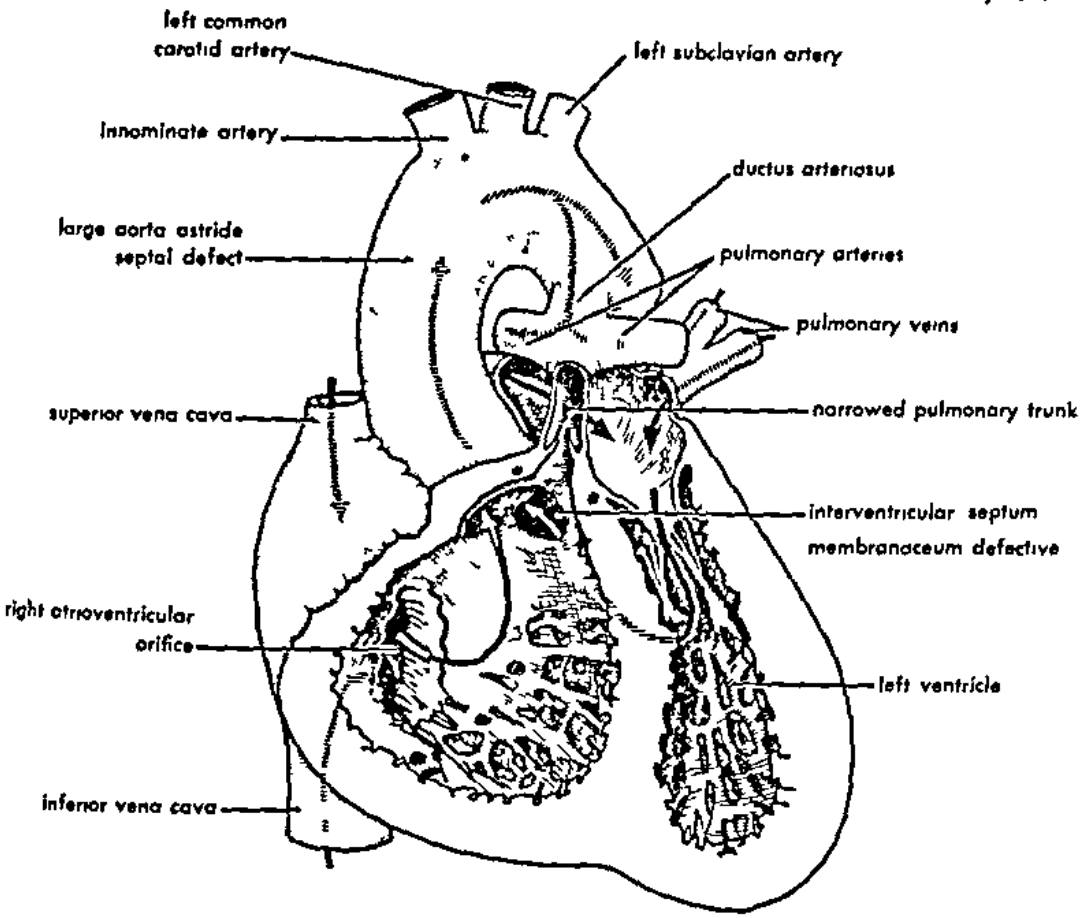


Fig 38 Schematic diagram showing the internal relations of the aortic and pulmonary orifices in the tetralogy of Fallot (*Slightly modified from A Blalock Surg Gynecol Obstet 87 385–409 1948*)

bryological story on obstruction of the conus outlet by abnormal configuration of its muscular walls is not yet entirely clear, but the little known about its origin indicates that it must have its incipience at almost as early stages as unequal partitioning of the truncus

It is a difficult diagnostic problem to determine which type of origin was involved in any particular case of pulmonary stenosis, it is nevertheless, of considerable clinical importance If surgery is being considered, the operation of choice will differ according to the location of the stenosis, and this in turn depends on how the stenosis arose and what structures were involved Moreover, a knowledge of the developmental type may help in assessing the probable concomitant conditions Unequal truncus division occurs before the normal time of closure of the interventricular septum and disturbs the location of the conus ridges with which they are involved in this closure It is, therefore, almost always accompanied by an unclosed interventricular foramen A stenosis at valve level in contrast arises after the seventh week during which the interventricular foramen normally closes and is therefore less likely to be accompanied by an interventricular septal defect

Cardiac anomalies There are many types of congenital malformation of the heart which do not involve defects of the cardiac septa Very early in its development the heart may be caught outside the chest during the midventral closure of the body wall This condition known as ectopia cordis, has not as yet proved amenable to surgical repair

Situs inversus Instead of being placed in the body with its apex slanting to the left as is normally the case the position of the heart may be reversed with the apex directed to the right This anomaly is known as dextrocardia It rarely occurs by itself being usually one factor in the mirror image position of the viscera as a whole known as situs inversus It is interesting from the standpoint of developmental mechanisms but, fortunately, involves no disturbance of function

Cardiac valves Anomalies of the cardiac valves are not uncommon The semilunar valves of the aorta or the pulmonary artery may show two or four cusps instead of the usual three Similarly there may be irregularities in the configuration of the flaps of the atrioventricular valves or of the manner in which they are stayed by tendinous cords and papillary muscles Provided the orifices are not stenosed and the valves adequately close the openings which they guard such anomalies are not likely to be of serious functional importance

Arteries and veins Intimately associated with the heart and frequently involving disturbances in cardiac function are anomalies of the great arteries and veins Disturbances in the relations o

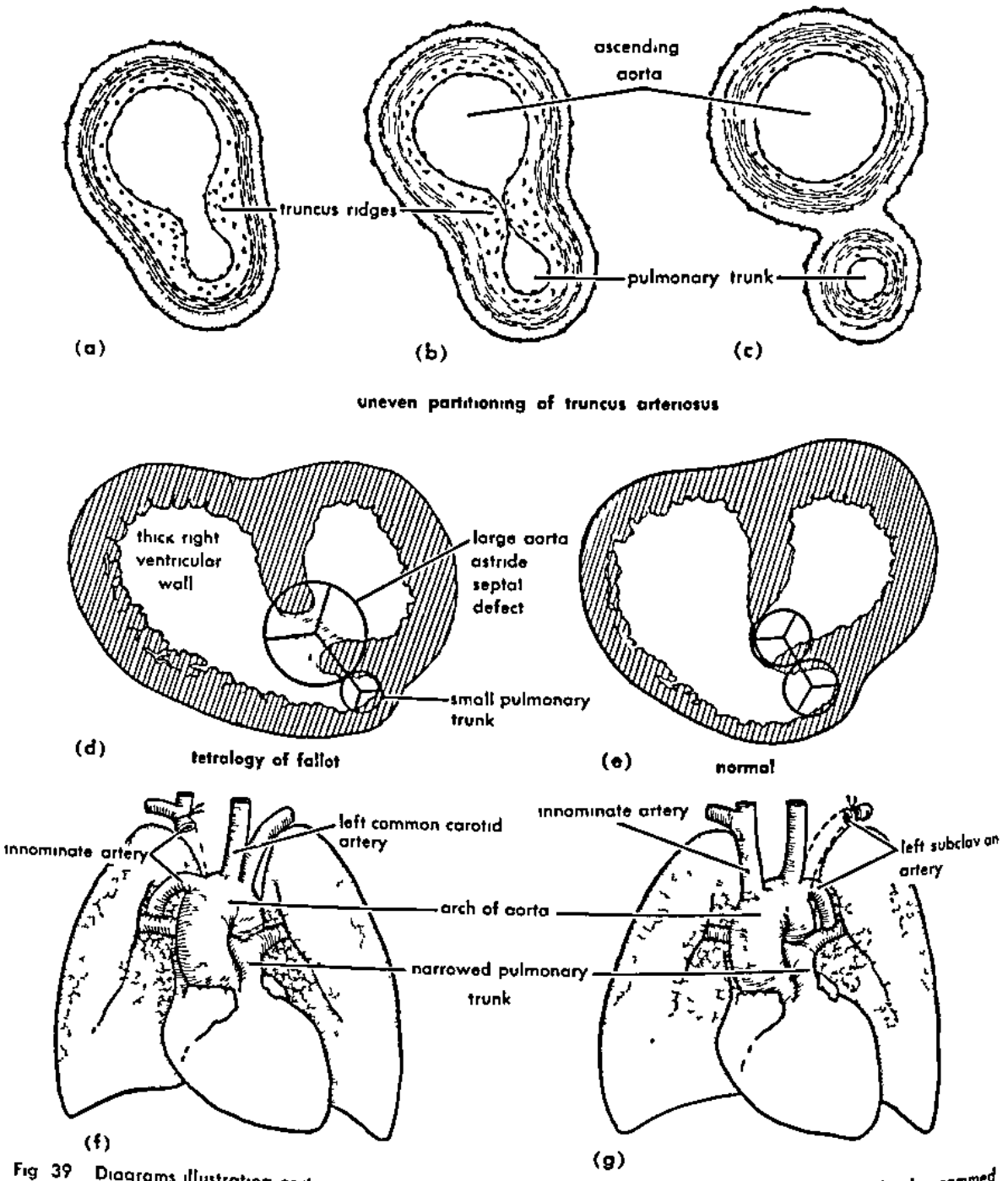
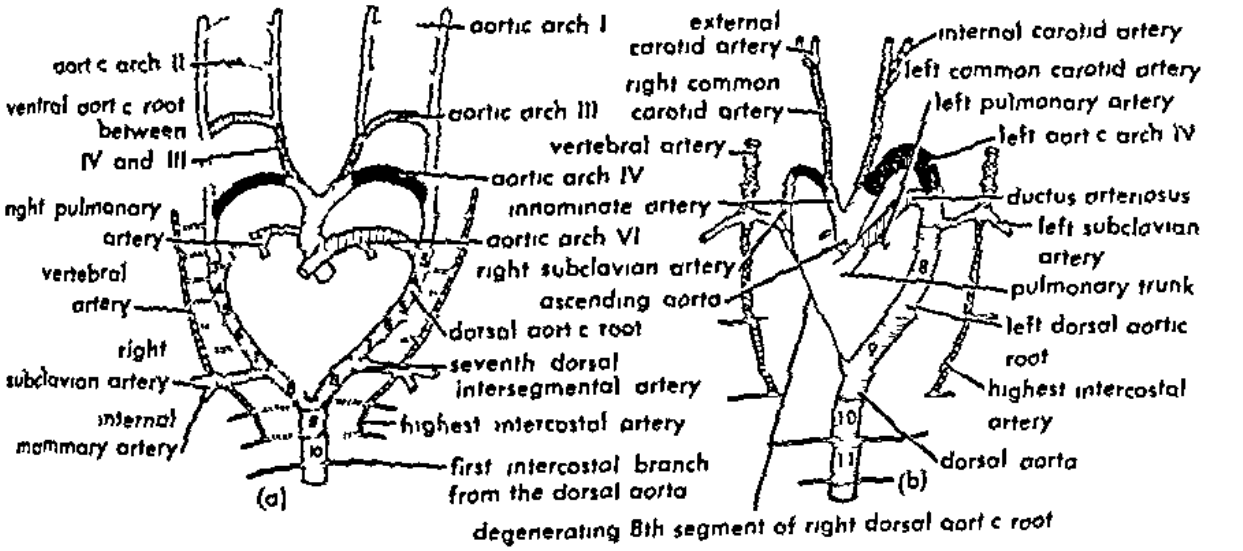


Fig 39 Diagrams illustrating certain points of interest in connection with the tetralogy of Fallot (a) (c) Hypothetical stages in the unequal division of the truncus arteriosus that are believed to be initial factors in one type of pulmonary stenosis (*from B M Patten Human Embryology 2d ed Blakiston–McGraw Hill 1953*) (d) Diagram showing relations of pulmonary and aortic outlets to the ventricles and to the interventricular septal defect (e) Normal relations similarly diagrammed for comparison (*redrawn with slight modification after H B Taussig Congenital Malformations of the Heart 1947*) (f) and (g) Diagrams showing utilization of either the innominate or the left subclavian artery as a shunt to the pulmonary circuit in the Blalock Taussig operation (*after A Blalock and H B Taussig Pulmonary stenosis J Am Med Assoc, 87(3) 189–202 1945*)

the ascending aorta and the pulmonary trunk have been considered in this section because they have their origin in abnormal partitioning of the truncus arteriosus which is primarily part of the primitive tubular heart *See* TERATOGENESIS [B M P]

ANOMALIES OF GREAT VESSELS

Major vessels The great vessels are the major blood vessels of the body, such as the aorta and pulmonary trunk with their primary branches and the caval veins with their main tributaries Malformations of these vessels are so diverse in pattern that they appear at first to be almost infinite in variety However, a careful study of such anomalies leads to the conclusion that the vast majority fall into a surprisingly limited number of categories Such anomalies do not appear to represent completely random variability and most anomalous



Fg 40 Schemat c d agrams indicating the various components of the aortic arch complex in the human embryo (a) Bas c plan Those components which do not normally persist in the adult are ind cated by broken outl nes Because the fifth arch appears if at all in rud mentary form it has been omitted from the dia gram altogether (b) Extent of alterat on of the basic plan which has occurred in embryos of the seventh week (After A Barry The aortic arch derivatives in the human adult Anat Record 111(2) 221–238 1951)

patterns of blood vessels can be interpreted as de partures from the normal ontogenetic sequence of events These anomalies show clear evidence that the primary vascular pattern was of normal config uration at least in early embryonic stages For this reason it is possible in most cases to identify the specific embryonic vascular channels which have abnormally persisted or failed to persist

One factor underlying the relatively limited num ber of malformations that are seen is physiological If the vascular pattern is too profoundly distorted it fails to be adequate for the physiological needs of the individual In such a case death will ensue Because the manner of functioning of the organ systems of the fetus differs markedly from that of the individual after birth some types of vascular abnormality can be tolerated during intrauterine l fe but are lethal postnatally For example if development were so profoundly distorted that the heart failed to attain functional competence then the embryo would die probably about the end of the f st month of gestation when the circulation normally is just beginning to be functionally ef fective On the other hand if only the pulmonary circulation failed to be established the fetus would in all probability survive to term but would die immediately at birth when it could no longer de pend upon its placenta to supply its respiratory needs This line of reasoning explains why most vascular anomalies are relatively minor departures from the normal configuration and have slight if any functional significance

Arterial abnormalities Clinically the most im portant types of abnormalities of the great vessels are those involving the two arteries leaving the heart the ascending aorta and the pulmonary trunk These anomalies were discussed in the sec tion on congenital malformations of the heart

The major proportion of anomalies of the great arteries can be interpreted as the result of varia tions in the normal pattern of persistence or of dropping out of identifiable segments of a normal

symmetrical (Fig 40a) The heart pumps its blood through paired vessels the aortic arches that pass around the pharynx and thence into paired longi tudinal arteries the dorsal aortic roots that lie dorsal to the digestive tube There are potentially six pairs of aortic arches in vertebrates They do not however exist in the mammalian embryo si multaneously but are developed sequentially the before the last pairs have of this sym whereas oth ers regress and cease to be major channels Fig ures 40b and 41 summarize the changes undergone by the vascular system as it is altered from the symmetrical embryonic pattern to the definitive configuration of the adult

Subclavian artery As an example of the way de velopment can be distorted to produce arterial anomalies the relatively common condition of anomalous origin of the right subclavian artery may be considered The right subclavian arises from the aorta immediately caudal to the origin of the left subclavian artery (Fig 42) The proxim

part of the anomalous right subclavian artery can be interpreted as a persistence of the *eighth* segment of the right dorsal aortic root With this abnormal supply to the right arm the right fourth aortic arch and the upper seven segments of the right dorsal aortic root failed to persist (Fig 42)

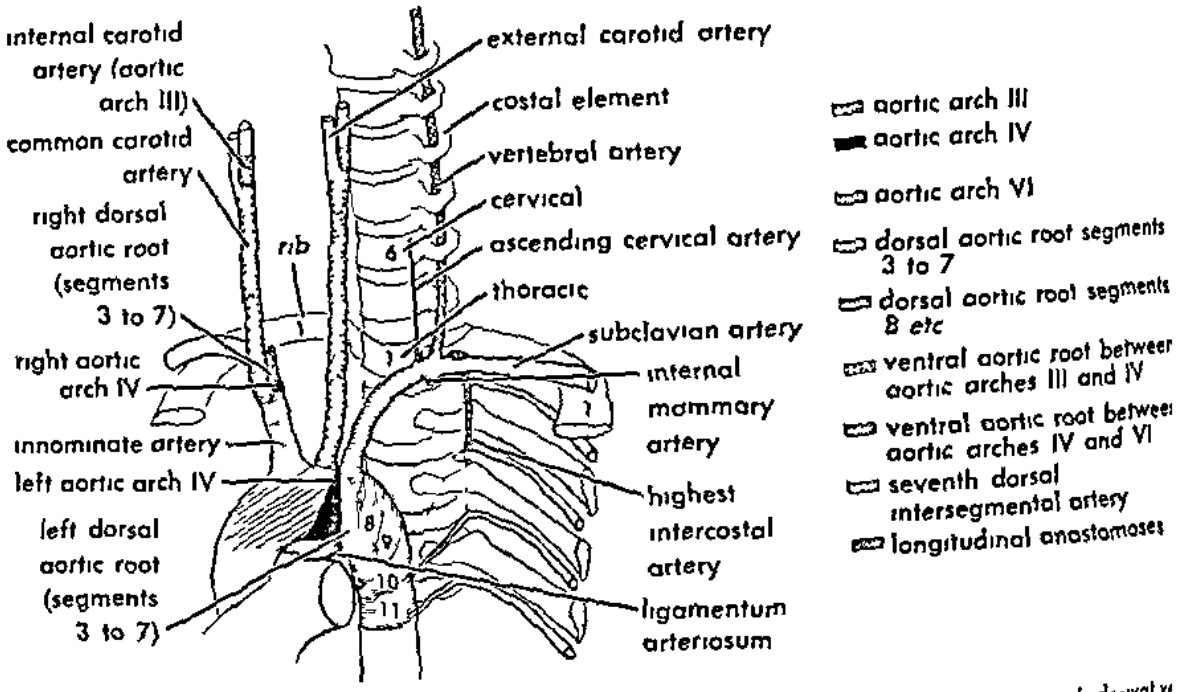


Fig 41 Diagram of adult aorta and its main branches with the location and extent of the vessels derived from the various embryonic aortic arch components indicated by use of the same schematic analysis employed in Fig 40 (*After A Barry, The aortic arch derivatives in the human adult, Anat Record,* 111(2) 221–23[illegible] 1951)

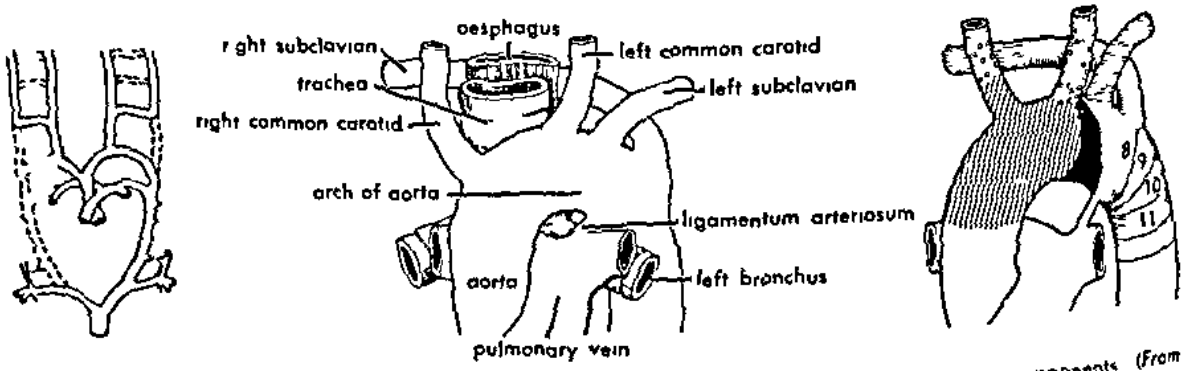


Fig 42 Right subclavian artery arising from the arch of the aorta The schematic shading is the same as that used in Figs 40 and 41 to indicate the parts contributed by each of the embryonic components (*From B M Patten Human Embryology 2d ed, Blakiston–McGraw Hill, 1953*)

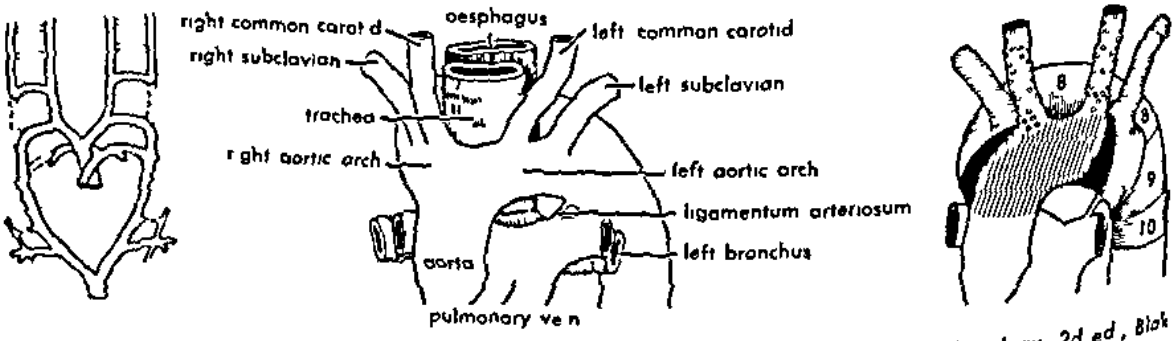


Fig 43 Double aortic arch or aortic ring The same schematic shading is used as in the preceding figures (*From B M Patten, Human Embryology, 2d ed, Blakiston–McGraw Hill, 1943*)

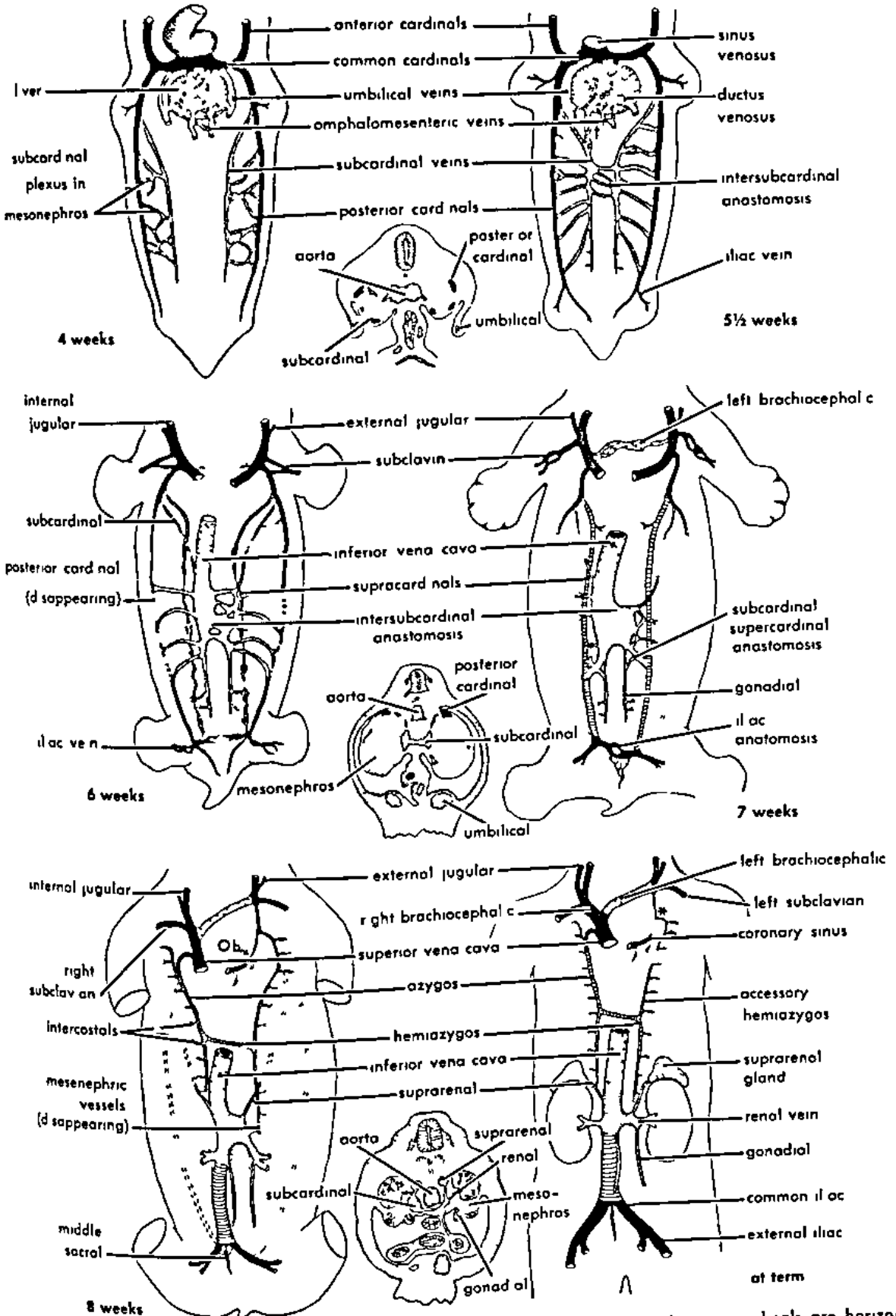


Fig 44 Schematic diagrams showing some of the steps in the development of the inferior and superior venae cavae (based on the work of C F W McClure and E G Butler) Cardinal veins are shown in black subcardinals are stippled, supracardinals are horizontally hatched Vessels arising independently of these systems are indicated by small crosses (From B M Patten, *Foundation of Embryology*, McGraw Hill, 1958)

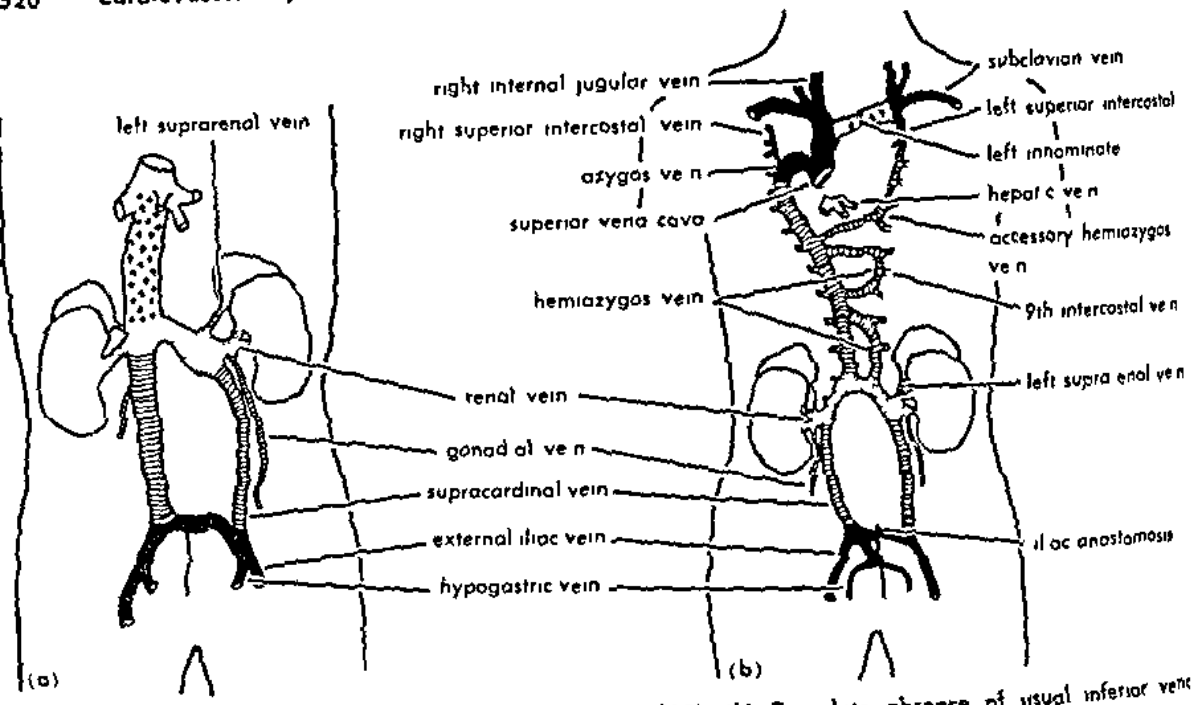


Fig 45 *Anomalous patterns of inferior vena cava* Schematic shading *is the same as in Fig 44 to show the embryonic origin of the various segments involved (a) Double inferior vena cava caudal to renal veins, the result of persistence of supracardinals on both sides (after C F W McClure and G S Huntington, Mammalian Vena Cava Posterior Am Anat Mem 15 1929) (b) Complete absence of usual inferior vena caval pattern Systemic drainage from caudal region of the body is entirely by way of various parts of cardinal venous channels (after R A Huseby and E A Boyden Anat Record, 81, 1941, as modified by B M. Patten Human Embryology, 2d ed, Blakiston–McGraw-Hill 1953)*

This abnormal pattern will ensure that the arterial supply to the right arm is adequate in the embryo and remains so in the adult Because the proximal portion of the anomalous artery is derived from the right dorsal aortic root it can be predicted that it will course dorsal to the esophagus This is found to be the case in almost all individuals exhibiting this malformation

Aortic ring Another example of the abnormalities that may develop from the original arterial pattern is the condition of aortic ring or double aortic arch In this condition the eighth segment of the right dorsal aortic root persists in addition to all the usual segments (Fig 43) Thus a vascular ring surrounds the trachea and esophagus giving rise to symptoms of dysphagia caused by the compression of the esophagus

Abnormalities of veins The venous system is especially prone to depart from the normal morphological pattern In most cases such variations are not functionally significant and, although they may be of importance to the surgeon are asymptomatic Certain of the abnormalities of the great veins however especially those near the heart [illegible] of

[illegible] changes that take place in an originally bilaterally symmetrical pattern

Brachiocephalic vein These normal changes are summarized in Fig 44 One striking anomaly encountered with relative frequency is that of a left superior vena cava This condition is the result of a failure of the left brachiocephalic vein (innominate) to develop during the seventh week of gestation As a predictable consequence of this failure the venous drainage from the left side of the head and the left arm continues to reach the heart by way of the left common cardinal vein This channel remains of essentially the same caliber as the right common cardinal vein, because the two carry about the same quantity of blood As a result the upper part of the body retains a bilaterally symmetrical venous drainage both common cardinal veins becoming superior venae cavae Because the persistence of the left common cardinal vein is the result of a failure of the left brachiocephalic vein to develop one would expect to find intermediate conditions in which the brachiocephalic vein was not absent but was smaller than usual In such a condition the left common cardinal vein would be expected to persist and to be inversely proportional in size to that of the shunt furnished by the brachiocephalic vein This range of patterns is actually found In fact cases of completely symmetrical right and left superior venae cavae are less common than are the intermediate conditions

Inferior vena cava In view of the complex series of changes undergone by the cardinal system in the development of the inferior vena cava it is not surprising to find that this vein exhibits many variations and abnormalities An example of the sort of

anomaly that can develop is the condition of dou ble inferior vena cava caudal to the renal veins This pattern is readily understood as a persistence of both left and right postrenal portions of the *supracardinal veins (Fig 45a)*

Another type of anomaly is that in which the blood from the caudal part of the body drains into the superior vena cava by way of the azygos vein (Fig 45*b*) This condition is the result of a fail ure of the mesenteric portion of the inferior vena cava to form in the caval plica of the emb ryo dur ing the fifth week of gestation This channel serves normally to shunt blood from the right sub cardi nal vein into the liver If it fails to develop the blood from the intersubcardinal anastomosis will continue to drain into the right supracardinal vein and thence to the right common cardinal vein by way of the right postcardinal vein channels which become the azygos vein of the adult

Pulmonary veins One type of venous abnormal ity of great clinical importance involves the pulmo nary veins In one such type one or both of the right p ulmonary veins empty into the right atrium In s ch a condition some of the oxygenated blood from the lungs passes to the right heart and is re circulated through the pulmonary circuit Thus the cond tion is physiologically essentially the same as in a case of interatrial septal defect The precise way in which development departs from normal to prod ce this anomaly is not clearly understood It would seem that either the primary entrance of the pulmonary vein into the right atrium was multiple and abnormally related to the interatrial sep tum or else that the condition is the result of an abnormal secondary perforation between the dorsal wall of the right atrium and the pulmonary vein in vol ed

In a functionally similar abnormality of the pul monary veins one or more of these vessels empties into either the superior vena cava or one of its major tributaries Presumably this malformation has its origin in embryos of the fourth week of gestation when the capillary bed surrounding the developing lung buds drains into the anterior the posterior and the common cardinal veins This is the primary drainage route that exists prior to the formation of a pulmonary vein draining into the left atrium There follows a period during which both drainage routes exist concurrently These con nections to the cardinal venous system are of tiny s ze and do not normally persist However in rare in tances they may enlarge and are then seen as anomalous connections to the superior vena cava or one of its tributaries [A S]

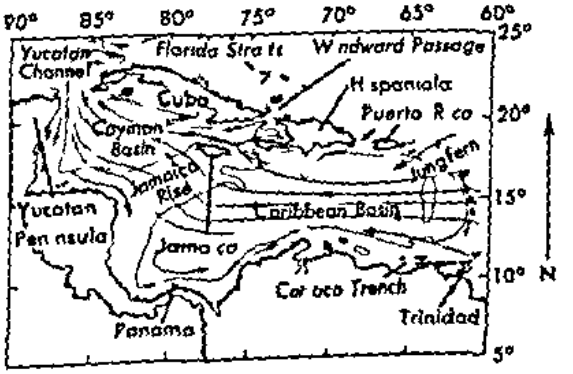
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Caribbean Sea

One of the largest and deepest enclosed basins in the world surrounded by Central and South Amer ica and by the West Indian island chains The North Equatorial Current enters the sea thro ugh th e various channels between the islands and leaves the sea through the Yucatan Channel where it be comes the Florida Current which carries about 30 000 000 m³ sec of water

There are two principal basins in the Sea the Caribbean Basin and the smaller but deeper Cay man Basin The deepest connection between the Atlantic Ocean and the Caribbean Basin is the Jungfern Passage and that of the Cayman Basin the Windward Passage Both these passages have sill depths of about 1600 m The Cayman and Car ibbean Seas are separated by the Jamaica Rise

In the view of G Dietrich (1939) bottom water is supplied continuously to each of these basins by flow over these sills but on the basis of dissolved oxygen measurements by L V Worthington (1955) and silicate measurements by F A Rich ards it seems more likely that the basins filled at



The Caribbean Sea Arrows indicate general surface circulation

some earlier date and that new bottom water is no longer cascading over the sills from the Atlantic

The Cariaco Trench a smaller enclosed basin with a sill depth of about 150 m has already lost all its dissolved oxygen and is anaerobic below 400 m At the present rate of oxygen consumption the Caribbean Basin will be anaerobic in about 300 years unless new bottom water passes over the sills Such passage of water could probably be occasioned by a cold climatic fluctuation which would have to lower the temperature of the Atlantic Ocean at the 1600 m level sufficiently to cause cascading *See* OCEAN CURRENTS SEA WATER [L V W]

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Caribou

Any of several species of northern deer of the genus *Rangifer* distinguished by the large multipointed antlers which are present on both sexes Caribou are extremely hardy but have been killed in great numbers by hunters They formerly roamed the American northland in great herds See ARTIODACTYLA REINDEER [J D B]

Carnauba

This product exudes from the leaves of the wax palm *Copernicia cerifera* a native of Brazil and other regions in tropical South America Before they have fully expanded young leaves are collected and dried in the sun The wax accumulates on the surface of the leaf and is subsequently removed and formed into cakes It is the hardest highest melting natural wax and is used in making candles shoe polish high luster wax varnishes phonograph records and surface coating of automobiles See PALMALES WAX ANIMAL AND VEGETABLE [P D S]

Carnivora

One of the largest orders of mammals including such well known forms as the dogs cats bears and seals The initial determining specialization in this order was for predation on other vertebrates A few carnivores (for example the bears and pandas) have secondarily become largely or entirely herbivorous but even in them the ancestral adaptations for predation are still clearly evident in the teeth and jaw articulation There are about 115 genera of living carnivores and more than twice as many extinct genera are known These were highly successful animals from their first appearance near the beginning of the Tertiary The Carnivora early occupied an important ecological zone (killing and feeding on other vertebrates) so successfully that no other order of mammals has succeeded in invading it when carnivores are present It is significant that carnivorelike predators have evolved in other mammalian orders only when true carnivores were absent as in Australia and in South America before the Panama land bridge was reestablished

Structural adaptations The structural adaptations characterizing the Carnivora chiefly involve the jaws and teeth and appeared very early in the history of this order The dentition is sharply divided into three functional units The incisors act as a tool for nipping and delicate prehension the large canines for heavy piercing and tearing during the killing of prey In the cheek teeth there is a constant tendency for one tooth above and one below to enlarge and form a longitudinal shearing blade (the carnassials) with the remaining teeth tending to degenerate This trend reaches its peak in the cats in some of the extinct saber tooth cats the huge carnassials were the only cheek teeth left In all carnivores the jaw articulation is a pair of transverse cylinders which limits movement to vertical hinge motions and transverse sliding The temporal muscle dominates the jaw musculature forming at least one half of the total mass of the jaw muscles Cursorial adaptations in the limbs appeared early in carnivore history and have always been characteristic of the order In all modern carnivores the brain is large and the cerebral hemispheres are highly developed *See* DENTITION

Phylogeny The history of the Carnivora is unusually well documented in the fossil record The first carnivores appear in the Lower Paleocene as small primitive creatures lacking the carnassial specialization and weasel like in general appearance These were the early creodonts typified by *Oxyclaenus* The creodonts underwent an extensive radiation during the Paleocene and Eocene but at the end of the Eocene they became virtually extinct, being replaced by the more progressive modern fissiped carnivores Various molar and premolar teeth evolved into carnassials in different creodont stocks as if these animals were experimenting to find the best combination In one stock the Miacidae the carnassial shear was on the fourth upper premolar and first lower molar as in all modern carnivores and the miacids were undoubtedly the direct ancestors of the modern carnivores They became extinct at the close of the Eocene

Taxonomy The order Carnivora is divided into three suborders Creodonta Fissipeda and Pinnipedia

Creodonta The Creodonta of which there are no living survivors is characterized by an assemblage of primitive morphological features The creodonts are divided into four major groups on the basis of tooth structure Some authorities place one of these the Miacoidea with the Fissipeda but such an allocation is illogical

Fissipeda The Fissipeda includes all modern land carnivores Most authorities divide this suborder into two superfamilies the Canoidea (or Arctoidea) doglike carnivores and the Feloidea (or Aeluroidea) catlike carnivores The Canoidea consists of four families the *Canidae* (dogs and their

allies), Procyonidae (raccoons and their allies), Ursidae (bears), and Mustelidae (weasels and their allies) The dogs, procyonids, and bears are well characterized groups closely related to one another, their kinship is strongly supported by the fossil record The Mustelidae, on the contrary, are much less clearly related to the other three families and are far more diversified The living mustelids are divided into five subfamilies· Mustelinae (weasels, martens, and minks), Mellivorinae (ratels), Melinae (badgers), Mephitinae (skunks), and Lutrinae (otters)

The Feloidea differing from the Canoidea most obviously (but not most importantly) in the structure of the middle ear, consists of three families the Viverridae (civets and mongooses), Hyaenidae (hyenas), and Felidae (cats). The Viverridae includes the most primitive of living carnivores, scarcely differing from the Eocene miacids but other viverrid lines have undergone complex radiation in the tropics of Africa and Asia There are no true civets in the New World The hyenas are closely related to the civets and throughout their history have formed a small group of highly specialized forms The cats are the most specialized predators among the Carnivora and form a compact and highly successful group Two main lines are evident, the heavy and relatively slow moving saber tooth cats, which became extinct in the Pleistocene and the more slender and active feline cats, which include all the modern cats

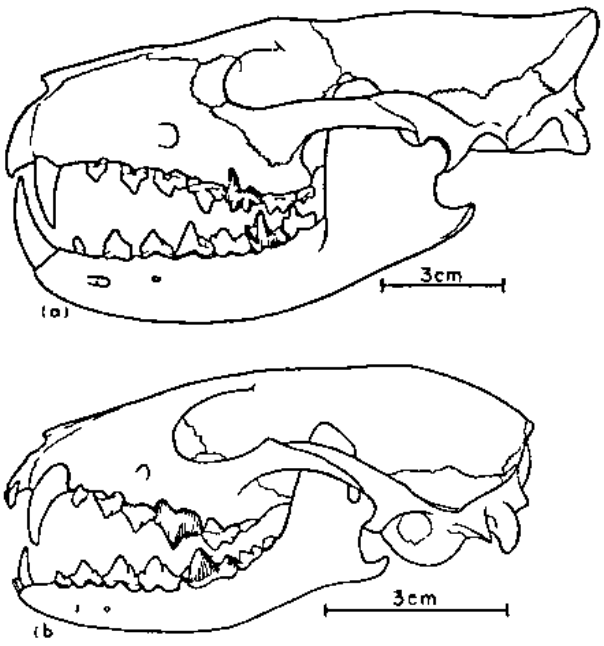
Pinnipedia The Pinnipedia which includes the seals walruses, and sea lions, is a distinctive suborder of aquatic, largely marine carnivores Most of the differences from fissiped carnivores are the result of extreme aquatic specialization, but as in the whales these specializations are so drastic that they obscure the morphological features that normally indicate relationships The picture is further complicated by the fact that the fossil record is very deficient for pinnipeds No pinnipeds earlier than the Miocene are known, and Miocene forms are already highly specialized for aquatic life far removed from either creodonts or early Tertiary fissipeds The Pinnipedia are divided into three families the Otariidae (eared seals), Odobenidae (walruses), and Phocidae (true seals) The true seals are the most highly specialized, almost incapable of locomotion on land, and are the most diversified and widespread of living Pinnipedia

Two carnivores, the dog and the cat, have been associated with man so long and so intimately that the wild forms from which they were derived are unknown Both are regarded as distinct domestic species under the names *Canis familiaris* and *Felis domestica* *See* CARNIVORA FOSSILS, EUTHERIA

[DDD]

Carnivora fossils

This is a diverse group of terrestrial aquatic, and pelagic mammals, primarily carnivorous, but with a tendency to favor an omnivorous diet in some groups The carnivorous members of the order typ



The skull and jaws of a middle Eocene creodont, *Sinopa grangeri* (a) Compared with an Oligocene dog, *Pseudocynodictis* (*after W Matthew, 1906*) (b) Carnassial teeth shaded (*after W Stott and G Jepsen, 1936*)

otters raccoons, pandas mongooses, civets, cats, hyenas, seals, walruses and many extinct groups, organized into 15 families The largest extinct forms surpass the living brown bear in size, but most are no larger than the living representatives Rarely abundant as fossils the record of the Carnivora is nevertheless surprisingly complete, although much additional material is needed to clarify the complex interrelationships within the order

Three suborders are recognized Creodonta, Fissipeda, and Pinnipedia Creodonta are extinct early and middle Tertiary, carnivorous and omnivorous forms having separate scaphoid and lunar bones, the dental formula is basically that for eutherian mammals, the carnassials are either absent or when present involve molars $\frac{1}{2}$ or $\frac{2}{3}$, ossified auditory bullae are lacking Fissipeda are modern terrestrial and aquatic carnivorans, ranging from middle Tertiary to Recent, but also included are their early Tertiary ancestors (superfamily Miacoidea), the scaphoid and lunar bones are separate in miacoids, fused in later fissipeds, the carnassials $\left(\text{premolar } \frac{4}{0}\right.$ and molar $\left.\frac{0}{1}\right)$ are always present but may be modified in omnivorous forms, ossified auditory bullae are present in most, absent or represented only by enlarged tympanic ring in miacoids, the primitive dental formula is eutherian Pinnipedia includes middle

Tertiary to Recent marine carnivorans the scaphoid and lunar bones are united the teeth are little differentiated cheek teeth are conical or have a high central cusp and accessory cuspules incisors and molars are reduced the basic dental formula is incisors $\frac{2}{3}$ canines $\frac{1}{1}$ premolars $\frac{4}{4}$ molars $\frac{2}{1}$ Limbs are adapted for pelagic life auditory bullae are ossified *See* DENTITION

Earliest Carnivora were represented by small creodonts in the early Paleocene of North America By middle Paleocene time small miacoid fissipeds had also appeared in the same area Of the Carnivora only the creodonts were present in the earliest known mammalian faunas (late Paleocene) in Europe Questionable carnivorans have been described from the later Paleocene deposits of Central Asia

The Creodonta underwent considerable diversification during the early Tertiary in the Northern Hemisphere where they were the dominant carnivores The peak of this radiation was reached in the late Eocene and early Oligocene when a variety of hyenoid and feloid forms roamed Eurasia and North America Among the gigantic Asiatic mesonychids was *Andrewsarchus* the largest known terrestrial carnivore Few creodonts survived the Oligocene Those that did found refuge in the Old World tropics where they survived until the beginning of the Miocene in Africa and the Pliocene in India

The relationships of the Creodonta to Fissipeda is uncertain Both groups appear at approximately the same time (earlier Paleocene) Their probable common ancestor must be sought in the later Mesozoic

An early Oligocene radiation in the fissiped Miacoidea gave rise with apparent suddenness to the modern fissipeds The felids and saber toothed cats viverrids canids mustelids and procyonids made their appearance at that time Adaptive radiation within these families produced considerable diversity by middle and late Tertiary time Last of the modern families to arise (in the Miocene) were the bears and pandas derived from a raccoonlike stock and the hyenas from a viverrid ancestry Only the saber toothed cats failed to survive to the present day

No less a mystery than the sudden appearance of the modern fissiped families is the early Miocene appearance of seals of modern type When first seen in the fossil record the seals possess all the subordinal characters of the Pinnipedia and give little more evidence of their ancestry than their recent representatives [RHT]

Carnot cycle

A hypothetical thermodynamic cycle originated by Sadi Carnot and used as a standard of comparison for actual cycles The Carnot cycle shows that even under ideal conditions a heat engine cannot convert all the heat energy supplied to it into mechanical energy some of the heat energy must be rejected

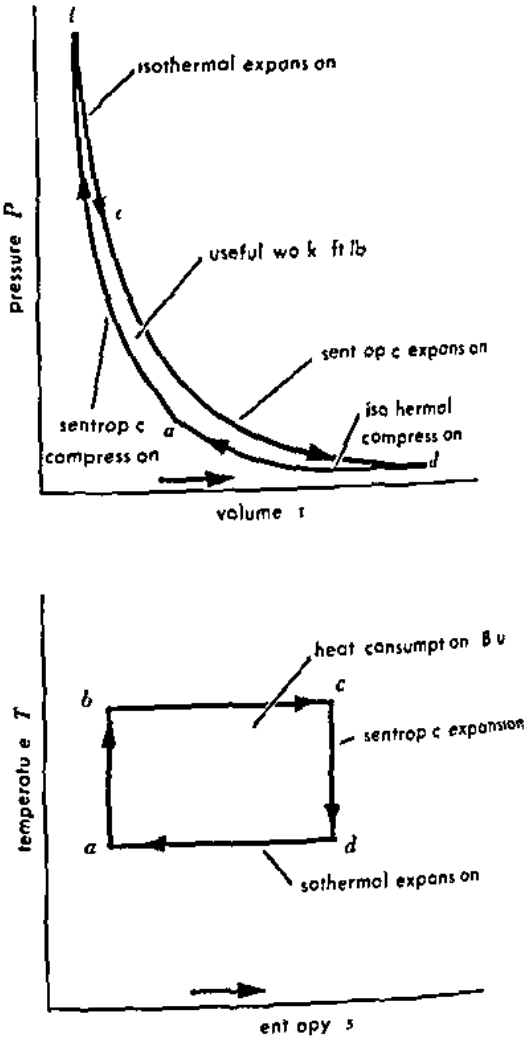


Fig 1 Carnot cycle for a gas

In a Carnot cycle an engine accepts heat energy from a high temperature source or hot body converts part of the received energy into mechanical (or electrical) work and rejects the remainder to a sink or cold body The greater the source and the heat engine sists first of an isentropic compression then an isothermal heat addition followed by an isentropic expansion and concludes with an isentropic heat rejection process In short the processes are compression addition of heat expansion and rejection of heat all in a qualified and definite manner

Processes in Carnot cycle The air standard engine in which air alone constitutes the working medium illustrates the Carnot cycle A cylinder of air has perfectly insulated walls and a frictionless piston The top of the cylinder called the cylinder head can either be covered with a thermal insulator or if the insulation is removed can serve as a heat transfer surface for heating or cooling the cylinder contents

Initially the piston is somewhere between the top and the bottom of the engine's stroke and the air is at some corresponding intermediate pressure but at low temperature Insulation covers the cylinder head By employing mechanical work from the surroundings the system undergoes a reversible adiabatic or an isentropic compression With no heat transfer this compression process raises both the pressure and the temperature of the air and is shown as the path *a b* on Fig 1

After the isentropic compression carries the piston to the top of its stroke the piston is ready to reverse its direction and start down The second process is one of constant temperature heat addition The insulation is removed from the cylinder head and a heat source or hot body applied that is so large that any heat flow from it will not affect its temperature The hot body is at a temperature just barely higher than that of the gas it is to heat The temperature gradient is so small it is considered reversible that is if the temperature changed slightly the heat might flow in the other direction from the gas into the hot body In the heat addition process, enough heat flows from the hot body into the gas to maintain the temperature of the gas while it slowly expands and does useful work on the surroundings All the heat is added to the working substance at this constant top temperature of the cycle This second process is shown as *b-c* on Fig. 1

Part way down the cylinder the piston is stopped the hot body is removed from the cylinder head and an insulating cover is put in its place Then the third process of the cycle begins it is a frictionless expansion devoid of heat transfer and carries the piston to the bottom of its travel This isentropic expansion reduces both the pressure and the temperature to the bottom values of the cycle For comparable piston motion this isentropic expansion drops the pressure to a greater extent than the isothermal process would do The path *c d* on Fig 1 represents this third process and is steeper on the *p s* plane than process *b c*

The last process is the return of the piston to the same position in the cylinder as at the start This last process is an isothermal compression and simultaneous rejection of heat to a cold body which has replaced the insulation on the cylinder head Again the cold body is so large that heat flow to it does not change its temperature and its temperature is only infinitesimally lower than that of the gas in the system Thus the heat rejected during the cycle flows from the system at a constant low temperature level The path *d a* on Fig 1 shows this last process

The net effect of the cycle is that heat is added at a constant high temperature somewhat less heat is rejected at a constant low temperature and the algebraic sum of these heat quantities is equal to the work done by the cycle

Figure 1 shows a Carnot cycle when air is used as the working substance The *p v* diagram for this cycle changes somewhat when a vapor or a liquid is used or when a phase change occurs during the cycle but the *T s* diagram always remains a rectangle regardless of phase changes or of working substances employed

It is significant that this cycle is always a rectangle on the *T s* plane independent of substances used for Carnot was thus able to show that neither pressure volume nor any other factor except temperature could affect the thermal efficiency of his cycle Raising the hot body temperature raises the upper boundary of the rectangular figure increases the area and thereby increases the work done and the efficiency because this area represents the net work output of the cycle Similarly lowering the cold body temperature increases the area the work done and the efficiency In practice nature establishes the temperature of the coldest body available such as the temperature of ambient air and river water and the bottom line of the rectangle cannot circumvent this natural limit

Carnot cycle with steam If steam is used in a Carnot cycle it can be handled by the following flow arrangement Let saturated dry steam at 500°F flow to the throttle of a perfect turbine where it expands isentropically down to a pressure corresponding to a saturation temperature of the cold body The exhausted steam from the turbine which is no longer dry but contains several per cent moisture is led to a heat exchanger called a condenser In this device there is a constant pressure constant temperature heat rejection process during which more of the steam with a particular predetermined amount of condensed liquid is then handled by an ideal compression device The isentropically compressed mixture may emerge from the compressor as completely saturated liquid at the saturation pressure corresponding to the hot body temperature The cycle is closed by the hot body evaporating the liquid to dry saturated vapor ready to flow to the turbine

The cycle is depicted in Fig 2 by *a b* as the isentropic expansion in the turbine *b c* is the constant temperature condensation and heat rejection to the cold body *c d* is the isentropic compression, and *d-a* is the constant temperature boiling by heat transferred from the hot body *See* STEAM ENGINE

Carnot cycle with radiant energy. Because a Carnot cycle can be carried out with any arbitrary system it has been analyzed when the working substance was considered to be a batch of radiant energy in an evacuated cylinder If the system boundaries are perfectly reflecting thermal insulators the enclosed radiant energy will be reflected and re-reflected with no loss of radiant energy and no change of wavelength

The electromagnetic theory of radiation asserts that the radiant energy applies pressure p to the cylinder walls This radiation pressure is equal to $u/3$ where u represents the radiant energy density or the amount of radiant energy per unit volume

The piston moves so that the cylinder boundaries expand and additional radiant energy is supplied to the system so that the temperature remains con

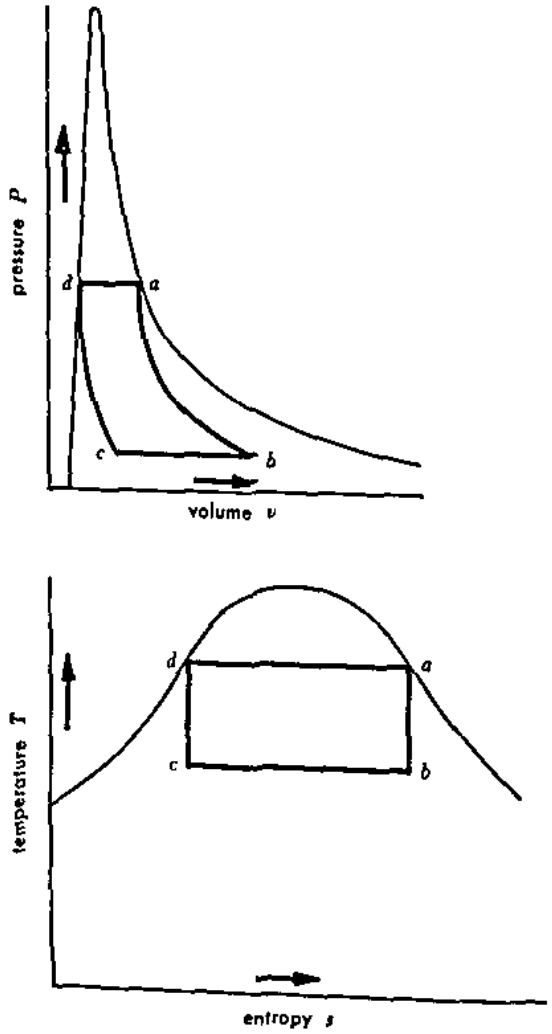


Fig 2 Carnot cycle with steam

stant Then cutting off any further supply of radiant energy, the system undergoes a further infinitesimal expansion with its associated pressure drop and temperature drop The third process is an isothermal compression at the low temperature level, accompanied by some rejection of radiant energy One last process closes the cycle with a reversible compression that raises the temperature to the original level The assumption is made throughout this analysis that energy density is a function of temperature alone Thus because this last compression process increases the energy density it raises the temperature

A record of all energy quantities in this radiant energy Carnot cycle indicates that energy density u is proportional to the fourth power of the absolute temperature Consequently the total rate of emission of radiant energy from the [illegible] black [illegible]

[illegible] been determined experimentally and previously labeled as Stefan's law

Conversion of heat to electricity Several physical phenomena convert heat energy directly into electrical energy The extent of this direct conversion of heat to electricity is limited by the temperature levels between which the process operates The ideal efficiency of such direct conversion thermoelectric cycles equals the efficiency of a Carnot cycle that operates between the same temperature limits of heat source and heat sink However the conversion efficiency obtained in practice is only a small fraction of the ideal efficiency at the present stage of development

The most widely known physical arrangement for direct thermoelectric generation is the thermocouple, which produces an electromotive force or voltage when one junction of two dissimilar conductors is heated while the other junction is kept cool Thermocouples made of metals are inefficient converters of heat energy to electric energy because metals that have good electrical conductivity unfortunately have equally good thermal conductivity, which permits heat loss by conduction from the hot to the cold junction In contrast thermocouples made of semiconductors offer the prospect of operation at high temperatures and with high temperature gradients because semiconductors are good electrical conductors but poor heat conductors Semiconductor thermocouples may have as large a junction potential as the metal couples do

Thermionic emission is another phenomenon that permits the partial conversion of heat energy directly into electrical energy Externally applied heat imparts kinetic energy to electrons liberating them from a surface The density of the emission current is a function of the absolute temperature and work function of the emitter material

For many years thermionic emission received little attention as a source of power because of its very low conversion efficiency However interest has been stimulated by development of a contact potential thermionic emission cell In this device current flows between the surfaces of two materials which have different work functions These materials are held at different temperatures and the gap between the electrode surfaces is filled with gas at low pressure

Such direct conversion techniques show promise of becoming small scale if unconventional power sources Although these techniques ideally can convert heat to electrical energy with the efficiency of a Carnot cycle operating between the same temperature levels laboratory devices do not surpass about 8% efficiency which is just a fraction of the ideal performance

Reversed Carnot cycle A Carnot cycle consists entirely of reversible processes, thus it can theoretically operate to withdraw heat from a cold body and to discharge that heat to a hot body To do so the cycle requires work input from its surroundings The heat equivalent of this work input is also discharged to the hot body

Just as the Carnot cycle provides the highest efficiency for a power cycle operating between two fixed temperatures so does the reversed Carnot cycle provide the best coefficient of performance for a device pumping heat from a low temperature to a higher one This coefficient of performance is

defined as the ratio of the quantity of heat pumped to the amount of work required, it is one of the few engineering indices with numerical values greater than unity *See* HEAT PUMP REFRIGERATION CYCLE

Practical limitations Good as the ideal Carnot cycle may be there are serious difficulties that emerge when one wishes to make an actual Carnot engine The method of heat transfer through the cylinder head either limits the operation of the engine to very low speeds or requires an engine with a huge bore and small stroke Moreover the material of the cylinder head is subjected to the full top temperature of the cycle thereby imposing a metallurgical upper limit on the cycle s tempera ture

A practical solution to the heat transfer difficul t es which beset the Carnot cycle is to burn a fuel in the air inside the engine cylinder The result is an internal combustion engine that consumes and replaces its working substance while undergoing a period c sequence of processes

The working substance in such an internal com bustion engine can attain very high temperatures far above the melting point of the metal of the cylinder walls because succeeding lower tempera ture processes will keep the metal parts adequately cool Thus as the contents change temperature rap dly between wide extremes the metal walls hover near a median temperature The fuel air mix ture can be ignited by a spark (*see* INTERNAL COM BUSTION ENGINE OTTO CYCLE) or by the rise in temperature produced by the compression stroke *See* DIESEL CYCLE DIESEL ENGINE

Even so the necessarily high peak pressures and temperatures limit the practical thermal efficiency that an actual engine can achieve The same theoret cal efficiency can be obtained from a cycle consisting of two isobaric processes interspersed by two isentropic processes (*see* BRAYTON CYCLE) The isobaric process requires that the cycle handle large volumes of low pressure gas which can best be done in a rotating turbine *See* GAS TURBINE

Although the Carnot cycle is independent of the work ng substance and hence is applicable to a vapor cycle the difficulty of efficiently compressing a vapor liquid mixture renders the cycle impracti cal In a steam power plant the sequence of states assumed by the working substance is (1) conden sate and feedwater are compressed and pumped into the boiler (2) heat is added to the water first at constantly increasing temperature and then at con tant pressure and temperature (3) the steam expands in the engine and (4) the cycle is com pleted by a constant temperature heat rejection process which condenses the exhausted steam *See* VAPOR CYCLE

By comparison to the Carnot cycle in which heat is added only at the highest temperature this steam cycle w th heat added over a range of temperatures s necessarily less efficient than is theoretically pos sible An analysis of engine operations in terms of thermodynamic cycles indicates what efficiencies can be expected and in what ways the operations should be modified to increase engine performance such as high compression ratios for reciprocating internal combustion engines and high steam tem peratures for steam engines *See* POWER PLANT THERMODYNAMIC CYCLE THERMODYNAMIC PRINCI PLES [J B]

Carnotite

The mineral carnotite is a hydrous vanadate of potassium and uranium $K_2(UO_2)_2(VO_4)_2\,nH_2O$ The water content varies at ordinary temperatures from one to three molecules

Carnotite generally occurs as a powder or as a slightly coherent microcrystalline aggregate Its microscopic crystals are monoclinic Color ranges from bright yellow to lemon yellow and greenish yellow

Carnotite is a secondary mineral resulting from the action of ground water on preexisting uranium bearing minerals In the United States the prin cipal region of carnotite mineralization is the Colo rado Plateau and adjoining districts of Utah New Mexico and Arizona where it occurs as relatively pure masses near fossilized tree trunks and other vegetal matter and as disseminated grains in cross bedded sandstones of Triassic and Jurassic age. It is found also in Wyoming and in Carbon County Pennsylvania Deposits are located at Radium Hill near Olary Australia and in Katanga, Belgian Congo Carnotite is the chief source of uranium in the United States It is a source of radium and vanadium *See* RADIOACTIVE MINERALS URANIUM VANADIUM [W R LO]

Carotenoid

A class of labile easily oxidizable light yellow yellow orange yellow red and purple pigments that are widely distributed in plants and animals and are notable for their preferential solubility in fats and in solvents for fats As a class the carote noids (formerly called carotinoids after carotin, an antecedent of carotene) have also been known as lipochromes chromolipids and lutems

Dilute solutions of the carotenoid pigments are light yellow like butter Concentrated solutions may be orange yellow like carrots or red like to matoes Carotenoids form yellow brown red or ruby red crystals

About 100 carotenoid pigments have been de scribed Some of these such as β carotene are widely distributed in plants and animals Others such as eschscholtzxanthin from flowers of the California poppy (*Eschscholtzia californica*) are restricted to one or a few species Several carote noids usually occur together in mixtures that can be resolved only with the mildest and most selec tive analytical methods (Fig 1) such as partition between immiscible solvents and chromatographic adsorption analysis (*see* CHROMATOGRAPHY)

Occurrence Each carotenoid pigment may oc cur in several interconvertible modifications namely the common relatively more stable trans isomer and its several less common and less stable cis isomers Interconversion of the trans form and

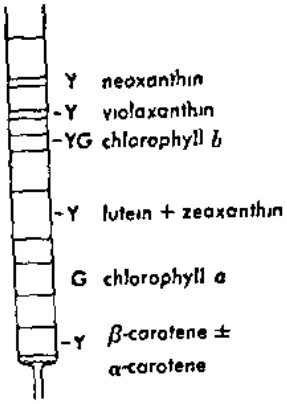


Fig 1 Carotenoids and chlorophylls separated from an extract of green leaves by chromatographic adsorption in a column of powdered sugar Xanthophylls and carotenes separate in yellow (Y) zones chlorophylls in yellow green (YG) and green (G) zones For separation a small amount of petroleum ether solution of the pigments is sucked into the upper region of the sugar column and this narrow initial zone is then washed with fresh petroleum ether containing 0 5% n propyl alcohol

its several cis modifications takes place when the solutions of each isomer are heated or exposed to light and iodine

In plants carotenoid pigments occur in the microscopic yellow plastids or chromoplasts of various yellow organs such as autumn leaves blanched or etiolated leaves yellow flowers (buttercups California poppies chrysanthemums dandelions marigolds and pansies) yellow and red fruits (apricots oranges peaches peppers pumpkins watermelons and tomatoes) and certain yellow roots (carrots rutabagas sweet potatoes and yams) (*see* CELL PLASTIDS) They are found in algae fungi and bacteria They are invariably associated with the chlorophylls in the microscopic chloroplasts of leaves and of all other green tissues wherein they are obscured by the more abundant green pigments These chloroplast carotenoids are an essential part of the photosynthetic apparatus (*see* CHLOROPHYLL, PHOTOSYNTHESIS)

In animals carotenoids are the principal coloring matter of fats eggs and many yellow and red feathers They are present in yellow and red fishes and crustaceans (lobsters shrimps and crabs) and are believed to play a role in the natural protective coloration Some of these animal carotenoids are absorbed from plant food others may be formed in the animals themselves Although usually present in fats some carotenoids may be linked to proteins In the liver of many animals certain carotenoids such as α and β carotene and cryptoxanthin absorbed from the plant food are converted into fat soluble vitamin A These carotenoids often called provitamins A are employed as vitamin A supplements in food and fodder (*see* VITAMIN)

In many plants and animals, colorless fluorescent substances that are closely related to carotenoids occur with the yellow pigments These substances may represent intermediate stages in the metabolism of the pigments

Chemical nature. From a chemical standpoint, carotenoids are highly unsaturated (polyene) compounds containing a chromophoric system of alternate single and double bonds (conjugated double bonds) in a multibranched chain of carbon atoms (as formed by condensation of dehydrogenated isoprene units) Their color varies with the number and conjugation of the double bonds Their vitamin A activity depends on the presence of a particular cyclic structure at one or both ends of the carbon chain Their isomerization depends upon the spatial configuration of the groups adjoining the doubly bonded carbon atoms Some of them have been prepared synthetically

Classification and characteristics Carotenoid pigments are subdivided into four principal sub-

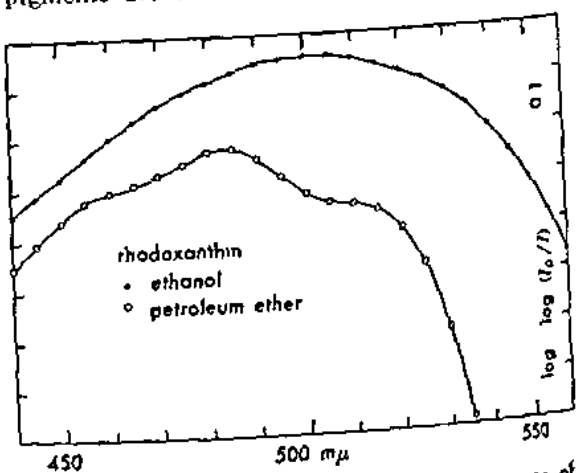


Fig 2 Characteristic spectral absorption curves of rhodoxanthin dissolved in ethanol and in petroleum ether

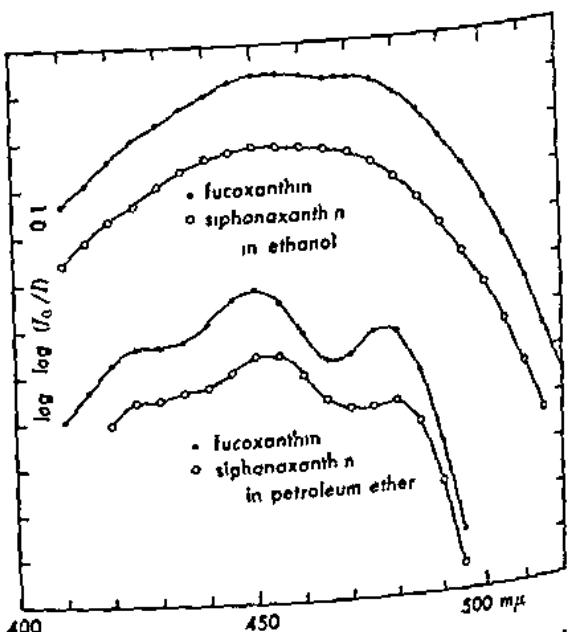
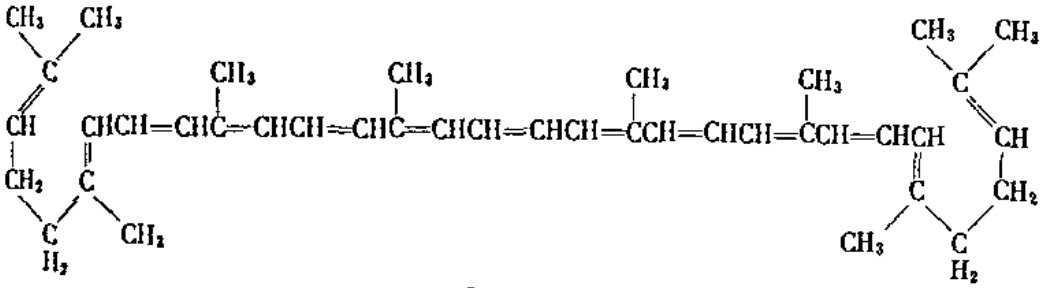
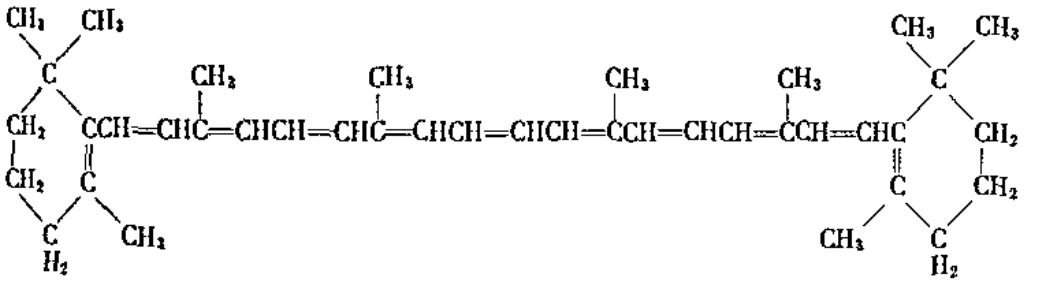


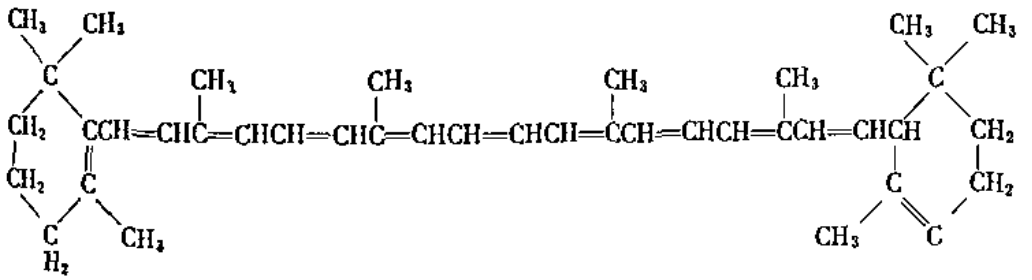
Fig 3 Characteristic spectral absorption curves of fucoxanthin and of siphonaxanthin dissolved in ethanol and in petroleum ether



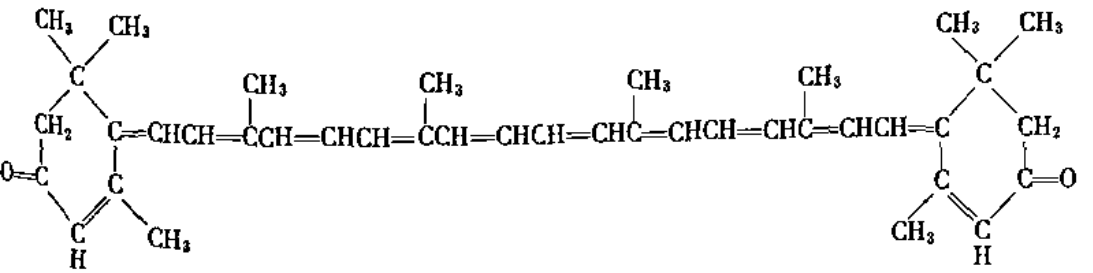
Lycopene
(11 conjugated + 2 =, most sorbed)



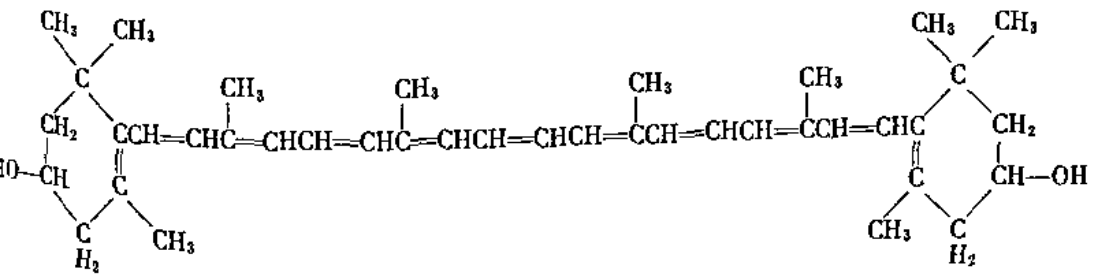
β Carotene
(11 conjugated = moderately sorbed)



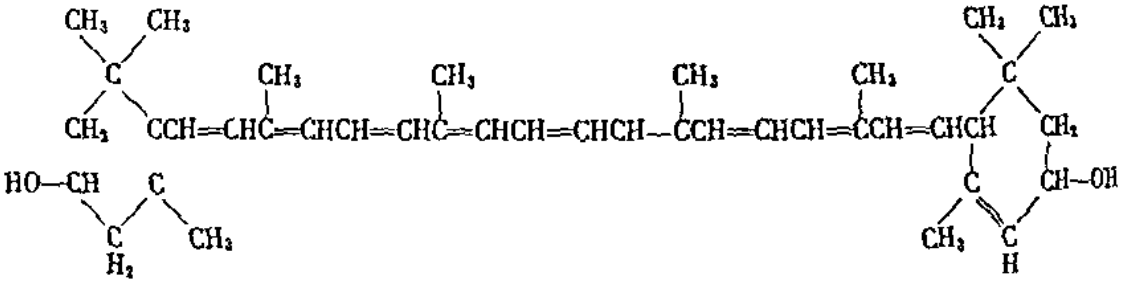
α Carotene
(10 conjugated + 1 =, least sorbed)



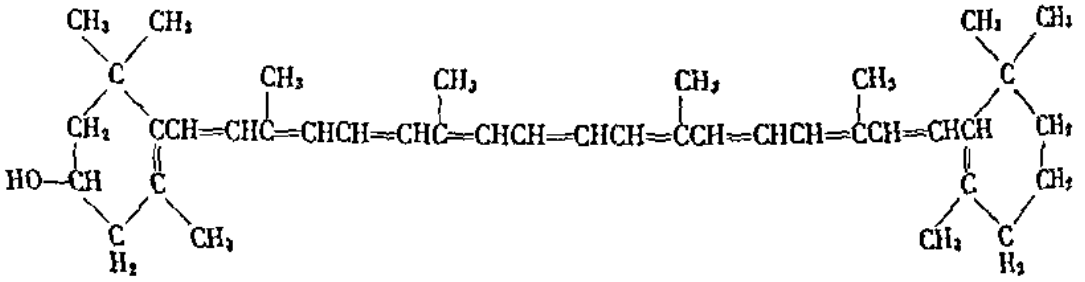
Rhodoxanthin
(14 conjugated =, including 2 C=O groups)



Zeaxanthin
(dihydroxy β carotene, 11 conjugated = + 2 OH groups)



Lutein
(dihydroxy-α carotene 10 conjugated + 1 = + 2 OH groups)

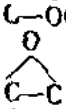


Cryptoxanthin
(monohydroxy β carotene 11 conjugated = + 1 OH group)

groups carotenes xanthophylls xanthophyll es ters and carotenoid acids This subdivision hinges upon the solubility and the molecular structure

Carotenes are characterized by their preferential solubility in petroleum ether relative to 95% aqueous methanol Chemically carotenes are carotenoid hydrocarbons many with the empirical for mula $C_{40}H_{56}$ Typical carotenes are α β γ and ζ carotene of carrots and lycopene of tomatoes (see formulas) Beta carotene with or without α carotene a nl

oxygen derivatives of carotenes one to several oxy gen atoms forming the following functional struc tures

Group	*Formula*
Hydroxyl	C—OH
Keto	C=O
Ether	C—OCH_3
Cyclic	

Several xanthophylls are always associated with the carotenes and chlorophylls in *green plants* In leaves the xanthophylls are neoxanthin violaxan thin *zeaxanthin* and lutein which is also called xanthophyll the name first used for the alcohol soluble yellow pigment of autumn leaves *In algae* of particular taxonomic *classes* the principal xan thophyll is distinctive of the major plant gro ps

[illegible] is like the carotenes are pref erentially soluble *in petroleum* ether relative to 95% aqueous methanol *but* upon treatment with alkal es they are converted into the hydroxy xan thophylls and colorless fatty acids Esters of lute n violaxanthin and taraxanthin are found in the yel low petals of many flowers (Fig 4) Except for siphonein an ester of siphonaxanthin of siphon

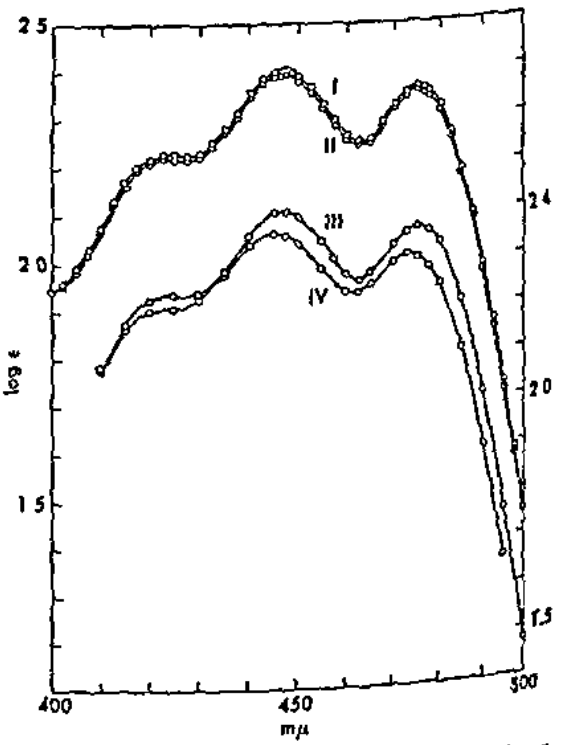


Fig 4 Specific spectral absorption curves of lutein dissolved in ethanol Curve I purified *lutein* dried in vacuum Curve II purified lutein containing 2 65% petroleum ether in the crystals Curve III purified and dried lutein compared with Curve IV the *same* solution after it had been heated at *77°C for* 3 hr The values of log ε for Curves I and II are shown at the left those for Curves III and IV at the right

alean green algae xanthophyll esters do not occur in the green parts of plants

Carotenoid acids are soluble in aqueous solutions of alkalies Chemically they are acid (carboxyl —COOH) derivatives of the carotenes A typical carotenoid acid is bixin which occurs in the seeds of *Bixa orellana* and which is employed as a fat and food coloring matter [H H SR]

Bibliography D L Fox *Animal Biochromes and Structural Colours* 1953, T W Goodwin *The Comparative Biochemistry of the Carotenoids* 1952 P Karrer and E Jucker *Carotenoids* 1950 H H Strain *Chloroplast Pigments and Chromatographic Analysis* Thirty second Annual Priestley Lectures Penn State Univ, 1958

Carotid body

The carotid body or glomus caroticum is a sense organ that lies in the upper part of the neck close to the bifurcation of the common carotid artery There are therefore two carotid bodies one on each side These structures are sensitive to chemical changes in the circulating blood Therefore they are classed as chemoreceptors—influenced by chemical stimuli In man each body is flattened and ovoid measures 5 mm or more in length and lies largely behind the upper end of the common carotid artery with only its upper pole projecting above the bifurcation In some animals it is round (measuring about 1 mm in diameter in the cat) and is situated a variable distance above the carotid bifurcation on some branch of the external carotid artery

Histology. The carotid body resembles endocrine tissue (ductless glands), for it is composed of cords of epithelioid cells between which lie numerous capillaries or small sinusoids In man the body is divided into lobules by connective tissue septa derived from the surrounding capsule but in the cat the connective tissue is not prominent and hence there are no lobules. The epithelial cells of the carotid body contain occasional vacuoles and numerous granules Some of the latter appear to be mitochondria (formed elements found in all cells) but others exhibit different staining reactions and are presumably related to the specific function of the cells Long continued stimulation of the carotid body produces marked but not complete loss of these granules

The carotid body differs histologically from most ductless glands in that it contains numerous nerve fibers (derived from the glossopharyngeal—ninth cranial—nerve) that end about its cells Further these nerve fibers have been shown by both anatomical and physiological techniques to be afferent (sensory) ones while the few endocrine tissues that receive nerve fibers at all receive motor ones Until the afferent nature of its innervation was understood the carotid body was usually classified as belonging to the chromaffin system which is endocrine tissue that secretes epinephrine (adrenalin) In both routine histological sections and sections stained specifically for nerve fibers the carotid body very closely resembles the adrenal (suprarenal) medulla, the largest collection of chromaffin tissue in the body but special stains bring out critical differences The carotid body does not show a chromaffin reaction (brown coloring by potassium bichromate) Further its apparently specific granules can be stained by vital dyes that do not stain the granules of chromaffin cells

Physiology Apparently the carotid body functions entirely at the reflex level for no sensation is known to be produced by stimulating it It is particularly sensitive to a reduced level of oxygen in the blood (hypoxemia) and is therefore a chemoreceptor of the vascular system In contrast to the respiratory center itself which is stimulated by an increased carbon dioxide (CO_2) content of the blood but depressed by hypoxemia the carotid body is stimulated by hypoxemia such as that induced by high altitudes or by inhalation of nitrogen instead of air When so stimulated it reflexly provokes a sharp increase in both the rate and the depth of breathing (that is stimulates the respiratory center) with a concomitant increase in the rapidity and strength of the heart beat Thus there is an increased output by the heart This increase in breathing tends to assure better oxygenation of the red cells (erythrocytes) of the blood than they would otherwise obtain in circulating through a lung containing air poor in oxygen The increase in cardiac output assures increased circulation to the tissues thus compensating for the possibility that the individual erythrocytes may be incompletely oxygenated The combined effect therefore tends to assure that a *maximum* amount of the available oxygen in the oxygen poor air is delivered to the tissues The carotid body thus serves to protect against paralysis of the respiratory center through lowered levels of oxygen in the blood that are not accompanied by increased levels of CO_2 It shares this function with other chemoreceptor tissue

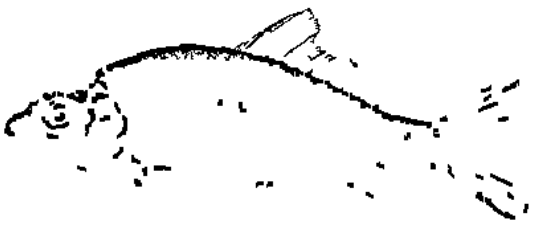
The carotid body can also be stimulated by poisons such as cyanides and sulfides These substances are known to interfere with intracellular oxidation Thus it is apparently the epithelial cells that are directly affected by oxygen lack The basic effect seems to be a change in intracellular pH Carotid body reflexes can also be evoked by substances that act at synapses (functional connections between nerve cells) including nicotine lobeline and the neurohumor acetylcholine It has been suggested that the latter may be the transmitter between the epithelial cells and the nerve fibers However indirect measurements of the acetylcholine content of the carotid body have not supported this concept and the manner of initiation of the nerve impulse is not understood

Embryology The embryonic origin of the carotid body has been said to be from neurogenic (neural crest) cells and from mesoderm The evidence favors the former origin

Tumors of the carotid body are largely vascular and produce effects through pressure only not through hyperfunctioning *See* AORTIC BODY CARDIOVASCULAR SYSTEM CHEMORECEPTION [W H H]

Carp

The type species is *Cyprinus carpio* of the family Cyprinidae the minnow family This fish is often called the European or German carp because it was introduced to America from Germany where it has been cultured in ponds for centuries It originated however in China where it was grown for a long time before it was brought to Europe



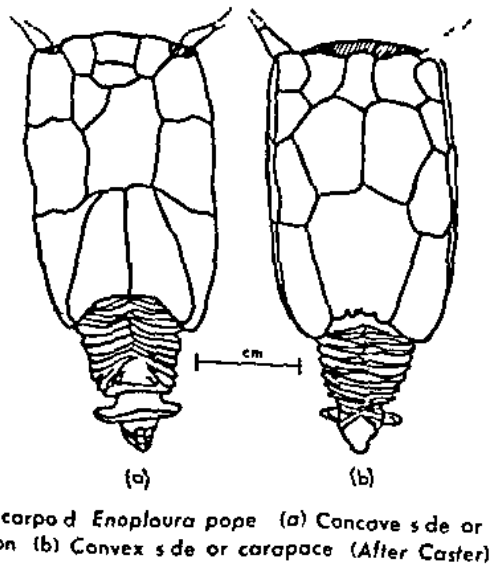
The carp *Cyprinus carpio* length at 2 years 12–15 in (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

The carp is considered a destructive or rough fish in America and is looked upon with great disfavor by most fishermen although it contributes over 20 000 000 lb per year to the commercial catch in the United States mostly in the Middle West Thus it is the most important single species of all the rough fishes in the commercial harvest

The carp is a bottom feeder and where abundant this fish roils the water badly It also uproots plants and generally makes the water unsatisfactory for the more desirable fishes Carp are extremely prolific a 5 lb female producing over 500 000 eggs per season Individuals may attain a weight of 60 lb although the vast majority are under 10 lb and specimens over 30 lb are rare There is a Swiss record of a 90 lb carp *See* Actinopterygii [J D B]

Carpoidea

A class of enigmatic rare Paleozoic echinoderms sometimes referred to as the Heterostelea which show pronounced bilateral symmetry They are regarded as Pelmatozoa although some of them may



A carpoid *Enoploura pope* (a) Concave side or plastron (b) Convex side or carapace (*After Caster*)

arranged plates roofed the dorsal side to form the carapace and similar plates formed a plastron to sheath the concave ventral side The mouth usually lay at the anterior end and often had a pair of fingerlike organs on either side which perhaps were brachioles The anus was variously placed At the posterior end was a tail like peduncle either stumpy or slender built up of paired plates The peduncle may have served both as an anchoring organ or temporary stem and as a locomotor organ Carpoids range from early Cambrian to Devonian [H B F]

See Pelmatozoa

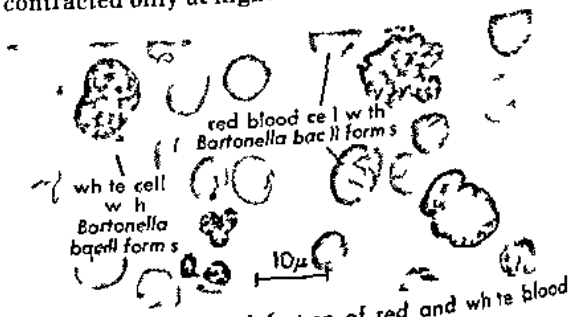
Carrier

Any wave to which modulation is subsequently applied Commonly encountered examples are a sinusoidal wave a recurrent series of pulses and a direct current or voltage *See* Amplitude modulation Angle modulation Frequency modulation Phase modulation For a definition of pulse carrier *see* Pulse modulation for a definition of subcarrier *see* Modulation

It is not always necessary or even desirable to transmit the carrier wave when not transmitted it is termed a suppressed carrier [H S BL]

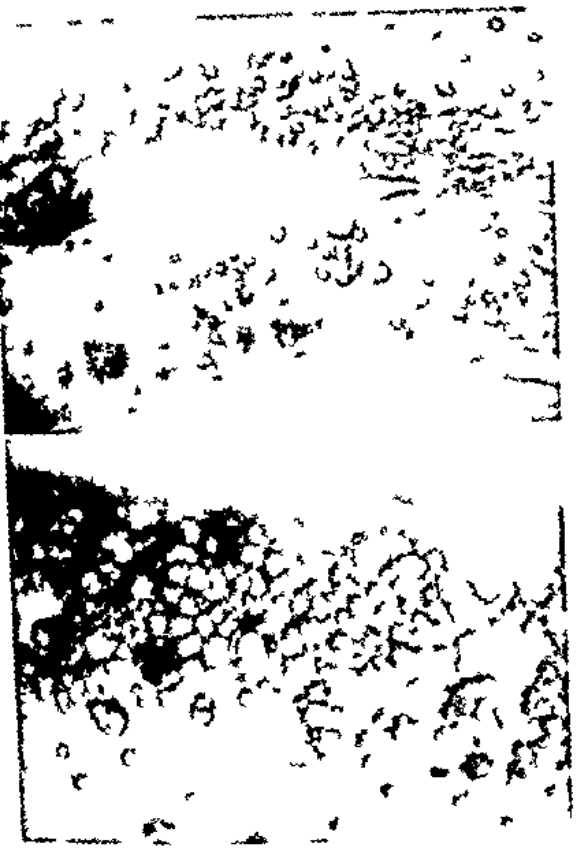
Carrion's disease

A term for two apparently different diseases caused by a gram negative rod shaped or coccoid microorganism *Bartonella bacilliformis* a species in the order Rickettsiales The two diseases are Oroya fever and verruga peruana The microorganism is restricted geographically existing only in tropical America on the western slopes of the Andean Cordilleras in Peru Colombia and Ecuador at altitudes between 2500 and 8000 ft The disease is contracted only at night



Human Oroya fever Infection of red and white blood cells

Oroya fever is an acute febrile anemia resulting from destruction of the red blood cells *B bacilliformis* is visible in the red blood cells occurring in a majority of them if the case is severe Death frequently occurs if there is no treatment Recovery is often followed by verruga peruana a skin eruption of highly vascular nodules in which *Bartonella* occurs in the tissue cells of the nodule but is not visible in the red cell The nodules are typically reddish purple and widely disseminated



Vascular nodules on skin of verruga peruana patient

giving the patient an unforgettable appearance However verruga is almost invariably benign *B bacilliformis* is transmitted by the predominantly night feeding biting fly *Phlebotomus* Several chemotherapeutic agents are known which will cure the Oroya fever condition although it is not proved that they will totally eradicate the *Bartonella* infection *See* BACTERIOLOGY MEDICAL RICKETTSIALES [D W]

Carrot

A biennial umbellifer (*Daucus carota*) of Asiatic and Mediterranean origin belonging to the plant order Umbellales The carrot is grown for its edible roots which are eaten raw or cooked

Propagation is by seed planted directly in the field Spacing varies plants are usually planted 1–2 in apart in rows of 18–24 in Temperature and soil moisture affect root color and shape 60–70 F is optimum for high yields of long deep colored roots Exposure of young plants to prolonged cold weather (40–50°F for 15 or more days) favors seed stalk formation Misshapen roots commonly result from nematodes aster yellows disease or compacted soils Most commercial plantings are weeded chemically

Varieties are classified according to length of root (long or short or stump rooted) and use (fresh market or processing) Popular varieties for fresh market are Imperator and Gold Pak for processing Red Cored Chantenay and Royal Chantenay

Harvesting of carrots for fresh market begins when the roots are ¾ 2 in in diameter usually 60–90 days after planting Harvesting by machine is becoming common Marketing in bunches is declining most carrots are sold in plastic bags with the foliage removed Carrots for canning generally have shorter roots and are grown to a larger diameter



Carrot *Daucus carota* (*From L H Bailey The Standard Cyclopedia of Horticulture vol 1 Macmillan 1937*)

Texas California and Arizona are important producing states The total annual farm value in the United States is approximately $45 000 000 *See* NEMATODA UMBELLALES VEGETABLE GROWING [H J C]

Cartilage

A specialized kind of connective tissue which is bluish translucent and hard but yielding While it serves as the model for most bones during development it persists in adults in certain limited regions in three forms hyaline or glassy cartilage elastic cartilage and fibrocartilage

Hyaline cartilage This is the type found at the ventral ends of ribs in joints and in the walls of the larger respiratory passages The cartilage cells (chondrocytes) are variable they are smaller at the periphery or perichondrium where they resemble fibroblasts they are larger in the deeper parts They have a rather large nucleus and the cytoplasm completely fills the space or lacuna by the cell They occupy about one-tl

ume of the cartilage The remainder is occupied by the matrix which separates the cells and is thought by many to contain collagen fibrils about 200 A in diameter which are infiltrated with a ground substance especially rich in chondroitin sulphate As there are no blood vessels in cartilage the exchanges with the blood take place over larger distances [illegible] tissue Hy

[illegible] mammals in the external ear the walls of the external auditory and Eustachian tubes and the epiglottis It is yellower than hyaline cartilage more opaque and more flexible It is rich in elastic fibers which course in all directions through the matrix

Fibrocartilage This form occurs in intervertebral disks in the symphysis pubis and in certain tendons near their attachment to bones It is rich in dense closely opposed bundles of collagen fibers and the cells are disposed in columns between the fibers *See* CONNECTIVE TISSUE [I G]

Cartography

The making of maps and charts for the purpose of visualizing spatial distributions over various areas of the face of the earth A map can be defined as a conventionalized picture on a much reduced scale of the earth s surface as seen from above Most maps are laid out on a parallel and meridian system and have lettering added for identification Some kinds of maps have long been designated charts such as aerial and marine navigation charts A most realistic earth representation the globe is less used than flat maps because of its comparative bulk (*see* GLOBE TERRESTRIAL)

Map compilation and representation Maps are based on original surveys are laid out from air photographs (photogrammetry) or compiled from existing maps and records The early stages of map design generally include selection of a projection and design specifications for the eventual presentation *See* MAP DESIGN MAP PROJECTIONS PHOTOGRAMMETRY

Map symbols Most features on the map are sym[illegible]

have developed traditionally such as a circle used to represent a city or stylized reed bunches to indicate swamps Government map sets have standard symbols used for the entire set Symbols are commonly identified in a key or legend

Map lettering The size and type of features are indicated by the size and type of lettering used For instance United States Geological Survey (USGS) topographic sheets use italics for hydrography (water features) gothic type for hypsography (relief features) and roman type for culture (man made features) Names of large areas and features are spread to indicate their extent All letters meant to lie horizontally on the map should parallel the map parallels

Relief representation Relief features such as hills mountains and plateaus are commonly shown on maps by contour lines These are lines drawn to show the shape of the land and its elevation above sea level On topographic sheets contour intervals of 10 20 50 or 100 ft are used depending on scale and ruggedness On small scale maps varying contour intervals as 100 200 500 1000 2000 5000 8000 and 12 000 ft are used the intervals are frequently layer tinted from green to brown The relief features can be made to stand out strikingly by applying plastic shading which gives the map the [illegible] used [illegible]APHIC

SURVEYING AND MAPPING

Map collections The greatest available map collections in the United States are at the Library of Congress the American Geographical Society the New York Public Library and the larger un[illegible] *National* he large[illegible] iety but cle One only a few types are considered in type is produced in a series of matching sheets generally at a common scale Outstanding examples of this type are as follows

Topographic maps These are the most basic maps recording the original surveys of the country All such maps have contour lines or other relief representation with standard symbol and numbering systems In the United States USGS prepares topographic maps based upon triangula[illegible] the United States Coast and [illegible] yconic projec 62 000 1 12 [illegible] tail including contour lines is currently obtai[illegible] from air photographs Some military areas are mapped by the Army Map Service on transverse Mercator projection generally at 1 25 000 Topographic map

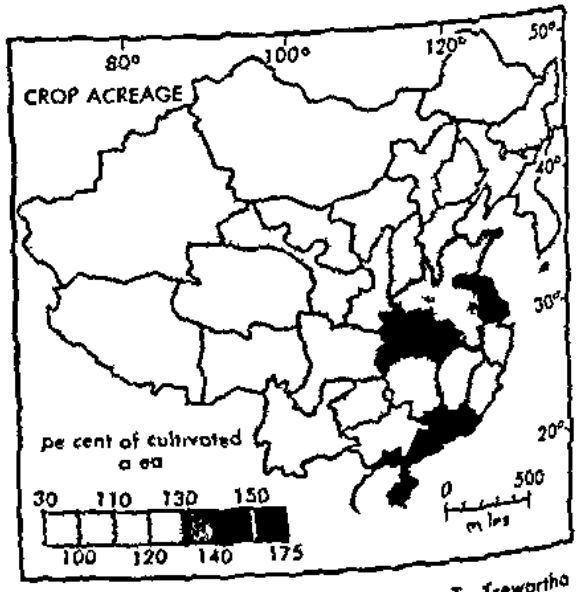


Fig 1 A choropleth map by *Glenn T Trewartha* (*Courtesy Geograph cal Rev ew 1938 from E Ro z General Cartography* 2d ed *McGraw-H ll 1948*)

coverage of the Americas lags far behind that of the European countries *See* MAP PROJECTIONS

Aeronautical charts These are similar to topographic sheets but on smaller scales The World Aeronautical Charts (1 1 000 000) cover all lands These charts are made primarily on Lambert conformal conic projection and are layer tinted The 1 2 000 000 jet navigation charts have plastic shading added Air navigational data is overprinted to allow for frequent revision Chief producer is the

ters by the Hydrographic Office British Admiralty charts are also much used Marine charts are made at various scales but almost always on Mercator projection as this shows compass directions as straight lines Depths are recorded by submarine contours and frequent soundings Lights buoys reefs shoals and radio beacons are emphasized The charting of the bottom configuration is greatly aided by echo sounding Loran charts showing a radio signal network established along many coast lines, help ships to fix their position (*see* LORAN) Monthly Pilot Charts for each ocean are rich in climatic data

Atlases These are collections of maps uniform in size and

United States except for the maps of the National

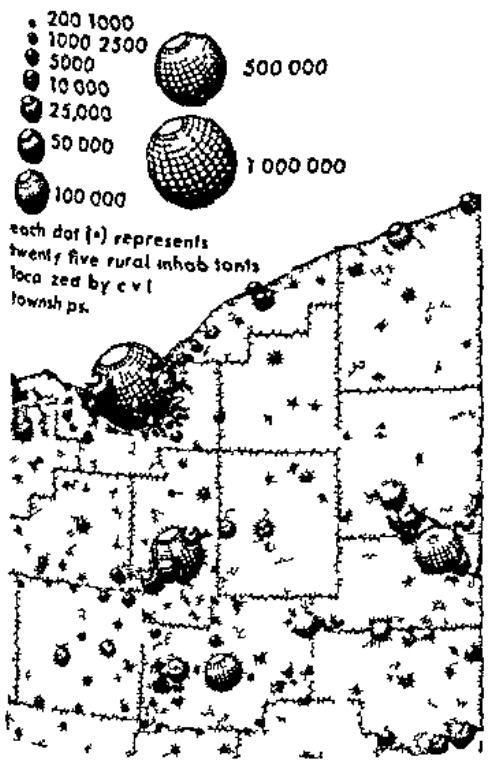


Fig 2 Density-of population map by Guy Harold Smith (Courtesy Geographical Review 1928 from E Raisz General Cartography 2d ed McGraw-Hill 1948)

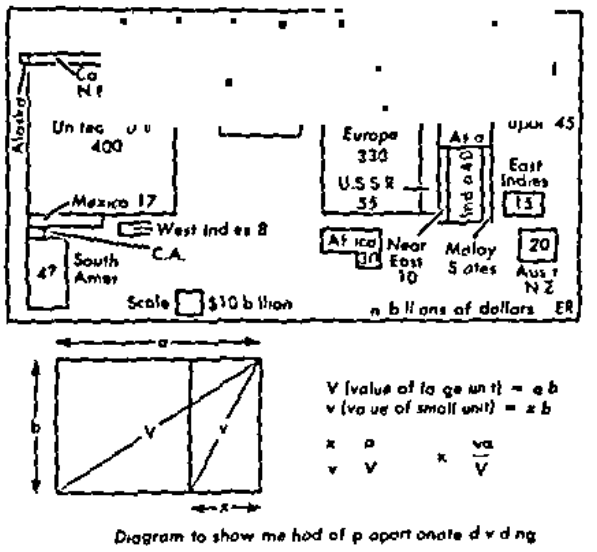


Diagram to show method of proportional dividing

Fig 3 Value by-area cartogram (Courtesy Journal Geography 1936 from E Raisz General Cartography 2d ed McGraw-Hill 1948)

Geographic Society National atlases are published by most nations

Single factor or topical maps The distribution of a selected topic is frequently presented on a separate map Color patch (chorochromatic) maps show such qualitative items as geology soil languages and the like by color tints or patterns commonly with index letters

Statistical maps Various methods are used to show variation in quantity of a factor such as rainfall population or crops In choropleth maps civil divisions such as states counties or townships are tinted or colored using darker tones for denser distribution In many cases isopleths lines of equal value are better to use Thus temperatures are shown by isotherms magnetic declination by isogones and height above sea level by contour lines Isopleth intervals may be tinted or colored Dot maps are the easiest to visualize a dot represents a selected unit for instance 1000 head of cattle or an acre of wheat. The size and value of dots is so chosen that they coalesce at the densest distributions Neither the isopleth map nor the dot map allows much lettering

Diagrams superimposed on maps This technique serves well to illustrate highly variable or subdivided factors For example manufacturing can be shown by proportionately sized circles subdivided for textiles machinery and the like Any kind of diagram can be superimposed such as bar graphs line graphs circles squares pictures of spheres or blocks These are easily labeled or rendered pictorially

Cartograms or diagrammatic maps Traffic flow maps time table maps and maps showing movements of people or goods are often diagrammatic

Land use maps On these maps colors or



Fig 4 A work sheet part on of the land use map of England On the 6 inches to the mile map of Great Br tain every f eld is marked with a letter to show ts use *From E Ra sz General Cartography 2d ed McGraw H ll 1948)*

and gardens Such features as roads railways har bors business centers mills manufacturing plants mines and oilfields are also emphasized Land use mapping of the world is still in its infancy

Economic maps With land use colors or symbols small scale maps show either the over all economy of an area or the production shipping and use of such products as steel rubber oil or wheat

vanced even in underdeveloped countries Weather maps have an ingenious symbolism showing every *element* of weather (see WEATHER MAP) Forest mapping is highly developed and soil maps of most *agricultural* countries are now available [E RZ]

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Caryophanales

An order of bacteria of the class Schizomycetes as defined in *Bergey s Manual of Determinative Bac teriology* (1957) The Caryophanales occur as tri chomes (many celled filaments) which produce *shorter structures* that function as reproductive units They contain Feulgen positive nucleoid bod ies Locomotion where existing is by *means* of peritrichous flagella Endospores may be formed The order is separated into the *three families* Caryophanaceae Oscillospiraceae and Arthrom taceae *See* SCHIZOMYCETES

This system is open to criticism The *genera Caryophanon* Peshkoff and *Lineola* Pringsheim *which have little* in common are included in the Caryophanaceae *Lineola species* are coenocytic *that is* they have many nucleoid structures in each *cell compartment* This seems sufficient for sepa rating a family Lineolaceae How far other mostly smaller bacteria share this coenocytic organization is not known

The difference between the motile Oscillospira ceae Peshkoff and the nonmotile Arthromitaceae Peshkoff is not well established because the for mer also lose motility upon exposure to oxygen Spores supposed to be an additional feature d f ferentiating these two families have also been found in *Oscillospira* Clarification of the taxonomy of Caryophanales requires further research

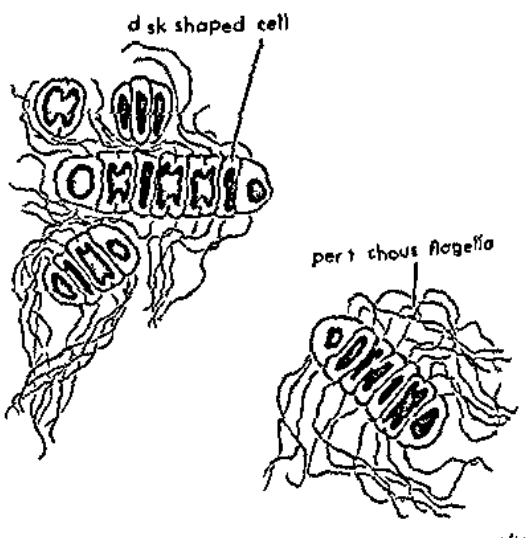
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margins In the best known species *Caryophanon latum* Peshkoff these chains are up to 20 μ in length and 3 μ in width This bacterium is the largest grown in pure culture on agar media The colonies are so characteristic in structure that they can be recognized with low magnification

Caryophanon latum and the smaller specie *Caryophanon tenue* Peshkoff are found in large numbers in one or two-day old cow dung on pas ture land The bacteria can easily be grown on agar with peptone yeast extract and a low con centration of acetate but do not develop so well in liquid media Because of their unusual size the cells of *Caryophanon latum* are suitable for the study of the inner structure of bacteria In this re spect they do not seem to differ appreciably from other species The chains are motile with flagella covering their surfaces The ends of the chains are often narrower than the middle part

Oscillospiraceae The Oscillospiraceae repre sented by *Oscillospira guillermondi* Chatton e Perard are similar in appearance to but even larger in diameter (4–5 μ) than *Caryophanon* They are also gram negative *Oscillospira* is mo tile in a manner similar to *Caryophanon* prov ded it is kept at blood temperature in sealed prepara *tions* It is found in the rumen of ruminants and in



D agrammat c sketch of *Caryophanon latum* (After K A B sset from M J Pelczar Jr and R D Re d M crob ology McGraw H ll 1958)

the cecum of rodents It loses its vitality when exposed to the air

Arthromitaceae The Arthromitaceae represented by several as yet poorly-defined species occurring in the intestines of millipedes insects and tadpoles are described as nonmotile and with large spores Since *Oscillospira* becomes immotile in ordinary preparations and has been found to produce spores, the taxonomic relationship of the two genera is not clear nor has the absence of flagella in *Arthromitus* been established Neither of the organisms has been grown in culture

A certain similarity of Caryophanales with Cyanophyceae the blue green algae, has misled some authors into believing them related However since motility in the Caryophanales where it occurs is by swimming and not by creeping as in the Cyanophyceae this similarity is only superficial *See* CYANOPHYTA [F G P]

Bibliography M A Peshkoff Phylogenesis of new microbes *Caryophanon latum* and *Caryophanon tenue* organisms which are intermediate between blue green algae and the bacteria *J Gen Biol (USSR)* 1 598 1940, E G Pringsheim and C F Robinow Observations on two very large bacteria, *Caryophanon latum* Peshkoff and *Lineola longa* (nomen provisorium) *J Gen Microbiol* 1 %7 1947

Cascade particle

An alternate name for the negatively charged Ξ hyperon (*see* HYPERON) This name is descriptive of the following sequence or cascade of decay events

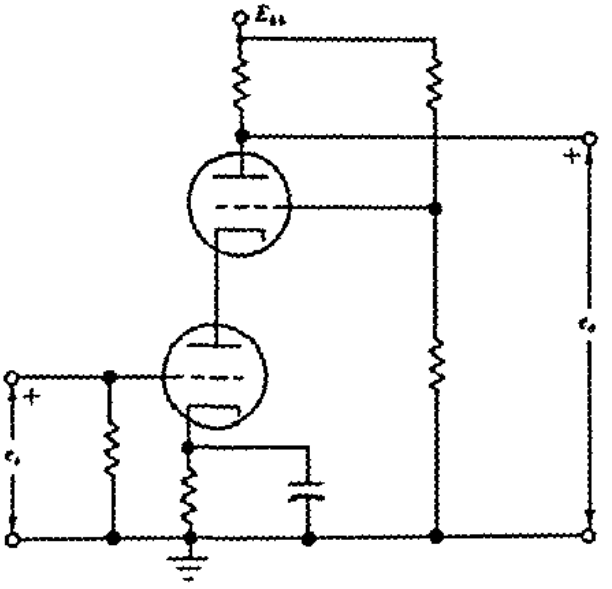
$$\Xi \rightarrow \pi^- + \Lambda \qquad \Lambda \rightarrow \pi^- + p$$

This cascade gives rise to a very characteristic pattern for the decay of a moving Ξ hyperon in a cloud chamber or bubble chamber At the point of Ξ decay the incoming Ξ track shows a change of direction accompanied by a nearby V of tracks (the subsequent Λ decay event) pointing back to the decay point *See* V PARTICLE [R H D]

Cascode amplifier

An electronic amplifying circuit composed of a grounded cathode amplifier connected to a grounded grid amplifier (*see* VOLTAGE AMPLIFIER) The dynamic load resistance for the grounded cathode stage is the input resistance of the grounded grid stage Under conditions which are not difficult to obtain the circuit has the characteristics of a pentode that is a high amplification factor and a large plate resistance A low frequency cascode amplifier circuit is shown in the illustration variations of the circuit are possible When the amplifier is used with high frequency signals the plate load resistor is replaced with a tuned circuit

The cascode amplifier finds its principal application in the amplification of high frequency signals, 2 Mc and higher It is particularly useful in low level input stages where the signal to noise ratio is a problem A pentode adds more noise to an amplified signal than does a triode because of the effect of the screen grid upon the electron stream The cascode amplifier with the characteristics of a pentode but composed of triodes has all the desirable features and few of the undesirable features of a pentode One widespread use for the cascode circuit is in the tuner of a television receiver In the fringe areas where the signal strength is small an amplifier is needed which can amplify the signal the required amount without introducing an excessive amount of noise *See* TELEVISION RECEIVER [H F K]



Cascode amplifier

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Casein

The principal protein of milk It is present in milk as calcium caseinate and amounts to 80% of the milk protein When casein is separated from the other constituents and washed free of impurities it has certain industrial uses such as in the manufacture of brush bristles buttons billiard balls jewelry paper glue paint sodium caseinate and protein hydrolyzates The competition from synthetic plastics has reduced the demand for casein for some of these uses *See* MILK

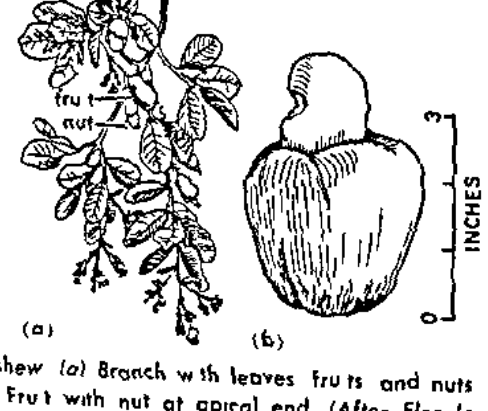
Casein is made by either of two methods coagulation by rennet or precipitation by acid The rennet method is used for producing casein for the plastics industry The acid precipitation method is used for casein production for other commercial uses including the food industry Dilute hydrochloric acid is added to skim milk having a temperature between 35–46 1°C When the pH is brought to a range of 4 8–4 0 the casein is precipitated in a coagulated mass or curd The curd can be washed relatively free of impurities When a premium grade is desired the curd is washed with water five or six times starting with water at the same temperature as the whey and using a final

wash with water at 15 6°C The whey, containing 42–44% of the total solids in milk is a by product in the manufacture of casein and cheese These solids contain over 90% of the milk sugar and lactalbumin a portion of the fat and minerals as well as a high percentage of the water soluble vitamins of the original milk If the curd is not freed of impurities it turns yellow The curd is pressed dried with hot air in a tunnel ground packed in bags and stored *See* FOOD ENGINEERING [P H T]

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Cashew

A moderate sized tropical evergreen tree (*Anacardium occidentale*) and its fruit The fruit consists of an astringent applelike basal part and a kidney shaped extension containing the nut



Cashew (a) Branch with leaves fruits and nuts × ⅛ (b) Fruit with nut at apical end (*After Florida Univ Agr Ext Serv Bull 109*)

The cashew is native to tropical America but is now widely grown in tropical countries throughout the world India and East Africa are the principal commercial producers In India most of the nuts are roasted in the shells which are later opened by hand The kernels are sweet of soft texture and are eaten as dessert nuts in Europe and the United States

The cashew is a relative of poison ivy and its shell contains an oil which is irritating to the skin *See* NUT CROP CULTURE [E F S]

Cashmere

The Cashmere goat is native to the Himalayan region of China and India The fleece of this goat has long straight coarse outer hair of little value, but the small quantity of underhair or down is made into luxuriously soft wool like yarns with a characteristic highly napped finish This fine cashmere fiber is obtained by frequent combings during the shedding season A microscopic examination reveals that cashmere is a much finer fiber than mohair or wool fiber obtained from sheep The scales being less distinct and farther apart the fiber appears to be made of telescoped sections

Cashmere first became familiar in the beautiful soft light cashmere shawls for which India has been famous Today it is used for such garments as sweaters sports jackets, and overcoats Cashmere is soft lighter in weight than wool and quite warm, but because of its soft delicate texture cashmere is not as durable as wool *See* ALPACA CAMEL'S HAIR, LLAMA, MOHAIR, VICUNA, WOOL *see also* FIBER NATURAL [M D P]

Cassava

The plant *Manihot esculenta* also called manioc or manihot of the spurge family Euphorbiaceae is, next to the sweet potato the most important tropical root crop It is native to South America but is now cultivated in most tropical and subtropical regions Cassava is a shrubby perennial about 9 ft high and has terminal starchy, tuberous root enlargements that are used as food There are two groups the bitter cassavas and the sweet cassavas, with 150 varieties most of which the natives use for food The roots contain prussic acid and some are quite poisonous but heat expels the volatile acid and makes the material harmless

A single plant yields up to 50 lb of the edible roots These are pared washed and scraped or grated The grated material is placed in a bag and pressed to squeeze out the liquid After the residue is dried and sifted the meal is baked into a thin cake which makes a wholesome food the parallel of wheat bread in the diet The poisonous milky juice is concentrated by boiling to make cassareep or West Indian pepper pot used as the basis of many sauces Raw cassava starch is used in laundry work and sizing as a healing agent to feed livestock and is fermented to make an intoxicating drink

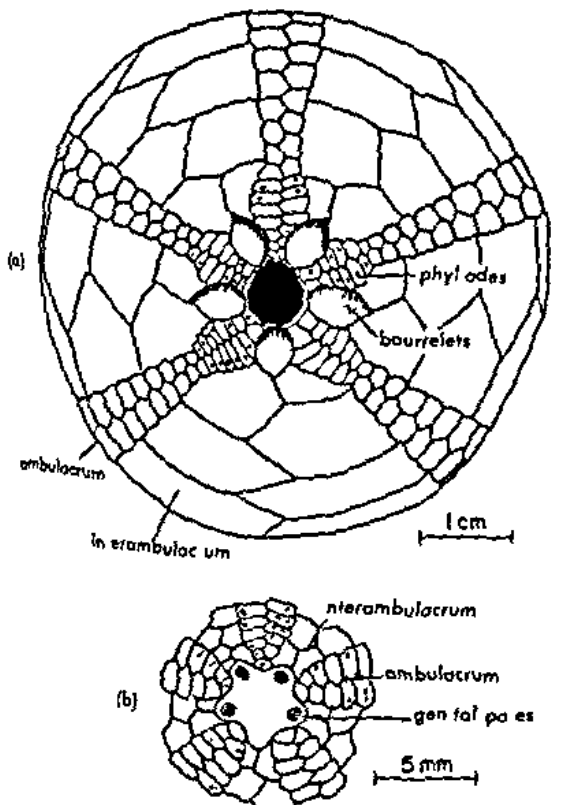


Cassava (*From L H Bailey ed The Standard Cyclopedia of Horticulture vol 2 Macmillan 1937*)

Much cassava is used in making tapioca The starchy paste left after the milky juice is squeezed out is soaked in water for a few days kneaded and strained to remove impurities It is then dried sifted and gently heated on iron plates This light cooking causes the material to form into little round balls the familiar tapioca *See* GRANULES [P D S]

Cassiduloida

An order of exocyclic Euechinoidea which possess 5 similar ambulacra which form petal shaped areas phyllodes around the mouth The innermost inter ambulacral plate between each pair of adjoining phyllodes is swollen and is termed a bourrelet The 5 bourrelets and 5 phyllodes thus form a flower shaped pattern around the mouth collec tively termed the floscelle The apical system is monobasal that is the genital plates fuse together (see illustration) The adult stages lack teeth and fasciole All extant forms live in shallow or mod erately deep tropical seas partly buried in sand There are two families The Cassidulidae includes about 20 genera of rounded or ovoid forms with short aboral petals which do not reach the margin They arose in the Cretaceous and reached a maxi mum in the Eocene but only three genera now



Diagnos c features of Cass dula da (a) Adoral aspect of test w th the mouth at the center surrounded by the floscelle (b) Monobasal ap cal system

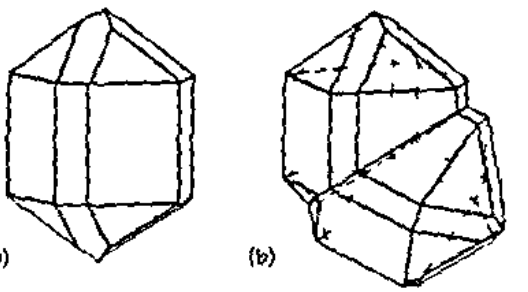
surv e All three genera are found in Indonesia and one (*Cassidulus*) in tropical America Echino lampad dae are rounded forms vaulted above with long and widely open petals They range the Ter tiary but declined after the Miocene and only a few genera survive in the Indo West Pacific and tropical Atlantic. *See* ECHINOIDEA EUECHINOIDEA. [H B F]

Cassiopeia

In astronomy a prominent northern circumpolar constellation as seen from the middle latitudes The five main bright second and third magnitude stars of Cassiopeia form the outline of a rather distorted W or M by which this constellation is usually identified The W is also popularly known as Cassiopeia's Chair because on its side the W suggests the shape of a chair Most old sky maps show Cassiopeia as a queen seated upon a throne Lying as it does in the Milky Way the entire re gion of Cassiopeia is rich in star fields containing several beautiful star clusters Cassiopeia and the Big Dipper (*see* URSA MAJOR) lie across the op posite sides of the North Celestial Pole *See* CON STELLATION [C S Y]

Cassiterite

A mineral having the composition SnO_2 Cassiter ite is the principal ore of tin It cry tallizes in the tetragonal system in prisms terminated by dipyra mids Twins with a characteristic notch called visor tin are common (see illustration) Cassiterite is



Cass ter te crystals (a) Tetragonal pr sm and d pyra m d (b) Elbow shaped tw n or v sor t n (From C S Hurlbut Jr Dana's Manual of M neralogy 16th ed W ley 1952)

usually massive granular but may be in radiating fibrous aggregates with reniform shapes (wood tin) The hardn gravity is 6 mineral)

Pure tin oxide is white but the color of cassiterite is usually yellow brown or black because of the presence of iron

Cassiterite is genetically associated with granitic rocks and pegmatites and may be present as a pri mary constituent More commonly it is found in quartz veins in or near such rocks associated with tourmaline topaz and wolframite Cassiterite is most abundantly found as stream tin (rolled peb bles in placer deposits) Early production of tin came from cassiterite mined at Cornwall England but at present the world's supply comes mostly from placer or residual deposits in the Malay States Indonesia, the Belgian Congo and Nigeria It is also mined in Bolivia *See* TIN [C S H]

Cast iron

A generic term describing a family of iron alloys containing 1.8–4.5% carbon Cast iron usually is di eat be un suitable for drawing into rods or wire although to

a limited extent it has been continuously cast into rods and shapes from a liquid bath or swaged from bars into smaller dimensional units Silicon usually is present in amounts up to 3% but special compositions are made containing up to 6% (Silal) and up to 12% (Duriron)

Cast iron of the above composition range is often made into blocks or rough shapes and called pig iron It is an intermediate form of cast iron used for remelting into iron castings Pig iron usually is produced from iron ore and coke smelted into liquid iron in the blast furnace In some cases this liquid iron is poured into sand molds of specific design which when cleaned and trimmed become ingot molds for steel manufacture In these [illegible]

furnace of the foundry which is common practice in the manufacture of iron castings

Classification of cast irons Cast iron may be purchased in several commercial grades called gray iron chilled iron mottled iron white iron malleable iron ductile iron spheroidal graphite iron nodular iron and austenitic cast iron

Originally cast iron was graded by examination of fracture characteristics of the surfaces produced when a sample was broken its true composition was unknown This method of grading first was applied to pig iron which was classified similarly as white mottled or gray The color of the fracture governed the classification of the product until about 1888 when extensive work by W J Keep revealed that the silicon content in a large measure determined the character of the fracture Further work clarified the relationships between composition microstructure and fracture characteristics and gradually the importance of the examination of fractures receded until the present time when it is used only to classify the products generally The chemistry of cast iron today is quite well known and gray white and mottled iron can be selected on the basis of composition charts which mark the areas of their occurrence

Further developments in cast irons have adapted heat treatment processes to produce special properties that permit classification of special grades of gray malleable and white cast irons

More recently metals such as cerium and magnesium have been used to produce the spheroidal graphite structures which are characteristic of ductile irons

Properties and uses of cast irons Gray iron is an iron base material within the broad composition limits mentioned above Of its total carbon content more than one half is in the form of graphite flakes It is the presence of the graphite flakes which produce a gray color in a fresh fracture The remaining carbon is dissolved in the metal and is called combined carbon It may be present in amounts ranging from 0 05 to 1 20% Gray iron is the mainstay of iron foundry production Its application covers practically all engineering fields involving construction machinery engines power transport mining, and many daily uses such as stove parts pots and pans and hardware

Mottled iron solidifies as a mixture of white and gray irons The fracture is a mottled mixture of white and gray areas The fracture may contain as few as 10% white areas in a gray background or the reverse namely, 10% gray areas in a white background Mottled irons are useful for abrasion or erosion resisting services, where their composite structure provides a hard surface with some ability to deform The high frictional resistance of its surface is occasionally utilized

Chilled iron is gradually disappearing as a descriptive term It was applied to cast iron which was poured into a metal mold or chill Frequently a gray iron would be processed in this manner and if the cooling rate was rapid enough a white iron casting or a surface zone of white iron on the casting would develop, backed by the less rapidly cooled gray iron inside Since glass molds for example are often made by casting one of their surfaces against a chill such castings would be called chilled iron Unfortunately, the term spread to the part white part gray types of cast iron and more inaccurately to a solid white iron which had been cast in a chill

White iron is an iron base material within the broad composition limits mentioned above whose total carbon content is in the combined form It therefore contains little or no graphite A fresh fracture is white (ground glass white) Its characteristic structure usually is obtained by lowering the carbon content or the silicon content or both so that the graphitizing power of the composition is subdued

Malleable cast iron is made as a white-iron casting within the narrower composition range that the term implies Annealing produces a tough benda



Fracture showing a zone of white cast iron at the top and gray cast iron over the remainder of the surface

ble and machinal le cast iron During the anneal all or most of the carbon is precipitated in ragged nodules of graphite The end product is available in a number of grades that vary in strength hardness and toughness Malleable iron is used widely in the transportation valve fitting and hardware industries for innumerable small parts

Ductile iron (also called spheroidal graphite iron or nodular iron) is a product of high carbon and high silicon content in which most of the carbon has been coagulated into spheres during processing in the liquid state During processing an ingredient such as magnesium or cerium is added followed by another substance such as silicon calcium or combinations of these ingredients The resulting product acquires the structure of steel peppered with spheres of graphite Its strength closely approaches that of steel and it may be heat treated to develop a ductility exceeding that of malleable cast iron Its properties make it useful for a great many engineering applications requiring strength and toughness levels which previously were beyond the reach of iron foundry products

Austenitic cast irons are available in the gray iron and ductile-iron classifications When gray or ductile iron is alloyed with substantial amounts of nickel manganese silicon or other elements to alter the basic crystalline structure from magnetic alpha iron to nonmagnetic gamma iron the resulting product becomes austenitic cast iron These irons generally offer better corrosion and heat resistance than the low alloy irons *See* CASTING HEAT TREATMENT (METALS AND ALLOYS) IRON ALLOYS STEEL WROUGHT IRON

[J S V]

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Casting

The pouring of molten metal into a cavity or mold and allowing the metal to solidify The objective of casting is to produce a metal object that completely fills the mold If a sound casting can be produced the process offers such advantages over other method of fabrication as practically unlimited size (sand casting) more complex shapes and isotropic properties (as compared to mechanical working processes)

The attainment of a solid casting of the desired shape is dependent upon the relationship of the metallurgical aspects of casting the mold process used foundry technology (melting and pouring gating and risering) and design considerations

Metallurgical aspects One factor affecting the serviceability of a casting is its structure that is the size and arrangement of grains the nature of shrinkage cavities porosity due to gas evolution internal or external cracks due to hot tearing and variations due to segregation

Grain structure Other things being equal the grain size of a casting is inversely related to cooling rate which in turn is dependent upon the section thickness and the thermal characteristics of the mold material Other factors also influence the grain size such as superheating inoculation treatments with additives and composition The shape of the grains is affected most by composition pure metals tend to have columnar shaped grains and alloys which solidify over a range of temperatures rather than at a constant temperature tend to have an equiaxed grain structure Cooling rate also will have an effect on grain shape

Shrinkage Practically all metal contract during solidification the amount depending upon the metal If conditions are such that liquid metal is not able to feed those portions of the casting where the solidification is occurring at any instant cavities result If the shrinkage is localized in one or a few areas it is called a pipe In a relatively long section of a casting solidification may proceed from the side walls toward the center of the section resulting in a more dispersed porosity along the midwall known as centerline shrinkage

In alloys the shrinkage is more likely to be dispersed on a microscopic scale known as interdendritic porosity or microshrinkage This is due to the existence in these alloys during solidification of a liquid plus-solid zone in addition to the normal solid zone and liquid zone present in any metal The growing solid crystal in this intermediate zone eventually meet and trap liquid metal between their growing branches When this remaining entrapped liquid metal solidifies and contracts the main body of still liquid metal is unable to flow through to take up the shrinkage Any factor which increases the temperature gradient in the casting during solidification will narrow the liquid plus-solid zone and thus minimize this type of shrinkage defect Factors which increase the temperature gradient include low thermal conductivity of the solidifying metal Thus for a given alloy and section size the thermal characteristics of the mold material are the major controlling factors

Gas evolution Liquid metals have considerably greater solubility for gases than solid metal Thus upon solidification most gases present in the molten metal are evolved If the freed gas is unable to

feeding in the normal manner and microporosity will result If the alloy is prone toward microporosity anyway gas evolution accentuates it

Hot tearing As castings cool after solidification contraction continues if this contraction is re

alloys are more prone to hot tearing but it is apparent that the design of the casting and the nature

or segregate to those portions of the casting that are last to solidify This resulting segregation occurs on two scales A general or macroscopic type results in a different composition in the outer portions of the casting than in the interior A microscopic type occurs in alloys that solidify over a range of temperatures and results in a different composition in the centers of the grains than in the grain boundaries Macroscopic segregation is minimized by fast cooling rates whereas microscopic segregation is reduced by very slow cooling

Molding processes Casting processes are generally classified according to the nature of the molding material and the method of feeding the mold In each type of mold a pattern produces the mold cavity To obtain a casting of a desired shape and dimensions allowances must be made in the production of the patterns These include shrinkage allowance machine finish allowance (if necessary) draft (to facilitate removal of pattern from the mold) size tolerance and distortion allowance The pattern should also include the gating and risering system as an integral part

Sand casting Any casting made in a sand mold regardless of the composition or nature of the sand mixture is called a sand casting The most common molding material is green molding sand a mixture of sand grains clay water and additives used to improve such properties as thermal stability surface finish and hot strength

The sand is packed around the pattern which is surrounded by a container or flask of suitable size The sand is generally rammed in place by molding machines, which produce the desired degree of packing by a squeezing action a jolting action a combination of squeezing and jolting or by a throwing or slinging action The gating system is included in this molding procedure preferably as an integral part of the pattern With the two halves of the mold made and the pattern withdrawn cores (made of sand with binder) are inserted into the mold cavity to form holes or internal cavities in the casting The two halves of the mold (cope and drag) are then closed and clamped or weighted to prevent the cope from floating when the casting is poured Tolerances of from $\frac{1}{64}$ in to $\frac{3}{32}$ in may be attained depending upon size and control practices

Dry sand molds are made from green sand and then dried in an oven at 300–650°F The major advantage over green molds is the absence of moisture which might result in surface defects due to evolution of steam or reactions with the molten metal Other sand molding materials are cement bonded sand and core sand which are used to obtain greater strength and consequently bet

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World War II Basically the process consists of allowing sand mixed with a resin binder to come in contact with a pattern heated at 350–500°F Excess sand mixture is removed leaving a thin shell of sand plastic mixture adhering to the pattern After heating in an oven (600°F) to cure the shell the latter is stripped from the pattern by an ejecting device The shell halves are clamped together and may be backed with metal shot prior to pouring although this is not usually necessary Excellent surface finish and closer tolerances than in a regular sand casting are obtained

Permanent mold casting Castings produced by pouring liquid metal into a metal mold are termed permanent mold castings The molds are usually made of cast iron or steel with the mold cavity and gating system machined to dimensions Vents must be included in any metal mold to allow the air in the mold to escape when the liquid metal is poured in To prevent deterioration of the mold surfaces and seizure of the liquid metal against the mold walls the surfaces of the cavity are normally coated with a refractory wash or carbon soot Most common nonferrous alloys and cast iron may be cast by this process High production rates better surface finish and closer tolerances than in sand casting are possible

Die casting In die casting the liquid metal is forced into a metal mold under pressures of 1000–100 000 psi There are two principal types of die casting machines the piston (or submerged hot chamber type) machine (Fig 1) and the cold chamber machine (Fig 2) In the former molten metal (usually low melting point metals) is in continual contact with the injection mechanism and flows through a port into a chamber where a piston forces it into the die cavity at pressures up to 2000 psi In the cold chamber process the liquid metal is ladled into the injection chamber and is forced into the die cavity by a plunger under much higher pressures than is used in the piston machine The higher

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Die casting processes are capable of high production rates close tolerances thin sections, excel

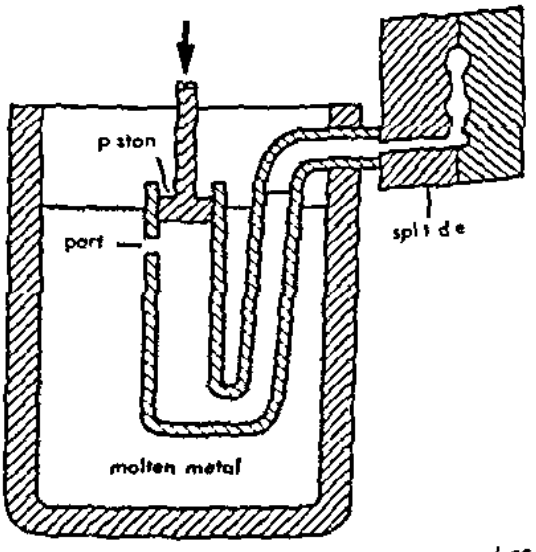


Fig 1 Principles of piston type die casting machine

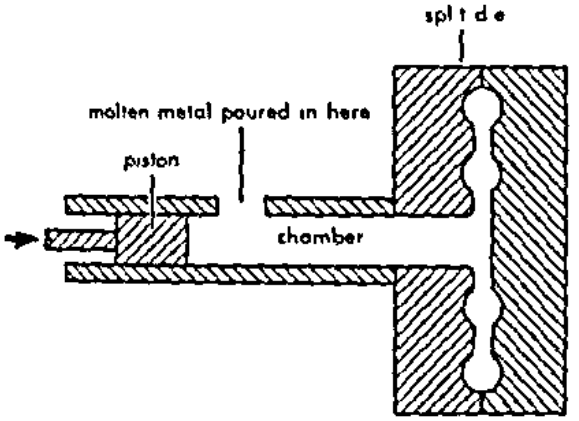


Fig 2 Principles of cold-chamber die casting machine

lent surface finish and high strength due to rapid cooling rate However in any metal mold process the design must be such as to permit the casting to be ejected from the mold cavity

Investment casting This process is also known as precision casting or lost wax process It involves making a wax (or frozen mercury) pattern for every casting to be produced These patterns are cast by injection molding into metal dies The patterns with gating systems attached are precoated by dipping in a refractory slurry (such as silica flour and water-ethyl silicate solution) After drying, the assembly is placed in a metal flask which is then filled with the refractory investment mixture (ca

the pattern is melted out The mold is then preheated at 1200–1900°F (depending on metal to be cast) and the metal is poured in After the metal solidifies the investment is broken away and the casting removed

The primary advantages of this process are close tolerances smooth finish intricate shapes and casting of high melting point alloys The process is limited to relatively small castings and is comparatively costly

Plaster mold casting Metals having melting points below about 2400°F can be cast in plaster or plaster bonded molds The plaster normally used is a mixture of gypsum (plaster of paris) and materials to improve strength or accelerate setting of the plaster such as magnesium silicate talc and asbestos fiber The ingredients are mixed with water and the mixture poured over the pattern After setting the pattern is removed and the mold baked (400°F or higher) Accurate dimensions smooth finish and ability to cast thin sections and fine details are the advantages of this process

Centrifugal casting This process uses sand lined or metal molds and is named from the manner in which the metal is distributed in the mold There are three categories true centrifugal casting semicentrifugal casting and centrifuged casting In the first two the mold rotates about its own axis (Fig 3) True centrifugal casting uses a cylindrical mold and the metal solidifies in the form of a hollow cylinder with the inner diameter dependent upon the amount of metal placed in the mold The semicentrifugal process uses a core to form the central cavity producing internal shapes other than a circular hole Centrifuged castings are rotated about an axis displaced from the mold cavity and centrifugal force increases the pressure on the metal in the mold cavity Several mold cavities may be gated to a central sprue into which the molten metal is poured

Foundry technology The techniques used in the foundry for melting pouring and feeding the liquid metal have an important effect on the casting

Melting The type of melting equipment used depends primarily on the composition and amount of metal being melted (*see* METALLURGY) the degree of control required and economic factors The type of furnace has a direct bearing on the nature of the chemical reactions which in turn have important effects on the casting

Melting furnaces may be classified according to the method of heating such as fuel fired or electric Fuel fired furnaces are further classified on the basis of whether the charge comes in direct contact with the fuel or with the products of combustion of the fuel

Crucible furnaces used for some nonferrous alloys, consist of clay graphite crucibles for the charge The crucibles are placed in floor pits or in floor level gas or oil fired furnaces In some in

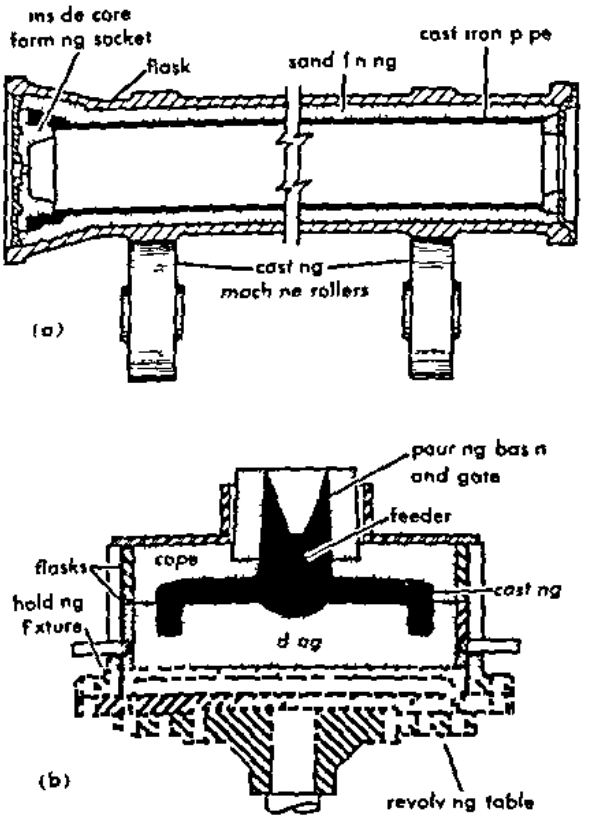


Fig 3 (a) Iron pipe cast in centrifugal mold (b) Flywheel cast in semicentrifugal mold

stances the crucible or the charge is heated by electric induction rather than by fuel Metal pot furnaces often used with die casting machines consist of an iron or steel pot heated by gas or oil

In reverberatory furnaces (such as used for melting aluminum and copper alloys air furnaces for melting white cast iron and the open hearth furnace for melting steel) the products of combustion of gas oil or powdered coal pass across the charge and thus are in direct contact with the molten metal increasing the tendency toward drossing and gas absorption The cupola furnace is most widely used for melting cast iron because of economic considerations Here the charge is in contact with the fuel (coke limestone and flux) and with the products of combustion Control of the melt is not as good as in some of the other furnaces

Electrically heated furnaces are of either the arc type (direct or indirect) or induction type The arc furnace obtains the heat from an electric arc drawn between two electrodes above the surface of the charge (indirect arc) or from the arc between electrodes and the charge (direct arc) Refining as well as melting can be accomplished in these furnaces

The electric induction furnaces induce an electric current in the charge by passing alternating current (high or low frequency depending on furnace design) through a coil that surrounds the chamber containing the charge As no combustion prod cts are

furnaces

Pouring The type of pouring equipment (such as ladles pouring basins or cups) pouring temperature and pouring techniques are major factors in preventing slag or dross from entering the mold cavity in minimizing gas and air entrapment and in minimizing turbulence or splashing The pouring temperature also affects the gas content of the liquid metal as well as its fluidity and the grain size of the resulting microstructure

Gating The gating system refers to the channels through which the molten metal flows to reach the mold cavity (Fig 4) From the pouring basin on top of the mold the metal flows down the sprue or downgate across the mold through the runners or crossgates and enters the cavity through the gates or ingates The design of the gating system constitutes the most difficult job for the foundryman as it has a major influence on the attainment of a sound casting The functions of the ideal gating system are to fill the mold minimize turbulence establish proper temperature gradient to minimize shrinkage cavities establish skimming action on dross and regulate the rate of entry of metal into the mold

Risering A riser is a reservoir of molten metal so located as to feed metal to the mold cavity to compensate for shrinkage Gating and risering are closely interdependent and should be considered

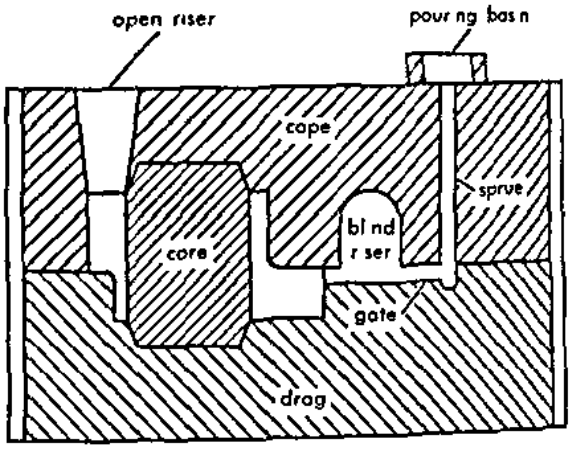


Fig 4 Section through a sand mold showing gating system and risers

simultaneously To obtain a sound casting free of shrinkage cavities it is necessary to produce directional solidification that is the solidification should proceed toward the location of sources of liquid metal which can then compensate for shrinkage This can be obtained by proper design and location of risers use of riser insulation or exothermic compounds use of chills use of padding (taper wall of casting with thickest section at riser) and proper casting design

Design consideration The size and shape of a casting have considerable influence on the cooling rate (and resulting microstructure) the attainment of directional solidification the occurrence of hot tears and the ability of the gating system to fill the mold completely Before a design is finalized consultation with the foundryman is important Some design principles that help minimize casting difficulties are maintenance of uniform section thickness if possible avoidance of abrupt ne s at ad

design *See* METAL FORMING [RLF]

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Castor bean

This plant *Ricinus communis* a member of the spurge family (Euphorbiaceae) is a coarse erect annual herb in temperate regions and a treelike perennial up to 40 ft tall in warmer climates When ripe the prickly seed pods separate into 3 parts each containing a seed the castor bean These seeds contain a thick colorless or greenish nondrying oil After this oil is pressed out of the seeds boiled with water and filtered to remove mucilage and



Castor bean plant *Ricinus communis* 3–40 ft high (L H Bailey *The Standard Cyclopedia of Horticulture* vol 3 Macmillan 1937)

proteins it is the commercial castor oil used medicinally in soap as a lubricant and as a leather preservative *See* GERANIALES [PDS]

Casuariiformes

An order of large flightless birds of Australia and New Guinea There are two families the cassowaries (Casuariidae) with six living species and the emus (Dromaeidae) with two species one of which became extinct in historic times All are somewhat ostrichlike in appearance the common emu (*Dromaeus novaehollandiae*) being the second largest of living birds Unlike the ostrich and the rhea with which they were formerly classified as ratites cassowaries and emus have the wings reduced to a mere rudiment Their legs are exceedingly powerful and are used in defense Cassowaries differ from emus in having featherless often wattled necks and bony casques on the head They are forest birds whereas emus inhabit grasslands

and cassowaries lay eggs with deeply colored shells Incubation is performed by the male *See* AVES [KCP]

Casuarinales

The most primitive order of the plant subclass Dicotyledoneae consisting of a single family There is only one genus (*Casuarina*) with 35 species of shrubs and trees chiefly Australian and a few Indo-Malayan species The long wiry jointed often drooping green twigs somewhat resemble the shoots of *Equisetum* (horsetails) The tiny scale leaves are borne in whorls at the nodes The flowers are unisexual and the fruit is a cone containing numerous winged seeds

The wood is very hard Because it is thought to resemble that of the oak the trees are called she oak and swamp oak Other common names are iron wood beefwood and horsetail trees Several species are valuable for timber and some are cultivated in subtropical sections of the United States for ornamental uses and as windbreaks The beefwood (*C equisetifolia*) has become widely naturalized in Florida where it is often erroneously called Australian pine *See* DICOTYLEDONEAE EMBRYOPHYTA PLANT KINGDOM [PDS]

Cat

Any member of the family Felidae order Carnivora Cats are highly carnivorous animals exhibiting the specialized carnassial teeth of this order to a marked degree the other jaw teeth are reduced both in size and in number Most cats have short broad heads and long tails although the genus *Lynx* is short tailed and an external tail is lacking in the Manx cat The family is world wide in distribution and native species occur on all continents except Australia

The house cat *Felis catus* exists in a wide variety of strains Apparently cats were first domesticated in Egypt around 1300 B C possibly earlier



Long haired domestic cat

House cats have been developed into a wide variety of short haired and long haired breeds *See* BOB CAT CARNIVORA COUGAR JAGUAR LEOPARD LION LYNX OCELOT TIGER [TDR]

Cat scratch disease

A benign disease affecting man and thought to be of viral origin The disease is a nonbacterial regional lymphadenitis which may proceed to sterile suppuration or subside spontaneously Sporadic cases occur more often in children occasionally small household outbreaks arise when cats scratch or bite the victim Suspected cats seem healthy and transmit the disease directly or indirectly Over 800 cases have been reported since 1950

The causative organism has not been isolated and the hypothesis that it is a member of the psittacosis lymphogranuloma venereum group requires confirmation An antigen must be obtained from pus in diseased lymph nodes and injected intradermally a positive reaction indicates past or present infection and differentiates this from other lymph node diseases *See* LYMPHOGRANULOMA PSITTACOSIS GROUP

A few days after a cat scratch a persistent scabbed ulcer or papule appears as the primary skin lesion About 1 3 weeks later the regional epitrochlear axillary or inguinal lymph nodes on one or both sides become enlarged Fever malaise and symptoms of infection usually develop The disease may last 2 weeks or 2 years The ocular form consists of conjunctivitis with enlargement of periauricular lymph nodes which occur around the external ear Meningoencephalitis which is an inflammation of the brain and the membranes covering it may complicate the disease Histologically the lymph nodes show an increase in the growth of the reticuloendothelial tissue These later become granulomas with necrotic centers

There is no conclusive proof that broad spectrum antibiotics are effective in treatment *See* ANTIBIOTIC

[KFME]

Catalysis

The phenomenon in which a relatively small amount of a foreign substance called a catalyst augments the rate of a chemical reaction without itself being consumed A large number of chemicals are produced by catalytic processes for example ammonia sulfuric acid and methanol Catalytic cracking is an important part of the petroleum refining process

The catalyst enters into reaction but is regenerated at the end of each reaction cycle Thus one unit of catalyst results in the conversion of many units of reactants For example consider a slow chemical reaction

$$A \rightarrow C$$

The addition of a catalyst X provides a pathway for a much more rapid reaction

$$\begin{aligned} A + X &\rightarrow B \\ B &\rightarrow C + X \end{aligned} \qquad (1)$$

X may now reenter into reaction and thus cause reaction of a large number of molecules of A

In many instances small quantities of a foreign substance decrease rates of reaction Such substances formerly called negative catalysts, are now known to be consumed in the process *See* ANTIOXIDANT, INHIBITOR Accordingly such material are not true catalysts and the term catalysis is reserved conventionally for increases in rate

Catalysts in living systems are called enzymes They are so important and the applicable techniques and phenomena so specialized that they are treated in a separate article (*see* ENZYME)

Catalysts are used in two somewhat different ways but the theories in the two cases are identical First they may merely increase a rate already detectable without the catalyst For example ethyl acetate hydrolyzes slowly in water at room temperatures

$$CH_3COOC_2H_5 + H_2O \rightarrow CH_3COOH + C_2H_5OH \qquad (2)$$

The addition of a strong acid increases the rate of hydrolysis in proportion to the concentration of the acid Similarly copper ion increases the rate of decomposition of aqueous hydrogen peroxide

$$H_2O_2 \rightarrow H_2O + \tfrac{1}{2}O_2 \qquad (3)$$

and platinum or vanadium pentoxide at 400°C accelerates the vapor phase oxidation of sulfur dioxide to sulfur trioxide

$$SO_2 + \tfrac{1}{2}O_2 \rightarrow SO_3 \qquad (4)$$

Secondly reactants may enter into several reactions (only one or none of which occurs at detectable rates without a catalyst) A catalyst may permit the realization of any one of these reactions by changing its rate but not the rates of the others The reactions of gaseous carbon monoxide and hydrogen on solid catalysts (see table) exemplify this

Reactions of $CO + H_2$

Catalyst	Conditions	Products
Nickel	100°C 1 atm	$CH_4 + H_2O$
Cobalt + ThO_2	190°C 1 20 atm	Mainly CH_4, C_3H_6, C_4H_8, and other alkanes and H_2O
Iron + alkali	315°C 15 atm	As with cobalt and ThO_2 plus olefins, alcohols, and acids
Ruthenium	200°C 200 atm	High molecular weight hydrocarbons waxes and H_2O
Thoria ThO_2	400°C 200 atm	Branched-chain paraffins and H_2O
Zinc chromite $Zn(CrO_2)_2$	400°C 500 atm	Methanol (CH_3OH) and H_2O

The degree to which one of several possible reactions is favored is called selectivity This is a matter of great practical importance since it determines the yield of the desired product in a catalytic reaction

If a catalyst increases the rate of a forward reaction it must also increase that of the reverse reaction In Eq (2) a small amount of acid cannot change the position of equilibrium in the reaction If hydrogen ion increases the rate of the forward reaction it must also increase that of the reverse reaction to the same degree

If the catalyst is in the same phase as the reactants the process is homogeneous catalysis if in a different phase it is heterogeneous catalysis A homogeneous catalyst is molecularly dispersed (dissolved) in the reactants which are most commonly in the liquid state The hydrolysis of ethyl acetate and the decomposition of hydrogen peroxide in Eqs (2) and (3) are examples A heterogeneous catalyst is usually a solid and the reactants are usually in the vapor or liquid phases Here reaction occurs on the surface of a solid The oxidation of sulfur dioxide Eq (4) and the reactions in the table are examples.

Homogeneous catalysis The formation of the [illegible] (1) [illegible] which makes the overall process catalytic In general then homogeneous catalysis proceeds by the same kinds of steps as noncatalytic processes and the chemistry of a homogeneous catalytic process usually has no unique chemical features due to the catalysis

Catalysis by acids or bases represents one of the most widespread types of homogeneous catalysis It often happens that RH_2^+ or R reacts faster than RH For example the enolization of acetone

$$CH_3COCH_3 \rightarrow CH_3COH{=}CH_2$$

is *catalyzed by acids*

$$(CH_3)_2C{=}O + HB \rightarrow (CH_3)_2C{=}OH^+ + B$$
$$(CH_3)_2C{=}OH^+ + B \rightarrow CH_3COH{=}CH_2 + HB$$

A base is necessary to remove the proton in the second step and in some cases it appears that an acid adds *a proton to the oxygen atom* while a base simultaneously removes a proton from one of the methyl groups

Bases catalyze the condensation of acetone to diacetone alcohol

$$CH_3COCH_3 + B^- \rightarrow CH_3COCH_2^- + HB$$

$$CH_3COCH_2^- + (CH_3)_2C{=}O \rightarrow CH_3\overset{O}{\overset{\|}{C}}CH_2\overset{CH_3}{\overset{|}{C}}O^-$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad CH$$

$$CH_3\overset{O}{\overset{\|}{C}}CH_2\overset{CH_3}{\overset{|}{C}}O + HB \rightarrow CH_3\overset{O}{\overset{\|}{C}}CH_2\overset{CH_3}{\overset{|}{C}}OH + B^-$$
$$\qquad\qquad\quad CH_3 \qquad\qquad\qquad\qquad\qquad\qquad\quad CH_3$$

Ions of transition elements with variable valence often act as catalysts in oxidation reduction reactions Reaction between ceric ion, Ce^{4} and thallous ion Tl to form cerous ion Ce^{++} and thallic ion Tl^{++} is slow because Tl must lose two electrons whereas each atom of Ce^{4} can take up but one Manganous ion Mn^{++} catalyzes the reaction thus

$$Ce^{4+} + Mn^{++} \rightarrow Ce^{+++} + Mn^{+++}$$
$$Mn^{+++} + Ce^{4+} \rightarrow Ce^{+++} + Mn^{4+}$$
$$Mn^{4+} + Tl^{+} \rightarrow Mn^{++} + Tl^{+++}$$

The Oxo reaction which became technically important in the period following World War II provides an example of a much more specific type of catalysis It involves the use of cobalt octacarbonyl $Co_2(CO)_8$ as an added catalyst A rather complicated series of compounds of cobalt and carbon monoxide and in some cases hydrogen are involved as intermediates The basic Oxo reaction is hydroformylation

$$RCH{=}CH_2 + CO + H_2 \rightarrow RCH_2CH_2CHO$$

Cobalt octacarbonyl or similar catalysts can also be used to add hydrogen to terminal olefins or to hydrogenate aldehydes to alcohols The catalyst has the specific ability to transfer carbon monoxide and to convert hydrogen molecules into usable hydrogen atoms

Heterogeneous catalysis Most commonly the individual steps of heterogeneous catalytic processes involve the following

1 Diffusion of reactants to surface
2 Adsorption of reactants on surface
3 Reaction of absorbed reactant to form adsorbed product
4 Desorption of product
5 Diffusion of product into main stream of liquid or vapor

Steps 1 and 5 may present considerable complications particularly with porous catalysts Unlike the situation in homogeneous catalysis steps 2 3 and 4 are not a part of the ordinary chemistry of the reactants and products In particular the adsorption process involves the properties of surfaces and theories of the solid state Also experimental procedures in heterogeneous catalysis involve rather specialized techniques For these reasons heterogeneous catalysis has become a particular specialty

Heterogeneous catalytic reactions are effected in one of three ways (1) in batch processes (see illustration *a*) (2) in continuous fixed bed processes (see *b*) and (3) in continuous fluidized reactor processes (see *c*) In the batch reactor shown for hydrogenation of for example an olefin

$$>C{=}C< + H_2 \rightarrow >CH{-}CH<$$

the catalyst is kept suspended in the reactant by shaking or stirring In the fluidized reactor the original level of the catalyst is at *A* As the velocity of the reactant stream is increased the catalyst bed expands upwards to level *B* and at a critical velocity it enters into violent turbulence The fluidized reactor is particularly useful for removing or

supplying heat necessary to maintain a fixed catalyst temperature However it can be employed only on a rather large scale since good fluidization requires a reactor larger than about 1 5 in in diameter (*see* FLUIDIZATION OF SOLIDS)

Heterogeneous catalytic processes are of great importance in industry In 1958 about 10 000 000 metric tons of ammonia was made throughout the world by direct combination of the elements

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad (5)$$

using iron catalysts at about 400°C and several hundred atmospheres pressure The production of sulfuric acid and methanol are other very large tonnage processes Heterogeneous catalytic processes are quite important in the refining of petroleum About 70% of all crude oil passes through such processes

Since the rate of a catalytic reaction is proportional to the effective area of the catalyst most catalysts are prepared by methods which develop large surfaces of the order of 100 square meters per gram A few exceptions exist The iron ammonia synthesis catalyst is a powder of but a few square meters per gram and the catalyst employed for converting ammonia to nitric acid via oxides of nitrogen which are then absorbed in water

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$4NO + 3O_2 + 2H_2O \rightarrow 4HNO_3$$

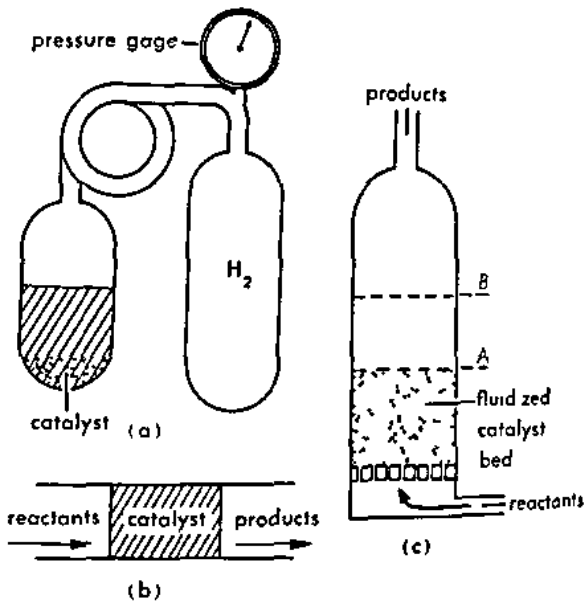
is platinum gauze maintained at about 750°C

Catalytic materials may be employed as fine powders for example platinum prepared by reduction of the oxide or they may be impregnated upon high area supports for example platinum on alumina Materials of the second type are called supported catalysts

In addition rather complex mixtures are often employed as catalysts In the ammonia synthesis reaction the catalyst is iron to which several per cent of K_2O and Al_2O_3 has been added Small quantities of materials which improve catalytic performance are called promoters

In general catalysts gradually lose catalytic activity Traces of impurity in the feed called poisons, may be strongly adsorbed and exclude the reactants from the surface Sulfur compounds arsenic compounds cyanides carbon monoxide, and water are common poisons Catalysts vary in sensitivity to poisons One effect of the promoter in the ammonia synthesis catalyst is to reduce sensitivity to poisons

In addition and particularly in reactions of hydrocarbons at higher temperatures nonvolatile by products may accumulate on the surface When catalyst stability permits the catalyst may be regenerated by burning off the by products



Catalytic reactors (a) Batch (b) Continuous fixed bed (c) Continuous fluidized reactor

In the catalytic cracking of hydrocarbons coke deposition very largely reduces catalytic activity within a few minutes Only the ready regenerability of the catalyst (either a synthetic or a natural silica alumina) makes it economically feasible to use the process for over 4,000 000 barrels of petroleum feed per day in the United States alone In a fluidized reactor (see *c*), regeneration is effected by a reactor geometry which causes the fluidized catalyst level *B* to pass out the top opening Catalyst is continually removed burned off and returned to the reactor In such a process the catalyst life is months

A catalytic cracking reaction is shown at bottom of page

Higher molecular weight kerosine or gas oil is cracked into more valuable material in the gasoline range The catalyst has strong acidic properties In general heterogeneous catalysts of an acidic nature are suitable for most of the reactions catalyzed homogeneously by acids

Hydrogenation catalysts constitute probably the most important class Hydrogenation converts carbon monoxide to a large number of possible products (see table), ketones to alcohols, olefins to alkanes, benzene to cyclohexane, nitro compounds to amines Nickel, platinum and palladium are typical catalysts of this type but certain oxides also have hydrogenating activity—chromium oxide zinc oxide and zinc chromite

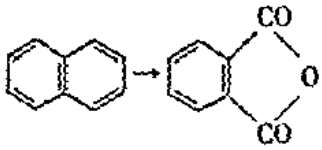
Oxidation catalysts are another category Platinum and oxides of transition metals of variable valence such as vanadium oxides may be used in the

$$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3 \xrightarrow{450°C}$$
$$CH_3C(CH_3)=CH_2 + CH_3CH(CH_3)CH_2CH_2CH_3 + CH_3C(CH_3)=CHCH(CH_3)CH_3$$

contact process for sulfuric acid, Eq (4), followed by

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Vanadium oxides are also employed for such oxidations as that of naphthalene to phthalic anhydride



Another class consists of dehydration catalysts of which alumina is typical Examples are

$$CH_3CH_2OH \xrightarrow[300°C\ 1\ atm]{Al_2O_3} CH_2{=}CH_2 + H_2O$$

$$2CH_3CH_2OH \xrightarrow[300°C\ 100\ atm]{Al_2O_3} (CH_3CH_2)_2O + H_2O$$

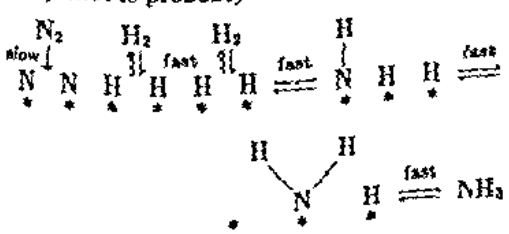
Mechanism. The detailed mechanisms of homogeneous catalytic processes are as well understood as those of homogeneous reactions in general The detailed mechanisms of heterogeneous catalysis are less well understood for they involve all of the complications of homogeneous reactions plus the problem of the surface of a different phase

Most commonly, it appears that reactants are adsorbed on the surface with dissociative cleavage of one or more bonds For example the initial product from the passage of a mixture of deuterium and cyclopentane over chromia catalysts at 200°C is monodeuterocyclopentane It is hard to avoid the conclusion that the process resembles

$$D_2(g) + C_5H_{10}(g) \rightarrow \underset{*}{D}\ \underset{*}{D}\ \underset{*}{C_5H_9}\ \underset{*}{H} \rightarrow HD(g) + C_5H_9D(g)$$

where g represents the gaseous state and the * represents adsorption sites Adsorbed hydrogen atoms and adsorbed cyclopentyl radicals represent the intermediates

The ammonia synthesis reaction Eq (5) has been extensively studied and represents one of the best understood cases At operating temperatures ammonia and hydrogen rapidly adsorb and desorb dissociatively The slow step appears to be the dissociative adsorption of nitrogen Adsorbed nitrogen atoms once formed rapidly hydrogenate to adsorbed ammonia and then desorb as ammonia gas The sequence is probably



Catalytically active adsorption is called either chemisorption or activated adsorption although the two terms are not exactly synonymous Much has been learned about the interrelations between chemisorption and catalysis but the field is far from resolved *See* ADSORPTION COKING (PETROLEUM REFINING), CRACKING, KINETICS (CHEMICAL)

[R L BU]

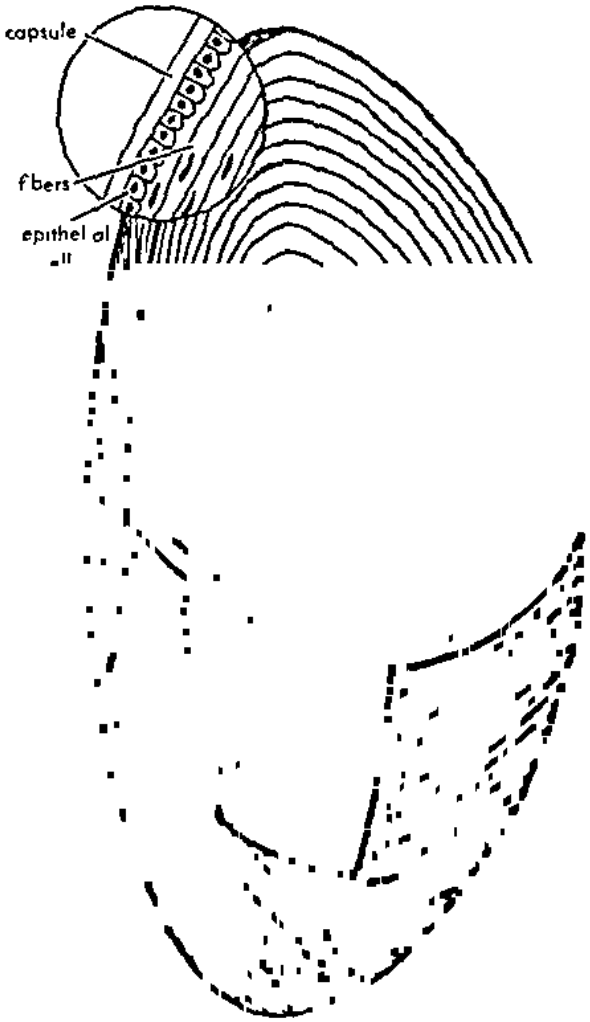
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Cataract

Any opacity in the crystalline lens of the eye It is the single most common cause of blindness and is responsible for 25–30% of all cases of blindness in the United States With certain exceptions it most frequently involves both eyes although rarely to the same degree at the same time

Lens structure and cataract formation. The occurrence of cataract is related to the unique structure of the lens (see illustration) The lens is covered by a thin delicate capsule beneath which is a layer of epithelial cells The remaining substance of the lens is composed of many concentric layers of threadlike fibers which may be likened to elongated flexible crystals These fibers have a flattened hexagonal cross section and thus fit neatly together with little intervening substance between individual fibers The optical transparency of the lens is dependent on this regularity of structure, any alteration of which results in a visible opaque zone (cataract) of varying size Although the lens contains no blood vessels it is not an inert object but rather a living organ As such it participates in the metabolic processes of the body although at a slower rate than most other organs Its metabolic activity is located chiefly in the layer of epithelial cells Damage to these cells from any cause leads to denaturation and breakdown of the proteins constituting the lens fibers This is followed by inflow of fluid and swelling of the lens with separation distortion and ultimate fragmentation of the lens fibers Once the process has begun the cataract usually grows steadily over a period of weeks months, or years and results in a shrunken, wrinkled opaque yellow brown lens which is totally useless for vision

Types of cataract *Two broad classes of cataract* are recognized Cataract developing in a mature previously normal lens is termed degenerative, if present at birth or apparently caused by abnormalities in the growth and development of the lens it is said to be developmental Several subtypes in each class are also recognized The vast majority of all cataracts are of the senile type a form of degenerative cataract This type is rarely seen before the age of 40 and its frequency increases with advancing age Its cause is unknown It has a definite hereditary tendency, and its close association with old age indicates that the subtle chemical changes which accompany the aging process play an important role in its development The rate of growth of a senile cataract is unpredictable and quite variable It may remain stationary at any stage, it may progress slowly over a period of several years or it may grow rapidly, involving the entire lens in a space of months



Crystalline lens of human eye

Other forms of degenerative cataract may follow mechanical injury, infection radiation, or ingestion of toxic substances and frequently accompany other diseases of the eye such as glaucoma Ionizing radiation in any form can cause cataract if given in sufficient dosage For x rays and gamma rays, 1500–2500 roentgen units are usually required, but neutrons are effective at considerably lower levels Ultraviolet light can cause cataract but is not of practical importance because the effective wavelengths are almost completely absorbed by the cornea before reaching the lens Infrared radiation is thought to contribute to the development of cataracts occurring in industrial workers exposed for long periods to the high temperatures encountered in the steel glass and ceramics industries Chemicals which seem capable of inducing cataract include naphthalene dinitrophenol and closely related substances Degenerative cataract is also seen following electric shock and in association with diseases characterized by abnormal or defective body metabolism such as diabetes and severe vitamin deficiencies

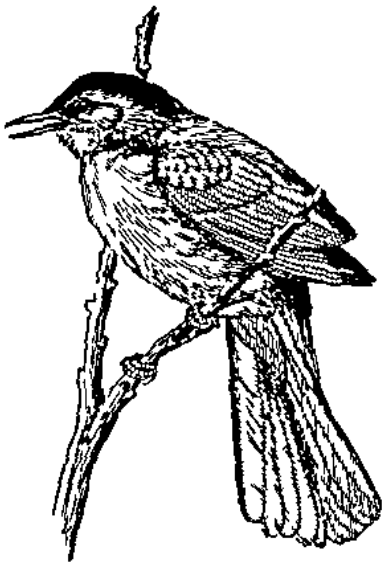
Developmental cataracts are much less common than the degenerative form They are termed congenital if present at birth and juvenile if they appear in childhood Very little is known concerning the cause of congenital cataract Some cases seem to be correlated with illness (usually German measles) on the part of the mother at a time during the pregnancy when the structures of the eye were being formed Juvenile cataract may be hereditary, may be associated with rickets or may occur without known cause *See* EYE, EYE DISORDERS

[W R AD]

Catbird

A member of the perching bird family, Mimidae which nests throughout southern Canada and in most of the United States The catbird, *Dumetella carolinensis*, is dark gray with a black cap and has chestnut red coloring under its tail coverts Like the related brown thrasher and mockingbird it is a bird of the fence row and underbrush and is a skilled songbird and excellent mimic It is easily recognized, however, because its song is frequently interspersed with catlike meowing sounds *See* MOCKINGBIRD, PASSERIFORMES, THRASHER

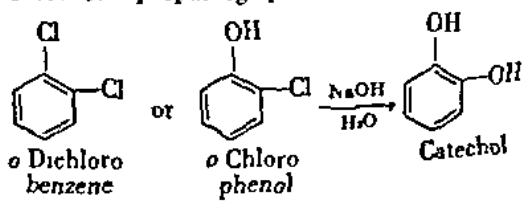
[J D B]



The catbird, *Dumetella carolinensis*, length to 9½ in. (From E L Palmer, *Fieldbook of Natural History* McGraw Hill, 1949)

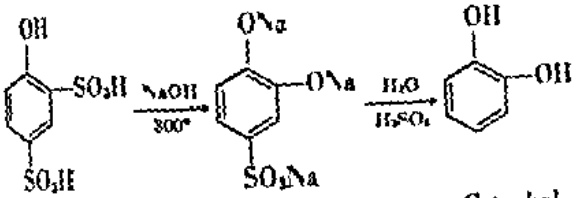
Catechol

A dihydric phenol in which the hydroxyl groups are ortho to each other on the ring of carbon atoms It is also called pyrocatechol and pyrocatechuic acid and it is produced by treating *o* dichlorobenzene or *o* chlorophenol with caustic soda as in the Dow process for preparing phenol Catechol is also



o Dichloro benzene — *o* Chloro phenol — Catechol

produced by treatment of phenol 2 4-disulfonic acid with caustic soda followed by hydrolysis Catechol is d colored and its solutions become brown very



rapidly when exposed to air and light It is used to protect substances against deterioration by atmospheric oxygen as an intermediate in the preparation of dyes and pharmaceuticals and as a photographic developer *See* PHENOL [A B C]

Catenary

The curve formed by an ideal heavy uniform string hanging freely from two points of support The lowest point A (Fig 1) is the vertex The portion AP is in equilibrium under the horizontal tension H at A the tension F directed along the tangent at P and the weight W of AP If the weight of the string is w per unit length and s is the arc AP $W = ws$ and from the force triangle $\tan \psi = ws/H = s/c$, where $c = H/w$ is called the parameter of the catenary Thus the catenary has the differential equation

$$dy/dx = s/c \qquad (1)$$

The horizontal line at a distance c below the vertex A is the directrix of the catenary With the x axis as directrix and the y axis through the vertex the integration of Eq (1) yields

$$y = c \cosh \frac{x}{c} \qquad s = c \sinh \frac{s}{c}$$

for the ordinate and arc of the catenary All catenaries are geometrically similar to the hyperbolic cosine curve $y = \cosh x$ These equations show that $y^2 = s^2 + c^2$ and from Eq (1)

$$s = c \tan \psi \qquad y = c \sec \psi \qquad (2)$$

The radius of curvature of the catenary at P is the length of the normal cut off by the x axis

$$\rho = ds\, d\psi = c \sec^2 \psi = y \sec \psi = PY$$

The tension at P

$$F = H \sec \psi = wc \sec \psi = wy$$

varies as the height above the directrix

The tangent PT is tangent to a circle of radius c about Q the foot of the ordinate and since $\tan \psi = s/c$ $PP = s =$ arc AP Thus arc AP unwraps on the segment PP The locus of P' is a curve whose tangent $P'Q$ has the constant length c namely a tractrix hence the tractrix is an involute of the catenary *See* TRACTRIX

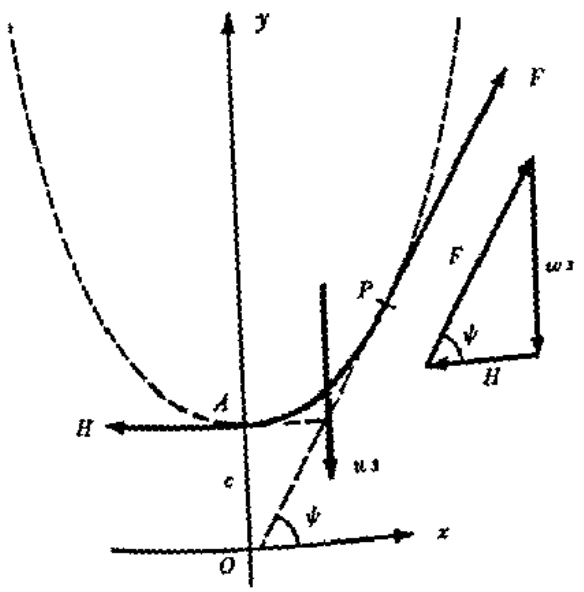


Fig 1 Catenary force triangle

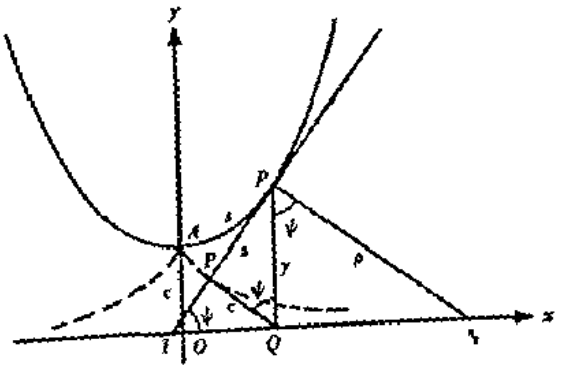


Fig 2 Catenary

The surface generated by revolving a catenary about its directrix is a minimal surface the catenoid The catenary is an extremal for the problem of finding a curve joining two given points so that the surface generated by revolving it about a given line has minimum area *See* HYPERBOLIC FUNCTION [L BR]

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Caterpillar

The larval form of butterflies moths and skippers Caterpillars are wormlike animals frequently heavy bodied and conspicuously marked in segments They have chewing mouthparts and usually feed upon plants although there are some such as the clothes moth that feed on dead organic material and a few that are predaceous on other insects Most caterpillars are smooth skinned but some are adorned with bristles or hairs notable examples being the wooly worms and wooly bears The tussock moth acquires its name from the tufts of hairs on the larvae

Typically caterpillars have 3 pairs of thoracic or true legs and 2-5 pairs of abdominal legs known

as prolegs Prolegs are usually equipped with claws which help the animals in walking and climbing

A few larval moths such as the bagworms are maggotlike and the larvae of some sawflies are similar to typical caterpillars Almost all caterpillars have silk glands with which they spin cocoons or make shelters for themselves including large community nests such as those of the webworms and tent caterpillars

Although most moths and butterflies spend the winter as pupae the caterpillar is the overwintering stage for some species

Caterpillars have an almost limitless range of variation in color pattern and ornamentation and bear no similarity to the adult

Most caterpillars are harmless to humans although a few of the wooly worms have stinging hairs a dermatitis caused by the hairs of the brown tailed moth caterpillar is common

Although caterpillars annually cause damage estimated at millions of dollars they are the principal food for many species of birds especially during the nesting season *See* BUTTERFLY LEPIDOPTERA MOTH [J D B]

Catfish

Any of several hundred fishes of the suborder Siluroidea order Cypriniformes The catfish is characterized by the presence of sensory barbels around the mouth and the absence of scales and is either naked or covered with bony plates The mouth is nonprotractile and the marginal bones bear teeth which are usually small Catfish are widely distributed occurring in Europe Asia Africa and North and South America They reach their greatest abundance and diversity in the tropics especially in fresh water being particularly abundant and diversified in the basin of the Amazon River Most catfish occur in fresh water but there are numerous marine species especially in the tropics



An American catfish the bullhead *Ameiurus nebulosus* length to 20 in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

The 30 or more North American species are characterized by a complete absence of scales an adipose fin and a stout spine on the anterior margin of the dorsal and pectoral fins Originally they were nearly all limited to the Atlantic and Gulf Coast drainage systems but now the larger species have been widely introduced in the West

American catfishes large enough to be used for food include (1) the bullheads *Ameiurus* sp (called horned pouts in New England) which are among the most common and easily caught of all food fishes (2) the channel catfish *Ictalurus lacustris* usually considered to be the most delicate of the blue cat channel catfish but much larger growing to 150 lb or more and usually limited to large rivers and (4) the flathead catfish *Pilodictis olivaris* sometimes growing to 150 lb although usually it is smaller and common in larger streams

The stone cat *Noturus flavus* and the several madtoms *Schilbeodes* sp are small fishes usually less than 10 in long The madtoms have venom glands at the bases of the pectoral fin spines and if carelessly handled they can inflict a sting comparable to that of a honeybee

The European wels *Silurus glanis* which reaches a length of 10 ft is one of the largest of all freshwater fishes

All the catfishes are omnivorous and usually nocturnal Food is located by the olfactory organs on the barbels and skin Most of them prefer running water but several live in lakes and streams *See* CYPRINIFORMES [J D B]

Cathartics

Drugs which cause defecation A wide variety of such agents exist, both as recognized medicinals and in the form of home remedies of obscure and doubtful origin In general a cathartic works in one of three ways by irritation of the intestine by increasing fecal bulk or by lubrication and softening the stool

Cascara rhubarb castor oil and phenolphthalein are examples of irritants that vary in the severity of their action

The salt or saline, cathartics increase the bulk in the intestine thereby promoting peristalsis Magnesium sulfate (Epsom salts) salts of tartrate (Rochelle salts) and magnesia magma (milk of magnesia) release heavy ions into the intestine which cannot be absorbed through the wall Osmosis then draws tissue water into the intestine so that a large watery stool is formed

Liquid petrolatum or mineral oil and certain vegetable oils may also increase bulk but they act by softening the feces and as lubricants thus permitting easier passage of waste

Three general classes of cathartics may be described based on effects the milder laxatives the intermediate purges and the violent drastics In creasing amounts of the same preparation will in many cases produce an increasingly severe response [E G S T]

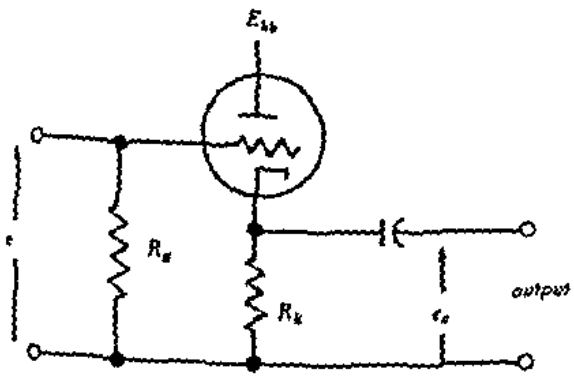
Cathode follower

A vacuum tube amplifier possessing a current gain and a power gain that may vary from one to several hundred but a voltage gain that is less than unity This amplifier stage possesses several outstanding features that offset the fractional voltage gain they

are a high input impedance low signal distortion adaptabil ty to broad band amplifier design and low output impedance The cathode follower is also known as a grounded plate amplifier

A typical cathode follower circuit is shown in the illu tration The input signal e_s is applied between the common terminal which is normally grounded and the grid The anode is connected directly to the power supply and is therefore at ground poten tial for alternating current signals Because the large filter capacitors of the power supply possess a very small ac impedance at audio frequencies The signal is developed across the cathode resistor R_k *See* VOLTAGE AMPLIFIER

The cathode follower is often used as an imped ance matching device Because of its high input im pedance and low output impedance it can be used



Typical RC-coupled cathode follower

to couple a high output impedance device to a low input impedance device This enables better trans fer of power *See* IMPEDANCE MATCHING

The signal voltage drop across the cathode load resistor also appears as input grid to cathode volt age Thus the cathode follower possesses 100% negative feedback (*see* FEEDBACK CIRCUIT) This results in greatly reduced distortion *See* DISTOR TION (ELECTRONIC CIRCUITS)

The low input capacitance of a cathode follower stage makes it desirable for video or broadband op eration The input capacitance is essentially the gr d to cathode capacitance

The voltage gain of a cathode follower is always less than but is normally close to 1 Typical values are about 0 90–0 95 The output voltage is always in phase with the input [R L H]

Cathode rays

The name given to the electrons originating at the cathodes of gaseous discharge devices The term has now been extended to include low pressure devices such as cathode-ray tubes Furthermore cathode rays are now used to designate electron beams originating from thermionic cathodes whereas the term was formerly applied only to cold cathode devices *See* CATHODE RAY TUBE

The basis for the nomenclature is purely histori cal The first outward evidence was fluorescence from the glass walls of cold cathode di tubes This fluorescence appeared as the pressure was reduced to the region where the mean free path became greater than the tube dimensions At these pressures the gas in the tube no longer emitted an appreciable amount of light It was ascertained that the wall fluorescence had its origin in rays of particles coming from the cathode Furthermore it was demonstrated that these par ticles traveled in approximately straight lines If an object was interposed between the cathode and the wall the fluorescence disappeared in the opti cally shadowed region of the wall In 1897 J J Thomson was able to show using electric and mag netic fields that the particles were negatively charged In his experimental arrangement he eliminated all but a very narrow beam of these rays By producing an electrostatic deflection of the beam and then counteracting this with a mag netic deflection he was able to determine the charge mass ratio e/m This was found to be the same as that of the electron and resulted in the identification of these particles *See* ELECTRON

The electrons produced at the cathode were the result of positive ion bombardment Thus the pres ence of gas in the tube was necessary for the pro duction of the cathode rays The descendants of this first type of cathode ray tube include fluores cent devices such as oscilloscopes and television tubes The major changes have been the introduc tion of the thermionic cathode and the addition of a very efficient fluorescent screen Because gas is no longer necessary for electron production the tubes are evacuated and the scattering of the electron beam is reduced An even more advanced applica tion of a cathode-ray device is the electron micro scope Here use is made of diverging rays of elec trons to obtain tremendous magnification The science of electron and ion optics has been ad vanced to a high degree so that such devices have become useful reliable and efficient *See* ELEC TRON LENS OSCILLOSCOPE CATHODE RAY

It is interesting and appropriate to note that Thomson s measurements also form the basis for modern β ray spectroscopy In this ca e e/m is known so that either an electric or magnetic field may be used to determine the energy of the elec trons which emanate from various radioactive ma terials such as β rays *See* BETA RAYS

An additional application of a cathode ray de vice is an x ray tube Here a beam of electrons is accelerated in an evacuated tube and allowed to strike a target The major part of the electron en ergy is dissipated as heat in the target A small part of the energy, however, comes off as short wavelength electromagnetic radiation *See* ELEC TRICAL CONDUCTION IN GASES, ELECTRON EMISSION, PARTICLE ACCELERATOR X RAY(S) PHYSICAL NA TURE OF [C H MI]

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Cathode ray tube

An electron tul e in which a beam of electrons can be focused to a small area and varied in position and intensity on a surface In common usage the term cathode ray tube is usually reserved for de vices in which the surface referred to is cathodo luminescent that is luminescent under electron bombardment In these tubes the output informa tion is presented in the form of a pattern of light The character of this pattern is related to and con trolled by one or more electrical signals applied to the cathode-ray tube as input information

The most familiar form of the cathode-ray tube is the television picture tube found in home tele vision receivers Cathode-ray tubes are also used in large quantities in measuring instruments such as oscilloscopes which have become indispensable in laboratories devoted to experimental studies in the physical and biological sciences and in engineer ing The oscilloscope has also been adopted as a vital tool in the fields of automobile aircraft and television receiver maintenance and repair Large users of cathode ray tubes are the military services which employ these devices to display data to guide the employment of weapons systems These data may be direct signals from relatively simple radar and sonar receivers or they may be signals synthe sized by large computers which correlate evaluate and summarize the information introduced by large numbers of input sensors *See* OSCILLOSCOPE CATH ODE RAY STORAGE TUBE TELEVISION RECEIVER

The basic elements of a cathode ray tube are the envelope the electron gun and the phosphor screen

Envelope This serves as the vacuum enclosure the substrate for the phosphor screen and the sup port for the electron gun The envelope of a cath ode ray tube is typically funnel shaped its small opening is stopped by the stem This stem is es sentially a disk of glass through which the metallic leads which support and carry applied voltages to the several elements of the gun are sealed The e leads are generally arrayed on one or more circles concentric with the tube axis Usually the exhaust tubulation through which the envelope is evacu ated during processing joins the envelope at the center of the stem In most cases the stem leads are carried through and soldered to tubular pins in a plastic base cemented to the neck of the en velope in the immediate vicinity of the stem This base serves to protect the stem and the tipped off exhaust tubulation as well as to provide means of contact between the tube socket and the elements of the tube itself

The large end of the funnel is closed by a glass faceplate on the inside of which the phosphor screen is deposited In most cases the faceplate is spherically shaped to resist the forces of atmos pheric pressure Often however an optical or near optical flatness is desired for certain tube ap plications In these cases the faceplate must be substantially thicker

The envelopes of most types of cathode-ray tube are glass although metal ones are not uncommon The current tendency among designers of cathode-ray tubes is to specify all glass envelopes Glass envelopes can be made at least as cheaply as metal ones in large volume production Furthermore in sulation against the high voltages applied to ele ments of the tube may be more readily obtained with glass enclosures than with metal ones The metal type however tends to be lighter in weight

A number of typical cathode-ray tubes are shown in Fig 1 Cathode ray tubes are made in a wide variety of sizes Tubes having faceplate diameters

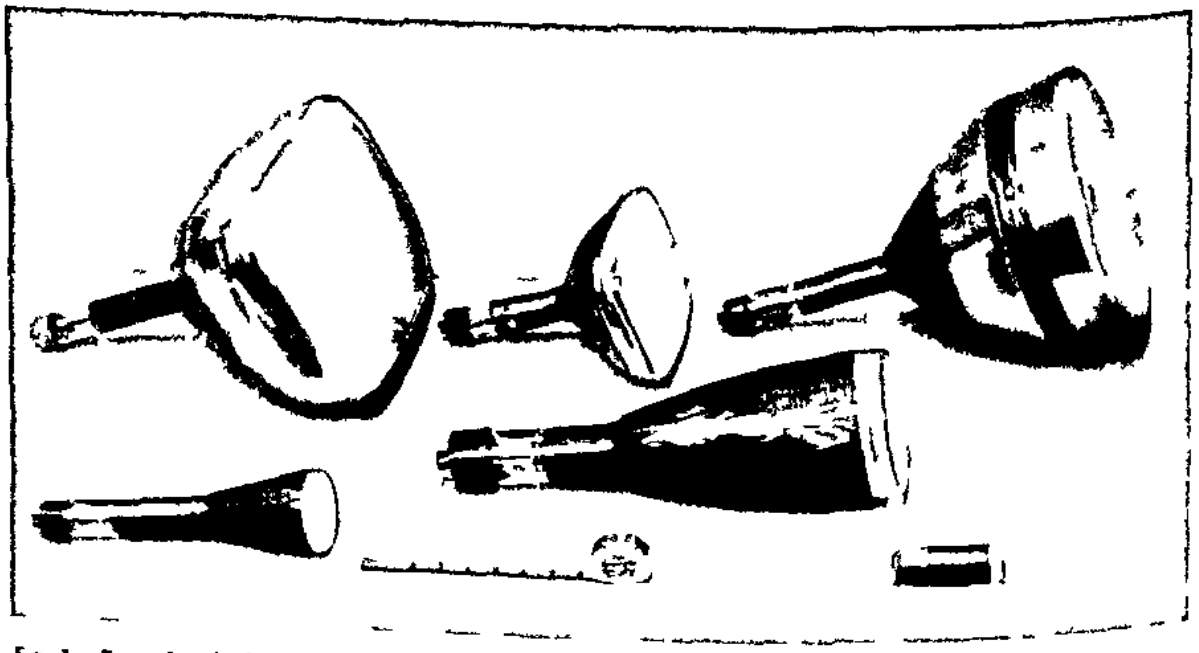


Fig 1 Typ cal cathode-ray tubes

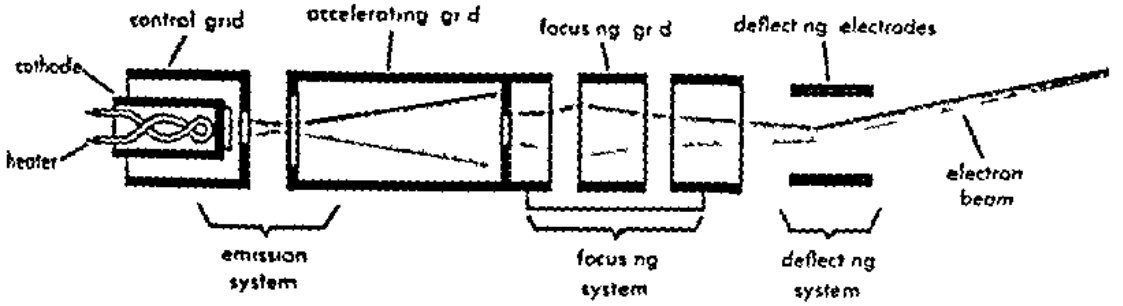


Fig 2 Simplified electron gun employing electrostatic focus and deflection

of from less than 1 to 22 in are produced Picture tubes having faceplates of rectangular outline are considered standard in the television industry These faceplates range in diagonal dimension from about 8 to 27 in Rectangular faceplate tubes are also fabricated in smaller sizes for use in instrumentation where space availability is restricted

Electron gun. This electrode structure produces controls focuses and deflects an electron beam In some cases one or more of the functions enumerated above are performed by components not included in the gun or even in the cathode ray tube itself These components are invariably electromagnetic field producing devices a common example is a magnetic solenoid used for beam focusing A typical electron gun used in a cathode ray tube for oscillographic applications (Fig 2) is functionally self contained because no external components are required to perform beam intensity control focusing or deflection

Emission system This part of an electron gun includes the thermionic cathode which is the source of electrons in the beam The emitting material is generally a barium calcium-strontium oxide coating deposited on the end of a deep drawn nickel cup with cylindrical walls The walls enclose a twisted tungsten wire coated with a refractory insulating material such as aluminum oxide The passage of current through this wire generates sufficient heat transmitted by conduction and radiation to the nickel cup to maintain the oxide coating at emitting temperatures of the order of 1050°K This heater cathode structure is supported coaxially within and insulated from a cylindrical cup having a greater diameter called the control grid The planar section of the control grid cup is spaced several thousandths of an inch from the cathode surface and has a circular aperture of diameter somewhat smaller than that of the cathode cylinder Spaced some 0 02–0 25 in from the control grid plane is a second apertured disk called the accelerating grid *See* ELECTRON EMISSION

The voltage applied to the accelerating grid sets up a field which penetrates the opening in the control grid and determines the magnitude of the space charge limited current drawn from the cathode As the control grid is made more negative in potential the penetration of the accelerating field and consequently the beam current are reduced

The electrostatic field in the emission system of a cathode ray tube electron gun is so shaped by the geometry of the several elements that electrons leaving the cathode perpendicularly enter trajectories which carry them across the axis of the system in the vicinity of the control grid accelerator grid space The location at which the electrons cross the axis is called the crossover point Were it not for space-charge effects nonhomogeneity of emission velocities nonperpendicularity of emission directions and certain imperfections in the shape of the field itself the crossover would be a point in fact as well as in name Because of these effects unavoidably encountered in practice the ideal crossover point is only approximated by the electronic equivalent of the optical disk of least confusion Even so the crossover represents the minimum beam cross section in the vicinity of the cathode surface Beyond this point beam electrons enter the field free drift space within the cylindrical electrode attached to the accelerating grid and travel along straight diverging trajectories toward the focusing system

Focusing system After traversing the drift space beam electrons enter an electrostatic field in which they experience forces which in combination redirect the electron trajectories toward the gun axis The electrode structure to which voltages are applied to produce this field is known as the focusing system or main electron lens The performance of such an electron lens can be described in terms familiar to the science of light optics For example the location of principal planes and focal points for a particular electrode configuration operated at a given set of voltage conditions can be deduced from the potential gradient along the lens axis Typical electrostatic lenses are shown in Fig 3 *See* ELECTRON LENS ELECTRON OPTICS

The voltages applied to the electron lens in a cathode-ray tube are adjusted to produce the smallest possible beam area at the phosphor screen It is generally agreed that this condition exists when the object plane of the main lens coincides with the axial location of the crossover previously discussed

Electron lenses are subject to aberrations very closely analogous to those encountered in glass lens technology Excluding those aberrations introduced inadvertently during fabrication the most troublesome from the point of view of the cathode-ray tube designer is spherical aberration This aberration is usually minimized by making lens elements large in diameter compared with the beam

or conversely by restricting the beam diameter by means of a stop or limiting aperture as has been done in the gun of Fig 2 It is obvious that the current available for excitation of the phosphor screen has been reduced by this approach

Deflecting system In the electron gun shown in Fig 2 the deflecting system consists of a single pair of parallel electrodes mounted symmetrically about the axis of the gun The electron beam entering and traversing the space between the electrodes does so at a constant axial velocity corresponding to the average potential of the electrodes This potential is usually adjusted to be

amplifier in which two components equal in voltage but opposite in polarity are generated These two components can be applied to the opposing deflecting electrodes without affecting the average potential in the space between them Under the influence of the applied deflection signals an electric field is set up between the electrodes This field imparts an acceleration to the electron beam which is perpendicular to the direction of constant beam velocity In the space between the electrodes therefore the beam travels in a parabolic path After leaving this transverse field the beam continues to the phosphor screen on a straight path tangent to the parabola The assumption is made that no postdeflection acceleration is present If the signals applied to the electrodes vary with time a straight line is traced out upon the phosphor screen In a practical tube a second pair of deflecting electrodes is mounted further along the gun axis at right angles to the first These electrodes provide a second independent axis of deflection orthogonal to the first

The deflection produced by a pair of parallel electrodes is given by

$$y = \frac{LbV_d}{2aV_a}$$

where y is the deflection observed at the phosphor screen in any linear units L is the distance from axial midpoint of electrodes to phosphor screen in the same linear units b is the deflecting electrode length in the same linear units a is the deflecting electrode spacing in the same linear units V_d is the potential difference between electrodes in volts, and V_a is the beam acceleration potential in volts *See* ELECTRON MOTION IN VACUUM

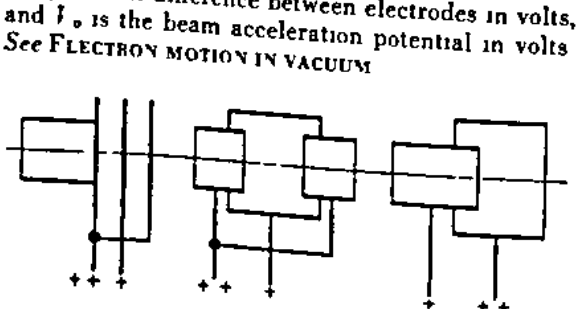


Fig 3 Typical mechanical arrangements of electrostatic focus lenses

The effectiveness of a pair of deflecting electrodes is often described in terms of its deflection factor, that is, the number of volts necessary to deflect the beam a unit distance (usually in inches) at the phosphor screen for a given accelerating potential (usually 1 kilovolt)

Plane parallel electrodes are rarely found in modern cathode ray tubes Over all improvements in performance are obtained by forming the electrodes so that spacing increases with distance in the direction of beam travel The theoretically ideal curved electrode structure is approximated in practice by electrodes consisting of two or three planar sections, each tilted at a slight angle to the plane of its neighbor

Deflection systems, particularly electrostatic systems, invariably distort, to some degree, the circular cross section of an electron beam which undergoes deflection This distortion increases with angle of deflection Taking into consideration all factors the designer of practical cathode-ray tubes using electrostatic deflection rarely attempts to design for angles of deflection much greater than 15° with respect to the gun axis

Electrostatic deflection is usually preferred over magnetic deflection for cathode ray tubes intended for instrumentation applications because of the wider frequency range over which operation is readily possible The bandpass of an electrostatic deflection system is limited in a practical sense by the amount of power the equipment designer can justifiably expend in achieving adequate display brightness and size Some relief in this regard is obtained if deflection structure reactances both capacitive and inductive, are kept to a minimum A straightforward way of minimizing reactances is to bring the deflecting electrode leads directly to contacts sealed through the neck wall instead of through the base, as in cathode ray tubes for less critical applications Laboratory oscilloscopes designed around conventional cathode ray tubes and having useful bandpass to the order of 50 megacycles are readily obtained Even higher performance can be obtained if needed although at increased instrument cost

A more fundamental limitation to the high frequency performance of deflection structures such as that discussed above is related to the time required for the beam to traverse the axial length of a pair of electrodes It is understandable that a deflecting signal might well reverse in polarity during the electrode transit time, resulting in a completely erroneous indication at the phosphor screen A practical solution to this problem used in cathode ray tubes for specialized instrumentation applications is to use a traveling wave structure for instance a helix, as an electrostatic deflection element In this case the speed of propagation of a signal along the deflection structure is made to match the velocity of an electron beam passing between the structure and an rf plane Thus a particular beam electron traveling through the system "sees" what appears to be a constant field trans-

verse to its initial motion and experiences a deflection which is truly indicative of the amplitude of the deflecting signal at the time the electron entered the deflection structure Such deflection systems have been demonstrated to operate at kilomegacycle frequencies

Many cathode ray tubes especially those intended for television or radar display service employ magnetic deflection systems An elementary system of this kind takes the form of a pair of coils, each wound on a rectangular form positioned with major planes parallel on opposite sides of the neck of a cathode ray tube The magnetic field lines are thus perpendicular to the axis of the electron gun mounted therein On entering this field the beam electrons encounter forces which impart acceleration in the form of a change in direction If the flux density is uniform the path followed by the electrons is circular and lies in a plane perpendicular to the lines of flux On leaving the deflection field the beam travels in a straight line path tangent to the circle just described The deflection given an electron beam which traverses a field of uniform flux density limited to the space between two planes perpendicular to the initial direction of the beam motion that is, the tube axis, is given approximately by

$$y = \frac{LbB}{3\,37\sqrt{V}}$$

where y is the deflection observed at the phosphor screen in cm L is the distance from axial midpoint of field to phosphor screen in cm b is the axial extent of uniform field in cm B is the flux density in gausses and V is the beam acceleration potential in volts By an appropriate arrangement of the windings of a magnetic-deflection coil pair more commonly called a deflecting yoke it is possible to obtain useful total deflection angles up to 110°

Figure 4 shows a typical electron gun designed for use with magnetic deflection This gun employs the so-called tetrode configuration in contrast to the triode configuration characteristic of the all electrostatic gun previously discussed The addition of an accelerating element grid no 2 to be operated at several hundred volts potential with respect to the cathode serves two purposes It isolates the performance of the emission system from fluctuations in the final accelerating voltage source, and it serves as one element in an electron lens which prefocuses the beam, reducing its diameter in the vicinity of the main lens and the deflecting system This gun is also designed for use with a magnetic main focus lens This lens takes the form of a solenoid almost completely encased in a suitable high permeability shell

As will be discussed in a following section the light output from a cathode ray tube increases with acceleration potential The equipment designer therefore will usually specify the largest acceleration potential consistent with de

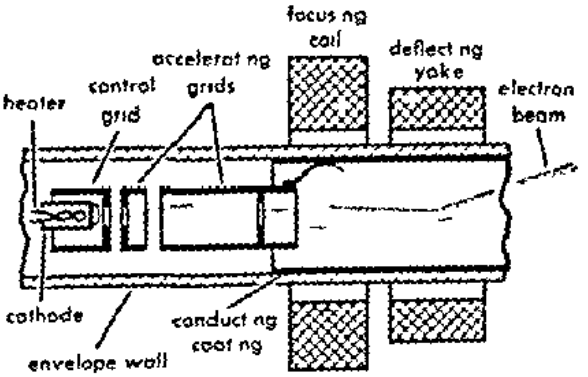


Fig 4 Simplified electron gun employing magnetic focus and deflection

flection voltage or power considerations as well as others such as freedom from corona and personnel safety The limitation imposed by deflection considerations is often severe in the case of electrostatic deflection because required deflection voltages increase linearly with acceleration potential In an attempt to defeat this limitation the concept of postdeflection acceleration (PDA) was developed In a tube employing PDA the electron beam is not accelerated to its final velocity until after it has traversed the deflection fields In this way the deflection factor in relation to the final phosphor screen potential is decreased and thereby made more favorable The simplest practical approach to PDA is implemented by applying the envelope coatings in two sections separated by an insulating gap This arrangement displays electron optical lens properties in addition to the electron-acceleration function for which it is primarily intended The gain in deflection factor occasioned by PDA is therefore offset to some extent by the converging action of the lens formed by the wall coatings Furthermore this lens introduces distortions to the pattern displayed on the phosphor screen particularly at high ratios of postdeflection acceleration to acceleration voltage These effects are minimized by using several stages of PDA comprising a series of wall coatings each operated at a progressively higher voltage A modern approach is to replace a solid envelope wall coating by a narrow ribbon of resistive material arranged in a continuous helical spiral extending from the neck coating in the vicinity of the deflecting electrodes to the region of the phosphor screen The PDA voltage is applied across this spiral which serves to set up a gradual gradient extending practically the entire distance from the gun to the screen

PDA cathode ray tubes suffer in image contrast by comparison with those using a single accelerating voltage This situation arises because secondary electrons invariably produced in some degree by collision of the beam with deflecting electrodes or the edges of limiting apertures are attracted as a general spray to the phosphor screen by the post acceleration field

Phosphor screen This element converts electrical energy to visible radiation Materials known as phosphors are said to be luminescent that is they are able to emit light at temperatures substantially below those which produce incandescence A phosphor which is excited to luminescence by electron bombardment is described as cathodoluminescent In the case of phosphors for cathode ray tubes luminescence invariably persists after cessation of excitation Luminescence which continues for more than 10^{-8} sec after excitation is removed is called phosphorescence Luminescence which is coincident in time with excitation is known as fluorescence *See* LUMINESCENCE

Screen materials A wide variety of materials displays the property of cathodoluminescence Among these materials are nonmetallic elements large classes of both organic and inorganic compounds and many glasses All the phosphors used in commercially fabricated cathode ray tubes are inorganic nonmetallic crystalline materials Although some of these compounds are found in nature considerations of reproducibility and uniformity of product dictate the use of phosphors synthesized under controlled conditions Some nonmetallic crystalline materials notably calcium tungstate will emit useful quantities of radiation in the pure state Most however display practical luminescence only when activated by an impurity These impurities deliberately introduced in amounts ranging from 1 part in 100 to 1 part in 100 000 play a profound role in determining the efficiency color and persistence of the emission obtained from a given phosphor

Phosphors are fabricated by firing together the base material the activator and a flux (to promote crystallization) in a suitable vessel at high temperature By careful control of the cooling process after firing the phosphor powder can be made to crystallize in a form which lends itself readily to the usual methods of applying phosphor screens These methods are spraying dusting pouring or settling In each case except dusting the phosphor is mixed with a vehicle appropriate to the method of application For example in the settling process the phosphor powder is introduced into the envelope of the cathode ray tube in a suspension of distilled water to which have been added an electrolyte and a gelling agent to promote adherence of the screen After a period of hours the phosphor has settled out of the suspension and the remaining liquid is slowly and carefully decanted Drying of the screen by a gentle flow of warm air follows

Luminous efficiency Typical base materials and activators are shown in the table in which the properties of commercially important cathode ray tube phosphors are listed

One of the criteria by which a phosphor material is judged is its ability to convert electrical energy to useful radiation In most cases cathode ray tube screens are intended to be viewed by human observers It is therefore appropriate to speak in terms of visible flux output The luminous efficiencies of practically all commercially significant phosphors are 5–50 lumens/watt of exciting power measured under conditions where the beam bombarding voltage is about 8 kv and the beam current density about 1 5 microampere/cm² For a constant current density, the light output from a phosphor varies as the nth power of the beam accelerating voltage, where n is usually 1 5–2 0 Light output increases with increasing bombarding-current density exhibiting definite evidences of saturation at current density levels which are characteristic of particular phosphors For some phosphors, saturation effects are quite evident at the 10 μa/cm² level Others display relatively undiminished luminous efficiencies at levels of several hundred μa/cm²

The color of the emission from a phosphor is governed both by the base material and by the activator The spectral energy distributions of most phosphors are fairly broad although colors of high saturation are readily obtained A wide range of hues is available, the tube designer is restricted in this matter only insofar as particular efficiencies and persistences must be achieved simultaneously with a given color

Persistence The law governing the decay of phosphorescence is either an exponential or a power law in nature depending upon the phosphor under consideration Usually in both types of decay simple expressions are not adequate for an accurate description of a phosphor's performance Instead a multiterm expression involving several constants is required Phosphors are available for a wide range of applications from flying spot video signal generator service requiring fractional microsecond decay times to radar indicator service in which images are desired many seconds after screen excitation

Secondary electron emission It is necessary in the choice of a phosphor for a particular application to be aware of its secondary electron emission properties Even if penetration effects were ignored it would be impossible to increase the light output of a phosphor arbitrarily by unrestricted increase of accelerating potential Bombardment of a phosphor with electrons accelerated by voltages in excess of the potential at which the secondary electron emission ratio drops below unity the so-called second crossover potential will result in light output no greater than that obtained at second crossover potential Because of the low conductivity of the phosphor screen charges accumulate thereon driving the potential of the phosphor to a stable equilibrium at second crossover potential The potential at which equilibrium occurs can be increased by coating the phosphor particles with a less than monomolecular layer of some excellent secondary emitter such as magnesium oxide *See* SECONDARY EMISSION

A more complete solution to the problem is to coat the phosphor screen with a thin electron transparent film of aluminum by vacuum evapora

Characteristics of some cathodoluminescent materials

EIA* no.	Base material (activator)	Persistence category†	Decay law (approximate)	Fluorescent color‡	Phosphorescent color‡
P1	Zinc orthosilicate (Mn)	Medium	Exponential	Yellowish green	Yellowish green
P2	Zinc sulfide (Ag + Cu)	Medium	Power	Yellowish green	Yellowish green
P3	Zinc beryllium silicate (Mn)	Medium	Exponential	Yellowish orange	Yellowish orange
P4	Zinc sulfide (Ag) + zinc cadmium sulfide (Ag)	Medium short	Power	White	White
P4	Zinc sulfide (Ag) + zinc beryllium silicate (Mn)	Medium to medium short	Power + exponential	White	White
P4	Calcium magnesium silicate (Ti) + zinc beryllium silicate (Mn)	Medium	Exponential	White	White
P5	Calcium tungstate (W)	Medium short	Exponential	Blue	Blue
P7	Zinc sulfide (Ag) on top of zinc cadmium sulfide (Cu)	Long	Power	White	Greenish yellow
P11	Zinc sulfide (Ag)	Medium short	Power	Blue	Blue
P12	Zinc magnesium fluoride (Mn)	Long	Exponential	Orange	Orange
P14	Zinc sulfide (Ag) on top of zinc sulfide (Cu)	Medium	Power	Bluish white	Orange
P15	Zinc oxide (Zn)	Short Very short	Exponential	Green Ultraviolet	Green Ultraviolet
P16	Calcium magnesium silicate (Ce)	Very short	Exponential	Bluish purple	Bluish purple
P17	Zinc oxide (?) on top of zinc cadmium sulfide (Cu)	Long	Exponential + power	White	Yellow
P18	Calcium magnesium silicate (Ti) + zinc beryllium silicate (Mn)	Medium	Exponential	White	White
P19	Zinc fluorosulfide (?)	Long		Orange	Orange
P20	Zinc cadmium sulfide (Ag)	Medium short	Power	Yellow green	Yellow green
P21	Magnesium fluoride	Medium		Orange	Orange
P22	Zinc sulfide (Ag)	Medium short	Power	Purplish blue	Purplish blue
	Zinc orthosilicate (Mn)	Medium	Exponential	Yellowish green	Yellowish green
	Zinc orthophosphate (Mn)	Medium		Reddish orange	Reddish orange
P24	Zinc oxide (Zn)	Short	Exponential	Green	Green
P25	Calcium silicate (Pb Mn)	Medium		Orange	Orange
P27	Zinc orthophosphate (Mn)	Medium		Reddish orange	Reddish orange
P29	Zinc cadmium sulfide (Cu)	Long	Power	Yellow green	Yellow green

*Electronic Industries Association designation. P6, P8, P9, P10, P13, P26, P28 are not identified.

†Persistence is the time required for the screen to fall to 10% of initial level following interruption of excitation.

Long	1 sec or more	Medium short	10 μsec to 1 msec
Medium	100 msec to 1 sec	Short	1 μsec to 10 μsec
	1 msec to 100 msec	Very short	less than 1 μsec

‡Colors listed here are in accordance with the Kelly system for color designation, see *J Opt Soc Am* 33 629 1943

tion techniques This process not only stabilizes the phosphor potential at the applied acceleration voltage
beca
laye
ne be lost in the interior of the envelope

Depositing of screen The fineness of detail in an image presented on a phosphor screen is limited to some extent by the granular nature of the screen Both particle size and layer thickness affect performance in this regard Substantial improvement may be obtained by the use of phosphor screens in the form of transparent films Such films which owe their transparency to their microcrystalline nature may be prepared by one of several techniques including simple evaporation of the powder material evaporation of the powder followed by refiring at high temperature or vapor phase reaction of the constituents In general transparent phosphor films have displayed substantially lower efficiency than conventional powder screens This reduced efficiency is explained in part by the loss of light trapped within the transparent film itself and piped to the edge of the screen However the advantages of high resolution high contrast in ambient illumination and thermal stability are important

Cathode ray tube photography It is sometimes necessary or desirable to photograph the pattern displayed on a cathode ray tube Users of oscilloscope instruments frequently resort to photography for purposes of record keeping In some cases such as in the study of highly transient phenomena the photographic capture of a waveform alone permits its full analysis Until the advent of high performance video-tape recorders many live television programs were recorded for delayed broadcast
film exposed to pictures
bes
rec
op-
erational or training missions as evidenced by the

signals displayed on PPI or fire control radar indicators In combination with the character display cathode ray tube photographic techniques provide a rapid means of printing hard copy comprising the output of high speed digital computers

The technique of photographing oscilloscope patterns is readily mastered because instrument manufacturers offer cameras especially adapted for the purpose These cameras often are designed to use Polaroid Land film which has found wide acceptance among oscilloscope users *See* PHOTOGRAPHY

For more specialized photographic applications care is taken to match cathode-ray tube characteristics (especially phosphor color and persistence) with those of the photographic medium Because of its high actinic brightness the blue phosphor designated P11 is widely used In choosing a film for cathode ray tube photography the ASA Index should be used only as a rough guide Preliminary exposure experiments are always recommended in this matter

Computer applications The special requirements of computer technology have led to the development of character display cathode ray tubes *See* STORAGE TUBE

Charactron This employs an electron gun of essentially conventional design to illuminate one at a time characters etched in a thin metal stencil *mounted in the envelope* neck perpendicular to the tube axis The electron beam issuing from the *stencil having* assumed a cross section corresponding to the character in question is deflected to an *appropriate position* on the phosphor screen where a luminous image of the selected character appears

Compositron In this tube electron beams having character shaped cross sections are produced by *projecting a white on black* image of a font of alpha numeric symbols upon a photoemissive cathode The resulting *bundle* of character beams is focused by electron optics upon a disk bearing an axial *aperture just* large enough to pass only one of the individual beams Selection of a particular beam is *accomplished* by controlled magnetic deflection of the entire bundle of beams The selected beam is *also positioned* by crossed magnetic fields

Flat cathode ray tube A novel development in the cathode ray tube field is the so called flat pic ture tube This *device may* take the form shown in Fig 5 The electron beam from the gun in the appended neck is first *deflected* essentially 90° in a vertical direction and then 90° in a direction perpendicular to both previous directions Thus the beam is directed to the phosphor screen sometimes transparent deposited on one of the large walls of the envelope The opposite large wall bears conductive strips (sometimes transparent) extending parallel with its long axis The voltage pulse trains which set up the final 90° deflecting field are applied to these strips The initial 90° deflecting field is established by applying appropriately timed voltage pulse trains to a series of U-shaped elements situated astride the gun axis

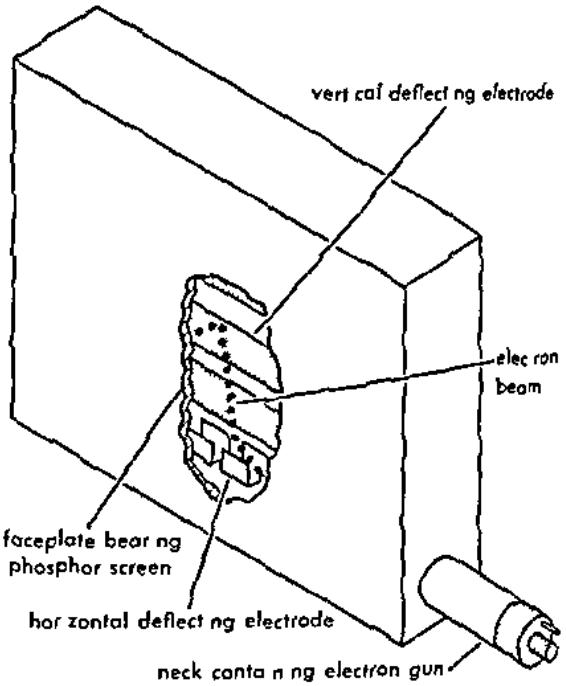


Fig 5 Schematic diagram of flat cathode ray tube

Application of this device is anticipated in airborne data display systems where the indicator must be in line with but must not essentially interrupt the pilot s vision

Traveling wave cathode ray tube An interesting tube is the Wamoscope which combines features of a traveling wave tube with those of a cathode ray tube An electron beam is directed along the axis of a traveling wave helix to which the modulated microwave signal carrier is applied The beam electrons leave the helix with a spread of velocities corresponding to the modulation on the input carrier A velocity sorting system determines which velocity groups enter the cathode ray tube section of the device These selected electrons are deflected and accelerated to the phosphor screen where they produce a pattern corresponding to the modulation in the microwave carrier This tube was initially designed to permit the elimination of conventional microwave receiver stages in radar sets

Cathode-ray tubes employing multiple independent electron guns are often required for use in oscilloscopes for the simultaneous display of a number of concurrent signals Tubes having two guns are quite common Some have been produced with as many as ten guns [M D H]

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Cathodoluminescence

A luminescence resulting from the bombardment of a substance with an electron beam The major application of cathodoluminescence is in cathode-ray oscilloscopes and television picture tubes In

these devices a thin layer of luminescent powder is evenly deposited on the transparent glass face plate of a cathode-ray tube The electron beam originating in the cathode, after undergoing acceleration focusing and deflection by various electrodes in the tube, impinges on the luminescent coating The resulting emission is normally observed through the glass face plate of the tube that is, from the unbombarded side of the coating Depending on the type of signal information to be displayed on the tube, phosphors or phosphor blends of various emission colors and persistences are used

The brightness, B, of a phosphor under cathode-ray bombardment depends linearly on the current density j for sufficiently small values of j but saturation effects set in at higher current densities B depends on the bombarding voltage according to the empirical relation $B = kf(j)(V - V_0)^q$, where k is a constant of the face plate material $f(j)$ represents the dependence of brightness on current density, V is the accelerating voltage V_0 is a so-called "dead voltage," and q is a constant for the particular phosphor, the values for different phosphors lying between 1 and 3 The efficiency of conversion of the electron beam energy into light energy is at most about 20%, considerably less than the best efficiencies found with photoluminescence This relative inefficiency is due to the complex mechanism of excitation by the electron beam which loses its energy by interaction with the ions of the crystal lattice and consequently dissipates a large fraction of its energy before reaching a luminescent center

An important requirement for a good cathodoluminescent phosphor is that it have good secondary electron emission properties, otherwise it will charge up negatively and decrease the effective potential of the bombarding beam Phosphors in cathode ray tubes are subject to deterioration by prolonged action of the electron beam and by bombardment by residual gas ions that remain in the tube or are generated at the electrodes or tube walls. *See* LUMINESCENCE, SECONDARY EMISSION

[C C K, J R S]

Cattle

A term applied to any species of the genus *Bos* family Bovidae but commonly limited to domestic cattle *Bos taurus* Other forms are frequently known as buffalo or yak

Domestic cattle probably developed from the aurochs (bison) of Europe and possibly from the Celtic shorthorn They have been domesticated for at least 4000 years and there is now a variety of breed Cattle are usually divided into two groups, those developed primarily for milk production such as the Jersey and those developed as beef animals such as the Angus *See* CATTLE PRODUCTION, BEEF CATTLE PRODUCTION, DAIRY

Cattle are still used in many parts of the world as draft animals Oxen (males castrated after maturity) make the best work animals and were commonly employed for this purpose in America until about 1900 Males castrated when young are called steers, they produce beef of the best quality *See* ARTIODACTYLA BISON YAK

[J D B]

Cattle production, beef

Raising of cattle for meat The flesh from cattle under 6 months of age is veal and from older cattle is beef Lean beef is a highly nutritious human food containing approximately 25% high quality protein and the necessary B vitamins and minerals

Cattle belong to the zoological family Bovidae and are called ruminants because they have a 4-compartment stomach and chew a cud Most domestic breeds common to the Temperate Zone originated from *Bos taurus* ancestry whereas Zebu or Brahman originated from *Bos indicus* indigenous to tropical areas. *See* ZEBU

World beef production. World cattle numbers in 1958 were estimated at about 972 000 000 a 7% increase above the 1951 1955 estimate The major cattle countries of the world are shown in the table

Cattle production in China and Southeast Asia as well as in Central America and North and Central Africa has expanded markedly since 1951 Further increases are likely in these and other countries as the economy and agriculture expand The United States with 94 000 000 head of cattle (beef dairy and mixed) is the major beef producing country The cattle of India regarded as sacred are unimportant in world trade as edible beef In 1956 Argentina was the leading beef exporter but Mexico Australia New Zealand Denmark Brazil and Uruguay produced considerable surplus for export

Much of the world's beef is produced from grass alone (*see* GRASS CROPS) The pampas of Argen

Estimated cattle population of the world 1958*

Countries	Cattle
India†	203 800 000
United States	93 96[illegible] 000
Brazil	68 120 000
China†	66 [illegible]48 000
U S S R	66 700 000
Argentina†	44 [illegible]03 000
Ethiopia and Eritrea†	20 000 000
France	17 928 000
Mexico	16 900 000
Colombia†	13 390 000
Turkey	12 706 000
West Germany	11 918 000
United kingdom	10 831 000
Canada	10 293 000
Italy	8 614 000

Continents	Cattle
Asia	378 818 000
South America	151 367 000
North America	134 998 000
Europe	106 847 000
Oceania	22 069 000
Australia	16 500 000
New Zealand	5 569 000

* From foreign crops and markets
† 1956 estimate
‡ 1957 estimate

tina provides year round grazing and produces quality beef directly from alfalfa pasture (*see* ALFALFA) Much Mexican and Australian beef is also produced from pasture alone whereas many cattle in England Canada and the United States are grain fattened before slaughter *See* GRAIN CROPS

United States beef production Approximately 3% of the beef cattle in the United States are in registered herds which supply the majority of bulls for commercial herds In order of rank the three most popular beef breeds in the United States are Hereford Angus and Shorthorn (Fig 1) In the Gulf Coast area Brahman or cattle with some Brahman blood such as Santa Gertrudis Brangus and Beefmaster seem best adapted to the hotter climate and heavier insect infestation (Fig 2) Numbers of Charolaise a French breed have increased markedly since 1950 Production of feeder cattle and feedlot fattening are the major phases of beef production in the United States The topography and limited rainfall in the Rocky Mountains and in the central and western plain states adapt these areas to production of feeder calves yearlings and some 2 year olds The Corn Belt certain areas of the South and the Pacific Coast produce surplus grains for feedlot fattening of cattle

Feeding beef cattle Feed is the major item of cost of beef production It is estimated that approximately 80% of the total feed of beef cattle is constituted of roughages The large rumen compartment of an adult bovine stomach has a capacity of 40–60 gal The ruminant processes of regurgitation and chewing of the cud and the microbial fermentation in the rumen enable cattle to obtain energy from the cellulose material of roughages

The nutrient requirements of cattle are water vitamins minerals carbohydrates fat and protein Quality forages and good pastures can furnish adequate nutrients for maintenance growth and reproduction After 6 months of age cattle need a ration of approximately 11% crude protein but younger cattle breeding bulls and cows in advanced pregnancy require somewhat more protein Urea and other nonprotein nitrogenous materials can serve as partial substitutes for protein for beef cattle since the microorganisms of the rumen can synthesize these into digestible protein For each 100 lb of their weight mature cattle will eat daily about 2 lb and younger cattle about 2 5 lb of air dry feed (cured forages and grains of approximately 10% moisture) The National Research Council gives the maintenance requirements of cattle as 0 8 therm (1 therm is 1000 cal) of net energy in the form of feed per 100 lb live weight One pound of gain requires approximately 3 53 therms of net energy above maintenance Grains vary in therm values but they average between 72 and 80 therms of net energy per 100 lb air dry weight The therm values of cured roughages average 40–50% of their weight in pounds Balanced grain rations have higher net energy values and generally produce larger daily gains The average daily gains of calves over 6 months yearlings and 2 year old steers on a full feed of grain of 1 75 lb per hundredweight are about 2 10 2 25 and 2 50 lb respectively Heifers make slightly lower gains than steers Efficiency of gains (feed per pound of gain) favors calves over yearlings and yearlings over 2 year olds Estrogenic hormones such as stilbestrol used prior to 1960 in the feed or as skin implants increased gains and efficiency 12 18% (*see* ESTROGEN) Cattle need bulk in their diet and for good results should receive at least ¼ lb of roughage daily for each 100 lb of their weight

The feeding of certain antibiotics with predominantly roughage rations has enhanced beef gains (*see* ANTIBIOTIC) Numerous feeding tests have shown consistent gain improvements from pelleting both roughage and grain rations so pelleting is becoming more common in cattle feeding Ensilage is excellent cattle feed and as ensiling reduces curing losses it can provide more pounds of nutrients from an acre *See* AGRICULTURAL SOIL AND CROP PRACTICES

Marketing and slaughter Cattle of both sexes and of both dairy and beef breeds varying greatly in weights ages and degrees of fatness are slaughtered for meat (*see* CATTLE PRODUCTION DAIRY) For clarity and uniformity of description cattle



Fig 1 (a) Hereford bull (*American Hereford Assn*) (b) Angus bull (*American Angus Assn*)



Fig 2 Brahman bull (*Photograph by American Brahman Breeders Association*)

are classified according to sex and use as steers heifers, cows, bulls stags veals and calves Consumer preference is for beef from young fat cattle weighing 800–1200 lb alive Steer beef from males castrated at a young age is generally the highest priced Young fat heifers if not pregnant yield carcasses comparable to steers however heifers mature and fatten sooner and are sold at lighter weights As pregnancy reduces carcass grade and yield, heifers undersell steers $1 $3 per hundredweight. Cows (mature females) yield carcasses more angular than those of heifers Bulls (uncastrated males) and stags (late castrated males) yield coarser and darker-cutting carcasses than steers A veal is a young calf up to about 300 lb older and heavier cattle up to about 550 lb yield calf carcasses The flesh of young cattle has more moisture and a lighter colored lean than that of older beef

Slaughter cattle are bought primarily on carcass quality and probable dressing per cent and are graded accordingly in descending value as prime choice good commercial standard utility cutter and canner Dressing per cent is the carcass yield based upon live weight and may vary from 70% for prime to 40% for cutters Fat increases dressing per cent, whereas water and feed fill (weight of feed remaining in the paunch) and heavy bones and hides reduce dressing per cent Condition or fatness, body conformation (angular vs blocky) and quality are the major factors in grading carcasses. An ideal prime carcass is blocky compact straight lined and thick fleshed and it carries a smooth, firm uniform covering of white fat and shows a cherry red well marbled lean of fine texture Grades lower than prime lack one or more of the ideal characteristics Marbling (interspersion of fat with lean) fine texture and cherry red color are quality factors desired by the meat trade Marbling contributes to flavor whereas texture (diameter of muscle bundle fibers) and youth determine meat tenderness Young carcasses have soft, porous, reddish bones and pronounced cartilage as contrasted to the flinty white bone of older beef Well fleshed carcasses suitable for butcher retail cuts are called block beef whereas low grading carcasses such as cutter and canner are boning beef and are processed into sausage and canned dried and smoked meats To increase tenderness the better grades of carcasses are usually aged 2–6 weeks at temperatures of 34 38°F

In slaughtering carcasses are split through the backbone into sides For wholesale trade beef sides are divided into fore and rear quarters and retailed primarily as steaks and roasts The major forequarter cuts are chuck and rib the hindquarter cuts are loin and round Major wholesale and retail cuts of the beef carcass are shown in Fig 3

An attempt is made to utilize all the offal of slaughter Included in edible offal are heart liver and tongue often called meat specialties The hide used as leather represents about 8% of the live weight and is the major inedible by product Wide use is made of inedible offal in the production of bone meal blood meal and meat scraps for livestock feeds of pharmaceutical products such as insulin and adrenalin from organs and glands (see EPINEPHRINE INSULIN) of glue and fertilizer from hooves and horns of sausage casings from intestines and of many other products manufactured from leather

Reproduction Cattle are polyestrus that is they will breed at all seasons Depending upon nutrition heifers usually reach puberty or sexual maturity at 5–12 months of age The estrus period or heat in cattle averages about 18 hours and the cycle occurs at intervals of 18–21 days Well grown heifers can be bred to calve at 2 years of age but many cattlemen prefer to wait until heifers are 2½–3 years old The average gestation or pregnancy period is about 283 days Twin births occur about

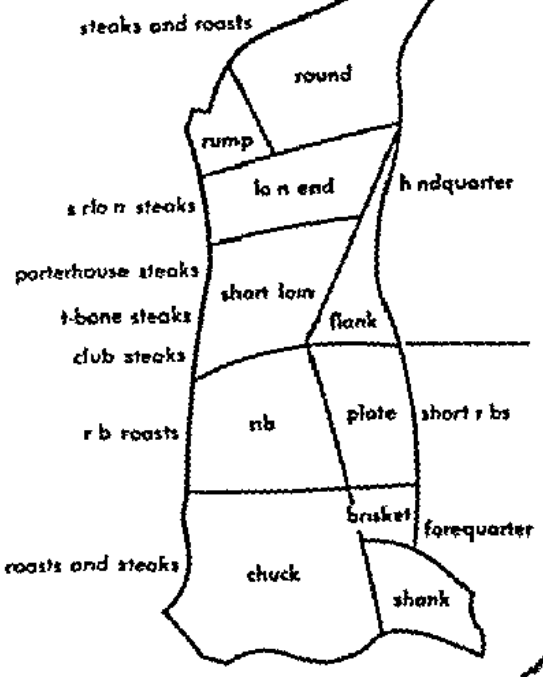


Fig 3 Wholesale and retail cuts of beef

once in 200 Other multiple births are comparatively rare A heifer born twin to a bull is usually sterile and is called a freemartin A young bull is virile at about 8 months of age but should be used sparingly even as a yearling In range areas one active mature bull is usually kept for each 20–30 cows Artificial insemination is not used as extensively with beef as with dairy cattle but the practice is increasing *See* BREEDING (ANIMAL)

Performance test programs have been established for the purpose of selecting cows that will wean a 500–600 lb calf at 7 months and cattle that will gain 3 lb daily and weigh 1000–1100 lb at 12 months Studies show that rate of growth and efficiency in the use of feed are correlated and highly heritable which means that fast gaining parents generally produce fast gaining progeny The trend is toward leaner beef and measures for identifying lines of meat type cattle are being studied

Diseases Cattle are afflicted with only a few serious diseases Diagnosis and treatment of such diseases by a competent veterinarian are important The most universally destructive cattle diseases are tuberculosis contagious abortion foot and mouth disease anthrax and blackleg

Tuberculosis or TB is highly contagious transferable from cow to cow and transmissible to man through milk TB is caused by a specific bacterium that may attack all parts of the body but particularly the lymphatic glands Many slaughter cattle are condemned because of evidence of tuberculosis There is no specific treatment but reactors can be identified with a tuberculin test Annual herd tests and disposition of reactors have greatly reduced the incidence of TB *See* TUBERCULOSIS

Contagious abortion or Bang's disease is a serious reproductive disease caused by *Brucella abortus* a nonsporeforming bacterium It is characterized by the birth of premature or dead calves Herds can be freed of Bang's disease by identifying reactors with the blood agglutination test and slaughter of carriers Vaccination of calves 4–8 months old with Strain 19 of an attenuated *Brucella* culture provides immunity *See* BRUCELLOSIS

Foot and mouth disease caused by a virus is characterized by blister lesions on the feet and in and on the mouth The disease is seldom fatal but as animals cannot eat or refuse to eat economic loss is great An outbreak in Mexico in 1947 was controlled and supposedly eradicated through inspection vaccination and quarantine *See* FOOT AND MOUTH DISEASE VIRUS

Anthrax (splenic fever) is very infectious and is usually fatal The anthrax organism a bacillus can live many years and can be spread to other animals including man The disease has been prevalent in Europe since the seventeenth century Positive diagnosis can be made by microscopic examination of a blood sample for the specific bacillus When outbreaks occur the best preventive measures are burning or deep burial of infected dead and prompt vaccination with antianthrax serum *See* ANTHRAX

Blackleg is an acute infectious bacterial disease of young cattle Vaccination of calves is practiced annually in areas where the disease prevails *See* BLACKLEG

Bloat. Bloat is a world wide digestive disorder of cattle that causes an annual loss of millions of dollars The disorder is recognized by a distention of the animal's left side caused by excessive gas formation in the rumen as the result of digestion of fermentable feeds particularly pasture forages such as clovers and other legumes. Bloated cattle if not relieved of the gas often die from suffocation In 1957 scientists reported fair control of bloat by feeding an antibiotic or by adding a miscible oil to the drinking water or spraying it on the forage *See* AGRICULTURAL SCIENCE (ANIMAL)

[W W A.]

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Cattle production, dairy

The section of animal agriculture concerned both with the management and improvement of dairy breeds for efficient production of milk and with the marketing of the milk It includes selection breeding rearing feed production nutrition housing milking procedures, milk handling sanitation, and disposal of milk, surplus animals and manure Some of the highest priced agricultural lands of the world are utilized for the keeping of dairy cattle However dairy cattle husbandry is adaptable to many of the humid grassland areas that cannot be plowed close to the centers of population

Dairy development in America. Christopher Columbus brought the first cattle to the West Indies in 1495 The descendants of these or similar Spanish animals were brought to Florida by Ponce de Leon in 1521, and Coronado drove cattle to the Southwest in 1542 The first United States milk cows of Channel Island and English origin were brought to Jamestown Virginia in 1611 to the Plymouth Colony in 1624 and to New York in 1621 and 1625 These cows were largely dual purpose chosen for hardiness and adaptability rather than milking ability Excess milk was made into butter and cheese in the home Not until about 1850 was much effort expended to improve the quality of milk cows or to establish a dairy industry to supply the rapidly growing city population The first milk train was run into New York City in 1850 and the first cheese factory was established in 1851 The condensed milk process was invented by Gail Borden in 1856, the first purebred dairy cattle association was formed (Jersey) in 1868, the first creamery was built in 1871, and the centrifugal separator was patented in 1877 (*see* DAIRY AND CREAMERY) Refrigeration came into use in 1880 and the Babcock test for impartial buying and

testing of milk and for the keeping of records of production on the farm was inaugurated in 1890 The establishment of schools for teaching improved dairy methods of experiment stations for research on feeding breeding and nutritional value of milk and of organized agricultural extension services and other educational facilities among dairy farmers has accelerated dairy production in the last 70 years Artificial insemination introduced in 1938 is now practiced on over 6 000 000 cows yearly *See* BREEDING (ANIMAL)

Dairy breeds According to the United States Department of Agriculture there were about 93 000 000 head of cattle of all types and ages in the United States in 1957 of which 33 600 000 were used for dairy purposes alone (*see* CATTLE PRODUCTION BEEF) Approximately 70% are of the five major dairy breeds Ayrshire Brown Swiss Guernsey Holstein Friesian and Jersey about 18% are dual purpose animals such as Milking Shorthorn or other beef breeding stock kept for milking and 12% are Red Dane Dutch Belted or of mixed breeding Only 10% of the total are registered purebreds However much of the recent improvement in dairy cattle stems from the increased number of superior registered animals and especially from the artificial breeding of superior sires to cows of mixed and grade breeding

Efforts since 1853 have been concentrated mainly on selective testing showing and advertising of outstanding animals of the registered cattle The introduction of the dairy herd improvement associations in 1905 for testing all milking cows and culling out low producers gave needed data and focused more attention on grade cows Over 2 000 000 cows are tested yearly Herd test systems for purebred herds which started in 1925 and the early bull associations and circles that gave way to artificial insemination in 1938 have also furnished data for proving sires and superior strains of cattle The services of outstanding sires are now available to every dairy farm

The five major dairy breeds are represented by the Purebred Dairy Cattle Association which was organized in 1940 and has its headquarters at Peterborough N H These major breeds include over 3 000 000 registered purebreds They furnish the sires and the methods to dairymen for improving the 33 000 000 cattle showing dairy character istics The principal features of each of the five major dairy breeds are set forth in the following discussion

Holstein Friesian This is the breed largest in number and in body size it was developed in Friesland and northern Germany The breed was first imported from Holland to Massachusetts about 1861 Large importations were also made from 1875 to 1885 There were 212 445 head of purebreds registered in the United States in 1957 most of them in New York Pennsylvania Wisconsin Ohio and Michigan They account for 52% of all the purebred dairy cattle in the United States These cattle are black and white ...gh about 1500 lb at maturity Tested cows produced an average of 13 187 lb of 3 69% butterfat milk in 1957 Mature bulls weigh about 2000 lb calves at birth weigh 75–105 lb giving the breed an advantage in the production of veal and beef as well as milk The highest milk record cow of this breed in the United States is Green Meadow Lily Pabst which in 1951 produced 42 805 lb of milk and 1 246 4 lb of butterfat in 365 days (Fig 1) Headquarters for registration and promotion of the breed is in Brattleboro Vt

Guernsey The second breed in numbers but smaller in size Guernseys were developed in the Channel Islands of Alderney Guernsey and Sark The first purebred animals were imported to Massachusetts from Guernsey in 1830 and the breed increased in number until 1914 They are found in large numbers in Pennsylvania Wisconsin New York Ohio and Indiana There were 75 899 head registered in 1957 in the United States Guernseys represent about 20% of purebred dairy cattle and are popular in market milk areas for Golden Guernsey milk They are fawn to red in color with white markings Mature cows weigh about 1100 lb In 1957 tested cows produced an average of 8874 lb of 4 9% milk Most mature bulls weigh about 1700 lb Calves, at birth weigh 55–85 lb The breed is not strong in the production of veal or beef but the milk is remarkable for its golden yellow color In 1957 Langmeadow Minnie a prize Guernsey produced 26,695 lb of milk containing 1461 lb of butterfat in 365 days the highest butterfat record for any cow of any breed milked twice daily Headquarters for the breed association is in Peterborough N H

Jersey This is the third breed in number but smallest in size and was developed on the Island of Jersey The first purebreds were imported to Connecticut in 1850 Large numbers were also imported from 1870 to 1890 Jerseys are now widely dispersed over the United States especially in the South Largest numbers are found in Ohio Texas Tennessee New York and Pennsylvania There were 68 403 head registered in the United States in 1957 Approximately 17% of all purebred dairy cattle are Jerseys These cattle are fawn to black and some have white markings Mature cows weigh about 1000 lb mature bulls average approximately 1500 lb In 1957 herd tested cows produced an average of 7558 lb of 5 32% milk In the United States highest milk record of the breed is that of Marlu Milady (25 293 lb of milk in 365 days in 1958) In 1954 an English Jersey Barings Flower produced 25 096 lb of milk and 1501 lb of butterfat in 325 days milked three times daily a world's record for the breed Headquarters for the breed association is in Columbus Ohio

Brown Swiss A close fourth in number with the Ayrshire but larger in size and more rugged Brown Swiss were first developed in Switzerland as a triple purpose breed The first purebreds were imported to Massachusetts in 1869 It is the only important dairy breed in which high grade cows

meeting minimum standards for type and production are acceptable for registration Largest numbers are found in Wisconsin Illinois Iowa Ohio and New York There were 20 861 head registered in the United States in 1957 These cattle are brown shading from silver to dark brown Mature cows weigh about 1400 lb mature bulls about 1900 lb In 1957 herd tested mature females milked twice daily produced an average of 11 138 lb of 4 05% milk The breed has an advantage in the production of veal and beef over the smaller dairy breeds. In 1958 Lees Hill Keepers Raven produced in 365 days and 3 milkings per day 34 850 lb of milk containing 1579 lb of butterfat the highest butterfat record of any cow in the United States (Fig 2) The only higher butterfat records are 1614 lb by a Milking Shorthorn in Australia and 1799 lb by a Friesian in England both milked three or more times per day and specially fed Headquarters for the breed association is in Beloit Wisc

Ayrshire The most recent of the dairy breeds Ayrshire were first imported from Scotland to Massachusetts in 1837 Within the last 30 years an improved type of Ayrshire cattle has come in from Scotland or from eastern Canada where they are quite numerous The largest number is found in New York Pennsylvania Ohio Kansas and Maryland with 19 238 head registered in 1957 These cattle are a mahogany red in color with white markings Mature cows weigh approximately 1150 lb mature bulls about 1800 lb and calves at birth 60–80 lb In 1957 herd tested females averaged 10 478 lb of 4 12% milk The breed is known for longevity and life time production rather than for high records The highest record was made by a cow in Ontario Ardgowan Valda that produced 31 156 lb of milk containing 1356 lb of butterfat in 365 days Headquarters for the breed association is Brandon Vt

Milking Shorthorn One of the oldest breeds in the English speaking countries of the temperate zone Milking Shorthorns were introduced to Virginia in 1783 but for nearly 100 years the tendency was to emphasize their beef qualities (Fig 3) About 1885 a few breeders began placing emphasis on the milking qualities of this breed A club was formed in 1912 which in 1915 became the American Milking Shorthorn Breeder's Association Headquarters are in Springfield Mo with 14,500 animals registered in 1957 Leading states are Iowa Kansas Illinois and Oklahoma The color of these

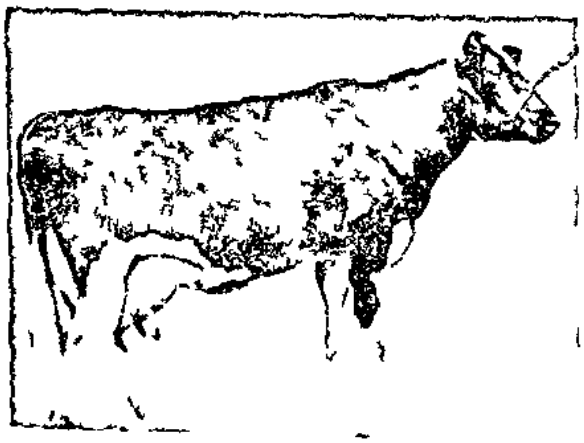


Fig 1 Champion milk producing Holstein Friesian dairy cow Green Meadow Lily Pabst (Owner Merle H Green Elsie Mich)

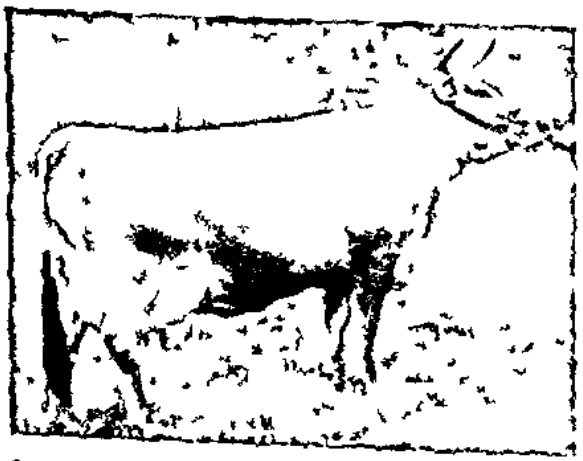


Fig 2 Champion butterfat producing Brown Swiss dairy cow Lees Hill Keepers Raven

weigh 70–80 lb at birth The breed is well suited to the production of beef and milk on general farms

Red Poll This breed originated in England and purebreds were imported to New York about 1873 (Fig [illegible] very few [illegible] tered Illinois Ohio and Michigan Color is medium to deep red with white restricted to the switch (end of tail) and underline Adaptability and other characteristics are similar to Milking Shorthorns although Red Poll cattle are smaller and without horns All females tested through 1955 averaged 8223 lb of milk with 4 23% test Headquarters of the Red Polled Cattle Club is at Lincoln Neb

Minor breeds These are of limited effect on the total dairy industry Dutch Belted cattle have been bred in North Holland for over 200 years and were imported into the United States as early as 1838 They are now most numerous in the East especially in New York Pennsylvania New Jersey and Ohio but only 100 head were registered in 1953. Except for the white belt around the middle of a black body and the smaller size they are similar to Holsteins French Canadian cattle were imported from western France to Quebec more than 250 years ago but a herdbook was not established until 1886 Their color is black or black with fawn but other characteristics are quite similar to small low testing Jerseys A few head are found in New York and the New England states and are appar

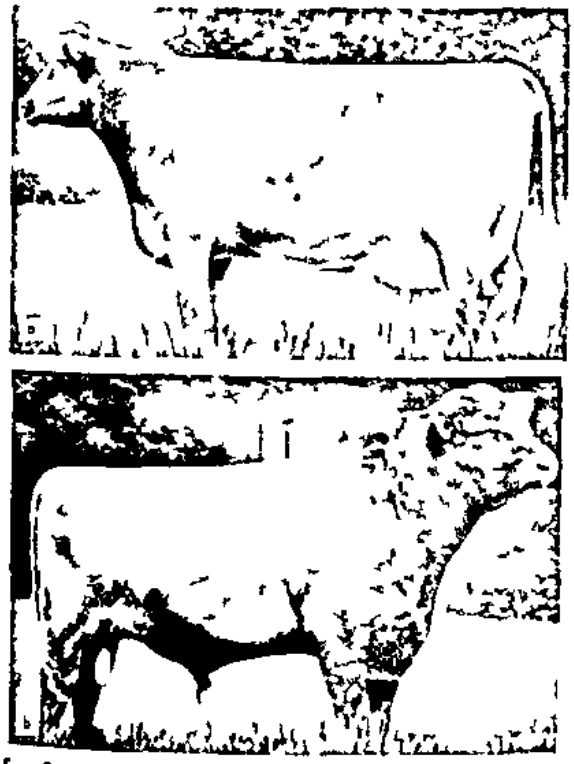


Fig 3 Milking Shorthorn cattle (a) Cow (b) Bull (Photographs by American Milking Shorthorn Society



Fig 4 Red Poll cattle (a) Cow (b) Bull (Photographs by Red Poll Cattle Club)

ently well adapted to cold weather Kerry cattle developed in southern Ireland are solid black smaller than French Canadian but well adapted to severe weather and scanty pastures Production is about 6000 lb of milk yearly with a 4% test Very few are found in the United States and none was registered in 1957 Devons deep-red dual purpose cattle were first imported from southern England in 1817 They were once popular as oxen Red Danish a large red dairy breed from Denmark were imported in 1935 by the U S Department of Agriculture About 6000 are now found in Michigan and nearby states with 43 registered for production in 1957 They are adapted to much the same conditions as Milking Shorthorns but are more persistent in production Headquarters for the breed is Marlett Mich Red Sindi a high testing milk breed of zebu cattle were more recently imported by the U S Department of Agriculture from India and have been largely used in cross breeding experiments in Georgia Louisiana and Maryland *See* ZEBU

Milk production and manufacturing Although the establishment of specialized dairy breeds and consequent improved breeding methods have been major factors in dairy progress many other developments have contributed in recent years Chief among these has been the increased production of high quality milk and other dairy products through improved processing and packaging to meet consumer demands

The first compulsory pasteurization law for a large city was enacted in 1908 for Chicago Pasteurization spread rapidly and in World War II all milk for the Armed Forces was pasteurized More than 90% of the fluid milk used in cities of the United States is now pasteurized Since about 1910 investigations in nutrition have shown the value of milk as a source of vitamins proteins and minerals in the diet *See* PROTEIN VITAMIN

Good roads and improved transportation have made it possible to furnish nearly everyone with dairy products daily Milk now moves hundreds of miles from surplus to deficient areas Decline in soil fertility in older farming sections has aided in the change from specialized crops to more cows and a more stable type of farming (*see* SOIL SOIL CONSERVATION) Less risk was involved income was constant and soil was better conserved Dairying also gave an opportunity to convert grass and other roughage more efficiently into good human food *See* AGRICULTURAL SOIL AND CROP PRACTICES GRASS CROPS

fluid milk and cream 22 3% as creamery butter 11 0% as cheese 5 0% as evaporated and condensed milk 6 7% as frozen dairy products 0 7% as dried whole milk and 1 9% as miscellaneous dairy products In 1850 there were slightly over 6 000 000 so-called milk cows in the country the

peak was reached in 1945 with over 27 000 000 head of milk cows and heifers over 2 years of age While 3 600 000 farmers keep these cows only 2 000 000 sell milk or cream and of these about 648 000 list dairying as their chief source of income

There are still many possibilities for more efficient production with the application of the knowledge developed over a century Recent studies in rapid milking methods new arrangement of barns improved nutrition and bulk milk handling equipment indicate that much can be done to reduce the cost of milk production and distribution and to increase the profit of dairy farmers

Per capita consumption of fluid milk and cream was 355 lb in 1956 and milk equivalent consumption was about 707 lb Total production of milk in 1956 was 125 000 000 000 lb 2 000 000 000 lb above the 1955 record Preliminary figures for 1957 indicated an increase to about 127 000 000 000 lb Leading milk producing states are Wisconsin New York Minnesota California and Pennsylvania It is estimated that dairy farmers earned $4 460 000 000 from milk sales alone in 1956 They collected $1 250 000 000 more from the sale of dairy cattle, or a total of $5 700 000 000 which represents 18% of the cash farm income in the United States *See* BUTTER CHEESE ICE CREAM MILK [R H LU]

Bibliography See AGRICULTURAL SCIENCE (ANIMAL)

Caudata

One of the orders of the class Amphibia also known as *the Urodela* The members of this order are the tailed amphibians or salamanders and are distinguished superficially from the frogs and toads *the order Salientia* by the possession of a tail and from the caecilians the order Gymnophiona by the possession of limbs

The Caudata are subdivided into three suborders *the Cryptobranchoidea* Salamandroidea and Meantes The Salamandroidea is sometimes considered as three separate suborders Ambystomoidea Salamandroidea and Proteida There are slightly less than 300 species of salamanders known to be living today and these are distributed among *approximately 9* families and 60 genera

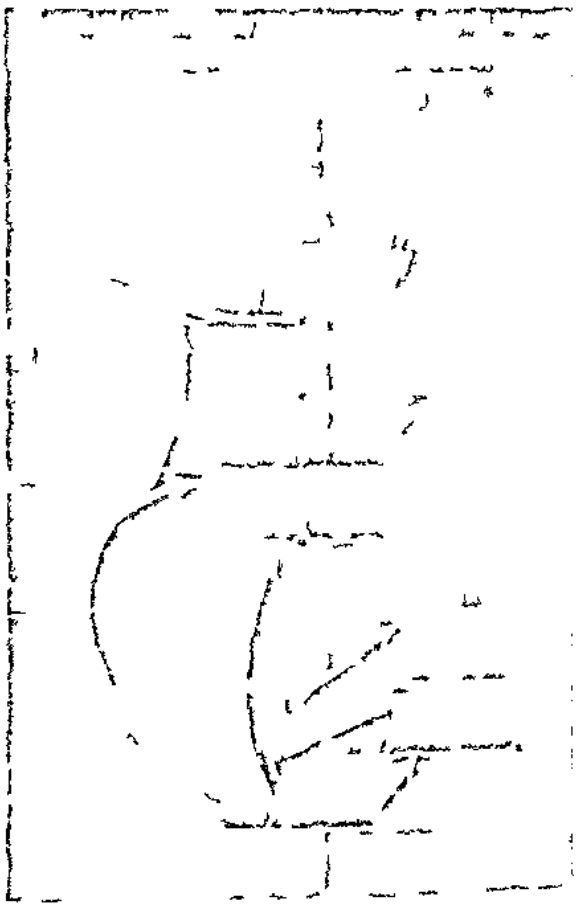


Fig 1 Diagram illustrating the phylogeny of the caudates The heavy black arrows indicate the phylogenetic relations The narrow horizontal arrows represent the ontogeny of the various families The degree of metamorphosis of the hyobranchial apparatus is employed as the chief criterion of metamorphosis in this diagram The permanent larvae are not closely related but have been derived from different groups (*From G K Noble The Biology of the Amphibia Dover 1954*)

Morphology In appearance salamanders resemble *lizards in* that members of both groups normally have a relatively elongate body four limbs and a tail The similarity is however only superficial The *most* obvious external difference the moist glandular skin of the amphibian and dry scaly skin of the *reptile* is underlain by the numerous characters that distinguish reptiles from amphibians

The vast *majority of salamanders* are small in size well under a foot in length The largest is the giant salamander *of Japan* and China which may attain a length of 5 ft A close relative the hellbender which *lives in streams* in the eastern United States grows to over 2 ft in length

Four well-developed limbs are typically present in salamanders *but the legs* of the mud eel *Amphiuma* of the southeastern United States are very tiny appendages and of no use in locomotion The sirens genera *Siren* and *Pseudobranchus* also aquatic salamanders of the same region have undergone even further degeneration of the limbs and retain only tiny forelimbs Salamanders with normal limbs usually have four toes on the front feet and five on the rear though a few have only four on all feet A feature of the Caudata not shared with the Salientia is the ability to regenerate limbs If a leg is bitten off or otherwise lost a salamander can grow a whole new limb

Physiology The moist and highly vascularized skin of a salamander serves as an organ of respiration and in some forms shares with the buccal region virtually the whole burden In one entire family of salamanders the Plethodontidae lungs are not present Even in those forms with lungs and gills dermal respiration plays a very important part

The tympanum is absent in salamanders and the middle ear is degenerate Hence these animals are deaf to airborne sounds Undoubtedly correlated

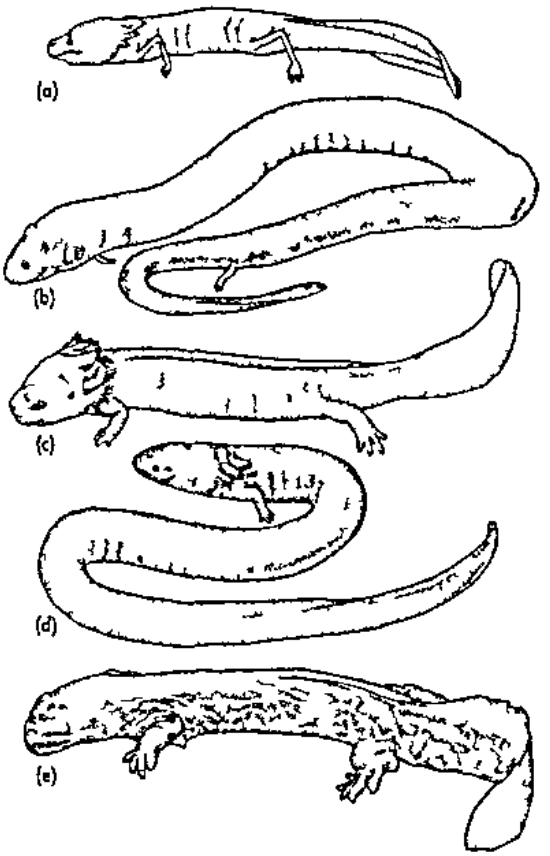


Fig 2 Permanent larvae the perennibranch and deciduous salamanders (a) *Typhlomolge rathbuni* length to 3 in (b) *Amphiuma means* length to 3 ft (c) *Nectu us maculosus* length to 18 in (d) *S iren lacer tina* length to 25 in (e) *Cryptobranchus allegan ens s* leng h to over 2 ft (*From G K Noble The B ology of the Amph b a Dover 1954*)

with this is the reduction of voice In contrast to the highly vocal frogs salamanders are mute or produce only slight squeaking or rarely barking sounds when annoyed However salamanders can detect sounds carried through ground or water

Ecology Salamanders live in a variety of aquatic or moist habitats Many forms are wholly aquatic liv ng in streams rivers lakes and ponds Others live on land most of the year but must return to water to breed The most advanced species live out the r l ves in moist places on land or in the case of some tropical species in trees and never go in the water

Reproduction The habit of producing the young alive rather than laying eggs is very rare among salamanders and almost all species lay eggs The eggs of salamanders may be deposited in water or in moist places on land Presumably aquatic breed ng is the more primitive Fertilization is external in the Cryptobranchoidea internal by means of spermatophores in the remaining suborders The spermatophore is a gelatinous capsule of sperm de posited by the male salamander in the course of an often elaborate courtship The female salaman der picks up the capsule with her cloacal lips and reta ns the sperm in her body until the eggs are fert lized and laid The young salamander that hatches from the egg may have the adult mor phology in the case of advanced forms but usually it emerges as a larva The larva of a salamander resemb les the adult closely in contrast to the larva of a frog and differs in possessing gills and in be ing sexually immature as well as in histological and other internal characters There are sala manders in which metamorphosis from larval to adult morphology does not take place and sexual maturity is attained in the larval condition This condition is known as neoteny In some forms it is a permanent unchangeable condition while in oth ers the larva can be made to undergo metamor pho is by treatment with thyroid hormone *See* NEOTENY THYROID GLAND

Nutrition Both as larvae and as adults sala manders are almost wholly carnivorous Few spe cies take anything but invertebrates in their diet alth ugh larger forms may eat small vertebrates such as frogs and fish Some are known to eat both plant material and invertebrates

Distribution The greatest concentration of fami lies and genera of salamanders is found in the east ern United States and these animals are one of the few major groups of animals that is distinctly non tropical No salamander occurs south of the Equator in the Old World and only a few species of the evolutionarily advanced family Plethodonti dae are found as far south as South America in the New World *See* AMPHIBIA GYMNOPHIONA SALIENTIA [R G Z]

Cauliflower

A cool season biennial crucifer (*Brassica oleracea* var *botrytis*) of Mediterranean origin Cauliflower belongs to the plant order Papaverales It is grown for its white head or curd a tight mass of flower



Caul flower *Brass ca oleracea* var *botryt s*

stalks which terminates the main stem Cultural practices are similar to those used for cabbage however cauliflower is more sensitive to unfavor able environment Strains of the variety Snowball are most popular purple headed varieties are less common Cauliflower is slightly tolerant of acid soils and has high requirements for boron and molybdenum A cool moist climate favors high quality Harvest is generally 3–4 months after planting California and New York are imp cauliflower producing states Annual farm the United States is $15 000 000 *See* PAPAVERALES VEGETABLE GROWING

Caulobacteraceae

A family of stalked aquatic bacteria Each bacterial cell forms a stalk by which attachment to a solid substrate is accomplished The four genera (*Caulobacter Gallionella, Siderophacus* and *Nevskia*) of the family are placed in the Pseudomonadales, an order of gram negative true bacteria possessing polar flagella The family is merely a convenient taxonomic grouping at the present time and probably does not represent any true relationship among the four genera *See* PSEUDOMONADALES

Caulobacter. In the genus *Caulobacter* the stalk is part of the living cell being a continuation of the long axis of the cell Free swimming cells are motile by a single polar flagellum a flagellum may also be formed at the end of the stalk Cells measure 0 5–1 2 μ in width by 1 5–3 0 μ in length Rosettes of cells are commonly found in the surface film of lakes and ponds as well as attached to solid substrates in deeper water Cultivation is obtained on agar containing low concentrations of peptones or yeast extract Colonies may reach diameters of up to 5 mm and may be pigmented orange or red

Gallionella In the genus *Gallionella,* a twisted stalk composed of ferric hydroxide is formed from one side of a bean shaped cell The stalk is composed of fine strands Transverse binary fission of the apical cell gives rise to dichotomous branching of the stalk The organism is found only in iron bearing waters, and may be continuously cultivated in water containing ferrous sulfide carbon dioxide ammonium chloride calcium chloride magnesium sulfate and phosphate Evidently energy is obtained from the oxidation of ferrous ions



Fig 1 Electron micrograph of *Caulobacter* species showing cells and stalks. (J Wachsman)



Fig 2 Electron micrograph of *Gallionella ferruginea* showing apical cells which have secreted a multistranded stalk of ferric hydroxide (*From A E Vatter and R Wolfe, Electron microscopy of Gallionella ferruginea J Bacteriol , 72(2) 248–252, 1956*)

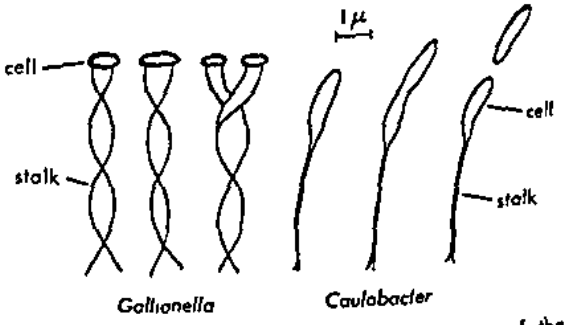


Fig 3 Line drawing showing a comparison of the mode of cell division by two types of stalked bacteria

Cells are usually about 0 6 μ in width by 1 5 μ in length Width of the stalk depends upon the degree of branching, and length may be several hundred microns

Siderophacus and Nevskia. The genera *Siderophacus* and *Nevskia* accommodate two little studied, stalked organisms *Siderophacus corneolus* produces an unbranched horn shaped stalk containing ferric hydroxide whereas *Nevskia ramosa* produces a dichotomously branched stalk composed of gummy material In both organisms, stalks arise from a common holdfast [R S W]

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Causality

Causality often is equated with strict determinism namely the principle that complete knowledge of the present state of the universe enables complete prediction of its future course On this basis classical mechanics is a causal theory but quantum mechanics wherein predictions of the results of experiment are intrinsically statistical seems not to be causal For instance according to quantum theory while the average position of an electron in a series of identical experiments is exactly predictable its measured position in any one experiment is not predictable The correspondence principle explains this apparent failure of causality on the basis that the complete knowledge necessary for complete prediction is inherently unattainable any experiment that gains some information loses other information Consequently the most completely attainable information at time t_0 describes the electron by a wave function $\psi(t_0)$ which predicts average or expectation values only nevertheless quantum mechanics is deterministic in the sense that the wave function $\psi(t)$ at times $t > t_0$ is completely predictable from knowledge of $\psi(t_0)$ *See* QUANTUM MECHANICS

Causality also has been taken to mean that the fundamental laws of nature do not depend on the origin of time that is that predictions about the future course of a system must be precisely repeated if the original state should be precisely duplicated at a future time this definition of causality is clearly tautological however

The term causality has also been employed with reference to the principle that an event cannot precede its cause in relativistic theories this principle implies that the effects of a causative event cannot propagate more rapidly than the speed of light (*see* RELATIVITY) This simple principle leads to surprisingly stringent restrictions on the possible forms of physical theories for example one infers that the dependence on wavelength of the index of refraction of a medium bears a necessary relation to its absorption [E G]

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Cave

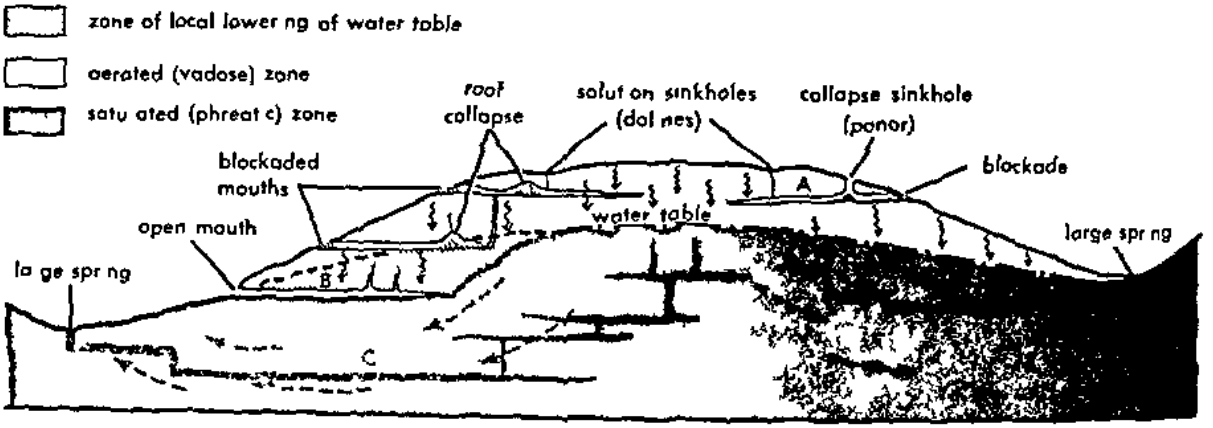
A natural cavity in rock beneath the surface of the earth Most caves have been formed in calcareous rock (limestone and dolomite) by the dissolving action of ground water circulating along the partings in the rocks Such partings include already existing joints and bedding (stratification) planes Joints commonly occur in sets as semi parallel and nearly vertical planes the sets intersecting each other at large angles Bedding planes usually are horizontal The intersection of these planes accounts for the three-dimensional pattern observed in caves but in most caves the horizontal extent greatly exceeds vertical development

Only beneath swamps and marshes does ground water completely saturate subjacent soil and the deeper bedrock Beneath uplands the saturated zone may be far below the surface of the land with a zone of aeration intervening In this zone meteoric water (of atmospheric origin) moves downward through the partings and interstitial spaces until it reaches the top of the saturated zone or water table Below the water table ground water movement is largely lateral Where the underground flow nears the surface of adjacent lowlands it may emerge as springs and seepages The zone of aeration is known as the vadose zone and the saturated zone as the phreatic zone Enterable caves must be in the vadose zone

Many caves have streams with fairly low gradients This has given rise to the idea that the cave is essentially a stream made valley with a roof the vertical dimensions of the cave being considered a measure of the stream s downcutting since its initiation as a subterranean watercourse Dry caves by this view have simply lost their causal streams In 1930 W M Davis challenged this once prevalent idea Davis proposed that the cave floor stream found its route already largely developed that the cave had been made earlier by a hydraulic circulation below the water table a circulation comparable to that in a water main under hydrostatic pressure Under these conditions in the phreatic or saturated zone tube full flow attacked walls and ceilings as well as floors Caves thus become enlarged upward and sidewise as readily as downward

The Davis theory considered that because of later deepening of adjacent surface river valleys the water table became lowered to drain the cave and allow air to enter for the first time Being thus shifted to the vadose zone the cave collected drip water to constitute the free surface stream on the floor (Fig 1)

One of the most convincing evidences for the Davis concept is the ground plan of intersecting joint controlled passages in many caves Cameron Cave near Hannibal Missouri is an outstanding illustration of the network type of cave (Fig 2) With an essentially level floor the area involved is about 30 acres while the total of all passage lengths is almost 4 miles Four sets of joints are recognizable in Cameron s labyrinthine maze and widths of passages along them are nearly uniform The pattern cannot be resolved into a main channel and its tributaries Cameron Cave underlies the full width of a hill about 150 ft high and has about two dozen passage terminations in the hill s lower slopes now blockaded by debris which has crept or slid down the slope An impervious shale overlies the limestone formation which contains the cave and has denied any possible entrance of water from above The many intersections with the hillside make it clear that the cave system is older than the stream carved topography of the vicinity This conclusion is confirmed by the existence of another and very similar cave Mark Twain Cave just across local stream valley The two are but survivors of a once larger cave now largely severing valley Both caves



Fg 1 General zed cross sect on show ng relations of caves to water table in hor zontally bedded vert cally jointed rock A Streamless caves may have wet weather contr but ons from s nkholes B Caves w th streams on the floor may have perenn al flow if they tap the saturated zone C Tube full caves below water table are grow ng caves

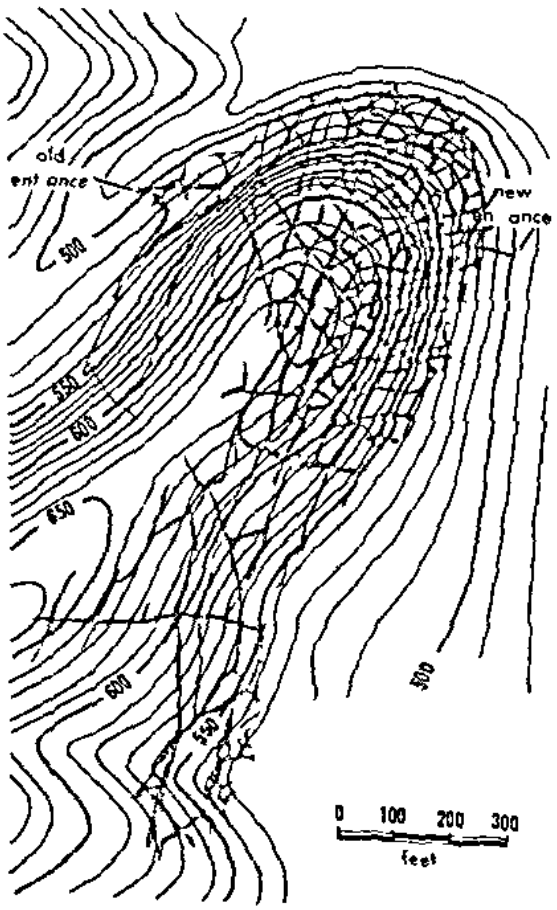
when that deepening valley lowered the water table past their level and thus brought the phreatic circu lation to an end

Bedding planes instead of joints may be the dominant factor that determines the ground plan of many caves A recurring feature in such caves is that of satellitic caves connected with the main cave Such systems of repeatedly uniting and divid ing passages may constitute very irregular anasto-moses chiefly in the horizontal Again is indicated a hydraulic circulation before the water table was lowered

Most enterable caves are undergoing deteriora tion from fall of ceiling rock deposition of stream debris and growth of stalactites stalagmites flow stone and other forms of secondary limestone de-posited by drip water These alterations result from transfer of the cave to the vadose zone *See* STA LACTITES AND STALAGMITES

Caves of no great length may be formed by me-chanical erosion of waves against coastal cliffs and by weathering attack on cliffs of jointed rock Lava flows may on cooling develop a stiff upper cru t over still molten rock which continuing to flow after supply at the source has ceased may leave long caves *See* KARST TOPOGRAPHY WEATHERING PROCESSES [J H B]

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Fg 2 Map of Cameron Cave Hannibal M ssour (M ssouri Geolog cal Survey)

Cavitation

The formation of vapor or gas filled cavit es in liquids by mechanical forces If understood in this broad sense cavitation includes the familiar phe-nomenon of bubble formation when water is b ro ught to a boil and the effervescence of champagne wines and carbonated soft drinks In engineering termi nology the term cavitation is u sed in a narrower sense namely to describe the formation of vapor filled cavities in the interior or on the solid bounda ries of vaporizable liquids in motion when the pressure is reduced to a critical value witho t change in ambient temperature Cavitation in the engineering sense occurs at suitable combinat ns of low pressure and high speed in pipe lines in hydraulic machines such as turbines pumps and propellers on submerged hydrofoils behind bl nt

submerged bodies, and in the cores of vortices This type of cavitation has great practical signifi cance because it restricts the speed at which hy draulic machines may be operated and when se vere, lowers efficiency produces noise and vibra tions and causes rapid erosion of the boundary surfaces even though these surfaces consist of con crete cast iron bronze or other hard and nor mally durable material The subsequent discussion will be limited to cavitation in the narrower sense as understood in engineering terminology

As mentioned cavitation occurs when the pres sure in a liquid is reduced to a critical value For the present it will be assumed that this critical value is the vapor pressure p_v of the liquid For clean fresh water at 70°F and at sea level p_v has a value of about 52 lb/ft² hence when a body is moving with velocity V through water at ordinary temperature and the pressure on its surface is re duced to or near 52 lb/ft² cavitation may be ex pected to occur The condition for the onset of cavitation is therefore

$$p_m \leqslant p_v \tag{1}$$

where p_m is the minimum pressure at any point on the surface of a moving body and p_v is the vapor pressure of the liquid at the prevailing tempera ture Inversely the condition for avoidance of cavi tation is

$$p_m > p_v \tag{2}$$

Bernoulli's principle A more practical relation than Eq (2) is obtained when the pressure p_m is expressed in terms of easily measurable reference values. This can be done by use of Bernoulli s prin ciple According to this principle the sum of pres sure head and velocity head in a frictionless in compressible medium remains constant along a streamline To make this clear assume a sphere to be held stationary in a stream flowing from right to left with constant velocity V as shown in Fig 1 Consider two points A and B lying on the same streamline and let point B be the point where the local pressure is minimum Writing Bernoulli s equation for these points yields the following ex pression

$$p_m = p_a + p_s - \frac{\rho}{2} V^2 \left[\left(\frac{v}{V} \right)^2 - 1 \right] \tag{3}$$

where p_m = absolute local pressure at point B
v = velocity at point B
V = velocity of undisturbed flow at point A
p_a = pressure on free surface
p_s = hydrostatic pressure at point A
ρ = density of liquid

The term in the bracket on the right side of Eq (3) is independent of the absolute speed V because v changes proportionally to V It follows that for constant values of p_a and p_s the pressure p_m may be reduced to the vapor pressure p_v to zero or even to negative values by increasing the speed V Negative values for p_m have been obtained in car fully conducted laboratory tests proving that a pure liquid such as clean air free water may sus tain tension However in most practical cases negative values are not obtained instead the flow is disrupted and cavities are formed at small posi tive values as previously explained Combining Eqs (2) and (3) the condition for avoidance of cavitation becomes

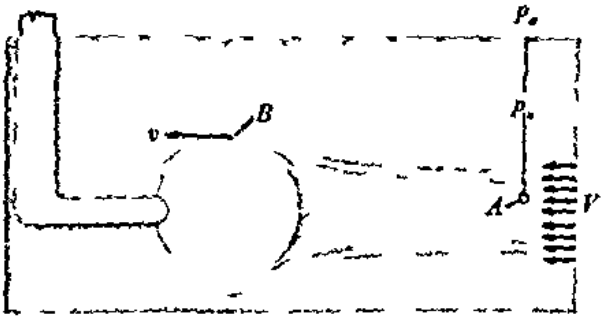


Fig 1 Flow around a sphere in a frictionless incom press ble fluid

$$\frac{p_a + p_s - p_v}{(\rho/2)V^2} > \left[\left(\frac{v}{V} \right)^2 - 1 \right] \tag{4}$$

Cavitation number The term on the left of this inequality contains easily measurable values and is usually denoted by σ It is called the cavitation number The magnitude of the term on the right can be calculated for the sphere and other simple bodies but for more complex configurations it can not be calculated and must be obtained by experi ment Denoting this value by σ_c the condition for avoidance of cavitation has the form

$$\sigma = \frac{p_a + p_s - p_v}{(\rho/2)V^2} > \sigma_c \tag{5}$$

The cavitation number σ is used for flow through pipes flow around submerged bodies and in the design of marine propellers In pump and hydraulic turbine work slightly different expres sions are used The simplest one is the expression first introduced by D Thoma which has the form

$$\sigma_T = \frac{H_{sv}}{H} > (\sigma_T)_c \tag{6}$$

where H_{sv} is the net positive suction head at the pump inlet or just below the turbine runner and H is the total head under which the turbine or pump operates The value of (σ_T) like the value of σ_c is a fixed number for a given design of pump or turbine which in general must be found by ex periment

Experiments to determine σ_c and (σ_T) are usu ally made on models geometrically similar to but smaller than the prototype installations This has the advantage of cheapness and flexibility and permits correction of undesirable characteristics of a design before the prototype machine is actually constructed For instance should it be found in a model test that a given propeller design cavitates heavily at the design operating value different com binations of diameter and pitch revolutions blade

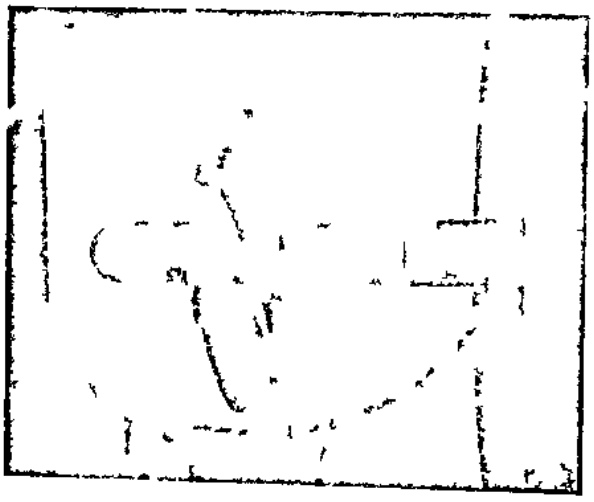


Fig 2 Transient cavitation on screw propeller observed in water tunnel at David Taylor Model Basin (*U S Navy photograph*)

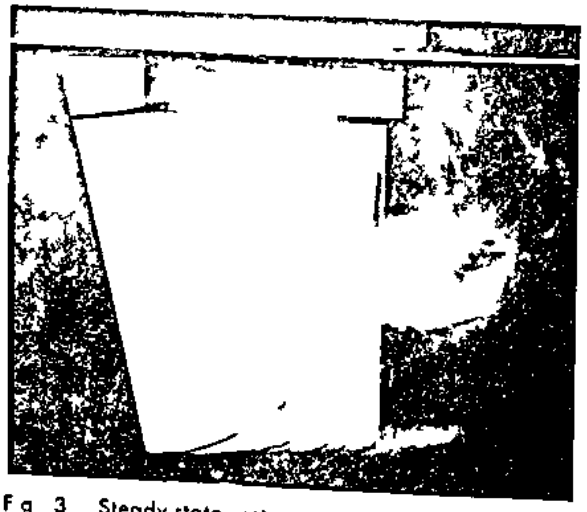


Fig 3 Steady state intermittent and vortex cavitation on model of ship's rudder observed in 24 in water tunnel at David Taylor Model Basin (*U S Navy photograph*)

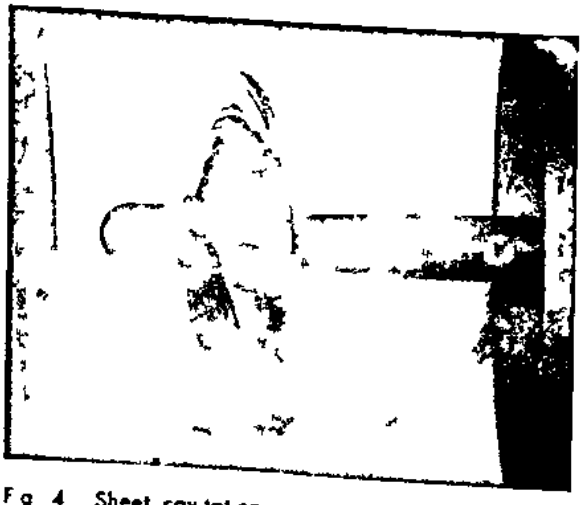


Fig 4 Sheet cavitation on screw propeller observed in water tunnel at David Taylor Model Basin (*U S Navy photograph*)

width and outline or section shape may be tried to eliminate or alleviate the observed cavitation The same procedure is followed in the case of pumps and turbines

Types of cavitation It has been found convenient to differentiate between a type of cavitation in which small bubbles suddenly appear on the solid boundary grow in extent and disappear and another type in which cavities form on the boundary and remain attached as long as the conditions that led to their formation remain unaltered The former type is known as bubble or transient cavitation the latter as steady state or sheet cavitation An example of the first kind is shown in Fig 2 examples of the second kind are shown in Figs 3 and 4

Physical causes of cavitation The exact mechanism of the disruption of a liquid when pressure is reduced is not fully understood Thus experiments and calculations show that pure air free still water may sustain tension up to several hundreds of atmospheres before disruption takes place on the other hand numerous experiments have shown that in ordinary flowing water cavitation commences as the pressure approaches or reaches the vapor pressure This discrepancy may be accounted for by the fact that ordinary water contains dissolved and entrained air or gas as well as solid particles and therefore is not pure in the foregoing sense By way of explanation it is postulated that the presence of these foreign substances together with pressure fluctuations in turbulent flow interrupts the continuity of the liquid and lowers its surface tension Microscopic cavities formed at these discontinuities or nuclei fill with vapor and small amounts of air or gas drawn from solution as the ambient pressure is reduced This process continues until equilibrium between the various forces acting on the surface of these cavities is established This postulate fits the observed facts that bubbles appear at discrete spots in low pressure regions grow quickly to relatively large size and suddenly collapse as they are swept into regions of higher pressure

Effects of cavitation It was mentioned initially that cavitation when severe lowers the efficiency of a machine produces noise and vibrations and causes rapid erosion of boundary surfaces An example of the drop in efficiency of a hydraulic tur

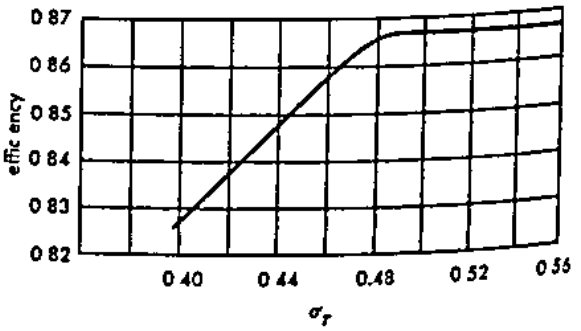


Fig 5 Drop in efficiency of hydraulic turbine caused by cavitation (*After G F Wislicenus*)

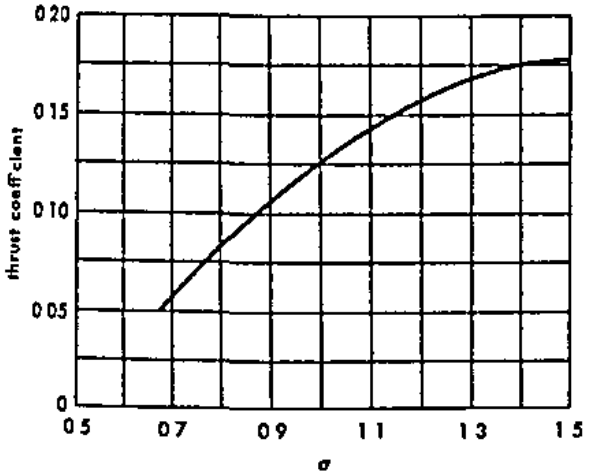


Fig 6 Loss of thrust of screw propeller due to cavitation

bine after cavitation is fully developed is shown in Fig 5

An example of the deleterious effect of cavitation on the thrust of a marine propeller with decreasing σ is shown in Fig 6 Examples of the destructive effect of cavitation on solid surfaces are shown in Figs 7 and 8 This effect may be explained as follows When cavitation bubbles form they grow to full size in a very short time—about 2 milliseconds This time interval is too short for much air or gas to come out of solution so that the bubbles are highly evacuated On subsequent collapse in an equally short time interval the liquid particles rush toward the center of the bubble virtually unimpeded and impinge on the surface with very high velocities It is estimated that the surface stress caused by the impingement is on the order of 1000 atmospheres which is sufficiently high to cause fatigue failure of the material in relatively short time Some investigators hold that the explosive formation of the bubbles intercrystalline electrolytic action and the collapse of the bubbles all are factors contributing to the observed destruction

Supercavitating propellers The limitation on ship speed caused by loss of thrust when cavitation is severe has been overcome by a radical departure from conventional propeller designs In this new design cavitation on the backs of the blades (forward side) is induced by special blade sections at relatively low forward speed so that when revolutions and engine power are increased the whole back of each blade becomes enveloped by a sheet of cavitation When this is completed further increase in thrust at still higher engine power and rpm is obtained by the increase in positive pressure on the blade face (rear side) erosion is avoided because the collapse of the cavitation bubbles occurs some distance behind the trailing edges of the blades A photograph of such a supercavitating propeller in action is shown in Fig 9 The supercavitating propeller is no replacement for the conventional propeller being suitable only for very high ship and engine speeds At present (1959) it



Fig 7 Cavitation erosion on concrete specimens (*U S Bureau of Reclamation photographs*)



Fig 8 Cavitation damage on a marine propeller (*U S Navy photograph*)

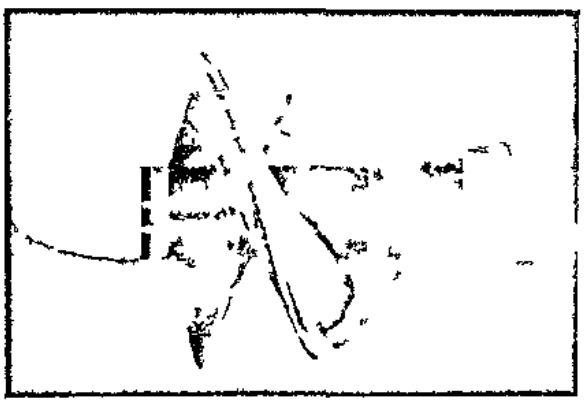


Fig 9 Supercavitating propeller in 24 in water tunnel at David Taylor Model Basin (*U S Navy photograph*)

has few applications (for example on hydrofoil craft) but as new hull forms and new engines are developed it undoubtedly will find increasing use
See BERNOULLI'S THEOREM PROPELLER MARINE ULTRASONICS [K E S]

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Cavity resonator

An enclosure with conducting walls surrounding a dielectric medium capable of resonating with electromagnetic waves It is used mainly as a source of electromagnetic oscillations at microwave or ultra high frequencies The conducting walls are usually made of metal such as copper or silver while the dielectric medium is usually air or vacuum The enclosure has at least one aperture for coupling the electromagnetic energy between the inside and outside of the cavity

Cavity resonance For an electromagnetic wave to exist inside a cavity the electric and magnetic field intensities must be solutions of Maxwell's equations and at the same time they must satisfy the boundary conditions on the inside surfaces of the cavity walls For all practical purposes it can be assumed that the wall conductivity is so high that the tangential component of the electric field vanishes everywhere along the inside walls This restriction requires that only waves of certain discrete frequencies be allowed in the cavity Thus when the frequency of an exciting wave is varied the cavity does not extract or contain any energy from the wave unless the exciting frequency happens to be one of the allowed values When the latter condition holds then the cavity will resonate strongly with the exciting wave by absorbing a part or all of the incoming energy The cavity is thus acting as a resonator

The values of the resonant frequencies of a cavity depend on the size shape dielectric material and the mode of operation (TE or TM modes for definition *see* WAVE GUIDE) The values can be calculated with high precision for cavities of regular shapes (rectangular circular cylindrical and so on) or they can be directly calibrated by measuring the resonant frequencies with respect to a frequency standard When there is a choice it is customary to use a cavity at its lowest resonant frequency

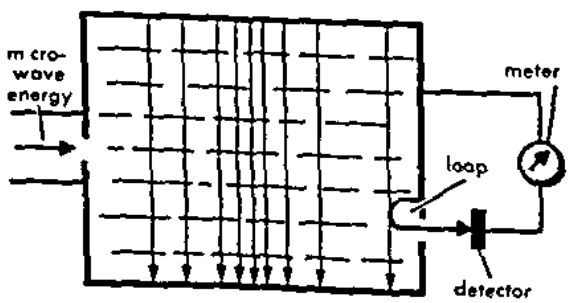


Fig 1 A resonant cavity with a field measuring probe Solid lines indicate the electric field and dashed lines the magnetic field

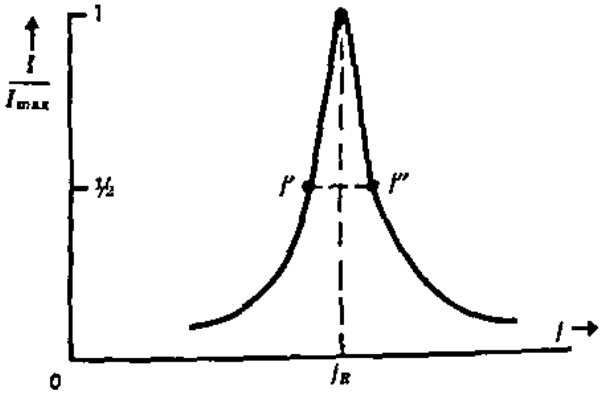


Fig 2 Typical resonance curve of a cavity

Cavity quality factor For simplicity of discussion assume the cavity has a single resonant frequency f_R Suppose a field probe like a small loop is placed inside the cavity which can measure the field intensity by an external detecting circuit (Fig 1) while drawing negligibly small power from the cavity The current I in the meter can be taken to be proportional to the square of the magnetic field intensity As the exciting frequency f is varied resonance spreads over a narrow band of frequencies instead of being a sharp line at f_R (Fig 2) As a measure of resonance width a quality factor Q_L is defined by the expression

$$\frac{1}{Q_L} = \frac{f - f'}{f_R} \tag{1}$$

where $f'' - f$ is the frequency width of resonance at $I/I_{max} = \frac{1}{2}$ points

It can be shown that the quality factor has the physical significance given by

$$\frac{1}{Q_L} = \frac{\text{energy lost by cavity per radian of oscillation}}{\text{energy stored in cavity}} \tag{2}$$

Combining Eqs (1) and (2) it is seen that for a constant energy storage in the cavity the smaller the energy loss the sharper the resonance A cavity which has a small energy loss is commonly known as a high Q cavity Except for special requirements a cavity's Q is usually preferred to be as high as possible

The energy loss in a cavity can be divided into the internal loss due to energy dissipation on the cavity walls and in a lossy dielectric material (if any) and the external loss of energy through the coupling aperture sometimes called the window Application of Eq (2) leads to the expression

$$\frac{1}{Q_L} = \frac{1}{Q_i} + \frac{1}{Q_e} \tag{3}$$

where Q is known as the internal or unloaded Q Q_e the external or window Q and Q_l the

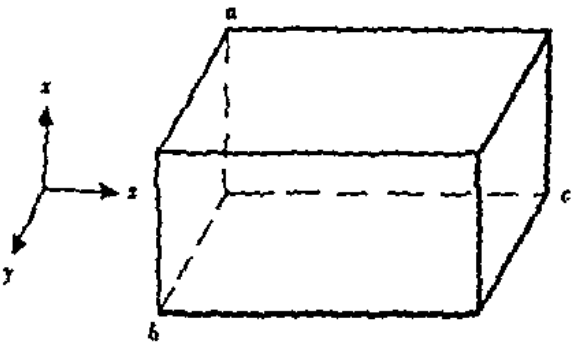


Fig 3 A rectangular cavity (coupling hole omitted)

loaded Q Since the ratio Q_e/Q_l can be directly determined by measuring the standing wave ratio (caused by incident and reflected waves) external to the cavity, the individual quality factors can all be evaluated In particular, if $Q = Q_e$, then the cavity becomes nonreflective at f_R with respect to the incident wave and is said to be matched a condition often desired in practice

Forms of resonators. Various forms of cavity resonators have been used for microwave or ultra high frequency application A rectangular cavity is particularly simple for construction and analysis For instance, a short section of wave guide closed by two end conducting plates forms a usable cavity The resonant frequency of a rectangular cavity (Fig 3) can be determined by the formula

$$f_{nml} = v_0 \sqrt{\left(\frac{n}{2a}\right)^2 + \left(\frac{m}{2b}\right)^2 + \left(\frac{l}{2c}\right)^2} \qquad (4)$$

where n, m, l are integers (only one of them can be zero for a TE mode and none can be zero for a TM mode) v_0 is the velocity of propagation in the dielectric medium (substantially the velocity of light for air or vacuum), and a, b, c are the dimensions of the cavity Loaded Qs for rectangular cavities are typically of the order of 5000–10 000

Circular cylindrical cavities are much used particularly the tunable ones, for wavemeter application (Fig 4) Here the movable cavity wall is in the form of a circular piston Lack of intimate contact between the piston and the cylindrical cavity wall is either nonessential in some cases (where

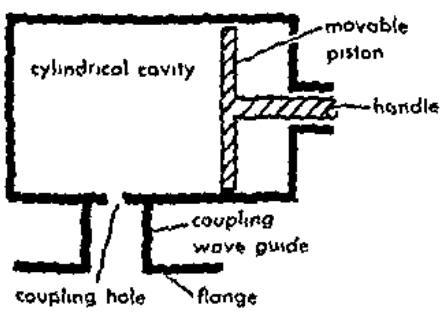


Fig 4 A circular cylindrical cavity used as a wavemeter

no current flows across the gap), or can be compensated for by a choke arrangement which artificially creates a nodal zone for the current at the gap Wavemeters can be made into accurate direct reading instruments for measuring wavelengths (*see* WAVEMETER) In other areas of application circular cylindrical cavities are particularly desirable for obtaining higher Qs (for instance with a TE_{011} mode) than is possible with a rectangular cavity

Coaxial cavity resonators are often used as wavemeters, particularly for lower than microwave frequencies The so-called reentrant cavities are sometimes used for certain special purposes

Since cavity resonators are essentially frequency selective circuit elements for microwaves, they are very useful as components in a microwave filter network In a radar set a resonant cavity can be used in a so called TR box where a gas filled cavity breaks down to a short circuit impedance to protect the receiver from damage when the high powered transmitter starts working (*see* RADAR) In high energy linear accelerators, resonant cavities are used to accelerate charged particles in intense high frequency electric fields *See* PARTICLE ACCELERATOR, *see also* KLYSTRON [C K J]

Bibliography *See* MICROWAVE

Cayley-Klein parameters

A set of four complex numbers used to specify the orientation of a body They can be expressed in terms of the Euler angles ψ θ and ϕ (*see* EULER ANGLES)

$$\alpha = \cos\frac{\theta}{2}\, e^{-i(\psi-\phi)/2} \qquad \beta = -i\sin\frac{\theta}{2}\, e^{i(\psi-\phi)/2}$$

$$\gamma = -i\sin\frac{\theta}{2}\, e^{-i(\psi-\phi)/2} \qquad \delta = \cos\frac{\theta}{2}\, e^{i(\psi+\phi)/2}$$

Often the set $\delta \; -\beta \; -\gamma \; \alpha$ is used with slightly different properties from those given here The four complex numbers contain eight real numbers and satisfy the relations

$$\delta = \bar{\alpha} \qquad \gamma = -\beta \qquad \alpha\delta - \beta\gamma = \alpha\bar{\alpha} + \beta\bar{\beta} = 1$$

where the bar denotes complex conjugate These constitute five real relations leaving three independent parameters as required

The Cayley Klein parameters combine in a simple way under compound rotations when they are arranged in the square matrix array,

$$\begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix}$$

If α β, γ δ correspond to a rotation R_1 and α', β γ' δ' to R_2 then the parameters α'', β'', γ'', δ'' of the rotation R_2R_1 (R_1 first then R_2) are found by matrix multiplication (*see* MATRIX THEORY) Thus

$$\begin{pmatrix} \alpha'' & \beta'' \\ \gamma'' & \delta'' \end{pmatrix} = \begin{pmatrix} \alpha' & \beta' \\ \gamma' & \delta' \end{pmatrix}\begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix}$$

A rotation $R(\psi\,\theta\,\phi)$ can be produced by three successive rotations The corresponding decomposition of the Cayley Klein parameter matrix is

$$\begin{pmatrix}\alpha & \beta\\ \gamma & \delta\end{pmatrix} \quad \begin{pmatrix}e^{i\psi/2} & 0\\ 0 & e^{-i\psi/2}\end{pmatrix}\begin{pmatrix}\cos\frac{\theta}{2} & -i\sin\frac{\theta}{2}\\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2}\end{pmatrix}\begin{pmatrix}e^{i\phi/2} & 0\\ 0 & e^{-i\phi/2}\end{pmatrix}$$

Although these parameters have been used to simplify somewhat the mathematics of spinning top motion their main use is in quantum mechanics There they are related to the Pauli spin matrices and represent the change in the spin state of an electron under the space rotation $R(\psi\,\theta\,\phi)$ [B G]

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Caytoniales

A group of Mesozoic plants first recognized in 1925 The remains consist of palmately compound leaves with 3 6 lanceolate leaflets previously known as *Sagenopteris phillipsi* pinnately branched microsporophylls (named *Caytonanthus arberi*) that bore winged pollen in 4-chambered microsporangia and fruit bearing inflorescences *Caytonia* (with two species) which bore a dozen or more globular short stalked fruits in subopposite rows Each fruit was 5 mm or less in diameter Near the attachment stalk at the lower part of the fruit was a small transverse lip beneath which was a minute depression marking the place where a small opening formed at pollination time This opening admitted the pollen into the interior where small orthotropous ovules were attached to the surface The inflorescence thus resembled a simply pinnate frond of which the individual pinnules were curved so as to enclose the seeds When first discovered it was believed that the flap served as a stigmatic surface to receive the pollen in a manner similar to the stigma of a modern flower Later it was found that the pollen actually entered the young fruit through the small opening and germinated on the nucellus of the ovule after the manner in gymnosperms The Caytoniales appear related to the pteridosperms They range from Triassic to Cretaceous *See* PALEOBOTANY [C A AR]

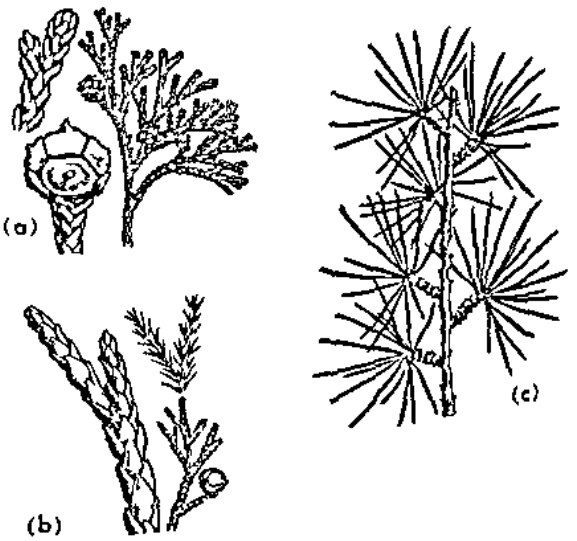
Cedar

Any of a large number of evergreen trees having *fragrant* wood of great durability Arborvitae is sometimes called northern white cedar (*see* ARBORVITAE) *Chamaecyparis thyoides* is the botanical name of the southern white cedar which may grow to a height of 75 ft It is characterized by small *spherical cones* with peltate seed bearing scales fitted together to form a little ball and by small scalelike evergreen leaves It grows only in swamps near the *eastern coast* of North America where it is also known as Atlantic white cedar The wood is soft fragrant and durable in the soil and is used for boxes crates small boats tanks woodenware poles and shingles

The Port Orford cedar, *Chamaecyparis lawsoniana* also known as Lawson cypress grows to 180 ft has spherical cones a little larger than those of the eastern species and is native to southwestern Oregon and northwestern California It is the principal wood for storage battery separators but is also used for venetian blinds and construction purposes It is an ornamental tree which is sometimes used in shelter belts

Alaska cedar, *Chamaecyparis nootkatensis* found from Oregon to Alaska grows to 120 ft and has larger spherical cones which are nearly ⅓ in in diameter The wood is used for interior finish cabinet work, small boats and furniture It is also grown as an ornamental tree

Incense cedar *Libocedrus decurrens* a beautifully formed tree which grows to 135 ft is found from Oregon to western Nevada and Lower California The cones ¾–1 in long resemble those of arborvitae Incense cedar provides one of the chief woods for pencils but it is also used for venetian blinds, rough construction fence posts and as an ornamental and shade tree



(a) Southern white cedar, *Chamaecyparis thyoides* (b) Eastern red cedar *Juniperus virginiana* (c) Atlas cedar *Cedrus atlantica* (From A H Graves *Illustrated Guide to Trees and Shrubs* Harper 1956)

Eastern red cedar *Juniperus virginiana* which may reach a height of 90 ft is widely distributed over the eastern United States and adjacent Canada Its leaves evergreen and scalelike occur in four rows lengthwise on the branchlets giving a four sided appearance On young trees or on vigorous shoots the leaves are needlelike sometimes in threes The fruit is spherical berrylike about ¼ in in diameter, and borne on the female tree Male trees bear only stamens The very fragrant wood is durable in the soil and is used for fence posts chests wardrobes flooring and pencils Cedarwood oil is used in medicine and perfumes

Cedar of Lebanon and Atlas cedar *Cedrus libani* and *C atlantica* resemble the larch but the leaves are evergreen and the cones are much larger and erect on the branches (*see* LARCH) The cedar of Lebanon a native of Asia Minor has cones 3–4 in long and 1½–2¼ in in diameter and is sometimes cultivated in the United States The Atlas cedar is hardier and the variety *glauca* is popular as an ornamental

The Deodar cedar *Cedrus deodara* a beautiful tree with large leaves and drooping branches is a native of India and although not hardy in the northern United States it is widely cultivated in the Southeast and in California

The cigarbox cedar *Cedrela odorata* also known as the West Indian cedar belongs to the mahogany family is a broad leaved tree with pinnate deciduous leaves and is related to the *Ailanthus* and sumac The wood is very durable and fragrant and is valued in the West Indies for the manufacture of cabinets furniture and canoes It seldom grows well in the northern United States *See* FOREST AND FORESTRY TREE [A H G]

Celery

A biennial umbellifer (*Apium graveolens* var *dulce*) of Mediterranean origin and belonging to the plant order Umbellales Celery is grown for its petioles or leafstalks Celeriac or knob celery (*A graveolens* var *rapaceum*) is grown for its enlarged rootlike stem and is commonly eaten as a cooked vegetable in Europe

Propagation of celery is by seed planted in the field or sown in greenhouses or outdoor beds for the production of transplants Field spacing varies plants are generally grown 6–10 in apart in 18–36 in rows Celery requires a long growing season cool weather and unusually abundant soil moisture It has a high requirement for boron a deficiency of which results in cracked stem Exposure to prolonged cold weather (40 50°F for 10–30 days) favors bolting or seed stalk formation

Varieties are classified primarily according to their color green or yellow (self blanching) The most popular green variety is Utah of which a large number of strains are grown such as Summer Pascal Utah 52–70H and Utah 15 Important yellow varieties are Cornell 19 and Golden Plume Pink and red varieties are grown in England

Harvesting begins generally when the plants are fully grown but before the petioles become pithy usually 3–4 months after field planting In periods of high prices earlier harvesting is often practiced

California Florida and Michigan are important producing states The total farm value in the United States is approximately $53 000 000 *See* UMBELLALES VEGETABLE GROWING [H J C]

Celestial mechanics

The branch of astronomy in which theoretical mechanics is used to calculate motions of celestial bodies under the action of their mutual gravitational attractions Celestial mechanics is used to construct systematic dynamical theories of the actual translational motions of celestial bodies in space Although most highly developed for the solar system it has been applied to multiple stars and to a lesser extent to stellar motions in galactic systems Applications to rotational motion include the development of theories for precession and nutation as well as for tidal and other deformations of the figure of Earth

Basic concepts The mechanical principles involved stem directly from Newton s law of gravitation and represent the culmination of centuries of effort to associate observed effects with the forces that cause them The limited knowledge of mechanics during ancient and medieval times was restricted principally to statics only vague and mainly erroneous ideas prevailed about motion The principal error in thought that retarded the advance of mechanics during that period was the belief that a constantly acting force was required to keep a moving body in motion

In the sixteenth century on the basis of his experiments with falling bodies Galileo proposed the principle that acceleration or change of motion of a body is the result of the forces to which it is subjected With this principle Galileo was able to define mechanical laws governing the trajectories of falling bodies During the same period the famous Danish astronomer Tycho Brahe was completing a series of planetary observations from which his assistant Johann Kepler derived his three empirical laws of planetary motion summarized in the list below

1 The path of a planet about the Sun is an ellipse the Sun being at one of the foci

2 The line joining the Sun and a planet sweeps out equal areas in equal times

3 The squares of the periods of any two planets are in the same ratio as the cubes of their respective mean distances from the Sun

Sir Isaac Newton completed the formulation of the laws of motion begun by Galileo and Christian Huygens (see list below)

1 In the absence of external forces a body at rest remains at rest and a body in rectilinear motion remains in rectilinear motion (inertia)

2 The acceleration imparted to a body by a force is in the direction of the force proportional to the force and inversely proportional to the mass of the body $F = ma$

3 For every force there is an equal force in the opposite direction (reaction)

From these and the empirical laws of Kepler Newton deduced the general law of gravitation

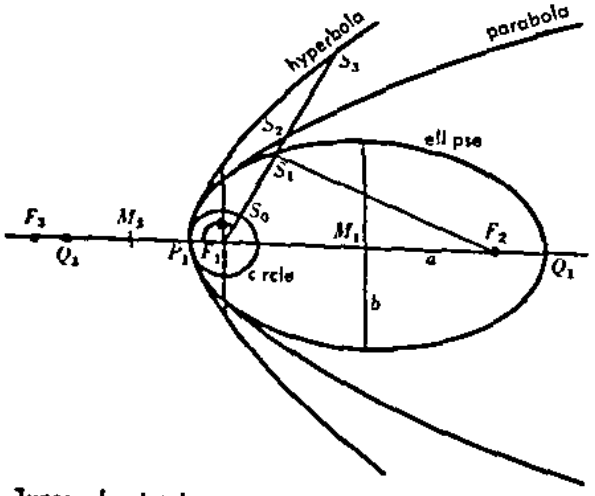
Application of Newton s first two laws to the motions of celestial bodies indicates that change of motion (either direction or speed) rather than motion itself is caused by a force This is a celestial body will speed up if under the influence of a force acting in the direction of its motion and will slow down if the force is oppositely directed If the

force acts transversely to the direction of motion the path becomes curved If several forces act si multaneously the celestial body responds to their resultant force If a force is always directed toward the same point the motion of the body will be a curve concave toward that point and in a plane containing the point (*see* CENTRAL FORCE) One consequence of the motion of a body under the ac tion of a central force is that the line joining the fixed point and the moving body sweeps out equal areas in equal times Kepler s observation of this relation in planetary motion shows that the plan ets move under the influence of a central force di rected toward the Sun (*see* ORBITAL MOTION) The law of areas does not indicate the size of the acting force but because the observed orbits of the plan ets are elliptical the force acting on a planet must vary inversely as the square of the distance be tween the planet and the Sun The combination of this information and Kepler s third law indicates that the forces acting on individual planets are in direct proportion to the planetary masses and in inverse proportion to the squares of the planetary distances from the Sun Taken in conjunction with Newton s third law of motion this leads directly to the general statement of the law of gravitation *See* GRAVITATION TIDE

Orbits Having demonstrated that the observed motions of the planets satisfied the law of gravita tion Newton deduced from the law that the motion of a body around a central mass must be a conic a circle ellipse parabola or hyperbola (*see* CONIC SECTION) Of the possible orbits only the ellipse and circle are closed curves as shown in the draw ing

A conic is the path of a point whose distance from a fixed point is in a constant ratio to its dis tance from a fixed straight line The fixed point is the focus the fixed line is the directrix and the constant ratio is the eccentricity A line through the focus and parallel to the directrix is called the latus rectum

The general equation for the distance r from focus F_1 to a point S_0 S_1 S_2 or S_3 on a conic is



Types of orbital trajectory

$$r = \frac{p}{1 - e\cos f}$$

where p is the semilatus rectum e is eccentricity (for a circle $e = 0$ for an ellipse $e < 1$ for a pa rabola $e = 1$ and for a hyperbola $e > 1$), and f is $\angle P_1F_1S$ Semimajor axis a semiminor axis b and p are related by

$$p = b^2/a = a(1 - e^2)$$

The distance F_1P_1 referred to in orbits about the Sun as the perihelion distance equals $a(1-e)$ *See* PERIHELION

Velocity v in the orbit is given by

$$v^2 = G(M + m)\left(\frac{2}{r} - \frac{1}{a}\right)$$

where G is the constant of gravitation and M and m are the masses of Sun and planet respectively For a circle $a = r$ so that

$$v^2 = \frac{G(M + m)}{r}$$

In an ellipse a is finite so the general equation can not be further simplified In a parabola a is infinite and the equation becomes

$$v^2 = \frac{2G(M + m)}{r}$$

For a hyperbola a is negative and the expression becomes

$$v^2 = G(M + m)\left(\frac{2}{r} + \frac{1}{a}\right)$$

These equations indicate increasing orbital veloci ties in going from circular to hyperbolic motion Parabolic velocity which is the lowest velocity at which the orbit ceases to be a closed figure is re ferred to as the velocity of escape *See* ESCAPE VELOCITY

Motion in the orbit according to Kepler s law of areas is expressed by

$$\tfrac{1}{2}r^2\frac{df}{dt} = \tfrac{1}{2}\sqrt{G(M + m)p}$$

This equation shows that the rate of description of area is proportional to the square root of the semi latus rectum Thus for all conics equal values of p indicate equal areal velocities (*see* AREAL VE LOCITY) This facilitates the computation of para bolic and hyperbolic motion where Kepler s third law cannot be applied because the orbits are not closed

Additional equations in elliptic motion give pe riod of revolution T as

$$T = \frac{2\pi a^{3/2}}{\sqrt{G(M + m)}}$$

and mean motion n as

$$n = \frac{2\pi}{T} = \frac{\sqrt{G(M + m)}}{a^{3/2}}$$

and, from Kepler's third law, $n^2a^3 = G(M + m)$, which is a constant The only angular argument in the orbit referred to thus far is f From the mean motion another angular argument can be defined mean anomaly $g = g_0 + n(t - t_0)$, where g_0 is the value at some epoch t_0 A third angular argument, eccentric anomaly E, is related to the mean anomaly by Kepler's equation $g = E - e \sin E$ Relations between true and eccentric anomalies in the orbit are

$$\tan \tfrac{1}{2}f = \sqrt{\frac{1+e}{1-e}} \tan \tfrac{1}{2}E$$

$$r \sin f = a\sqrt{1-e^2} \sin E$$

$$r \cos f = a(\cos E - e)$$

$$a(1 - e \cos E) = r = \frac{a(1-e^2)}{1 + e \cos f}$$

Undisturbed motion. Where only two bodies interact, direct application of the laws of motion makes possible the computation of the forces provided the masses and accelerations of the bodies are known Conversely, if the forces are known it is possible to compute the changes in the velocities of the bodies from instant to instant and thus derive their motions Because the greatest part of the mass in the solar system is contained in the Sun, an approximation to the motion of a planet may be obtained by considering only the central force The force of attraction acting between the Sun (mass M) and the planet (mass m), according to the law of gravitation is $F = G\ Mm/r^2$, where r is the distance from the Sun to the planet This mutual attraction has no effect on the motion of the center of gravity of the two bodies Both bodies trace out orbits of exactly the same form about their common center of gravity, the size of each orbit being inversely proportional to the mass of the body In a fixed rectangular coordinate system $\bar{X}$ $\bar{Y}$, $\bar{Z}$, having an arbitrary origin let the coordinates of the center of mass of the Sun be X, Y, Z, and of the center of mass of the planet x', y', z' The component of the attraction of the planet toward the Sun parallel to, and in the positive direction of, the $\bar{X}$ axis F_x is expressed by

$$F_x = \left(G\frac{Mm}{r^2}\right)\left(\frac{X - x'}{r}\right) = -\frac{GMm(x' - X)}{r^3}$$

Acceleration of the planet in the $\bar{X}$ direction is denoted by the second derivative of x' with respect to the time, d^2x'/dt^2 Therefore the equation

$$m\frac{d^2x'}{dt^2} = -G\frac{Mm(x' - X)}{r^3}$$

follows directly from Newton's second law Similar equations exist for the $\bar{Y}$ and $\bar{Z}$ components of the acceleration

Because gravitational attraction is mutual, the Sun is attracted toward the planet with the same force F, and the component of this attraction parallel to, and in the positive direction of the $\bar{X}$ axis is

$$F_x = \left(G\frac{Mm}{r^2}\right)\left(\frac{x' - X}{r}\right) = G\frac{Mm(x' - X)}{r^3}$$

If the acceleration of the Sun in the $\bar{X}$ direction is indicated by d^2X/dt^2 then by Newton's second law

$$M\frac{d^2X}{dt^2} = G\frac{Mm(x' - X)}{r^3}$$

with similar equations for Y and Z

Only the relative motion of the planet about the Sun is directly observable The planet will move relative to the Sun as though its own mass had been added to M and the planet had become a particle of infinitesimal mass The relative orbit will be of exactly the same form as the orbit of the planet about the center of gravity but enlarged in the ratio of $(M + m)$ to M Therefore referred to a noninertial rectangular coordinate system with origin at the center of the Sun in which the position of the planet relative to the Sun is given by $x = x' - X$, $y = y' - Y$, $z = z' - Z$, the equations of motion become

$$\frac{d^2x}{dt^2} = G(M + m)\frac{x}{r^3} \qquad \frac{d^2y}{dt^2} = G(M + m)\frac{y}{r^3}$$

$$\frac{d^2z}{dt^2} = G(M + m)\frac{z}{r^3}$$

The integration of this set of dynamical equations determines the motion of the planet relative to the Sun Kepler's laws are valid in the two body problem only, thus undisturbed motion is often referred to as Keplerian motion

The assumption of Keplerian motion is useful in establishing preliminary orbits over a restricted period of time An application in descriptive terms to the determination of the orbit of a minor planet is illustrative Suppose observations of the position of the minor planet with respect to the fixed background stars are made at times t_1 and t_2 a few weeks apart The position of the Earth (the moving space platform from which the observations are made) is known at times t_1 and t_2, and hence the angle at the Sun subtended by these positions Combining this angle with the direction of the line *of sight to the minor planet as seen from the Earth* at t_1 and t_2 gives the angle swept out by the minor planet during interval $t_2 - t_1$ as seen from the Sun It is assumed that in the short interval $t_2 - t_1$, the path of the minor planet is circular rather than elliptical An estimate is made of the distance from the minor planet to the Sun at the time t_1 By Kepler's third law the angle swept out in the time $t_2 - t_1$ is computed If this does not agree with the observed angle a new estimate of the distance is made and the computation repeated until agreement is reached

The determination of an elliptical orbit requires a minimum of three observations Assume the right ascension and declination of the minor planet have

been observed at times t_1 t_2 and t_3 at intervals of several weeks Heliocentric distances of the minor planet at times t_1 and t_3 must be determined by iteration such that the orbital elements conforming to these distances when used in Kepler s third law to compute the position at time t_2 produce a right ascension and declination that agree with the observed values

For the preliminary orbit of a comet because many of them are high velocity objects it is convenient to assume parabolic motion which fixes the eccentricity and facilitates the computation Although these descriptive procedures may seem awkward to use the precise mathematical methods of orbit computation perfected by P S Laplace K F Gauss H W M Olbers and others are both elegant and efficient

Disturbed motion Although the equations of the foregoing section suffice to describe undisturbed motion the exact motion of any celestial body is *affected* by the gravitational attraction of all the other bodies in the system *See* PERTURBATION (ASTRONOMY) The problem then consists of being able to describe the precise past present and future motion of a celestial body whose instantaneous position is a function of the instantaneous position of every other celestial body When the elements and masses of three bodies are specified at *some instant* of time their positions at any date are as exactly predetermined as in the two-body problem however the large deviations from their unperturbed elliptic motions which occur because of their mutual attractions severely complicate the prediction

This disturbance is illustrated by the motion of a minor planet whose orbit about the Sun passes near to the *orbit of Jupiter* The orbit of the minor planet is dominated by the central attraction of the Sun with usually *some slight* variations intro-

attraction of Jupiter may be so great that the character of the minor planet s orbit is completely altered and it *will leave* the vicinity of Jupiter on a trajectory entirely different from that on which it arrived The *velocity* of the minor planet may be either decreased or increased by this close approach The influence of Jupiter on objects passing near it is evidenced by the fact that among all the minor planets there now exist few whose orbital periods are commensurable with the period of Jupiter Certain other *minor* planets are so completely captured by Jupiter that they continually oscillate about those *moving points* which form equilateral triangles with Jupiter and the Sun *See* TROJAN PLANETS

The complexity of possible motions encountered in such examples as the *foregoing* has almost completely thwarted efforts to devise mathematical expressions capable of *predicting* these motions over extended periods of time More amenable to mathematical analysis and prediction are the orbits of satellites and planets whose motions are principally dominated by a central force with only small variations introduced by the disturbing attractions Although these orbits are ever changing and involved curves they may conveniently be described by their departures or perturbations from undisturbed elliptical motion

To represent the attraction of disturbing mass m_1 the right hand side of the equations of undisturbed motion are augmented by terms of the form

$$+Gm_1\left(\frac{x_1 - x}{\rho_1^3} - \frac{x_1}{r_1^3}\right)$$

where x_1 y_1 z_1 are the rectangular coordinates of the disturbing body ρ_1 is the distance of m from m_1 and r_1 is the distance of m_1 from the Sun The first (direct) term represents the attraction of m_1 on m, the second (indirect) term represents the attraction of m_1 on M The mathematical representation or general theory of a planet s motion may for instance comprise a set of mean elements with terms factored by the time representing the secular perturbations and numerous Fourier series having as argument combinations of the mean anomalies of the bodies concerned to represent the contributions to the elements due to the periodic perturbations The general theory may be evaluated to find the position of the planet for any instant of time For the more general problem illustrated previously where the ultimate motion of a body cannot be anticipated step by step numerical integration of the equations of motion provides the most practical method of solution The influence of the attracting forces on the positions of the bodies in the system are evaluated by iteration at one instant of time and the perturbed positions are used as the first approximation to compute the attracting forces at the next epoch Positions of the five outer planets—Jupiter Saturn Uranus Neptune and Pluto—were recently evaluated by this method with a high speed electronic computer for every fortieth day up to the year 2000 taking full account of their mutual attractions Tables of the positions of planets and satellites derived from general mathematical theories of their motion or from numerical integration of the equations of motion are published annually in the *American Ephemeris and Nautical Almanac*

Stability of the solar system From considerations of secular perturbations it can be surmised that the character of the planetary elements remains much the same over millions of years with small oscillations about their mean values Even though such results are based on an evaluation of the equations of motion which may not be valid over such an extended period they may be accepted as a first approximation The most stable feature is the plane that passes through the center of mass of the whole system and is perpendicular to the line through the center of mass about which the total angular momentum of the translational motions in the system is a maximum This plane is known as the invariable plane because its position

in space is not affected by the perturbations of the orbital motions from mutual gravitational attractions within the system However it is not absolutely invariable in position because of the continual interchange between the translational and rotational angular momentum in the system due to precessional motions and tidal frictions its position is also slightly affected by the attraction exerted by bodies external to the solar system

Relativity effect Although the introduction of the theory of relativity has provided a different picture of the mechanics of the universe for convenience of computation the principles of Newtonian mechanics are retained by astronomers In practice the only observable correction called for by the theory of relativity to the Newtonian law of gravitation concerns the rotation of an orbit within its plane (*see* RELATIVITY) The rate of this rotation of the line of apsides in radians per revolution of the body is

$$24\pi^3 \frac{a^2}{c^2T^2(1-e^2)}$$

where a is the semimajor axis T is the period e is the eccentricity and c is the velocity of light Observational confirmation of this relativity effect has been found in the orbits of Mercury Venus and the Earth *See* ASTEROID NUTATION (ASTRONOMY AND MECHANICS) PLANET PRECESSION OF EQUINOXES [R L D]

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Celestial navigation

Navigation with the aid of celestial bodies primarily for determination of position when landmarks are not available In celestial navigation position is not determined relative to the terrestrial objects observed as in piloting but in relation to the points on the earth having those bodies directly overhead

Celestial bodies are also used for determination of horizontal direction on the earth and for regulating time which is of primary importance in celestial navigation because of the changing positions of celestial bodies in the sky as the earth rotates daily on its axis

The navigator is concerned less with the actual motions of celestial bodies than with their apparent motions as viewed from the earth He pictures the heavens as a hollow celestial sphere of infinite radius with the earth at its center and the various celestial bodies on its inner surface He visualizes this sphere as rotating on its axis once in about 23 hours 56 minutes—one sidereal day The stars are then back where they were before the period started

Bodies closer to the earth appear to change position more rapidly than do those at a distance The sun appears to make a complete revolution among the stars once a year as the earth makes one revolution in its orbit The apparent motion is along a great circle called the ecliptic which is inclined nearly 23°5 to the plane of the equator of the earth All of the planets stay within 8° of the ecliptic in a band called the zodiac Within this band they appear to move among the stars The moon too stays within the zodiac as it revolves around the earth—or more properly as the earth and moon revolve around their common center of mass—once each lunar month

Body selection and identity The navigator does not use a large number of celestial bodies—the sun moon 4 planets and perhaps 20–30 stars Although 173 stars are listed in the Nautical Almanac and 57 of these are listed in the Air Almanac and on the daily pages of the Nautical Almanac the majority of them are normally not used unless the navigator's favorite ones are unavailable Some of the navigational stars are not seen at the latitudes traveled by many navigators

With relatively few bodies in use and little change in star positions from one evening to the next identification is seldom a problem A tentative selection is often made in advance by means of some form of star finder the most widely used by American navigators being H O 2102 D *Star Finder and Identifier* published by the U S Navy Hydrographic Office When set for the latitude of the observer and the time and date of observation this device provides a graphical selection from a tabulation indicating the approximate altitude and azimuth of each of the 57 navigational stars The relative positions of other bodies in addition to the 57 stars shown can also be plotted by the user Star finders tables and star charts may be used to identify bodies observed before identification

Celestial equator coordinate system Several systems of coordinates are available to identify points on the celestial sphere The celestial equator system of coordinates is an extension of the equatorial system commonly used on the earth The intersection of the plane of the terrestrial equator extended with the celestial sphere is a great circle called the celestial equator The earth's axis extended intersects the celestial sphere at the north and south celestial poles Small circles parallel to the celestial equator similar to parallels of latitude on the earth are called parallels of declination Each of these connects points of equal declination the celestial coordinate similar to latitude on the earth

Great circles through the celestial poles similar to meridians on the earth are called celestial meridians if they are considered to remain fixed in relation to terrestrial meridians and hour circles if they are considered to remain fixed on the rotating celestial sphere

Several different quantities on the celestial sphere are analogous to those of longitude on the earth Greenwich hour angle is measured westward from the Greenwich celestial meridian through 360° Local hour angle is similarly measured from the celestial meridian of the observer Meridian angle is measured eastward and westward from the local meridian through 180° Sidereal hour angle is measured westward from the hour circle of the vernal equinox the point at which the sun crosses the celestial equator on its northward travel in spring, through 360° Right ascension is measured eastward from the hour circle of the vernal equinox, usually in hours minutes and seconds from zero hours through 24 hours The various relationships of the celestial equator system are shown in Fig 1

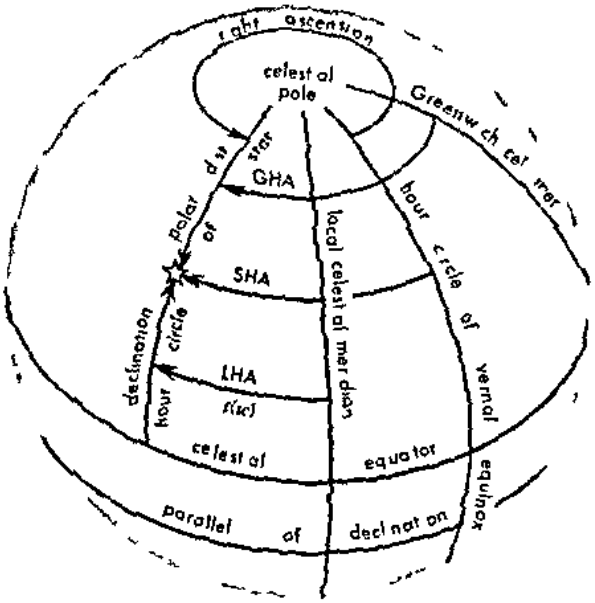


Fig 1 The celestial equator system of coordinates

In the illustration GHA is Greenwich hour angle SHA is sidereal hour angle LHA is local hour angle and t is meridian angle (shown here as westerly)

With the exception of right ascension all of these quantities are customarily stated to a precision of one minute of arc by the air navigator and to one tenth of a minute of arc by the marine navigator The celestial equator system is used in the almanacs for indicating positions of celestial bodies at various times

Horizon system of coordinates The navigator also uses the horizon system of coordinates which is similar to the celestial equator system The primary great circle is the horizon of the observer The pole vertically overhead is the zenith and the opposite pole is the nadir Small circles parallel to the horizon are called parallels of altitude each connecting all points having the same altitude Angular distance downward from the zenith is called zenith distance Great circles through the zenith and nadir are vertical circles The prime vertical circle passes through the east and west points of the horizon Azimuth is measured clockwise around the horizon, from 000° (it is generally expressed in three figures) at the north point, to 360° Azimuth angle is measured eastward and westward to 180° starting from north in the Northern Hemisphere and from south in the Southern Hemisphere Thus it starts directly below the elevated pole, the celestial pole above the horizon The various relationships of the horizon system are shown in Fig 2 The navigator uses the horizon system because it offers the most practical references for the origin of his measurements

Altitude and zenith distance are customarily stated by the air navigator to a precision of one minute of arc, and azimuth and azimuth angle to a precision of one degree, the marine navigator states

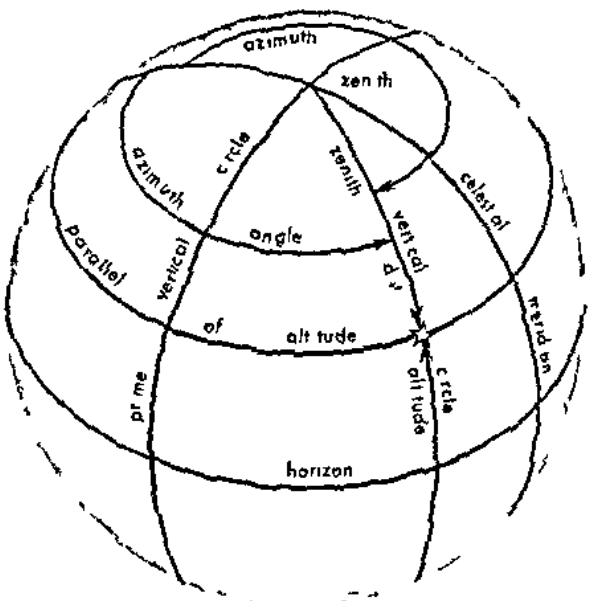


Fig 2 The horizon system of coordinates

them to one tenth of a minute and one tenth of a degree respectively

Two similar systems based upon the ecliptic and the galactic equator are used by astronomers but not by navigators

Position determination. Position determination in celestial navigation is primarily a matter of converting one set of coordinates to the other This is done by solution of a spherical triangle called the navigational triangle

The concept of the spherical navigational triangle is graphically shown in Fig 3 a diagram on the plane of the celestial meridian The celestial meridian passes through the zenith of the observer and is therefore a vertical circle of the horizon system Elements of both systems are shown in Fig 3 indicating that an approximate solution can be made graphically

The vertices of the navigational triangle are the elevated pole (P_n), the zenith (Z), and the celestial body (H) The angles at the vertices are respectively, the meridian angle (t), the azimuth angle (Z), and the parallactic angle (Y) The sides

of the triangle are the codeclination of the zenith or the colatitude (colat) of the observer the coal titude or zenith distance (z) of the body and the codeclination or polar distance (p) of the body

A navigational triangle is solved by ol taining ob served altitude and then converting this information to a line of position by a procedure known as sight reduction

Obtaining observed altitude To establish a celes tial line of position the navigator ol serves the al titude of a celestial body noting the time of ob servation Observation is made by a sextant so named because early instruments had an arc of one sixth of a circle By means of the double re flecting principle the altitude of the body is double the amount of arc used Similar instruments were

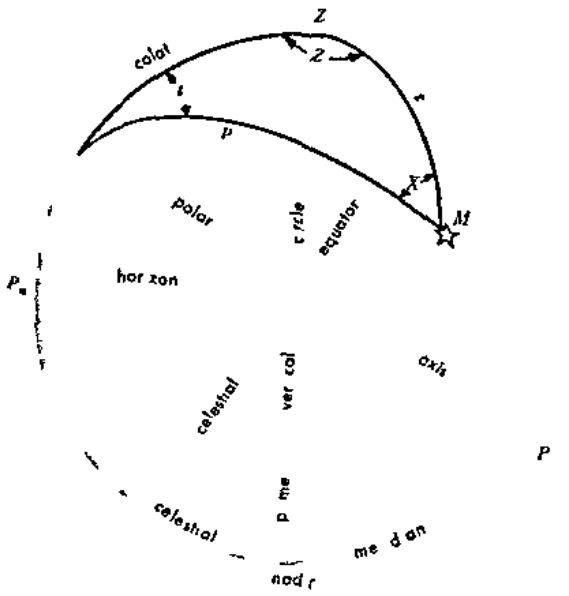


Fig 3 The navigational triangle

called octants quintants and quadrants depending upon the length of the arc Today all such instru ments regardless of length of the arc are generally called sextants

The marine sextant uses the visible horizon as the horizontal reference An air sextant has an arti ficial built in horizontal reference based upon a bubble pendulum or occasionally a gyroscope The sextant altitude however measured is subject to certain errors for which corrections are applied *See* SEXTANT

When a marine sextant is used observations can be made only when both the horizon and one or more celestial bodies are visible This requirement generally eliminates the period between the end of evening twilight and the beginning of morning twilight The navigational stars and planets are usually observable only during twilight Air naviga tion is not subject to this limitation star and planet observations being available all through the night

In selecting bodies for observation the navigator considers difference in azimuth magnitude (bright ness) of the body altitude (avoiding both ex tremes) and sometimes other factors If he is par ticularly concerned about his speed he selects a body nearly ahead or astern to provide a speed line A body near the ship s beam provides a course line One north or south provides a latitude line while one east or west provides a longitude line One per pendicular to a shore line provides an indication of distance offshore

Many air navigators prefer to observe three bodies differing in azimuth by about 120° or four bodies differing by 90° and preferably at about the same altitude In this way any constant error in the altitudes is eliminated

Sight reduction The process of deriving from an observation the information needed for establishing a line of position is called sight reduction A great variety of methods has been devised That now in general use is called the Marcq St Hilaire method after the French naval officer who proposed it in 1875 and is described as follows

Having obtained the body s corrected sextant al titude called the observed altitude the navigator uses the almanac to obtain the Greenwich hour angle and declination of the body He converts the former to local hour angle or meridian angle for an assumed position in the vicinity of his actual position With these two quantities and the latitude of his assumed position the navigator is able to solve the navigational triangle for altitude and azi muth

Each altitude of a given celestial body at any one instant defines a circle having the geographical po sition of the body (the point on the earth at which the body is momentarily vertically overhead) as the center and the zenith distance as the radius The difference between the computed altitude for the as sumed position and the observed altitude at the actual position of the observer called the altitude difference or altitude intercept is the difference in radii of the circles of equal altitude through the two positions

This difference may be measured along an azi muth line through the assumed position each min ute of altitude difference being considered one nautical mile A perpendicular through the point so located may be considered a part of the circle of equal altitude through the position of the observer This is the line of position sought The intersection of two or more nonparallel lines of position ad justed to a common time defines a fix (or running fix if the elapsed time between observations is more than a few minutes) locating the position of the ob server at the time of observation Although two lines of position are sufficient for a fix most navi gators prefer to observe three or more to provide a check and to decrease somewhat the probable er ror of the fix

Sometimes however the navigational triangle is solved in reverse starting with altitude assumed latitude and declination and solving for meridian angle This is then compared with Greenwich hour angle at the time of observation to determine the longitude at which the line of position crosses the

assumed latitude An American Capt Charles H Sumner used this method in his discovery in 1837 of the celestial line of position Others used one point found by this so called time sight method and the azimuth of the body to establish a line of position

Special short cut methods have been widely used for a body observed on or near the celestial meridian and for Polaris Since modern simple methods of sight reduction have become widely used the popularity of such special methods has decreased

A large number of methods has been devised for solution of the navigational triangle The most widely accepted have been mathematical but a great many graphical and mechanical solutions have been proposed Many of these methods are discussed in H O 9 the *American Practical Navigator* originally by Bowditch Most American navigators and many of other nationalities now use one of two methods both published by the U S Navy Hydrographic Office H O 214 *Tables of Computed Altitude and Azimuth* (nine volumes) is intended for use with the Nautical Almanac for marine navigation H O 249 *Sight Reduction Tables for Air Navigation* (three volumes) is intended for use with the Air Almanac for air navigation Editions of both of these sets are published in certain other countries

Time relationships Time is repeatedly mentioned as an important element of a celestial observation because the earth rotates at the approximate rate of one minute of arc each four seconds of time An error of one second in the timing of an observation might introduce an error in the line of position of as much as one quarter of a mile Time directly affects longitude determination but not latitude The long search for a method of ascertaining longitude at sea was finally solved two centuries ago by the invention of the marine chronometer a timepiece with a nearly steady rate

Several different kinds of time are used by the navigator His timepiece which keeps watch time usually has a small watch error When this is applied to watch time the result is usually zone time This is familiar to most people as standard time (such as Pacific Standard Time) or when clocks are set an hour ahead as daylight saving time (such as Central Daylight Saving Time) At sea time zones may be set by each vessel or aircraft but they are generally 15° wide centered on the meridians exactly divisible by 15°

When zone time is increased or decreased by 1 hour per 15° longitude (the amount of the zone description for example +7 for Mountain Standard Time) Greenwich mean time is obtained This is the time used in the almanacs

Local mean time differs from zone time by the difference between the longitude of the observer and the nearest standard meridian to the eastward having the later time Local mean time is used in tables indicating time of sunrise sunset moonrise moonset and beginning and ending of twilight

essentially uniform time Apparent time based upon the apparent (visible) sun may differ from mean time by a maximum of nearly 16½ minutes Apparent time plus or minus 12 hours indicates the actual position of the sun with respect to the

four digits without punctuation from 0000 at the start of a day to 2400 at the end of a day)

Sidereal time based upon motion of the stars is used (indirectly in many cases) with a star finder or a star chart

The custom of setting navigational timepieces to Greenwich mean time is growing, particularly among air navigators This time is used almost in

standard timepieces Marine chronometers are not reset by the user an accurate record being kept of chronometer time chronometer error and chronometer rate

Changing practices A typical day's work of a marine navigator at sea using celestial navigation is as follows

1 Plot of dead reckoning
2 Morning twilight observations for a fix
3 Report of 0800 position to the commanding officer
4 Morning sun line and compass check
5 Winding of chronometers and determination of error
6 Noon sun line advance of morning sun line for running fix and report of 1200 position to the commanding officer
7 Afternoon sun line and compass check
8 Determination of time of sunset and preparation of a list of bodies available for observation during evening twilight
9 Evening twilight observations for a fix
10 Report of 2000 position to the commanding officer
11 Determination of time of beginning or morning twilight time of sunrise and preparation of a list of bodies available for observation during morning twilight
12 Time of moonrise and moonset

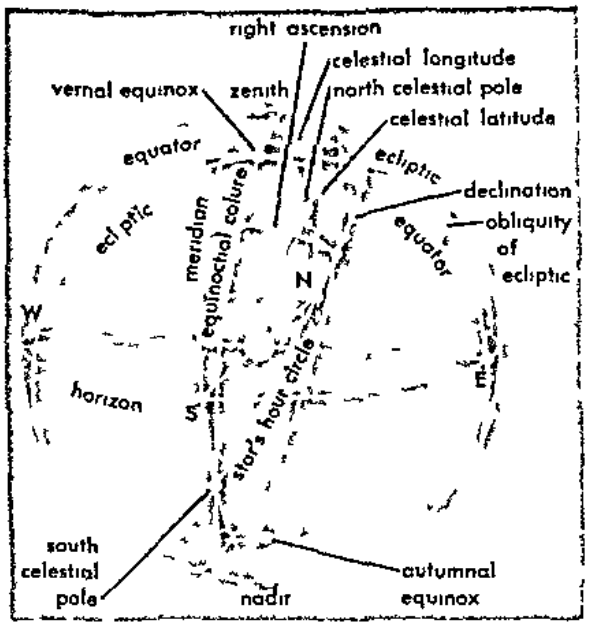
Electronic applications however are gradually changing the pattern of celestial navigation in at least three important respects (1) by providing noncelestial position information at sea (2) by providing devices for automatic observation and sight reduction and (3) by extending use of celestial navigation to all weather conditions at all times of day or night through the use of electronic star followers and radio astronomy *See* DEAD RECKONING

NAVIGATION, PILOTING, POLAR NAVIGATION, RADIO ASTRONOMY, TIME [A B M]

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Celestial sphere

A hypothetical sphere of infinite radius with its center at the observer Because all stars are so far from an Earth bound observer that they can be located solely by their direction it is convenient to consider them as located on the inside of a spherical surface centered on the observer Because the radius of Earth is negligible it is frequently convenient to consider Earth rather than the terrestrial observer, centered in the celestial sphere Stars are designated by their location on this sphere and planets and other heavenly bodies are located against this background *See* COORDINATE SYSTEMS ASTRONOMICAL [F H R]



Coordinates of a star on the celestial sphere

Celestite

A mineral with the chemical composition $SrSO_4$ Celestite occurs commonly in colorless to sky blue, orthorhombic, tabular crystals Fracture is uneven and luster is vitreous Hardness is 3–3 5 on Mohs scale and specific gravity is 3 97 It fuses readily to a white pearl It is only slowly soluble in hot concentrated acids or alkali carbonate solutions The strontium present in celestite imparts a characteristic crimson color to the flame

Celestite occurs in association with gypsum, anhydrite, salt beds limestone and dolomite Large crystals are found in vugs or cavities of limestone It is deposited directly from sea water, by ground water or from hydrothermal solutions

Celestite is the major source of strontium The principal use of strontium is in tracer bullets and in various red flares used by the Armed Forces Minor applications of strontium compounds are in ceramics, depilatories and medicine

Although celestite deposits occur in Arizona and California domestic production of celestite has been small and sporadic Much of the strontium demand is satisfied by imported ores from England and Mexico *See* STRONTIUM [E C T C]

Cell (biological)

A microscopic examination of any organism plant or animal will reveal that it is composed of one or more structural and functional units called cells About 1665 Robert Hooke first used the term cell to describe the small compartments he saw in thin sections of commercial cork As originally introduced the term cell was restricted to the tiny "rooms" surrounded by the nonliving walls Now the term is used to designate both the wall and the cell contents (protoplast)

CELL THEORY

Cell theory states that there is a basic unit of organic structure and function the cell which is essentially similar in all living organisms

Cell composition. A typical cell (see Fig 1) consists of a semifluid mass of living substance of microscopic dimensions completely enclosed by a thin differentially permeable plasma membrane and it contains a variety of bodies the most conspicuous of which is a large nucleus It is convenient, therefore, to regard the cell as being made up of two main parts the nucleus and cytoplasm The nucleus is enclosed by a membrane and contains a nucleolus and irregular masses of chromatin The cytoplasm of cells normally contains a number of small subdivisions called organelles For example, all cells possess mitochondria and in the cytoplasm of animals and some lower plants there are also two centrioles and a Golgi complex Many cells of plants contain plastids for example the chloroplasts bodies which impart a green color to leaves (*see* CHLOROPHYLL) The electron microscope has shown other structures such as the endoplasmic reticulum which are too small to be seen with the light microscope (*see* MICROSCOPE ELECTRON)

In addition to these inclusions of general occurrence special organelles appear in many cells, for example fibrillae of muscle cells, and most cells also contain visible masses of stored substances such as zymogen granules, fat droplets yolk, starch and glycogen

Cell function. All these structures of general occurrence in cells have separate important functions They are small organs of the cell, called organelles, and are analogous, on the microscopic level to the heart, brain muscles, kidneys, and

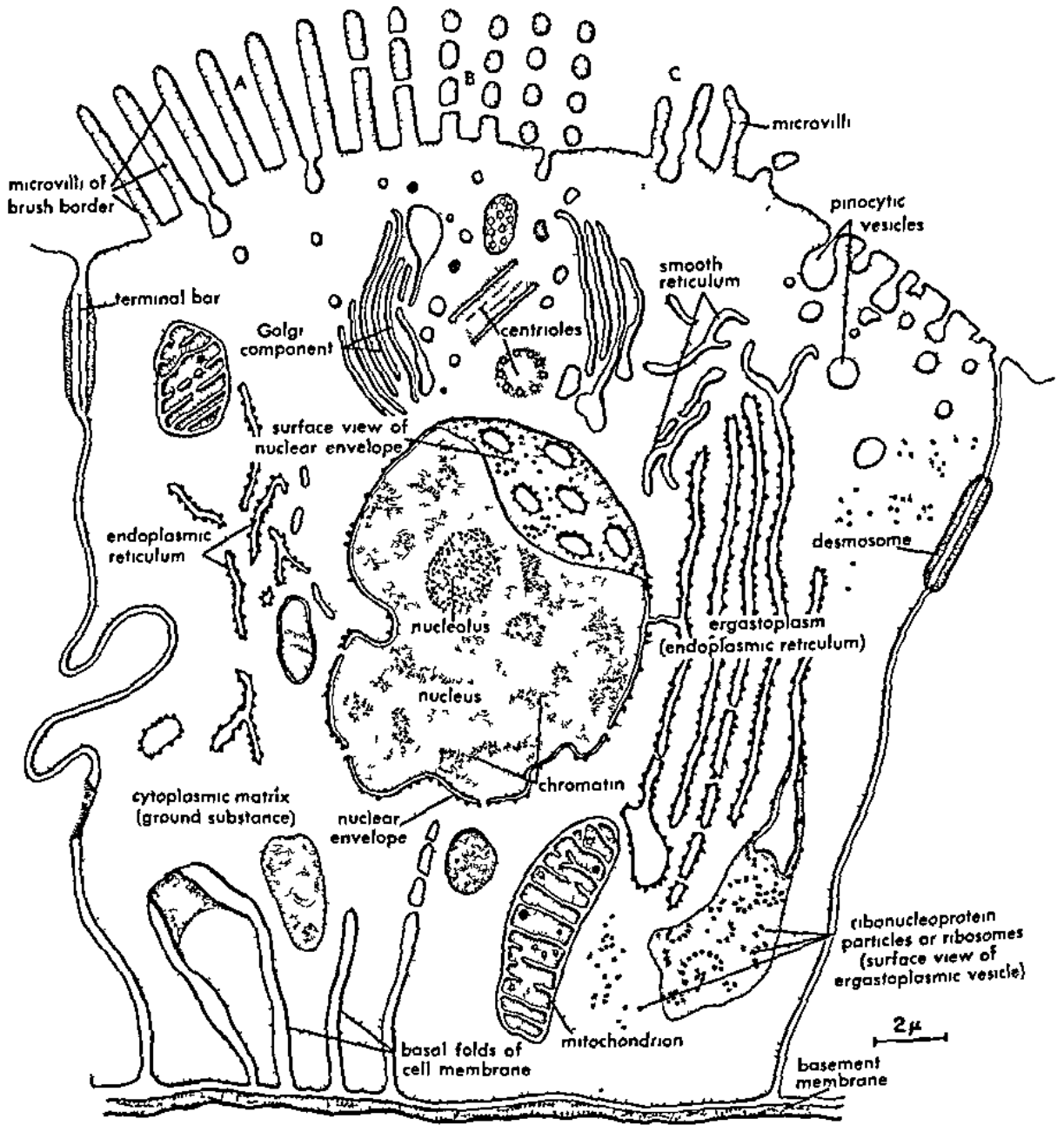


Fig 1 Diagram of composite cell no one cell has all structural features but all cells have a few The nucleus, which with its nucleolus is at the center, is limited by an envelope of two membranes separated by a space Continuity of the envelope is interrupted in places by pores shown also in surface view of envelope at upper right of nucleus Darker masses in the nucleus represent chromatin

Cytoplasm contains such organelles as mitochondria, Golgi component, and centrioles Electron microscopy has revealed the fine structure of these organelles and also a complex membrane-limited system of tubules and vesicules the endoplasmic reticulum Units of this system arranged in parallel and associated with particles form ergastoplasm It also occurs in a smooth, or particle-free, form The ribosomes revealed by high-resolution microscopy, are rich in ribonucleic acid associated with protein The continuous phase of cytoplasm, cytoplasmic matrix, is commonly structure-free

Surfaces of cells show various specializations One, found between cells, serves as an adhesion plate, or desmosome, for holding the cells together Near free surfaces of cells in epithelial sheets, this may be continuous around the cell and is then called a terminal bar Other specializations take the form of minute extensions from the cell surface, microvilli When closely packed, as at A, the microvilli constitute a brush border Their appearance in cross or oblique section is shown at B At other sites or on other cells they may be less uniform, as at C where they are simply microvilli Pinocytic vesicles are portions of the cell surface specialized to ingest tiny droplets of the fluid environment (pinocytosis) Epithelial cells of this type are usually underlain by a basement membrane (*Drawn by D Smith, Rockefeller Institute*)

other organs The nucleus is the site of the main units of inheritance the genes (*see* GENETICS) These units exert control of all processes in the cytoplasm so that each organism resembles its ancestors in form and behavior In the mitochondria there are systems of enzymes (*see* ENZYME) or biological catalysts which utilize oxygen to break down complex organic compounds and release chemical energy This energy is then stored in high energy phosphate bonds where it is available for biological activities such as recovery of muscle after contraction or synthesis of the peptide bonds of proteins (*see* BIOCHEMISTRY) The centriole mainly influences the orientation of the plane of cell division and is concerned in the development from cells of whiplike motile processes called flagella (*see* CELL SURFACE DIFFERENTIATION) The Golgi zone seems to be an organelle in which groups of substances are assembled or packaged for example into zymogen granules in a pancreas cell The plastids are the main site of synthesis of complex organic compounds from simple inorganic substances for example the formation of sugar from carbon dioxide and water in chloroplasts when the radiant energy of sunlight is absorbed by the green pigment chlorophyll (*see* PHOTOSYNTHESIS) Cells of all animals and of many plants also cause extensive formation of lifeless supporting or binding material (intercellular substance) These substances are mainly responsible for the toughness and firmness of bodies of animals and plants

Unicellular and multicellular organisms Animals such as Protozoa and plants such as Protophyta consist of only a single cell (unicellular) These are among the most complicated cells since they contain in addition to the nucleus mitochondria and other commonly occurring organelles a variety of special structures for motion digestion excretion and other necessary functions (*see* PROTOPHYTA PROTOZOA) Most larger organisms are many celled (multicellular) and each of the bodily functions is performed in an organ by cells that are specialized for one particular operation This is within the cell population there is a division of labor analogous to the organization of modern society

Although the operation of each cell is closely integrated with the functioning of the body as a whole it is one of the striking evidences of the validity of the cell theory that each cell nevertheless retains the capacity to act quite independently of its neighbors Thus one cell of a group may secrete divide or die while all the adjacent cells remain in a very different physiological condition The harmonious activity of large cellular populations is as a rule due to control imposed by the chemical (hormonal) or nervous integrating mechanisms of the body

Size and number of cells Some cells possess great bulk for example the hen's egg with its content of yolk other cells are very large in a single dimension such as some nerve cells which may have a process or fiber that is more than 1 meter (over 3 ft) long and only a few microns (one-millionths of a meter) in diameter Most cells however are so small as to be plainly visible only when magnified 100 times or more with a compound microscope (*see* MICROSCOPE OPTICAL) The dimensions of cells are usually expressed in microns The cell shown in Fig 1 is of average size cells less than one fourth as large or more than four times larger are rare In any one species all the cells tend to be relatively large or small in comparison with other organisms For example among vertebrate animals bony fishes have exceptionally small cells salamanders have large cells whereas human cells are intermediate in size The size of the nucleus is closely related to relative cell size but this is not true of the cytoplasmic organelles Some very small multicellular organisms such as rotifers (*see* ROTIFERA) consist of only a few hundred cells but in larger species the number of cells may approach astronomical figures To illustrate the human cerebral cortex has been estimated to contain over 10^{10} nerve cells whereas there are 2.5×10^{2} erythrocytes in the average man roughly 5×10^{8} in each drop of blood

The total weight of an average rat liver cell has been estimated fairly accurately to be 003 microgram of which about three fourths is water

Intercellular substances The living substance of cells (protoplasm) is a slimy fluid or a soft gel which seems quite inconsistent with the common knowledge that the bodies of most plants and animals are firm tough and often rather rigid structures This is explained by the fact that all plant cells and many cells of animals can cause to form in their vicinity a lifeless material (intercellular substance) which serves to bind and support the cell population The intercellular material of plants is in the form of a wall composed mainly of a carbohydrate cellulose (*see* CELLULOSE) surrounding each cell In animals a common intercellular binding tissue consists of bundles or feltworks of protein fibers (collagen or elastin) which become surrounded by a solid material to form a supporting framework The shapes of most multicellular organisms are due to the intercellular material for example a live and a dead twig look much alike although the latter consists almost entirely of cell walls Similarly the general appearance of an animal can be reconstructed from its dried or fossilized skeleton However one must not lose sight of the fact that in the final analysis this distribution of intercellular material is merely an expression of a pattern of the cells which control its formation

Subcellular organization Although the cell constitutes the basic structure of organization of the vast majority of living things there are organisms in which conformity to the cellular structure is not definitely known or is quite obviously incomplete For example although bacteria in complexity of physiological activity seem to be cellular the precise bacterial equivalent of mitochondria nucleus Golgi zone or plastids has not been demonstrated

microscopically (*see* BACTERIA) Although viruses are often referred to as cells it is perhaps more correct to compare them with certain parts of the cell for example the nucleoproteins of chromatin or proplastids since viruses are capable of synthesizing their own types (self duplication) but seem to lack nearly all other cell attributes (*see* VIRUS) This comparison however interesting in its historical implications is no challenge to the validity of the cell theory Even if the present cell organization may represent an assemblage of what were originally free living nuclei mitochondria and plastids the central fact of great use in modern experimental biology is that the functions of all these structures with the possible exception of self duplication are not separate and independent On the contrary they are closely integrated with those of the cell as a whole

Cellular viewpoint in biology In the years since 1838 1839 when the cell theory was first stated broadly by T Schleiden and M Schwann it has come to be the dominant unifying concept implying the embodiment in each living thing of the consequences of evolution from an original remote event the organization of living material from unorganized nonliving matter It has become far more than a principle of structural organization The theory dominates the study of development for organisms begin as single cells and develop by cell division and cell differentiation It is central to the study of heredity for the phenomena of biparental inheritance occur because the zygote is a result of the union of male and female sex cells The cell is the biochemical unit in which occurs nearly all the complex syntheses and other processes which uniquely characterize the chemistry of living things Even the grosser processes of physiology can readily be broken down into coordinated activities of huge populations of tissue cells Many of the most serious diseases such as cancer are related to more or less obscure conditions within cells It is indeed as difficult for a biologist to think broadly of his subject without reference to the cellular viewpoint as it is for a chemist to escape from the atomic theory Both are more than theories they are broad generalizations from the great bulk of facts about the biological and chemical organization of matter *See* CELL NUCLEUS CELL PLASTIDS CENTRIOLE CYTOPLASM GOLGI COMPONENT MITOCHONDRIA [A W P]

CELL DIFFERENTIATION SENESCENCE AND DEATH

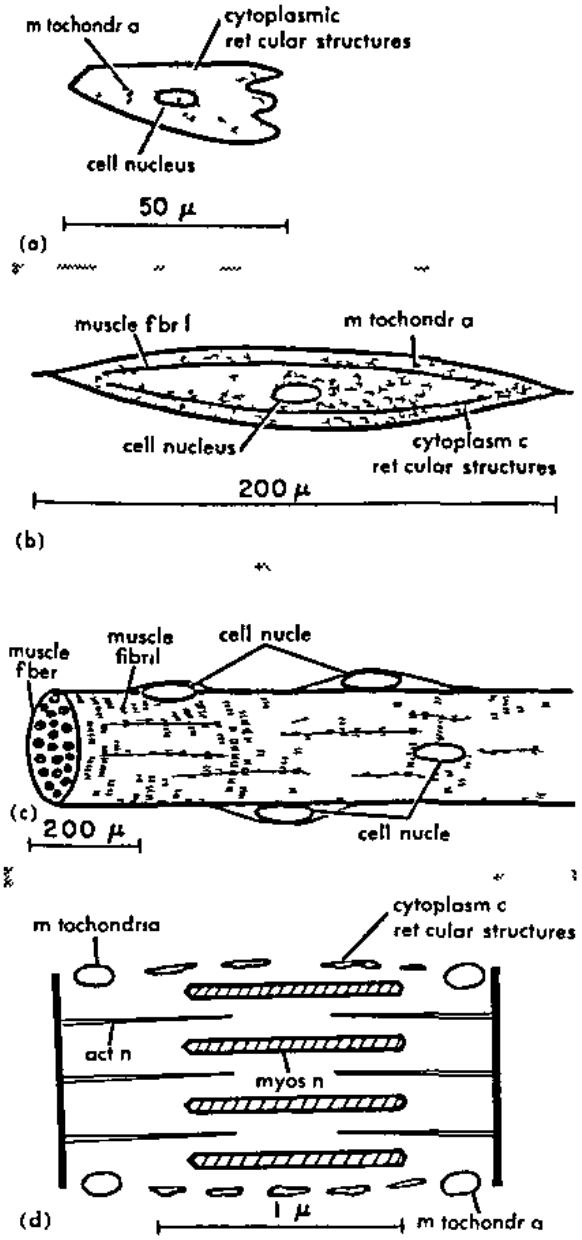
Following formation cells usually pass progressively through three phases of varying lengths differentiation senescence and death

Cell differentiation The term differentiation encompasses the morphological and physiological changes that occur in cells from the time they are formed until they no longer undergo modification At the beginning of embryonic development all of the cells of many organisms seem to be qualitatively more uniform than at the end of development when the cells of each tissue can be distinguished by structural functional and biochemical properties (*see* EMBRYOLOGY, MITOSIS) In its broadest sense differentiation not only applies to the appearance of such differences in the tissues and cells of multicellular plants or animals but can be extended to include changes in the properties of unicellular organisms during their life cycle for example spore formation and spore germination of bacteria or the appearance of differentiation products in protozoa The process of differentiation is very complex and its individual phases are not well understood Therefore an explicit definition cannot be given at the present time

In attempts to analyze cellular differentiation explorations of three different aspects of this process are pursued The first deals with the question of the time during development at which certain distinguishing cell properties can first be identified and the sequence in which the different properties make their appearance the second approach consists in the establishment of quantitative measures of the distinguishing parameters during development and the third is the investigation of the mechanisms by which certain cell properties arise and by which the course of their development is regulated

The appearance and quantitative changes of cell characteristics occurring in differentiation are determined by cytological methods (light electron phase microscopy for observation of cell structures) by functional tests (contractility permeability secretion) and by biochemical biophysical histochemical and immunochemical assays of the molecular composition of the cell and of its structural constituents

Phases of differentiation The course of differentiation can be illustrated by following the development of a single cell type such as the muscle cell of the back musculature of vertebrates The back musculature is formed from cells in the primitive segments (somites) which consist of small aggregates of cells along the axis of the early embryo (Fig 2) At an early phase of development all cells in these segments are alike in appearance and in the biochemical properties tested to date At a later time of development some somite cells become spindle-shaped and oriented parallel with the long axis of the embryo Specific antibodies in contact with the contractile proteins of muscle and marked by combination with a fluorescent dye can be seen to combine specifically with these spindle-shaped cells and not with the other cells of the somites This indicates that muscle proteins have been formed specifically in these cells Somewhat later in development the antibody is located mostly in certain crossbands of the increasingly elongated muscle cells and the appearance of distinct longitudinal fibrils can be observed During the following phase of development the first slow contractions of the back musculature can be noticed as the first expression of functional activity also at this time the muscle begins to respond to nerve stimuli Throughout the course of differentia



F g 2 (a) Und fferent ated mesenchyme cell w th ran dom d str but on of unspec f c cytoplasm c structures (b) Format on of a myoblast show ng elongat on of mesenchyme cell al gnment of m tochondria and ap pearance of f br ls in the outer layers of the myoblast cytoplasm (c) Format on of a muscle f ber show ng fu *s on of myoblasts and rap d increase n cross striated* muscle f br ls (d) Organization of prote n molecules n the muscle f br l g v ng r se to the cross striated ap pearance of the d fferent ated muscle f ber

tion the concentration of the muscle proteins con tinues to increase faster in the cell than the other cell proteins and at the end of differentiation the proteins which occur only in the muscle and not in other tissue make up about one half of the dry mat ter of the muscle cell

The other cells of the primitive segments form cartilage and bone and a third cell type may form connective tissue How many and which of the cells of the primitive segment will form each of the three cell types depends among other factors upon the *proximity of the primitive spinal cord and other ad* jacent tissues In some species the cells forming the primitive segments can be removed from their nor mal location and implanted into the ventral region of the same embryo In this new tissue environment these cells will form not muscle or bone but red blood cells A great many experiments of this kind have shown that during the early phase of develop ment the tendency of a cell to develop in a par ticular direction for example into a muscle cell is not entirely a fixed property of the cell which operates independently of the environment It de pends also upon extracellular factors including those contributed by adjacent cell groups and in the case of in vitro experiments those contributed by various chemical and physical conditions in the culture As soon as differentiation of such labile (adaptable) cells has progressed in one direction beyond a certain point a change in these environ mental conditions can no longer divert the final outcome of differentiation This stabilization of the developmental process suggesting a degree of ir reversibility of differentiation has been called de-termination

Irreversibility The apparent irreversibility of cell differentiation in embryonic development has been assumed to be the main distinction between cell differentiation and the changes in cells which result from different physiological activities such as hormonal cycles and secretion or which are ob served in cell cultures as the result of culture con ditions That such apparent irreversibility is not absolute however is indicated in experiments which show that at least in certain instances cells showing a distinct degree of differentiation can be transformed experimentally into another cell type The possibility of eliciting formation of a lens tis-sue from the iris in the eves of certain salamanders is well established Moreover changes characteriz ing the differentiation of cells have been observed not only in the cytoplasm of the developing cells but also in the cell nucleus Such changes were as certained either by functional tests of nuclear ac tivity or by direct observation of structural ele ments of the nucleus Such changes in the nucleus call attention to the possibility of interactions be tween the nuclear and cytoplasmic processes in the control of differentiation

Little is known as yet about the molecular mech anisms by which new chemical components arise in differentiating cells Attempts are being made to explore the extent to which the appearance and ac cumulation of enzymatically active and of struc turally significant proteins such as myosin and col lagen follows mechanisms similar to induction of enzymes in microorganisms and formation of anti bodies in response to an antigen

Cell senescence Upon completion of differentia tion a period of senescence occurs in cells In the beginning of the life cycle of an organism of cell cultures or of clones of microorganisms formation

of cell substance prevails over its degradation and the cells proliferate and grow At some later time point in the life cycle of many cell types forma tion and degradation of cell substance are in bal ance growth and proliferation coming to a stand still Eventually breakdown of cell substance or the formation of inert cell materials becomes the prev alent direction of cell metabolism This latter phase in cell life is regarded as cell senescence This very tentative generalization seems to be supported by certain specific changes in cell structure and com position of aging cells For example it was found that the activity of some enzymes which catalyze synthetic processes diminishes while the activity of enzymes involved in the breakdown of cell con stituents shows some increase during aging The fragmentation and disappearance of the structural centers of metabol energy production (mitochon dria) has been regarded as a part of the struc t iral change accompanying this deterioration The increase in calcium content in certain pigment gran ules and in the intercellular matrix has been re garded as an expression of the increasing deposi tion of relatively inert cell materials The changes characteristic for cell senescence are particularly pronounced in cells with a long life span such as nerve cells which persist in an organism during its entire life

Certain changes which accompany the aging process of cells can be retarded by hormones (*see* PLANT HORMONES) However no hormone or com bination of hormones has been found as yet which actually prevents the basic deterioration of aging cells and thereby counteracts the progress of cell sene cence

Cell death A living cell depends upon the con tinuous production of metabolic energy for the maintenance of its highly organized structure This organization is crucial for the delicately balanced interplay of metabolic reactions involved in energy production and its utilization for cell maintenance and function If this system of interdependent cel lular structures and functions is at any point im paired suff ciently disintegration or death of the cell follows Exactly how far changes in cell struc tures can progress without leading to irreversible damage has to be ascertained for each injurious condition For example a short immersion of cer tain egg cells in hypotonic salt solutions leads to parthenogenetic development whereas a longer im mersion leads to complete dissolution (cytolysis) and death of the egg cell (*see* PARTHENOGENESIS)

Cell death may occur at any phase of the exist ence of an organism Extensive cell death is ob served as a part of normal embryonic develop ment postnatally in the involution of the thymus throughout l fe in some forms of secretion and in the course of cell loss due to wear and tear at the skin surface The l fe span of different cell types varies greatly Nerve cells persist throughout the entire life of higher organisms whereas the life span of red blood cells was found to be much shorter (in man about 100–120 days) In some in stances the products of the living cell can persist while the cell as such has ceased to show any in dication of life (feathers scales bone matrix)

[H HR]

CELL PERMEABILITY

The permitting or activating of the passage of substances or materials into out of or through cells is called cell permeability In accomplishing this passage the materials traverse the plasma or cell membrane which demarcates the living cyto plasm inside from the extracellular space In many cases such materials also traverse the cell wall (*see* CELL WALLS IN PLANTS) The latter is an extracel lular coating rich in polysaccharide particularly well developed in plants and bacteria and lying just outside the plasma membrane The concepts of cell permeability are also applied at times to ex changes of substances across the membranes which enclose internal components of cells such as mito chondria nuclei or vacuoles of various types *See* AMEBA CELL STRUCTURES

The substances and materials participating in cell permeability include simple molecules and ions such as oxygen water carbon dioxide urea sugars potassium sodium chloride and amino acids Larger molecules such as proteins polysac charides and nucleic acids and even units such as viruses bacteria and carbon or silica particles can also be taken into or extruded from cells

Selectivity of cell permeability Cell permeabil ity is highly selective For example some cells will accumulate potassium ions freely but resist their loss Conversely the same cell may resist the ac cumulation of sodium A cell may copiously take in a certain sugar but exclude another type of sugar molecule differing only slightly from the one admit ted A cell may take up one type of large polysac charide molecules but not admit smaller proteins or in other instances take in or expel protein molecules of one kind while others remain unaf fected Thus the selective features of cell permea bility are not simply related to the size or electric charge of the permeating unit

Energy is required to drive a molecule ion or larger unit into out of or across cells Thermal kinetic energy which is responsible for diffusion and Brownian movement can motivate some per meability phenomenon (*see* BROWNIAN MOVEMENT

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charge inside cells can also influence entry or exit of ions The selective features of such movements into or out of the cell are determined by the molec ular structure of the plasma membrane wh ch per mits some particles to pass more freely than others Movements actuated by thermal kinetic molecular activity and spaced electrical charge are called passive permeab l ty phenomena But a very large numb er of permeability movements are activated by molecular pumping devices in the cell driven

by energy sources derived from the chemical reactions taking place in the cell. Much of the passage of potassium into cells and of sodium out of cells is mediated by ion pumps of this variety. Similarly proteins, carbohydrates, bacteria, and other large units too great to diffuse through the plasma membrane can be pumped or actively transported into cells and often out of cells as well. Substances or particles entering, leaving, or traversing cells by means of such pumps are said to be conveyed by active transport. Phagocytosis is a type of active transport or pumping mechanism for large particles such as bacteria. Pinocytosis is a corresponding mechanism that can pump ions, sugars, and proteins. Other types of pumping mechanisms may also exist.

Concentration gradients. Cells are able to concentrate within them substances which are found in lesser abundance in the medium around them. Thus a cell may concentrate iron, potassium, phosphate, or glucose within its cytoplasm by trapping any such ions or molecules and pumping them into the cell's interior. Similarly, a cell may retain many of its products of synthesis. These processes may lead to considerable differences in concentrations of substances within a cell as compared to the surrounding fluid outside the plasma membrane. These concentration differences may be reflected in osmotic pressure gradients between the inside and the outside of the cell. Such gradients tend to impede the passage of water from regions of high solute concentration to the region of lower concentration. This tends to favor accumulation of water within the compartment of high osmotic pressure, which is usually within the cell. Although these effects can be counteracted by active transport of water, moved by water-pumping devices associated with cell membranes, osmotic pressure gradients have important influences on permeability phenomena.

Variation in permeability phenomena. Permeability phenomena of both active and passive types are highly variable. Variations may occur from cell to cell, from species to species, from one cell part to another, and within the same cell at different times in accordance with variable physiological conditions. Thus when a nerve conducts, its plasma membrane is swept by a very rapid wave of activity characterized by a sudden outward passage of potassium ions and an inward flow of sodium. The normal tightness of the membrane to potassium and sodium is reestablished after a few thousandths of a second. Ion pumps slowly restore the original balance. [H S B]

CELL METABOLISM

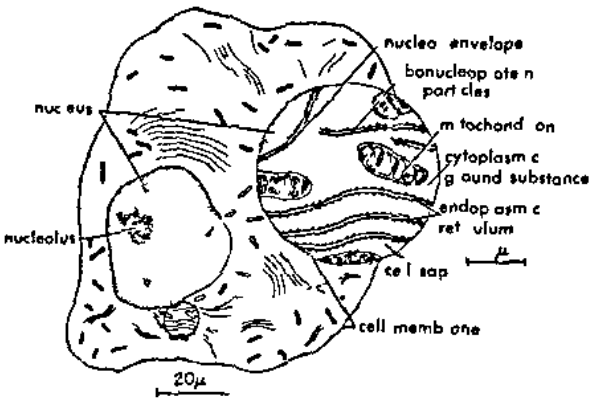
Cell metabolism is the sum of the highly organized chemical reactions in living cells by which foodstuff molecules undergo degradation with release of energy for energy-requiring activities of the cell such as synthesis of its own complex structures, motion, and transmission of impulses. The basic units of cell metabolism are the enzymes, specialized protein molecules each capable of catalyzing a specific type of chemical reaction. Foodstuff molecules are broken down and built up in the cell through the stepwise sequential action of series or "systems" of enzymes which often have a cyclic nature.

Carbohydrates, fats, and proteins or their derivatives form the major foodstuffs for nearly all types of cells in higher organisms. In more primitive cells, inorganic compounds such as carbon dioxide, ammonia, and sulfur also serve as foodstuffs. In anaerobic cells the foodstuff molecules are degraded to simpler products without utilization of oxygen through the process of fermentation (*see* FERMENTATION). For example, many cells in the absence of oxygen ferment sugar to lactic acid or to alcohol and carbon dioxide. In aerobic cells foodstuff molecules are oxidized by molecular oxygen with formation of carbon dioxide as the major end product (*see* PLANT RESPIRATION). In many cells oxidation of carbohydrate, fat, and protein involves a common metabolic intermediate, acetic acid, which is oxidized by a multienzyme system known as the Krebs citric (or tricarboxylic) acid cycle.

Metabolism has an exergonic or energy-yielding phase and an endergonic or energy-utilizing phase. The chemical energy liberated during fermentation or respiration is recovered in a useful form through the coupled formation of adenosine triphosphate (ATP) from adenosinediphosphate (ADP) and phosphate. This is known as the phosphorylation of ADP to ATP. ATP is the energy carrier between the exergonic phase of metabolism and the endergonic functions. The high-energy phosphate bond of ATP drives energy-requiring functions such as muscle contraction through other enzymatic reactions which cause the loss of the phosphate group from ATP to form ADP, the latter being the "spent" form of the energy carrier. *See* PLANT METABOLISM.

All the cellular constituents are in a constant state of flux or a dynamic steady state in which the rate of formation of cell components is balanced by the rate of degradation. The metabolic turnover rate of cellular constituents can be measured and is characteristic for each cellular compound and for each cell type.

Metabolic differentiation of cells. Although nearly all cell types in the mammal are capable of the basic energy-yielding reactions of fermentation, respiration, and the recovery of the energy through the phosphorylation of ADP to ATP, they may differ with respect to other features of metabolism. For example, most mammalian cell types oxidize both carbohydrate and fat but relatively little protein. The liver, however, oxidizes all three foodstuffs in varying proportions. The brain, on the other hand, has an absolute requirement for carbohydrate as its sole fuel source. Similarly, different cell types use their metabolically generated ATP energy in different ways: the muscle cell for contraction, the nerve cell for transmission of impulses, the kidney tubule cell for absorption or secretion in forming urine, and the liver cell for the



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synthesis of fat glycogen and blood plasma proteins (For metabolism of specific mammalian organs see separate articles on individual organs)

Studies of comparative metabolism indicate that metabolic activities are genetically linked and it has been postulated that the formation or activity of each enzyme in the cell is controlled by a single gene

Intracellular location of metabolic activities The various metabolic reactions take place in specific substructures of the cell (Fig 3) The fermentation of carbohydrate to lactic acid takes place largely in the soluble portion of the cell cytoplasm Oxidation of carbohydrate fatty acids and amino *acids* takes place in the mitochondria of the cell which also contain the enzymes necessary to convert the chemical energy liberated during biological oxidation into the phosphate bond energy of ATP The mitochondria are often spoken of as the power plants of the cell

The formation of the many different proteins of the cell from the simple amino acids (building blocks) is a very complex and still largely unknown process that takes place in the endoplasmic reticulum or ergastoplasm These systems are constructed of fine *membranes* and adhering nucleoprotein granules and they extend through the cytoplasm *Protein* synthesis requires the participation of ribonucleic acid present in the granules possibly to furnish templates or patterns *for the* formation of the different types of proteins Metabolic synthesis of fats occurs partly in the soluble portion of the cytoplasm and partly in the endoplasmic reticulum These *biosynthetic* reactions require ATP provided by the mitochondria Deoxyribonucleic acid presumed to be *the carrier* of genetic information is largely located in the cell nucleus which is otherwise metabolically *inert* except for some respiration and phosphorylation in the nucleolus

Endocrine control of metabolism In multicellular organisms metabolism is controlled by hormones secreted by *other cells* Thus carbohydrate metabol
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mones elaborated by the pancreas thyroid adrenal and pituitary glands are known to control metabolism Hormonal control also occurs in plants

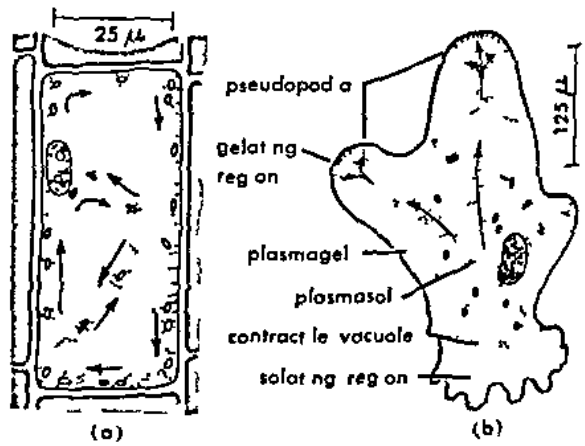
[A L.L.]

CELL MOVEMENTS

Movements of cells of their specially differentiated appendices or of their interior protoplasm and its organoids (structures resembling organs) are of varied type and complexity Living cells are seldom totally quiescent mild turbulence of the interior cytoplasm and its inclusions being usually evident Bending and shifting motions of mitochondria are often conspicuous and in certain cells oscillatory or rotatory movements of nuclei have been recorded

Cyclosis Rotational streaming of the cytoplasm without change in cell form occurs in certain algae fungal hyphae and pollen tubes and is commonly studied in *Elodea* leaf cells and staminal hairs of *Tradescantia* (Fig 4*a*) Cyclosis may be continuous or initiated by light or injury Its rate normally from 2 to 50 microns (μ) per second varies with temperature It may be accelerated by adenosine triphosphate hormones vitamins or a 1% solution of $CuSO_4$ or it may be retarded by high hydrostatic pressure ultraviolet light and certain respiratory poisons

Ameboid movement In slime molds ameba leucocytes and wandering cells of the connective tissues protoplasmic streaming accompanies changes in cell shape and progressive motion (*see* SARCODINA) Amebas move 0 5–4 6 μ/sec and the slime molds up to 1350 μ/sec Advancement is by flow of the protoplasm into constantly changing projections (pseudopodia) from the cell surface (Fig 4*b*) This involves reversible conversion of a firm peripheral plasmagel into a fluid centrally situated plasmasol Extension of a pseudopod is preceded by local thinning of the surface and plasmasol formed posteriorly is propelled forward by contraction of the surrounding plasmagel Adhesion of the cell to a solid substrate is necessary for pro



Fg 4 (a) Cyclos s in plant cell (b) Amebo d move ment

gression Under high hydrostatic pressure the gel can be experimentally liquefied and all movement ceases The energy for gel contraction appears to be derived from ATP ATP injected into an ameba accelerates cytoplasmic streaming and pseudopod formation A contractile protein isolated from slime molds responds to ATP as does the actomyosin of muscle

Ciliary movement This type of movement is effected by relatively permanent whiplike appendages of the cell surface termed cilia when they are small and numerous and flagella when large and few or single Ciliate protozoa free-living flatworms nemertean worms and many aquatic larvae are propelled by cilia Locomotion by flagella occurs in mastigophoran protozoa germ cells of plants sperm cells and many bacteria Cilia may also propel water and particles past the cells of many stationary epithelia such as those that line the gills of clams or the respiratory passages and oviducts of mammals

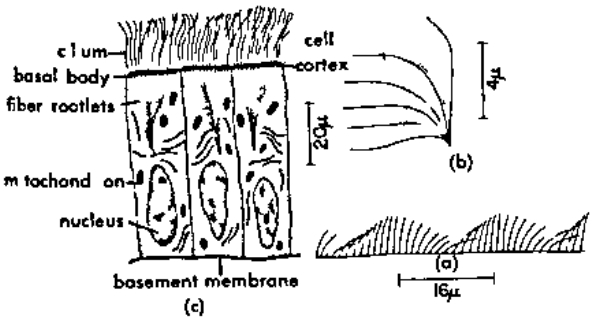


Fig 5 (a) Ciliary metachronism (b) Effective and recovery stroke of an individual cilium (c) Ciliated epithelial cells

Adjacent cilia in one direction along a ciliated epithelial surface may be slightly out of phase in their beats and this condition gives the entire surface a wavelike motion (Fig 5) High speed cinematography resolves the movement of individual cilia into a stiff and sweeping effective stroke and a limp and flaccid recovery stroke This cycle may be repeated 10–40 times per second Such metachromic rhythmic coordination can be destroyed by an intracellular incision that severs a system of fibrillar connections beneath the cell surface Flagellar movement is slower and usually undulatory Since ciliary movement continues in isolated epithelia protozoan fragments and headless sperm its mechanism appears to reside in the cilium itself and its basal body or point of attachment to the cell proper Ciliary activity is affected by temperature pH and the ionic environment it utilizes oxygen and it appears to be energized by adenosine triphosphate [E J D]

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Cell (electric)

A single unit of a device that generates stores or controls electric energy The commonest type of cell which converts chemical energy into electric energy is made in two forms (1) a primary cell such as the familiar dry cell used in flashlights which cannot ordinarily be recharged and (2) the secondary cell such as that used in automobiles which can be recharged many times by sending electric current through the cell in the reverse direction A standard cell is a primary cell that has a constant accurately known voltage (1 018636 volts at 20°C for a Weston standard cell) It is used as a reference standard when making precise voltage measurements A group of cells connected electrically is called a battery *See* BATTERY (ELECTRIC)

Another type of cell converts radiant energy into electric energy The solar cell used in space satellites to power radio transmitters converts the radiant energy of the sun into electric energy (*see* SOLAR BATTERY) In the photovoltaic cell used in photographic exposure meters the light reflected from the subject to the cell is converted into sufficient electric energy to operate a meter or automatically adjust the aperture of the camera (*see* PHOTOVOLTAIC CELL) In a photoconductive cell a change in the amount of light or other radiant energy falling on the cell causes a change in the resistance of the cell (*see* PHOTOCONDUCTIVE CELL)

An elementary unit of storage in a digital computer is also called a cell (*see* DIGITAL COMPUTER) [J MR]

Cell (pressure temperature effects)

All biological activities depend upon the chemical reactions whose sum total constitutes the metabolism of living systems Chemical and metabolic reactions in general are influenced to a greater or lesser extent by both temperature and pressure according to the properties of the reactant molecules and the nature of the reaction

Physicochemical aspects The fundamental physicochemical laws governing the behavior of molecules in simple systems are now well known and understood Reactions in cells however take place in a setting of unique organization and complexity In addition these reactions depend either directly or ultimately on large complicated organic molecules such as enzymes which serve as catalysts or other protein molecules and highly polymerized nucleic acids which are involved in preserving the structural and functional integrity of the cell In consequence metabolic reactions and biological processes in general have certain characteristics such as an optimum temperature that

are not ordinarily encountered in the nonliving world and often appear not to conform to the same basic laws which pertain to simple reactions Yet there is every reason to believe that these laws apply as exactly to any individual metabolic reaction in a living cell as to any chemical reaction in a test tube Moreover in spite of seeming deviations that are often encountered the quantitative relation to temperature and pressure exhibited by physiological processes as a whole sometimes conforms closely over a limited range to the laws governing simple reactions *See* METABOLISM

Dual action of temperature As a rule heat accelerates chemical reactions The same is true of biological reactions up to a point With continued rise in temperature however all biological processes reach a maximum usually referred to as the optimum temperature at which the process ceases to increase with temperature and beyond which a further rise in temperature has a slowing down effect In fact with only slight increases in temperature above the normal optimum the process may cease altogether accompanied by a fairly rapid thermal destruction if held at that temperature for more than a very brief period of time Practically full recovery of activity may follow on cooling after momentary exposure to such temperatures The actual range in temperature through which all this occurs is quite small in comparison to the range through which ordinary chemical reactions continue to be accelerated by rise in temperature The occurrence of an optimum within a relatively narrow range of temperature is a virtually universal distinctive characteristic of biological temperature relations The quantitative relation between temperature and activity of the system is known as the temperature activity curve

Basic cause of optimum temperature The basic cause of a maximum or optimum in biological temperature activity curves is that although heat accelerates the reaction heat also partially decomposes an essential component or components involved in the proc[illegible] Th[illegible]

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structure of the protein molecules comprising the enzyme As long as the protein remains in the normal or native state heat accelerates the catalytic reaction A little too much heat however loosens the intricate structural organization of some of these molecules causing them to become catalytically inactive or denatured At the optimum temperature roughly one-half of the population of enzyme molecules may be *denatured* but in equilibrium with the other half in the native state The ratio is one of statistical probability concerning the proportion of molecules in each state at a given moment and it is governed by the thermodynamic characteristics of the system or more specifically by the constants for the heat ΔH and entropy ΔS of reaction which together constitute the free energy of reaction ΔF With enzymes and most other proteins the values of these constants are such that the equilibrium constant K or ratio of denatured to native molecules is much more sensitive to temperature than the reaction catalyzed by the enzyme Thus although a rise in temperature beyond the optimum continues to accelerate the catalytic reaction it is far more effective in increasing the ratio of denatured over native molecules with the net result that the whole process rapidly slows down because of the lack of a sufficient amount of active catalyst

Reversible denaturation is usually accompanied by some measure of irreversible denaturation whereby the enzyme or protein breaks down to products that do not readily reassemble Both the extent of reversible denaturation and the rate of irreversible breakdown increase rapidly with rise in temperature Other factors including pH salts metabolic products drugs and others influence the actual temperature required for a significant amount of denaturation To illustrate with a simple example egg albumin coagulates or denatures rapidly in boiling water It will coagulate just as quickly at room temperature with the addition of an appropriate concentration of alcohol Heat is the primary factor in both cases alcohol catalyzes the denaturation with the result that less heat is required The phenomenon is analogous to the more specific action of enzymes in that they lower the temperature required for the reaction they catalyze to proceed at a significant rate

Biological temperature optima The phenomenon of an optimum temperature occurs in all sorts of biological processes such as rate of growth total amount of growth rate of respiration digestion specific enzyme action and also longevity and psychological processes Moreover within a given cell or multicellular organism the optimum temperature of one process may differ widely from that of another For example in the bacterium *Escherichia coli* the optimum temperature for rate of reproduction is about 100°F whereas one of the enzymes of this organism the formic dehydrogenase which splits formic acid to carbon dioxide and water has an optimum temperature as high as 176°F At this temperature the cells quickly die whereas the enzyme continues to function at a maximum rate This example is somewhat extreme as a rule the optimum temperatures for different cellular processes as well as for the different enzymes which function in that cell normally do not differ so widely Moreover they are somewhat correlated with the temperature of the environment which the organism inhabits Thus certain enzymes *isolated* from thermophilic bacteria which grow at temperatures of 120°F or above have optimum temperatures considerably higher than the corresponding enzymes in organisms that cannot grow at such high temperatures Evidently the thermal stability

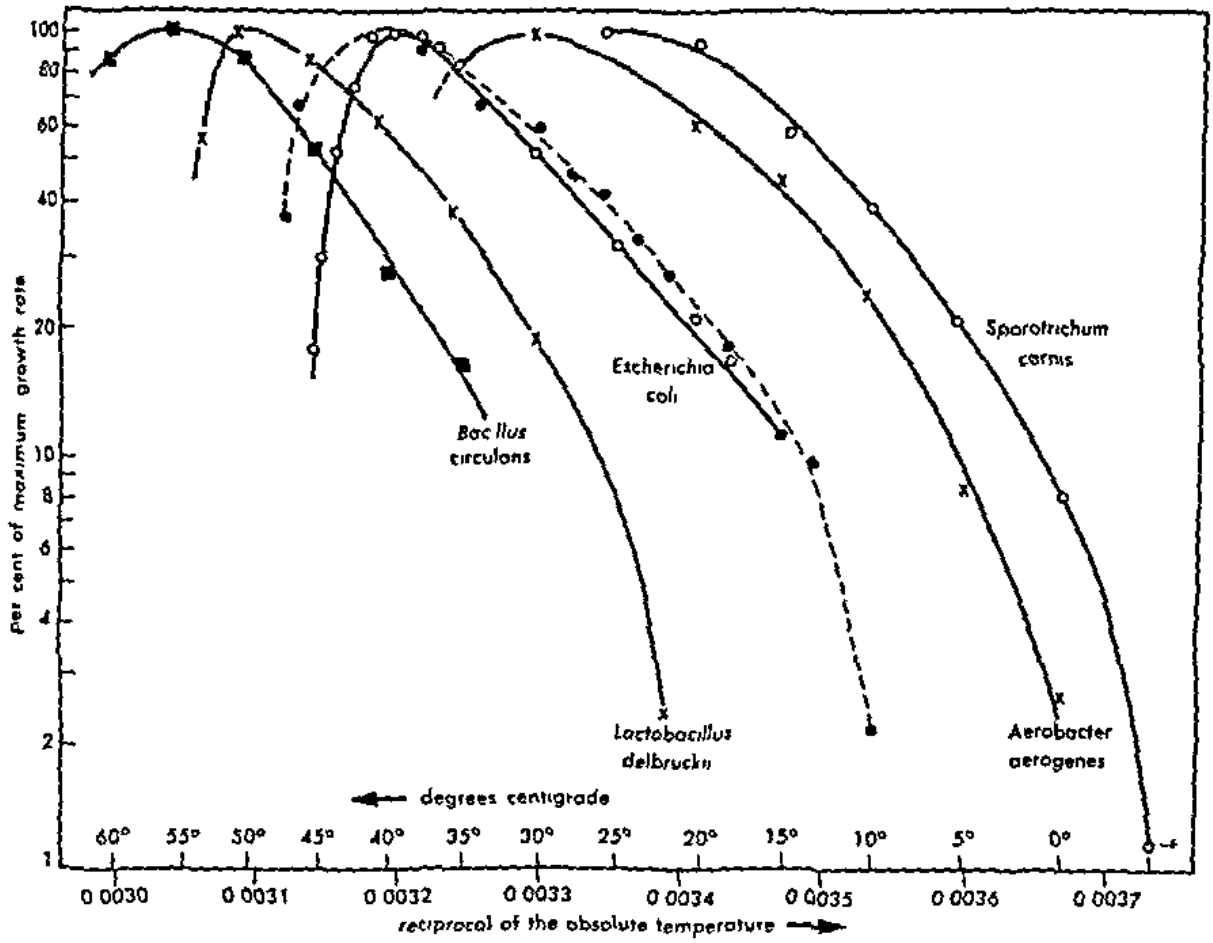


Fig 1 Influence of temperature on rates of growth of different species of microorganisms The maximum rate has been arbitrarily taken as 100 for each species (Data from various sources as given in R E Wilhams and C C Spicer, eds *Microbial Ecology, Soc* Gen Microbiol, Symposium 7 134–167, 1957)

of enzymes is under genetic control, a circumstance reflected also in the occasional occurrence of temperature mutants, wherein an inheritable change takes place in the optimum temperature for growth, or for activity of a specific enzyme or for necessity of specific nutrients *See* MUTATION

Although still subject to temporary or nonmheritable modification by environmental factors and to more lasting changes by mutation the optimum temperature for a given process may vary widely among closely related organisms Growth rates of bacteria and fungi provide a striking illustration (Fig 1) Data on a sufficient number of species would very likely reveal a virtually imperceptible gradation between the lowest and highest optimum temperature represented

A given process whether it be growth or something else, is influenced by various factors in relation to the temperature activity curve for that process in that species and under the particular conditions involved As an example, Fig 2 illustrates the action of a drug sulfanilamide whose quantitative effect is related to temperature on the process of bacterial luminescence in two species with different temperature optima The effect is obviously related to the specific temperature activity curve, rather than to temperature as such *See* BACTERIAL LUMINESCENCE

Optimum temperatures apply with respect to the various physiological processes and complex phenomena in warm blooded animals (birds and mammals), as well as in lower animals and plants Warm blooded animals have evolved subtle physiological mechanisms which ensure a relatively constant, normal temperature Although it can scarcely represent the optimum for each metabolic reaction or process, because these vary within the organism, it evidently represents the optimum for survival of the species and therefore the best compromise

Among the different animals in this category, the body temperature varies with the type of organism and in some instances with the state of activity Bats, for example, are warm blooded during flight, but their body temperature drops when at rest The body temperature of hibernating mammals, such as the ground squirrel or bear, falls to fairly low temperatures not much above those of the environment, during hibernation Among true homoiothermic animals, the normal temperature is not the same in all parts of the body (usually lower in the extremities) nor is it the same at all times (usually lower during sleep) In man, the normal oral

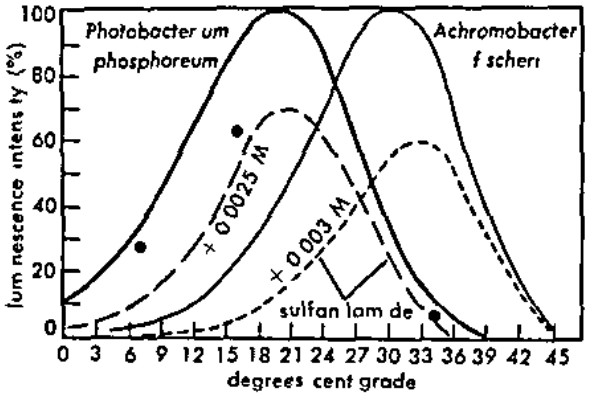


Fig 2 Luminescence intensity in cell suspensions of two species of luminous bacteria as a function of temperature with and without added sulfanilamide The three solid circles under the curve for *Photobacterium phosphoreum* represent the intensities observed at the temperatures indicated after rapidly heating the suspension from 0–38°C to record the temperature activity curve then cooling (*Data of F H Johnson F A Brown and D Marsland in F H Johnson H Eyring and M J Polissar The Kinetic Basis of Molecular Biology Wiley, 1954*)

temperature is considered to be 98 6°F Songbirds have a body temperature of 113°F Oddly enough the hottest body temperature occurs in a cold blooded animal the fish *Barbus thermalis* living in hot springs of Ceylon at a temperature of 122°F

tween absolute zero (−273°C or −459 4°F) and the temperature at the surface of the sun (about 6000°C or 10 800°F) as two extremes (vastly higher temperatures are known) active life is confined to the region (Fig 3) extending from a few degrees below the freezing point to perhaps a few degrees above the boiling point of water or a total range of about 110°C or 198°F (−5 to +105°C 23 to 221°F)

Survival without activity extends to very low temperatures Many types of cells and lower organisms survive temporary but sometimes quite prolonged exposure to extreme cold that is temperatures close to absolute zero in a state of practically complete cessation of metabolic reactions and all other manifestations of life Examples include bacteria yeasts fungus spores moss spores pollen grains plant seeds and some of the lower animals In nature certain molds grow in meat storage vaults at temperatures below freezing, and microorganisms occur in arctic soils where the temperature is below freezing most of the time Among animals the polar codfish remains active in sea water at temperatures slightly below the freezing point of fresh water

At the upper limits of the biological temperature range primitive algae have been found existing in hot springs at 185°F (85°C) and bacteria obtained from the hot brines of deep oil wells have been cultivated in the laboratory under increased hydrostatic pressure at temperatures above the boiling point of water Among animals the hot springs fish *Barbus thermalis*, mentioned above is accustomed to an unusually high temperature

The temperature activity curves of the cold and hot types are genetically placed in different temperature ranges In the tropics near relatives of the polar cod undergo a cold anesthesia and become quite inactive when placed at the low temperatures characterizing the normal habitat of their arctic kin

Biological range of pressure The vast majority of living organisms are never subjected in nature to any profound variations in pressure Yet the range of pressure in natural habitats is great At the surface of the earth from sea level to the highest mountains the air pressure differs by only a few pounds per square inch (psi), averaging about 15 psi at sea level, and decreasing to about 5 psi at the top of Mt Everest Physiological effects of such a difference in air pressures are profound but they stem from differences in concentration of atmospheric gases rather than differences in pressure alone From the surface to the greatest depths of the ocean 35 000 ft in the Philippine Trench the hydrostatic pressure increases from 15 psi to about 15 000 psi and a variety of living organisms inhabit such depths where the environment is perpetually cold (less than 38°F), dark (except for

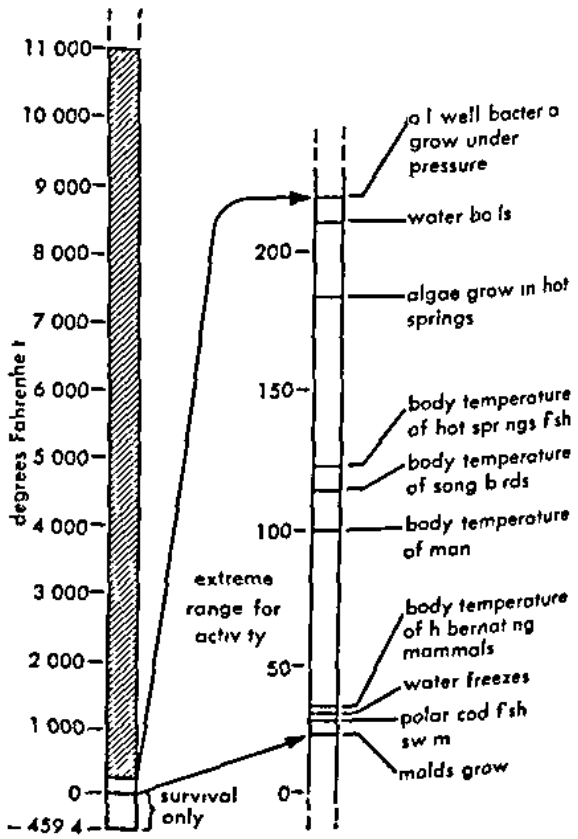
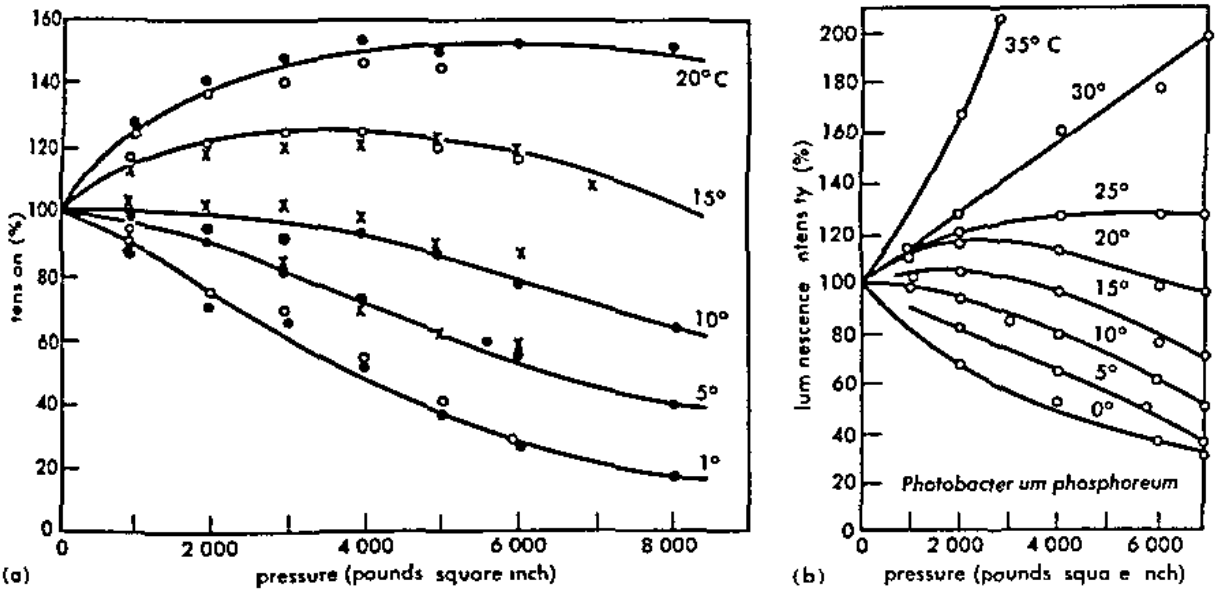


Fig 3 The biological temperature range with some representative phenomena



Fg 4 (a) Influence of pressure at d fferent temper atures on the tens on developed by auricular muscle of the turtle (*data of Brown in F H Johnson H Eyring and M J Pol ssar The K net c Bas s of Molecular B ol ogy 1954*) (b) Influence of pressure at d fferent tem peratures on the intensity of bacterial lum nescence (*data of F A Brown F H Johnson D Marsland in F H Johnson H Eyr ng and M J Pol ssar The K net c Bas s of Molecular B ology W ley 1954*)

the light of luminescent organisms) and under high pressure (several tons per square inch) The largest natural habitat in the world comprising more than one half the total area of the earth lies about 1⅘–1 mile deep in the ocean at a pressure of 4500–6000 psi It should be emphasized that these pressures are purely hydrostatic uniform in all directions and except in relatively few instances such as fish with gaseous swim bladders no gas space is present in the organisms Cells and tissues permeated with water are only slightly compressi ble but the volume of gas space decreases with pressure in accordance with the familiar gas laws As the volume decreases the concentration of the gas increases and the effects of pressure involve changes in concentration as well as the action of pressure as such In view of this circumstance the ability of the whale an air breathing mammal to dive to depths purportedly as great as a mile is all the more remarkable involving physiological adap tations that are not yet completely understood *See* SWIM BLADDER

The temperature of high pressure environments in the sea is constantly cold Another type of high pressure environment where the temperature is constantly hot is the brines of deep oil wells The only form of life found in these brines consists of certain species of bacteria

Biological action of pressure In nature so far as anyone knows the maximum pressure to which *any living cell* is subjected *amounts to roughly* 1000 atmospheres (atm) or 15 000 psi In the labo ratory the effects of much higher pressures (hy drostatic) about 50 000 psi on biological materials have been investigated Because water is only slightly compressible no considerable change in concentration of substances in solution accompa nies the application of these pressures The results therefore stem directly from the influence of in creased pressure on chemical reaction rates and equilibria In general the results are in the nature of destruction—enzymes and viruses lose their ac tivity bacteria die egg albumin coagulates and proteins denature all at room temperature These effects are essentially irreversible

The more moderate though still high hydro static pressures up to about 1000 atm may also cause irreversible destructive effects on cells of terrestrial organisms but in addition they cause many changes that persist only during the actual period of compression when the pressure is re leased the original state is more or less quickly restored Examples include the following inhibi tory effects of pressure in this lower range retarda tion of enzyme action cell division cell respira tion fermentation putrefaction and growth

Here again however increased pressure is a fac tor whose net effects on biological systems are re lated to the normal temperature activity curve of the system involved Thus the same pressures that cause reversible inhibitions at ordinary tempera tures may cause quite the opposite effect at tem peratures above the normal optimum of the process in question for example muscle tension or bacterial luminescence (Fig 4*a b*) These results are under standable on the basis that increased pressure re tards the activity of a limiting enzyme or other *essential component but at the same time and to* a greater extent increased pressure retards or re verses the thermal denaturation of the enzyme the latter reaction being unimportant except at the higher temperatures

Pressure like temperature therefore has effects on biological processes and the two

have a closely related mechanism of action It follows that the various processes have an optimum pressure as well as optimum temperature The positions of both types of optima are genetically determined and at the same time both are subject also to reversible modification by factors in the chemical environment of the cell The action of certain narcotics such as ethyl alcohol furnishes a striking example (Fig 5) At the normal optimum temperature for luminescence of a given species of luminous bacteria increased hydrostatic pressure has little effect on intensity of light emission At this temperature the inhibitory effect of pressure on the enzyme is approximately counterbalanced by the beneficial effect of pressure in reversing the thermal denaturation of the enzyme Addition of a small concentration of alcohol at normal pressure causes the denaturation equilibrium to shift towards the denatured state and the intensity of luminescence falls Under increased pressure the equilibrium now shifts back toward the native state as before and the inhibition due to alcohol is abolished With higher concentrations of alcohol the inhibition can be only partially abolished inasmuch as the amount of pressure required is sufficient to bring about a marked inhibition of enzyme activity The net result with the higher concentrations is that in the presence of alcohol the optimum pressure is greater though the actual intensity of luminescence is lower (Fig 5)

Alcohol also catalyzes an irreversible denaturation as in the coagulation of egg albumin at a rate that increases with rise in temperature or concentration of the drug The irreversible as well as reversible denaturation of certain enzymes and other proteins with or without alcohol is lessened by increased pressure

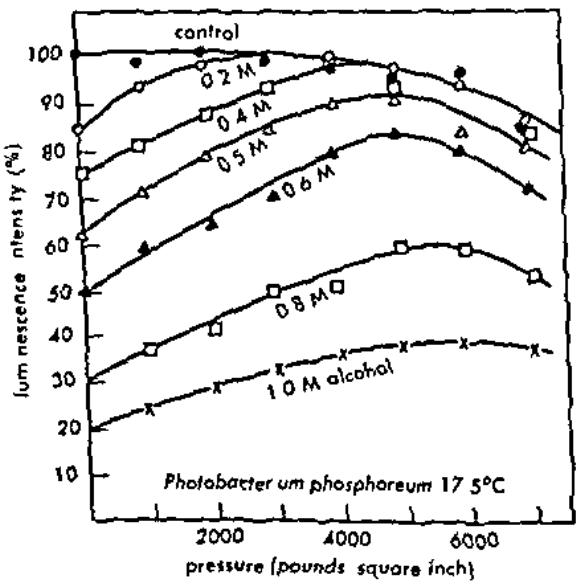


Fig 5 Influence of pressure on luminescence in cell suspensions of luminous bacteria containing various concentrations of ethyl alcohol Moderate inhibitions are reversed by pressure With higher concentrations of alcohol the inhibition is partially reversed and the pressure required for maximum intensity becomes higher (Data of F H Johnson et al in F H Johnson H Eyring and M J Polissar The Kinetic Basis of Molecular Biology Wiley 1954)

Analogous effects of pressure occur in aquatic animals under alcohol narcosis Tadpoles of frogs or salamanders lose all spontaneous activity in 2.5–3% alcohol at room temperature Activity is restored at once on raising the pressure to 2000–3000 psi Similarly, the decreased excitability of single nerve cells when placed in 2.5% alcohol is counteracted by raising the hydrostatic pressure several thousand psi At the molecular level the explanation is fundamentally the same among these diverse phenomena

Quantitative theory Some basic points of the quantitative theory of biological temperature pressure relations can be briefly mentioned

The theory of absolute reaction rates provides the quantitative basis of all elementary rate processes In accordance therewith the specific reaction rate constant k', equals $\kappa(kT/h)K$ where κ is the transmission coefficient k the Boltzmann constant (R/N) T the absolute temperature h Planck's constant and K the quasi equilibrium constant of [illegible] equilibrium can

$$e^{-\Delta F^{\ddagger}/RT} = e^{-\Delta H^{\ddagger}/RT} e^{\Delta S^{\ddagger}/R}$$
$$\approx e^{-\Delta E^{\ddagger}/RT} e^{-p\Delta V^{\ddagger}/RT} e^{\Delta S^{\ddagger}/R}$$

the double dagger superscript denoting of activation rather than of reaction appropriate to the analogous thermodynamic expressions The value of ΔF or ΔF characterizes the influence of temperature on a given reaction For enzyme reactions the values for ΔH and ΔS are usually much smaller than for protein denaturation but the ΔF for the two may be nearly the same The influence of pressure depends on the value of ΔV or ΔV respectively Although for most ordinary chemical reactions these values are small that is a few milliliters per mole at most they are often much larger of the order of 100 ml/mole in biological reactions where large molecules are involved Pressure has a correspondingly greater influence on biological processes than on simple chemical reactions

A generally important consideration regarding biological reactions is that because enzymes are involved the specific rate constants are actually more complicated including not only the three rate constants pertaining to the Michaelis Menten theory but also an equilibrium constant K_d for the reversible thermal denaturation of the catalyst as well as all other equilibrium constants K_n for reversible reactions between the enzyme E and other substances Y which combine in a given ratio r in a manner that affects catalytic activity Thus the k of an enzyme reaction actually represents at least $k'/[1 + K_1 + K_n(Y)^r + \quad]$ the quantitative

significance of the terms in the denominator depending on the conditions

Paradoxically complex physiological processes involving a series of simultaneous and consecutive reactions not infrequently behave as simple chemical reactions with respect to temperature pressure and other factors The simplest explanation is that under the conditions when this is true the whole process is limited primarily by one reaction With the aid of appropriate derivations numerical values for the various theoretical constants can be obtained from experimental data The values thus found provide a basis for a fuller understanding of the process at issue and sometimes for describing with considerable accuracy the quantitative effects of temperature and pressure See CELL (BIOLOGICAL) [F H J]

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Cell constancy

The condition in which the *entire body* or a part of the body of an animal or a plant consists of a fixed number of cells which is the same in every adult of a particular species This phenomenon sometimes termed eutely is characteristic of the entire body of rotifers nematode worms acanthocephalans and related animals It is also a property of certain tissues in annelids insects and vertebrates In plants an individual exhibiting cell constancy is called a *coenobium* Coenobia are found in many species of green algae with *Pandorina* and *Volvox* furnishing familiar examples

Scientific interest in cell constancy arises largely because of its relationship to the unsolved problem of the factors which regulate cell division In eutelic animals or tissues some mechanism brings cell proliferation to an end with great accuracy at a precise point in development or more specifically after a fixed number of cell generations The bearing of this fact on the cancer problem is obvious Some investigators have attempted to show a relationship between the possession of cell constancy and evolutionary kinship but beyond the fact that most though not all animals showing this trait belong to the phylum Aschelminthes no definite conclusions can be drawn

Cell constancy in animals In rotifers where cell constancy was first intensively investigated the number of nuclei in every organ and tissue can be counted exactly In the common species *Epiphanes* (*Hydatina*) *senta* which has been studied by several workers there are 968 nuclei in every individual The skin and associated structures have 301 the pharynx 167, and the digestive tract 76 of which 15 constitute the esophagus 35 the stomach 12 the gastric glands and 14 the intestine The urogenital system consists of 43 cells the general musculature 120 and the nervous system 247 of which 183 are in the brain and 4 in the retrocerebral organ A F Shull in an investigation of a large number of individuals of this species found almost no deviations The presence of 6 nuclei in each gastric gland and of 8 in the vitellarium is common to many species of rotifers

An outstanding anatomical feature of nematodes" according to L H Hyman "is their cell constancy This fact has been confirmed by several workers on various species including the well known *Ascaris* the vinegar eel *Turbatrix aceti* and *Rhabditis* In *Turbatrix* there are 251 nerve cells one excretory cell 18 cells in the midgut 64 in the body wall musculature 59 in the pharynx 5 in the esophagus and so on Since cell division comes to an end before the birth of the worm all subsequent growth is by cell enlargement The gonads are exceptions be au e they produce new eggs or sperms continuously throughout the reproductive life of the individual

In annelids and vertebrates cell proliferation is more or less continuous throughout life only in those tissues which are subject to wear Thus in adults cell division may be found in the germinative zones of the skin hair finger and toe nails the lining of the alimentary canal and especially in the blood cell forming tissues The muscles and nervous system however appear to undergo no cell division after early embryonic or fetal stages In both earthworms and mammals including man it has been demonstrated that the number of muscle nuclei and muscle fibers but not fibrils is fixed early and does not increase with subsequent growth An earthworm hatches from its egg cocoon with the adult number of muscle fibers and nuclei A human fetus about 5 in from crown to rump has as many muscle fibers and nuclei as a grown man It has been shown that the number of glomeruli in each kidney of a rat or a man and therefore presumably of any mammal is fixed before birth and that the subsequent growth of the glomeruli either normally or resulting from compensatory hypertrophy after unilateral nephrectomy is due entirely to the enlargement of cells already present The same holds true for the cells of the ciliated nephrostomes of earthworms *See* HYPERTROPHY

Cell constancy in plants Coenobia that is adult individuals composed of a fixed and predictable number of cells, are characteristic of the species of green algae belonging to the species of *Volvox* in the order Volvocales to the species of *Hydrodictyon* and *Scenedesmus* in the order Chlorococcales In these forms the number of cells in an adult ranges from 4 to 8 in certain species of *Gonium* 32 to 64 in *Pandorina* and from 500 (probably 512) to 60 000 (probably 65 536) in *Volvox* During asexual reproduction in these species either every cell or in the larger forms certain cells undergo a rapid series of cell divisions This results in the formation of a miniature replica of the adult as far as cell number is concerned within every single cell which has so divided Thus a very

small young volvox has as many cells as a large mature one The minute new individuals are released from the parent cell by the breakdown of the old cell wall It will be noted that the number of cell generations is always small Thirty two is 2^5 which means only 5 cell generations 512 is 2^9 and even 65 536 is only 2^{16} which means only 16 cell generations to make the largest volvox

Limiting factors The factors that sharply limit cell proliferation are unknown It is clear however that in both plants and animals a most fundamental distinction exists between growth by cell proliferation and growth by cell enlargement It is significant in this connection that heavy metals which will form mercaptides with the sulfhydryl groups of the cell will block cell division but not cell enlargement It is also true that the formation of a coenobium in a plant bears a certain resemblance to the cleavage of an egg in an animal In both cases a single large cell undergoes a rapid series of mitoses resulting in a group of many small cells It is conceivable that in both cases the final slowdown of cell division is due to an exhaustion of the readily available supply of nucleic acids and other constituents required for the rapid formation of new chromosomes Although plausible such a theory gives little insight into why it is that in one case the cells can continue to divide at a slow pace while in the other they must wait until the initial large size is again reached The work of G Fankhauser on salamanders has shown that unknown factors correlated with over all size of the animal are somehow important If these animals are made polyploid so that they have an extra set of chromosomes in every cell the individual cells are much larger than normal Nevertheless the size of the adults remains close to normal This is because in every tissue from the brain to the mucous glands of the skin there has occurred a reduction in cells so as to compensate exactly for their larger size

(G B M)

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Cell division

A process by which living cells reproduce their kind In the larger view biological increase must be described as an increase in numbers of cells The only cells which normally will not divide are found in differentiated tissues of multicellular organisms Cell division includes nuclear division which occurs most commonly by mitosis and cytokinesis (fission of cytoplasm) *See* CYTOKINESIS MEIOSIS MITOSIS

Cellular growth division cycle Over all growth of biological systems may be described in terms of what is called the cellular growth division cycle Living systems are composed of cells which have the capacity to synthesize new molecules similar to those already present As a result, cells grow in mass but the capacity of an individual cell to grow is limited Normally although there are exceptions a cell can only double its mass before growth ceases Division refreshes the capacity for growth because the daughter cells begin to grow immediately after division They normally cannot divide again until they have grown again Division makes growth possible growth makes division possible and thus biological systems increase by stages of doubling and halving

Genetic conservation in this cycle depends on the duplication of the genetic material before division followed by its exact qualitative and quantitative distribution to the daughter cells The distribution is accomplished by mitosis in all plant and animal cells and in many protozoa molds and other microorganisms (*see* BACTERIA FUNGI PROTOZOA) The distribution mechanism in bacteria and in some other microbial groups is not yet known (*see* BACTERIAL GENETICS) Multiplication of cells always involves multiplication of nuclei On the other hand there are cases in which cells do grow without division In these nuclear divisions parallel the growth but the division of the cell body is omitted Common examples are coenocytic algae slime molds and some animal tissues such as muscle (*see* ALGAE MUSCLE MYXOMYCETES) From this relationship it has long been supposed that a single nucleus can administer the growth of only a limited mass of cytoplasm and when this limiting sphere of influence has been attained cell growth stops until the nucleus has reproduced

Theories The typical sequence of growth and division has led to the view that the division is triggered by the attainment of a critical mass A number of workers have demonstrated that division without growth is possible under experimental conditions in a variety of cell types An alternative hypothesis favored by other authorities is that of parallel specific pathways to division According to this theory only some of the processes contained in the over all growth between divisions are directly related to the next division and all of these preparations must be completed before division begins The rest involving most of the biosynthesis is accounted for as the replenishment of active mass without which the cells would be diminished to the vanishing point by successive divisions A number of the preparations and prerequisites for mitotic cell division are now known undoubtedly more will be discovered Those that are known include the chemical duplication of the chromosome the reproduction of the mitotic centers (a functional term for the important particles often represented by visible centrioles in animal cells) and the synthesis of the proteins out of which the mitotic apparatus will be assembled Additional preparations for which the evidence is less certain include the

filling of an "energy reservoir," whose existence seems to be indicated by the fact that after the cell has entered division it can no longer be halted by such things as anaerobiosis carbon monoxide or dinitrophenol

Cell division initiators Considerable attention has been given to the question of the so-called specific triggers to division Although the stimulation and inhibition of division in various organisms by hormones and other substances is an important aspect of the management of cells by multicellular plants and animals the existence of a specific triggering event at the time of entrance into division is not proved Stimulation and inhibition of division may involve only the setting into motion or the completion of any one of the previously discussed prerequisite processes

Study techniques The biochemical and biophysical events leading to and during cell division were somewhat inaccessible until certain technical advances were made New possibilities include (1) cytochemical methods including microspectrophotometry and autoradiography (2) the synchronization of cell division in populations (3) optical advances especially great improvements of polarization microscopy and the invention of the interference microscope and (4) the mass isolation of the mitotic apparatus *See* AUTORADIOGRAPHY CYTOCHEMISTRY MICROSCOPE INTERFERENCE

The mitotic apparatus The entrance of cells into mitosis is marked by the contraction of the chromosomes in prophase (the first stage in mitosis) and by some chemical changes in the chromosomes notably the deposition of ribonucleic acid (RNA) and possibly of lipids (*see* LIPID NUCLEIC ACID) Simultaneously the polarity of the coming mitotic apparatus is established This is indicated by the separation of the mitotic centers in animal cells The mitotic apparatus is essentially completed at metaphase when the chromosomes are aligned on an equatorial plane and apparently connected to the poles by fibers The chemical study of the mitotic apparatus (apart from chromosomes) suggests that it is composed largely of proteins possibly of a single kind of protein and that it contains about 5% of nucleotides probably RNA It seems probable that this material is drawn in many cases from the cytoplasm and in others from the nucleus The mitotic apparatus may amount to more than 10% of all the protein of the cell Chemical evidence suggests that sulfur containing bonds (possibly S S bonds) and probably hydrogen bonds are implicated in the structural assembly Electron microscopic evidence suggests that the submicroscopic core of the spindle fiber is related to the fibrillar elements of cilia just as the structure of the centriole wherever seen is related to that of the basal granules of cilia

Chromosome movement Chemical information concerning the mechanism of poleward movement of the chromosomes at anaphase is sparse However the best current evidence implicates biochemical mechanisms analogous to but not identical with those known to exist in muscle A number of lines of evidence support the inference that the kinetochores play a direct part in chromosome movement Important changes at the end of anaphase include the loss by the chromosomes of the ribonucleoprotein deposited at prophase

Nucleolus The behavior of the nucleolus is one of the least understood aspects of mitosis It disappears (by conventional staining criteria) at prophase and reappears at telophase Some cytologists believe that a less stainable component of the nucleolus persists through mitosis In effect the nucleolus is reproduced during mitosis whereas all other duplicating structures are reproduced beforehand

The doubling of chromosome material before division does not affect the rate of growth or synthesis in the mother cell But it has been shown in a number of cases that the synthetic rate of daughter cells just after division is twice that of the mother cell Therefore a physiological reproduction has taken place during division even though the cell may not grow during that period Visibly this reproduction is correlated with the appearance of two separate nuclei and perhaps significantly with the emergence of two nucleoli [D M]

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Cell inclusions, noncytoplasmic

Small particles or inclusions not immediately vital to life processes present within cells The majority of these inclusions represent forms of stored food built up by the cell through the use of metabolic energy Consequently they are also called ergastic substances Special categories of ergastic substances have been defined under such terms as deutoplasm paraplasm or metaplasm but these terms are used only infrequently Such well known materials as starch and the yellow yolk of eggs are classed as cell inclusions along with the less familiar glycogen (animal starch) fat globules secretory granules melanin and various kinds of vacuoles

Starch An important carbohydrate cell inclusion starch occurs in the form of grains which vary greatly in [illegible] to be seen [illegible] an average [illegible] show concentric layering in their structure resulting from the diurnal rhythm of their growth The starch molecule is composed of long branching chains of the basic unit d glucose The polymerization of the latter into starch grains is achieved within chloroplasts or leukoplasts especially adapted to this function These plastids are closely related in structure and chemical composition to mitochondria Starch is stored mainly in fleshy roots and stems of plants in which it may be hydrolyzed to provide glucose for the plant during the process of rapid growth *See* CELL MITOCHONDRIA, STARCH

Glycogen The animal cell equivalent of starch is called glycogen It is also made up of branching chains of D glucose and occurs in small (0 1 μ) particles within the cytoplasm and in some association with protein It constitutes a more rapidly changing reservoir of energy than does starch *See* CYTOPLASM PROTEIN

Yolk granules These cell inclusions accumulate most conspicuously in egg cells in which they are apparently stored for later use by the developing embryo Like starch they seem to be formed inside mitochondria but unlike starch they are made up largely of protein and lipid They are organized into particles (macromolecules) of uniform character which are arranged in a crystalline lattice within the body of the yolk granule or platelet *See* LIPID

Secretory granules Accumulations of material produced within the cell for secretion to the outside are called secretory granules They are normally discharged from the cell when the organism as a whole requires a particular secretion to satisfy a functional demand Certain secretory granules made up largely of enzymes are called zymogen granules They are abundant in cells of the digestive glands such as the pancreas Another common type mucigen granules represents a condensation of mucoproteins When these are discharged from the cell they provide the mucin commonly required by the animal for lubricating and protecting epithelial surfaces Ergastic substances of this type are assembled into granules in elements of the Golgi component although they are probably synthesized elsewhere within the endoplasmic reticulum *See* ENZYME GOLGI COMPONENT

Fat or lipid inclusions Many plant and animal cells contain fat or lipid inclusions in the form of globules or droplets These also serve as reserve materials to be used during periods of fasting or growth Some animal cells for example part of the adipose tissue are specialized for fat storage and in these the lipid inclusion may have a greater volume than the cytoplasm that is stretched to a very thin layer around it These inclusions consist mainly of neutral fats When these fats are metabolized by the cell the mitochondria are closely associated with the droplet surfaces presumably near the source of fatty acids *See* CELL (BIOLOGICAL)

Melanin granules These and related inclusions give color to animals They occur as yellow to brown and black particulates in hair and cells of the epidermis and other layers of the skin In some animal forms particularly fish the pigmented cells or chromatophores are able to change shape under nervous or humoral control and thus quickly alter the color of the organism Melanin granules are chemically inert and appear to be products of protein decomposition The granules are formed within small vacuoles of the cytoplasm and once formed seem not to be destroyed or used for any other purpose than coloration

Crystals Inclusions representing excess inorganic material of various types are common in the vacuoles of plant cells but rare in animal cells In the majority of cases they are crystals of calcium salts especially calcium oxalate Recent explorations of cell fine structure have defined protein crystals in several kinds of animal cells but their significance is not known

Vacuoles Both plant and animal cells commonly contain other noncytoplasmic inclusions called vacuoles In plant cells they are characteristically large and may constitute the greater part of the total volume of the cell The content of these large plant vacuoles varies considerably but for the most part it consists of dilute solutions of inorganic salts sugars and inorganic acids Vacuoles may contain metabolites held in reserve for the protoplast and provide a place for the accumulation of wastes The large vacuole of the plant cell is a kind of built in environment for the cell a buffer tank which takes on many of the functions of the circulating extracellular fluids of animal tissues Vacuoles are commonly small in young meristematic (dividing) cells but they frequently fuse into one or a few large vacuoles as the cell matures The origin of the small vacuoles is still in doubt

In animal cells vacuoles vary in character and origin Many arise through pinocytic or drinking activity of the cell whereby it takes in as a vacuole a small part of its environment Water and other metabolites are then assimilated by the vital parts of the cell as needed Wastes that accumulate in these same vacuoles may be discharged

Essentially the same activity is carried on by protozoa in some cases by way of special morphological features of the cell surface The resulting vacuoles contain the food of the cell and digestion takes place in them *See* CELL PROTOPLAST PROTOZOA [KRP]

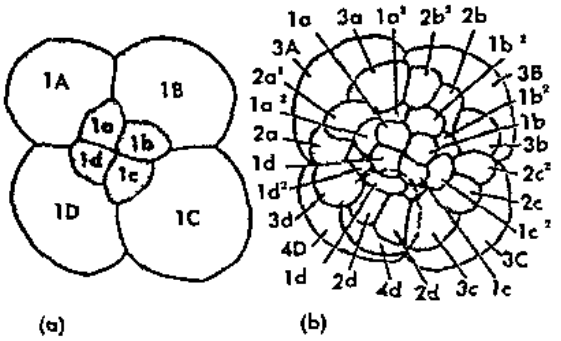
Cell lineage

A type of embryological study in which the history of individual blastomeres (cells formed during division of the zygote) is traced to their ultimate differentiation into tissues and organs The lineage of blastomeres can be readily traced only in certain invertebrate animals chiefly polyclad flatworms nemertines annelids mollusks and ascidians where [illegible] In these forms In size shape position composition and time of origin The fate of the blastomeres becomes fixed during early stages Such eggs are said to exhibit mosaic development

Cleavage pattern In polyclads rhynchocoels (nemertines) annelids and mollusks with the exception of cephalopods cleavage is basically similar and of the spiral type A standard system of blastomere nomenclature is used for all of these groups The first four blastomeres are designated A B C D The third cleavage separates an upper quartet of micromeres (1a 1b 1c 1d) from four basal macromeres (1A 1B 1C 1D) Additional quartets of micromeres usually four or five altogether are subsequently cut off from the macro-

meres The cells of the second micromere quartet are designated 2a 2b 2c 2d and their sister macromeres become 2A 2B 2C, 2D The third quartet cells are 3a 3b 3c 3d and so on for the remaining quartets The cleavages establishing the micromeres are oblique to the main egg axis As a result the first quartet cells as seen from the animal pole are rotated clockwise with respect to their sister macromeres (see illustration *a*) The second quartet rotates in the opposite direction the third in the direction of the first and so on in an alternating series This is the characteristic feature of spiral cleavage The direction of rotation of the quartets is the same in all species except for sinistral gastropods where the shell is coiled in a counterclockwise direction, here the first micromere quartet is rotated to the left instead of the right the second to the right and so on In dextral gastropods the usual plan of micromere rotation is followed

As the micromeres subdivide they are named so as to indicate their descent Thus the daughter cells



Cell lineage in the egg of the gastropod *Crepidula* (*after Conklin 1897*) (*a*) Eight cell stage seen from the animal pole showing the first quartet of micromeres (1a 1d) and the macromeres (1A 1D) (*b*) Twenty five cell stage the cells 3A, 3B 3C 4D will form endoderm exclusively 4d will form the primary mesoderm and a little endoderm the remaining 20 cells will form the ectoderm and mesectoderm

of 1a are called $1a^1$ and $1a^2$ the exponent 1 being given to the cell lying nearest the animal pole The daughter cells of $1a^1$ become $1a^{11}$ and $1a^{12}$ and so on (see illustration *b*) The system can be expanded indefinitely

Fate of the blastomeres In annelids and mollusks the first three quartets of micromeres produce the ectoderm and mesectoderm The macromeres 3A 3B 3C 4D are purely endodermal The micromere 4d called the mesentoblast cell gives rise to all of the primary mesoderm and to the endoderm of the distal part of the intestine Much the same picture is seen in polyclads and nemertines The homologies of cleavage pattern and blastomere fate are regarded as evidence of a common descent of all of these forms

Ascidians likewise show mosaic development but the cleavage pattern is quite different from the mollusk annelid plan In ascidians the cleavage is non spiral and bilateral An entirely different system of nomenclature is used for the blastomeres in these forms *See* CLEAVAGE EMBRYONIC *see also* EMBRYOGENESIS [A C C.]

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Cell membranes and monolayers

Some of the major constituents of living things in particular proteins and lipids form stable oriented films one molecule thick (monolayers) at the surfaces of separation (interfaces) between watery fluids and various other substances such as air oil or glass which do not mix with water There is reason to believe that similar films occur within living cells singly or in combination and that the monolayer can be regarded as the fundamental type of molecular aggregate in many of the membranes septa and laminae found in cells The biological significance of monolayers is apparent since these cellular structures are associated with some of the activities common to all cells such as controlled exchange of substances between cell and environment and also with specialized functions such as locomotion phagocytosis nerve conduction and conversion of light into energy suitable for photosynthesis and vision There are also in the cell many small molecular aggregates which probably act as sites for formation of monolayers so minute in area as to be unrecognizable as sheets or membranes in the usual sense and these may be of importance in bringing together reactive chemical groups and thus catalyzing biochemical processes Finally the existence of life has resulted in the dispersal of substances of biological origin throughout the inanimate world so that many natural surfaces are occupied by monolayers these in turn have produced significant ecological consequences Thus the ecology of organisms will be modified considerably if by human intervention large bodies of water are coated with synthetic monolayers for the purpose of evaporation control

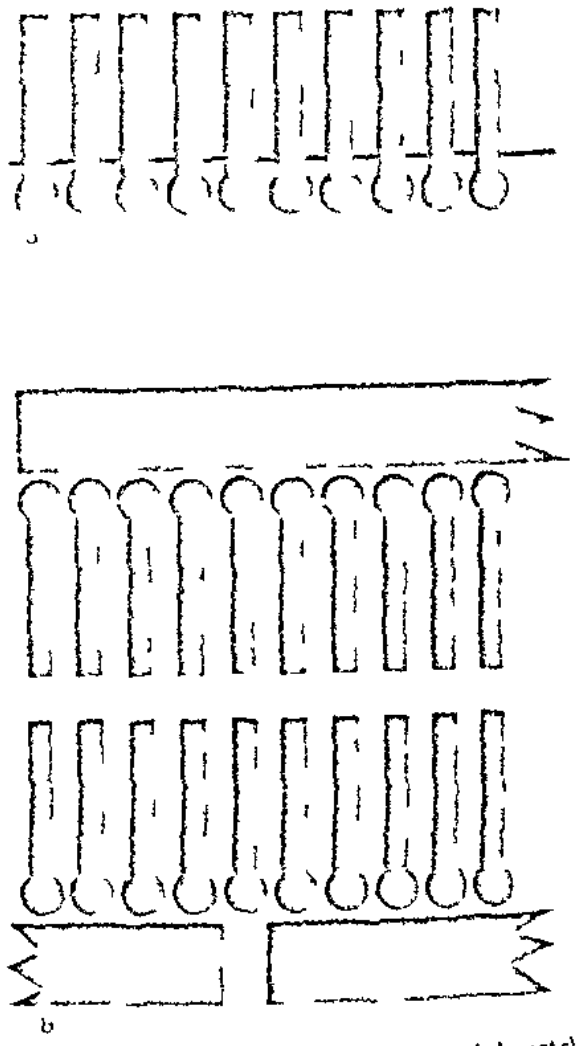
Nature of the cell membrane Generalizations about the cell membrane are based largely upon studies of isolated cells of a few types such as red blood cells and the eggs of marine invertebrates Electrical measurements show the cell membrane to be like a leaky dielectric with a capacitance of 1 microfarad/cm² a fact that combined with chemical data and the unproven assumption of a dielectric constant around 3 suggests a double molecular layer of lipid 30–50 angstroms (A) thick This conclusion has to be modified in view of the discovery that the tension at the cell surface is very low often around 0 1 dyne/cm while that of the lipid double layer would be about 20 dynes/cm The necessary reduction in tension occurs spontaneously in the presence of dissolved protein by the coating of the lipid on both sides with a protein monolayer This would result in a lipid protein membrane consisting of two lipid monolayers sandwiched between two protein monolayers Sections of cell membranes stained with osmic acid and viewed by the electron microscope often appear as

continuous lines some 50 A wide with thin l lack edges assumed to represent the layers of protein Convincing independent evidence for the existence of this kind of structure is derived from the polari zation optics x ray diffraction and electron microscopy of the lipid rich myelin sheath of nerve a jellyroll spiral struct ire formed by the mem brane of the parent cell These studies show that the sheath must consist of many alternating layers of radially oriented lipid and tangentially oriented protein *See* BIOELECTRIC MODEL

Properties of oriented lipid and protein The reasonableness of the lipid in protein sandwich meml rane struct ire hinges upon the known prop erties of oriented lipid and protein Lipids are characteristically elongated oil like (hydrophobic nonj olar) organic compounds with wettal le (hy drophilic polar) end groups they form mono layers on water which can be transferred to solid carriers as successive doul le layers stabilized by segregation of polar and nonpolar end groups re spectively Proteins unlike lipids are often solul le in water They are folded giant molecules which form insoluble monolayers by being unfolded under the influence of surface forces with the exposure of previously concealed hydrophobic groups Protein monolayers are formed spontaneously from aque ous solutions at many interfaces Their character is very varied because the degree of unfolding de pends upon the interfacial energy which is for ex ample almost complete at some oil water inter faces and slight at the surface of a stearic acid leaflet in the former case a second layer of protein may be adsorbed by the first usually without un folding Such layers of protein upon oriented lipid provide an instructive model for one side of the postulated sandwich membrane with the required interfacial tension of less than 0 1 dyne/cm Com plete membranes bounded on both sides l y dilute protein solutions have been made in the laboratory

Interfacial structures The frequency with which membranelike features of macromolecular thick ness appear in electron micrographs of cell and tis sue sections is quite remarkable They apparently form continuous boundaries around all types of cells and around organized structures inside the cell such as nucleus mitochondria and Golgi bod ies They appear within the cytoplasm and they traverse the mitochondrial body as incomplete *septa* In the photoreceptors of the plant chloro plast and of the visual rods and cones they form stacks in which are embedded the oriented pigment molecules Because of chemical and cytological re *semblances* among membranes in these varied sur roundings it is tempting to assign to them a com mon ultrastructure such as the lipid in protein sandwich already discussed

Macromolecular membrane functions From *their varied surroundings* it is natural to associate these membranes with different cell processes Only in the case of the cell membrane is there defi n te but incomplete knowledge it mediates mate rial exchanges between cell and environment In



Monolayer and membrane structures (schemat c) (a) Lip d monolayer on water Rods are nonpolar cha ns c rcles are polar end groups (b) Double layer of l p d w th prote n monolayers attached to both po lar surfaces Polypeptide chain of prote n is repre sented by filled in areas S de cha ns of prote n are not shown

the specialized cell membrane of the nerve fiber this control is modified rapidly from point to point dur ing the transmission of the nerve impulse and in the subsequent recovery Similar disturbances in volving material transfer occur in muscular con traction It is less certain that material transfer ac companies other phenomena such as phagocytosis and ameboid movement As for the cytoplasmic and mitochondrial septa it is not known whether they serve to isolate regions of biochemical specializa tion whether they control communication between compartments or whether they offer large areas for the adsorption of important chemical reactants In the plant and animal photoreceptors the function seems obvious they present to the incident light a series of membranes with photochemically excita ble centers somehow specialized for energy trans fer In view of this astonishing diversity of function the q iestion arises as to where the versatil ty of such a ubiquitous structure lies

The lipid protein membrane hypothesis The normal permeability of cells to a few organic substances is the only property for which the sandwich structure accounts effortlessly Attempts to explain more important phenomena such as facilitated diffusion and active transport have led to the introduction of new features as an example polar pores with enzymatic or contractile properties In electron micrographs of the red blood cell the external structure appears to be dominated by pores in a tangentially oriented lipid component an external protein monolayer is not seen Even without such revisions however the sandwich structure is very flexible The number of lipids available and the variety of their possible liquid crystalline configurations (which need not be limited to one double layer) provides for a wide range of properties including perhaps the spontaneous appearance of self-sealing molecular holes The protein components may vary as to chemical individuality degree of unfolding permanence and receptivity toward other reactive substances They may also have mechanochemical properties like those of certain synthetic polyelectrolytes endowing them with general or local contractility which might provide the basis for osmotic pumping or locomotion Finally the protein lipid multilayer with incorporated pigment may possess semiconductor properties which could provide a basis for energy transfer While the potentialities of the monolayer sandwich structure should be exhaustively explored it is important to remember that many processes can be reasonably attributed to contiguous elements operating separately or in cooperation with the membrane It is significant that the continuous macromolecular membrane frequently seems to be the site of other types of structure such as the honeycomb system seen within the nuclear membrane There is often a distinct accumulation of granules helices and mitochondria in the vicinity and these may with some justification be defined as part of the surface structure the apparent functional location of which may tend to shift according to the biochemical criterion employed

Monolayer reactions In living systems molecular orientation is a significant factor in directing chemical reactions Many attempts have been made to find monolayer reactions exhibiting some of the special properties of processes such as lysis phagocytosis narcosis ion antagonism fat digestion growth regulation muscular contraction and even carcinogenesis The results have been inconclusive but monolayer studies have made at least two important general contributions to biology first in showing the versatile behavior of proteins at interfaces second in proving that chemical and photochemical reactions involving monolayers can be controlled by steric changes accompanying compression The inactivation of many enzymes antibodies and hormones by surface unfolding and the stability of others similarly treated is also of much significance Other more specific facts have emerged including a correlation between the ability of certain dissolved substances to penetrate lipid monolayers and their lytic effects *See* ADSORPTION CATALYSIS CYTOLOGY CYTOPLASM ELECTRIC ORGAN (BIOLOGY) MICROSCOPE ELECTRON INTERFACE OF PHASES LIPID NERVOUS SYSTEM OSMOREGULATORY MECHANISMS PHOTORECEPTION PROTEIN SURFACE TENSION [J B B]

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Cell nucleus

A highly specialized portion of the cell protoplasm which is of crucial importance to cell physiology and heredity All living cells depend for their existence on a nucleus If the nucleus is experimentally removed from a cell the cell dies if the nucleus is put back the cell lives Some highly specialized cells such as mammalian red blood cells lose their nuclei at maturity

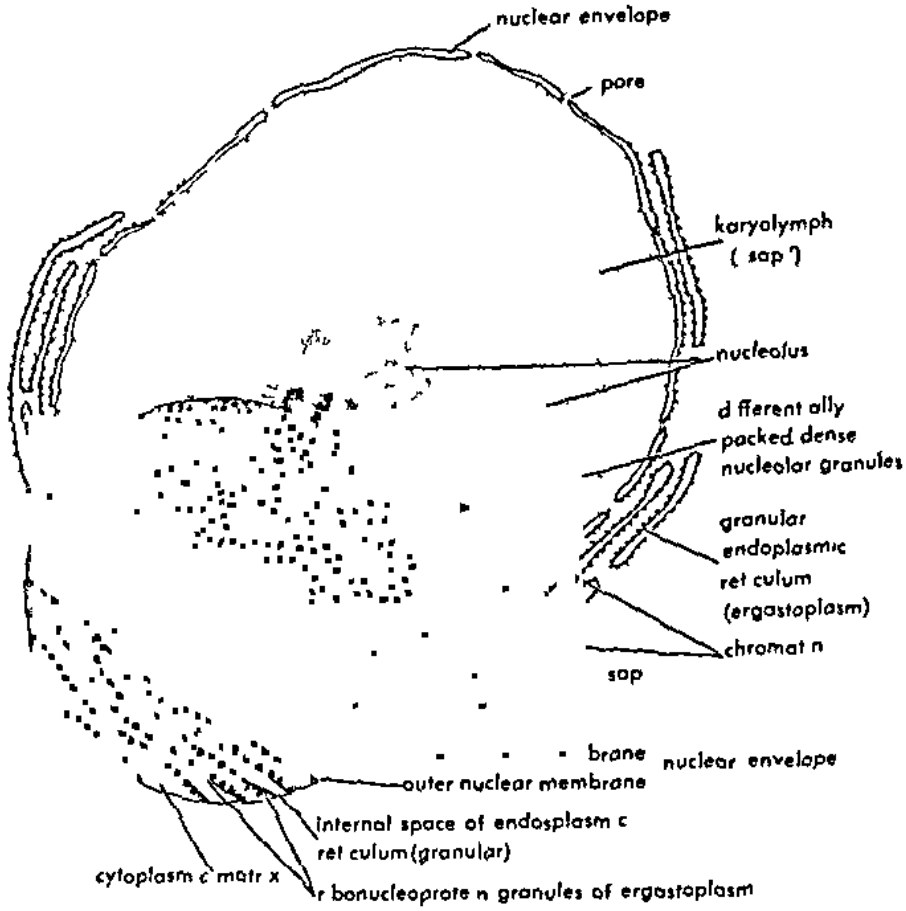
Structure and composition Cells usually contain one nucleus though multinucleate conditions are not uncommon The nucleus is generally spherical in shape although exceptional cases have been found which show a highly folded or lobed appearance In primitive forms such as bacteria and blue-green algae the nucleus may be disposed about the cell as scattered granules In size nuclei range from less than 1 micron as in bacteria to several thousand microns (several millimeters) as in amphibian eggs It is common for the nucleus to be enclosed in a definite envelope consisting of two closely apposed membranes the outermost of which is continuous with membranes limiting a vacuolar system of the cytoplasm (endoplasmic reticulum) The nuclear envelope breaks down only at the time of mitosis or when the nucleus degenerates Small pores penetrate the nuclear envelope at intervals but because they appear plugged it is not known whether materials pass freely through them in

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nucleus is often clumped It represents dispersed chromosomal material which reorganizes into discrete chromosomes at cell division reverting again at the following interphase upon the formation of a new nuclear envelope *See* CELL DIVISION CHROMOSOME

The space between the chromatin or chromosomal areas is filled with a protein material the nuclear sap or karyolymph (*see* NUCLEOPROTEIN) One or more dense spherical basophilic nucleoli are associated with the chromatin Other nuclear inclusions are rare



D agrammat c representation of an nterphase nucleus showing its relationsh p with the cytoplasm

Chromatin is composed chiefly of deoxyribonu cleic acid (DNA) and several kinds of protein In the normal cell DNA is exclusively chromosomal metabolically stable and is thought to be the sub stance mainly responsible for heredity Unlike DNA the activity and amount of protein con stituents are variable depending on cell function Ribonucleic acid (RNA) associated with protein synthesis is concentrated in the metabolically active nucleoli together with protein Variable amounts of lipid are also present in the nucleus *See* LIPID PROTEIN RIBONUCLEIC ACID

Functions The functions of the nucleus are two fold (1) to carry and perpetuate hereditary (genetic) information throughout generations of cells and individuals and (2) to translate the in formation into metabolic specificity for example the kind of protein a cell makes and hence to determine the cell s destiny (*see* GENETICS) When their specific function is to transmit genetic con tinuity as in a sperm cell or during mitosis the nuclear components are stripped down to DNA and a minimum of essential protein nucleoli are absent In an actively synthesizing cell as in the pancreas which produces digestive proteins the metabolic nuclear components (other proteins RNA nucleoli) are also present and the cell depends on participation of the nucleus in its activities *See* CELL ORGANIZATION CELL PROTO PLAST [M J M]

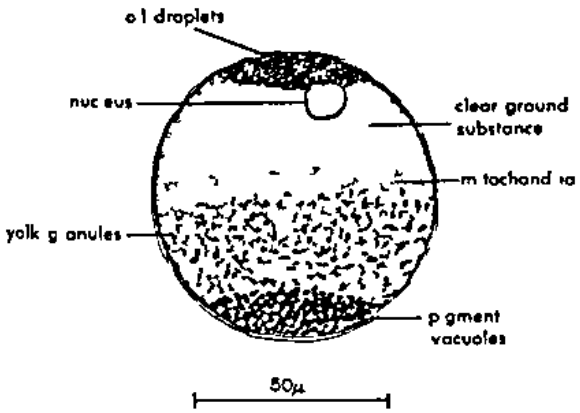
Bibliography See CELL (BIOLOGICAL)

Cell organization

The living cell is a highly organized self regulat ing chemical mechanism whose constituents are proteins nucleic acids carbohydrates lipids a small number of other organic compounds and some mineral salts These molecules reside within the cell in an aqueous medium the water molecules greatly outnumbering all others The variety of the chemical constituents of cells and protoplasm is not in itself sufficient to explain the cell s autoregu lation the directed catalytic pathways of metab olism or any one of the complex physicochemical processes ordinarily considered to be characteris tic of life Thus the chemical constituents of pro toplasm must be present in an orderly assembly

The cell's components display a very h gh de gree of submicroscopic and molecular order All components may be regarded as members of a di mensional hierarchy beginning with the smallest units the protons and passing from larger ions to small molecules to larger organic molecules through the macromolecular polysaccharides pro teins and nucleoproteins to the small subcellular particulates and finally to the major compartments of the cell itself the nucleus and the cytoplasm Although it is dynamic and subject to constant change the spatial arrangement of these elements within the confines of a living cell is orderly A differentiated surface structure known as the plasma membrane surrounds the entire assemblage

Protoplasm manifests colloidal behavior, that is its physical properties resemble those of certain nonliving systems whose parts are a dispersion medium or continuous phase and a discontinuous phase of dispersed particles The discontinuous liq or a mol ecules In all cases the special properties of the colloidal system arise directly as a result of the large size of the dispersed particles relative to that of ordinary molecules and of their small size relative to that of ordinary microscopic and macroscopic objects The dimensional domain of colloidal particles is from about 10^{-4} cm (1 micron) to about 10^{-7} cm (10 angstroms) Thus the largest particles are barely resolvable by a good optical microscope working near its high resolution limit the smallest are not much larger than ordinary or



Cell organization

ganic molecules The special properties of colloids and particularly of biocolloids arise as a result of the preeminence of surface forces in these systems these properties such as high viscosity capacity for gelation non Newtonian flow and phase separation are predictable from the ordinary laws of physical chemistry and no mysterious residual valencies need be invoked to explain them

In biological systems the observed colloidal properties are attributable almost entirely to dissolved macromolecules rather than to the presence of colloidal aggregates With the possible exception of certain microscopic fat droplets found in some cells no colloidal aggregates of ordinary small molecules are known to be primarily responsible for the colloidal behavior of protoplasm The important dispersed colloidal particles in protoplasm are therefore macromolecules and only secondary roles are assignable to fat droplets and crystals In addition the cell always contains a population of highly organized and differentiated microscopic particles the subcellular organelles Where the simple colloidal aggregates do occur as in the case of fat droplets they do not seem to be involved in those dynamic alterations in local order characteristic of protoplasm *See* PROTOPLASM

Two types of local order are found in protoplasm one in the relatively permanent subcellular particles or organelles the second in a group of transient macromolecular assemblies associated with certain mechanical functions of the living cell for example ameboid movement cytokinesis (the division of one cell into two) and the formation of the achromatic (nonstaining) division figure including the mitotic spindle *See* MITOSIS

For discussions of the detailed structures and functions of the relatively stable and permanent cell structures *see* CELL INCLUSIONS NONCYTOPLASMIC CELL PLASTIDS CENTROSOME CHROMOSOME GOLGI COMPONENT MITOCHONDRIA For descriptions of the transient structures associated with movement and mitosis *see* CELL (BIOLOGICAL) CELL DIVISION

Permanent subcellular organizations These are condensed systems showing a high degree of internal order which is always a manifestation of underlying molecular architecture based upon repeating units of macromolecules often interconnected in complex arrays with paucimolecular films or layers of lipid When the cell is studied by electron microscopy x ray diffraction and polarization microscopy there is a pronounced tendency for the permanent cell inclusions to show highly developed laminar structures These are often composed of alternating layers of radially disposed lipids (fats phosphatides and sterols) and tangentially disposed fibrous protein molecules Many of these inclusion bodies which show the type of laminar structure sometimes found at the interfaces of detergent stabilized emulsions possess highly complex and organized catalytic activities for example mitochondria and enzymes therefore it is presumed that the biocatalysts or enzymes are either bound tightly to the structural elements or are in fact themselves a part of the structure (*see* ENZYME) This is as though a building were both the containing space and the device used to accomplish some operation Since all subcellular organelles either can be manufactured by a living cell or can be reproduced therein from preexisting particles it must be assumed that the less ordered parts of the cell can store the information necessary for the control of such syntheses The intelligence itself must reside in macromolecular particles Its transmission from one cell generation to the next is the task of the genetic machinery

The figure shows the appearance of a sea urchin egg which has been centrifuged The permanent inclusion bodies have been stratified (layered) by the excess gravitational field and can be identified for this cell as oil droplets nucleus mitochondria yolk and pigment vacuoles The region separating the light (less dense) nucleus and the oil droplets from the heavy (denser) mitochondria yolk and pigment layers is structureless when observed with the ordinary optical microscope This clear material has therefore been named hyaloplasm or now more commonly the ground substance *See* CYTOPLASM

Transient structure assemblies All of the fundamental transient structure assemblies of the cells take place within the ground substance it thus displays the capacity to produce increased local order in response to the needs of the cell for mechanical work and structure

The fine structure of the ground substance is not the same in all cells In muscle cells where the evolutionary demand has been for a system poised for efficient rapid and energetic changes in length and tension the ground substance is occupied to a significant extent by linear assemblies of contractile protein molecules (actin and myosin) Assemblies of this specific type are found only in contractile cells with a high degree of differentiation Thus while all cells show some degree of contractility only muscle possesses linear arrays of actin and myosin filaments with certain characteristic local differentiations The latter are perhaps associated with the electrical excitation processes common to muscle and nerve *See* MUSCLE (BIOPHYSICS)

The tissue cells of animals are often highly specialized with respect to specific synthetic processes Observed with the electron microscope such cells frequently show a complex interconnected system of cisternae and lamellae known as the endoplasmic reticulum or ergastoplasm This structure escapes detection by the ordinary microscope so that the ground substance of the pancreatic acinar cell of mammals which shows the endoplasmic reticulum clearly is usually hyaline or structureless when observed with the visible-light microscope *See* MICROSCOPE ELECTRON

Components of the ground substance Common to all cells are water mineral salts some few types of dissolved organic molecules and all of the macromolecules which are in true solution such as the polysaccharides proteins nucleoproteins mucoproteins and mucopolysaccharides Being macromolecular these manifest colloidal properties In addition in the ground substance all cells contain a large number of small angular or spherical particles which are made of protein and ribonucleic acid (*RNA*) and which give to the ground substance its basophilia (affinity for basic dyes or stains) in instances where it displays this property These particles are associated in some cells with the membranous ergastoplasm fragments of this membrane particle complex isolated from broken tissue cells of animals have been called microsomes The RNA rich particles may however be free in the ground cytoplasm In cells which must ordinarily move or which divide frequently these small particles are present in very large numbers and float freely in the hyaloplasm Since they are very small (about 160 angstroms in diameter) they are not detectable by ordinary microscopical means and can be seen only by means of high resolution electron microscopy These small RNP particles or ribosomes (suggesting their high content of ribonucleic acid) appear to be the sites of assembly of activated amino acids into protein molecules Some suggestions have also been made concerning their possible cyclic aggregation and disaggregation to produce the sol gel transformations in the hyaloplasm *See* AMINO ACIDS

The optically empty ground substance is capable of remarkable types of ordering in local regions of the cell as illustrated by ameboid motion The cell in ameboid motion experiences continual local cycles of sol gel transformation, the outer region or cortex of the cell is relatively rigid that is it is gelled The inner region (endoplasm) of the cell is relatively fluid Continuous cycles of breakdown and reconstitution of the gelled region of the cortex at some specific point on the surface produce the protrusions known as pseudopodia (false feet) while increasing gel rigidity or perhaps contraction at the posterior end of the cell completes each cycle to produce motion along the substratum

Gels in biological systems Gels of the type likely to be encountered in biological systems are produced by the appearance or activation of sites for cross linking of linear polymers or structures the non cross linked high polymer solution is a more or less viscous liquid, upon cross-linking among a suitable fraction of the macromolecules present an infinite network is produced and the viscosity of the fluid becomes either high and non Newtonian or infinite ultimately a type of solid or gel is formed The mechanism of ameboid movement must involve a reaction of this kind which is readily reversible It is not necessary to suppose that the cell contains from the beginning any large numbers of fibrous linear gel precursors such as unfolded peptide chains There is a well known tendency for the ordinary corpuscular proteins of cells to aggregate into long beaded chains and these could well be the units which in the presence of a cross linking agent become an infinite network and hence a gel The imposition of a stretch upon such entangled networks of polymer chains may produce regions of crystalline order and hence the birefringence (double refraction) observed in some cells either directly or under mechanical deformation

One of the most striking variations in the degree of organization of the cytoplasm is seen during mitosis Variations in the viscosity (resistance to flow) of the hyaloplasm of an egg cell can easily be demonstrated during the mitotic cycle It is seen that there are sharp variations in this property and that these are correlated with certain nuclear events of mitosis Most important a manyfold increase in viscosity immediately precedes the formation of the mitotic spindle This is indeed a dramatic example of the autoregulation of order in the ground substance At the very beginning of a division (or cleavage) cycle the interior of the cell behaves like a liquid not much more viscous than water some minutes (or hours in other cells) later there has appeared a highly orderly structure (the mitotic apparatus) whose function it is to partition with exquisite accuracy the hereditary material of the parent cell equally to each of the daughter cells

Mitotic spindle The shape of the mitotic spindle has tempted some investigators to suggest that its production is like the production of tactoids in highly concentrated solutions of stiff rodlike macromolecules Tactoids which are paracrystals represent a type of ordered arrangement of molecules other than strictly crystalline generally tactoids and paracrystals combine the properties of anisotropy with plasticity or fluidity The two types of paracrystals nematic (needlelike) and smectic (platelike), do appear to be represented among the colloidal organizations found in the more permanent subcellular inclusion bodies Coacervates are phases of high colloid concentration arising from the spontaneous separation of a colloidal suspension into a dilute and a concentrated phase in equilibrium with one another Perhaps some of the lipid containing droplets and vacuolar structures found in cells are such coacervates Tactoids then are paracrystalline coacervates and the classical example of such spontaneous ordering in colloidal systems is that of tobacco mosaic virus Solutions of this virus separate into two phases by formation of spindle shaped highly ordered aggregates of either high or low density These then rise or fall to coalesce with the light or heavy phase respectively *See* PLANT VIRUS

Recent studies on the submicroscopic fine structure of the mitotic spindle make it appear unlikely that it is produced by so simple a process as tactoid formation although the physical condition which underlies tactoid formation (available volume per particle less than the covolume per particle) may well operate to align the components of the spindle at some stage of its manufacture However the spindle appears to be a more complex cross linked and rigid structure than would be expected if it were a tactoid

Basis of cell organization The remarkable states of organization both transient and permanent obtaining in the living cell appear finally to derive at least in principle from the predictable properties of macromolecular colloidal solutions their variety and complexity must be assumed to reflect no more than the variety and complexity of the macromolecules themselves *See* CELL (BIOLOGICAL) [PRG]

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Cell plastids

Small specialized bodies found in plant cells One type the chloroplast is capable of forming sugar from carbon dioxide and water in the presence of light a process called photosynthesis This type of synthesis is the basis for the autotrophic existence of green plants Green plants owe their color to the chlorophyll found in the chloroplasts and these are the pigments essential for photosynthesis When plastids contain predominantly yellow or red pigments (carotenes) they are termed chromoplasts They can be formed as such or in autumn coloring they may arise from chloroplasts after the chlorophyll disappears When plastids are free of pigment they are called leukoplasts In contrast to the first two plastid types which are found primarily in leaves and other parts of the shoot leukoplasts occur mainly in the storage regions of roots where they transform soluble sugars into starch

Shape and size In lower plants such as the algae plastid shape varies greatly They may be disks rings or ribbons they may be smooth lobed or grid shaped and they may reach lengths up to 100 microns (μ) In higher plants the shape is more uniform being that of a lens or a disk with a diameter of 4–6 μ The number per cell may differ greatly In algal cells there are specific regions in the chloroplasts the pyrenoides which are capable of transforming sugar into starch

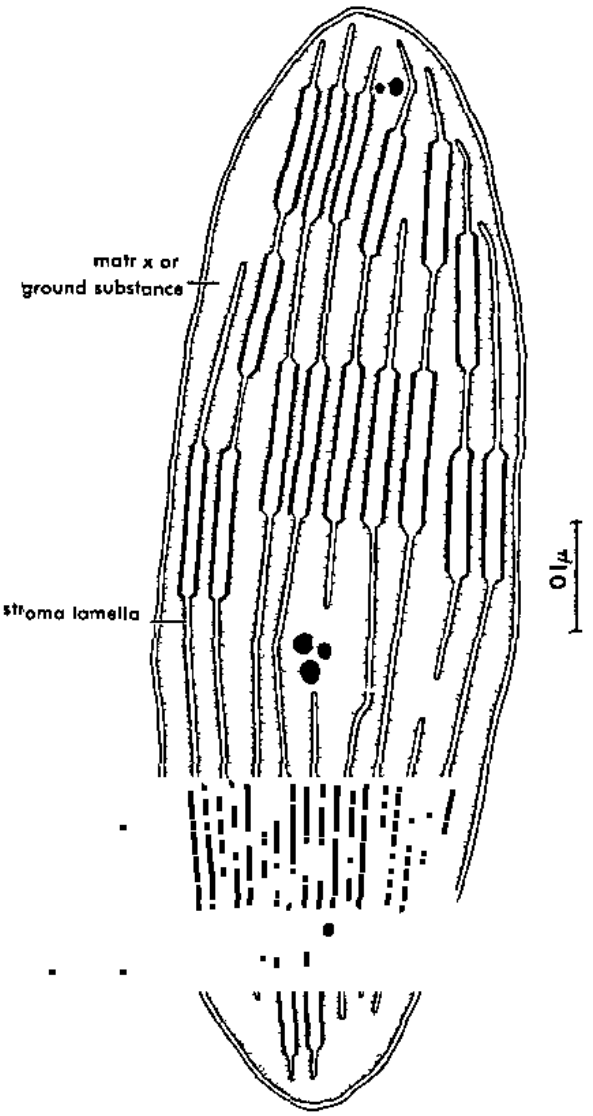


Diagram of section through typical chloroplast showing lamellar structure (*After D von Wettstein Brookhaven Symposia in Biology no 11 1958*)

Composition The chloroplasts of higher plants contain many green inclusions called grana Their diameter ranges between 0 5 and 0 8 μ and their number per plastid varies from 20 to 100 They contain the chlorophyll and are themselves im bedded in a colorless stroma Chemical analysis of chloroplasts yields about 30% lipid 50% protein 5 10% pigments and the remainder ash The elec tron microscope has shown that algal chloroplasts consist of alternating protein and lipid lamellae each about 250 A thick and are split in the region of the grana into the double layered grana struc ture The disk shaped grana lie above each other like a stack of coins (see illustration) The outer region of the plastid the peristromium has no la mellae and may show ameboid movement

Origin Whereas algal plastids increase only by division the plastids of higher plants have a com plicated developmental history They take their origin from mitochondrialike particles called pro plastids which are limited by two membranes In plastid development the inner of these membranes invaginates into the stroma to create a content of vesicles and lamellar units These proliferate to form a crystal like prolamellar body which in turn differentiates into the grana and stroma layers

Starch grains and lipid droplets are often recog nized in chloroplasts chromoplasts may contain large carotene crystals as in the root of carrot *Daucus carota* Leukoplasts have no lamellar sys tem and only starch grains can be distinguished in the structureless stroma *See* ALGAE CAROTENOID CHLOROPHYLL PHOTOSYNTHESIS *see also* CELL STRUCTURES [K M]

Cell protoplast

Protoplast refers to a living cell stripped of its outer coverings Not all substances found in it are necessary to or part of the living mechanism many are nonvital inclusions Vital substances are d stributed universally nonvital ones more or less irregularly A rough analysis of the living fabric is given in the table

Approximate composition of some protoplasts

Protoplasts	Components %						
	Water	Pro- te ns	Lip- ds	Nu cle c ac ds	Car- bohy drates	M n erals	Others
Sl me mold	82	7	2 5	0 5	3 5	1	4
L ver	73	16	5	1	2	1 5	3
Gray matter of b a n	83	8	5 0	0 ~	3	1 5	2

Components of protoplasts No single set of proportions is common to all cells but there are certain limits beyond which individual components do not vary

Water This component constitutes 75–95% of the weight of all functioning protoplasts It is the medium through which almost all movement of nutrients and building materials takes place In plant cells water is found in droplets of varying size (vacuoles) but in all cells water surrounds or is adjacent to each of the molecules that forms the vital fabric Only protoplasts such as are found in seeds or spores have water contents of the order of 10% or less

Minerals Although they occur in trace quanti ties minerals are spread throughout the protoplast They are fixed or flexible links that bind molecules, large and small for structural and metabolic pur poses Or as in chlorophyll or hemoglobin they may be part of the molecule itself It is a general characteristic of life that components classed as molecules by the chemist occur in a variety of associations within the protoplast Some associa tions are loose and rupture instantly when the protoplast is disturbed or killed others are chemi cally stable and thus permit a much fuller study *See* CHLOROPHYLL HEMOGLOBIN

Protein The most abundant solid component of the protoplast is protein It constitutes the bulk of the ground sul stance it is about half the dry matter of the peripheral and internal membranes and it is the principal structural material of the discrete subcellular bodies (*see* CELL ORGANIZA TION PROTEIN) Many proteins of the nuclear and cytoplasmic ground substance occur free or in loose combination (*see* CELL NUCLEUS CYTO- PLASM) Those soluble in water are called albu mins those soluble in dilute salts are called globulins (*see* ALBUMIN GLOBULIN) Much of the protein in the protoplast however occurs in com bination with other components the subcellular particles being noteworthy in this respect The nucleoproteins function primarily though not en tirely as the reproductive units of the protoplast (*see* NUCLEOPROTEIN) In nuclei most of the pro- tein moiety is highly basic in character (prota mines histones) but acidic proteins also enter the combination Membranes are important seats of the lipoproteins and in some protoplasts for example the brain these proteins may be present in very high proportion Carbohydrates of varying degrees of complexity combine with proteins Where the carbohydrate moiety is a relatively simple one the compound is classed as a glyco- protein the role of such protein in protoplasmic organization is poorly understood Mucopolysac charides are components of the highly viscous mucoproteins Wherever these are produced in large amounts they are secreted out of the proto plast often serving some structural or protective purpose such as the mucus of the digestive tract the mucus of the snail the body of the jellyfish and the intercellular cement in animals

Many cellular pigments are compounds of pro teins with a variety of color donating substances A most important group is that which derives its color from the porphyrins hemoglobin chloro- phylls and cytochromes (*see* CYTOCHROME) This group is indispensable to the chain of reactions mak ng energy available for functioning and growth The orange colored carotenoid complexes (vitamin A type compounds) are found in organs as diverse as the light sensitive cells of the eye

and the plastids of plant cells (*see* CAROTENOID) Many yellow proteins derive their color from the riboflavins (vitamin B type compounds) and these have a nearly universal distribution probably owing to their critical importance in respiration *See* RIBOFLAVIN

A number of complex proteins for example the phosphoproteins have a nutritional rather than a vital function In many seeds the protoplasts store proteins in granules or even in crystals The deposition of crystalline compounds within a living protoplast extends to a variety of compounds Calcium oxalate crystals occur widely those of organic acids and glycosides are best known in the cells of citrus fruits and in citrus leaves *See* GLYCOSIDE

The most distinctive role which proteins play in the protoplast is in their function as enzymes (*see* ENZYME) These are the organic catalysts of that tremendous body of chemical reactions which must take place in every protoplast to make possible its growth survival and reproduction Enzymes are everywhere—in membranes particles and ground substance They are formed of protein and in turn must form protein for natural machinery is its own rebuilder The amino acids which occur free in protoplasts are important primarily as building blocks of protein (*see* AMINO ACIDS)

Animal cells which cannot synthesize many of the amino acids do not tend to accumulate amino acids as such but convert them into some form of protein soon after absorption Plant cells are also devoid of appreciable amounts of free amino acids but in many cases they are known to accumulate derivatives called amides It has been supposed by some that aberrations in plant protein metabolism lead to the production of alkaloids for example caffeine in coffee nicotine in tobacco and opium in poppy This view is not general Whatever their origin the alkaloids are stable by products which are usually stored in vacuoles Their usefulness to the protoplast producing them is doubtful Frequently they are formed in one set of cells and accumulate unused in another

Nucleic acids These are the dies which in ways not fully understood stamp the complex molecular forms whose synthesis the enzymes catalyze They are the principal agents in hereditary transmission Commonly they occur in the cellular particles rarely are they dissolved in the ground substance Nucleic acids are closely related to coenzymes in that they possess identical primary constituents (purines pyrimidines pentoses) The coenzymes however are low molecular weight substances associated with proteins in the enzyme systems of the protoplast Some coenzymes move freely through the ground substance transferring specific metabolic products from one enzyme to another some are in firm combination with protein and as such are responsible for specific catalytic properties of the enzyme *See* COENZYME

Most vitamins are important in nutrition because they are constituents of coenzymes or are coenzymes themselves Since animals cannot synthesize many of the vitamins they must depend on plants whose protoplasts often synthesize in excess vitamins or their immediate precursors Fat soluble vitamins are found either in particles for example chloroplasts or in fat bodies Water soluble vitamins may be found in many regions of the protoplast *See* VITAMIN

Lipids These substances play at least three distinctive roles in the organization of the protoplast As neutral fats they accumulate in masses varying in size from microscopic droplets to the large fat depots familiar in animal tissues Such accumulations function mainly as stores of food Seeds may store up to 60% of their weight in fats of this type In combination with phosphorus and certain organic bases the lipids exercise important physiological functions Most notable is the role of the phospholipids in protoplasmic membranes where they constitute 25–50% of the dry matter (*see* PROTOPLASM) The dual nature of the phospholipid molecule water soluble at one end and fat soluble at the other is considered to be a major reason for immiscibility of protoplasm with water The proportion of phospholipid in protoplasts varies greatly In muscle it is one sixth the amount of protein in brain the two components are present in approximately equal quantities Phospholipids having no organic base the phosphatides have been identified in plants and lipids combined with carbohydrates cerebrosides are important structural components of brain cells *See* PHOSPHATIDE

Of entirely different molecular structure though fatlike in physical properties are the sterols or phytosterols (*see* STEROL) Cholesterol like the phospholipids is an essential component of membranes but precisely what role it plays at the cell surface is undetermined (*see* CHOLESTEROL) The activities of the sterols as hormones are well established Hormones may be regarded as regulators of the metabolic activities of protoplasts They may act by controlling specific enzymes groups of enzymes or other hormones Their importance is great in multicellular organisms where they may be required to integrate the activities of as many as several billion protoplasts with one another The diversity of their effects is matched by their diversity of chemical types The sterols are but one of several chemical groups contributing to the hormone class In plants the recognized hormones are water soluble in character The production of hormones is limited to special groups of cells such as the adrenals or pituitary in animals and the stem apex in plants *See* HORMONE PLANT HORMONES

Chemically the sterols are derived from small units called the terpenes If such was their evolutionary origin then Nature must have adapted the terpenes to create a most varied family of compounds (*see* TERPENE) Related to this group are the fat soluble pigments chlorophyll and carotene vitamin A D and E rubber resins and essential oils The sweet smelling essential oils are the sim

plest of terpene compounds found only in 0.5% of the known plant species They are by products of secretory cells they cannot be metabolized by protoplasts and they accumulate either as droplets in the cytoplasm or in extracellular ducts The resins including turpentines lacquers and shellac are more complex but similarly unused terpenoid compounds secreted in resin canals principally of coniferous trees

Carbohydrates These compounds are best known as energy yielding foodstuffs and there are but few areas of the protoplast in which they are not present (*see* CARBOHYDRATE) They are found in nucleic acids in most coenzymes in compound proteins and in lipids As basic nutrients the simple sugars are found throughout the protoplast Generally in nonfermenting organisms they are metabolized to carbon dioxide and water but frequently intermediate products accumulate Succulent plants in particular accumulate large quantities of organic acids in their vacuoles Many plants store sucrose in their plant sap but polysaccharides are Nature's choice for food reserves (*see* POLYSACCHARIDE) Of these starch is the most abundant its characteristic microscopic granules are unique among the polysaccharides (*see* STARCH) Glycogen the principal storage form in animals is dispersed in exceedingly fine submicroscopic granules through much of the protoplast possibly in combination with protein (*see* GLYCOGEN) Other forms such as inulin occur in solution in plant saps (*see* INULIN) Polysaccharides also have nonnutritional functions The immunological reactions of cells are in many instances due to specific polysaccharides and neutral mucopolysaccharides (those containing hexoseamine) They are commonly present at the surface of bacterial cells (*see* BACTERIA) Acid mucopolysaccharides include heparin a blood anticoagulant hyaluronic acid the intercellular cement of animals and chondroitin sulfuric acid the major component of cartilage (*see* CARTILAGE HYALURONIC ACID) Another class of polysaccharide constitutes the principal substance of plant gums and mucilages These are most often produced and secreted in response to injury but they do occur as slimy masses in the c

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stance of side reactions which have no function for the protoplast performing them

Water soluble pigments These pigments in plants are sugar compounds (glycosides) As such they usually accumulate in vacuoles and are the major source of Nature's splendid array of floral colors The broad group of so-called tannins is chemically related to these pigments The simple molecular forms are best known for their astringency particularly in unripe fruits, the complex ones the c

the protoplast although it has been suggested that they might act in detoxification They are quite common in tropical plants but the most spectacular instance of their accumulation is tumorous growths In oak galls they constitute 50% of the dry weight [H.ST.]

Bibliography See CELL (BIOLOGICAL)

Cell structures

The cell is the smallest independently functioning unit into which living matter can be subdivided It depends for its functioning on numerous subcellular structures Whereas many of these structures can be seen with the light microscope a more nearly complete and detailed inventory has only become possible since 1950 with improvements in biological electron microscopy *See* MICROSCOPE ELECTRON

All living cells are bounded by a highly plastic plasma membrane and contain a nucleus (occasionally several) The remainder of the cell is called the cytoplasm The nucleus is surrounded by a membranous envelope and includes the chromosomes (which contain the hereditary determinants or genes) one or more nucleoli and interchromosomal material (nuclear sap) The contents of the cytoplasm can be divided into membrane and nonmembrane limited components Of the latter the semi solid ground substance (hyaloplasm) shows little structure itself and forms a continuum in which visible structures lie Otherwise membrane free structures are usually either granular or fibrillar The essential metabolic apparatus in the cytoplasm of most cells consists of membrane-limited mitochondria some form of a complex continually changing vacuolar system called the endoplasmic reticulum (often continuous in places with the plasma membrane) and membrane free nucleoprotein granules which may be free or attached to the membranes of the vacuolar system The latter may exist as free vesicles but these are more often flattened interconnected stacked or tubular depending upon their function They may organize into complex structures such as plastids or Golgi complex or extraordinarily specialized ones such as cilia or flagella which extend from the cell surface On the borderline between membranous and nonmembranous elements are the centrioles located in a differentiated region of cytoplasm called the centrosome Various inclusions crystalline and noncrystalline with and without surrounding membranes may result from accumulations of ingested matter metabolic by products storage products or secretory materials and may or may not participate in the cell's functions

Cells fall into many types according to their functions The kind appearance and number of structures within a cell may be characteristic of a given cell type A better knowledge of cell structures leads to a clearer understanding of cell function *See* CELL (BIOLOGICAL), CELL INCLUSIONS NONPROTOPLASMIC CELL NUCLEUS CELL PLAS

TIDS, CELL SURFACE DIFFERENTIATION; CENTRO SOME; CHROMOSOME; CYTOPLASM; GENETICS; COLGI COMPONENT; MITOCHONDRIA [M J M.]

Cell walls in plants

In most plant tissues, each cell is enveloped by a wall which is structurally distinct from the plasma membrane (*see* CELL STRUCTURES) The presence of such walls is the most prominent feature differentiating plant from animal cells These walls varying in thickness from a fraction of a micron (0 000039 in) to many microns in cells of different types and ages, are classified as primary and secondary.

Primary walls, enveloping meristematic (embryonic) cells during cell division, enlarge and therefore grow in surface area (*see* MERISTEM, APICAL) In some types of cells they are the only walls to be deposited Usually they are thin, highly hydrated and possess weak optical anisotropy (variation of optical properties with direction of incident light)

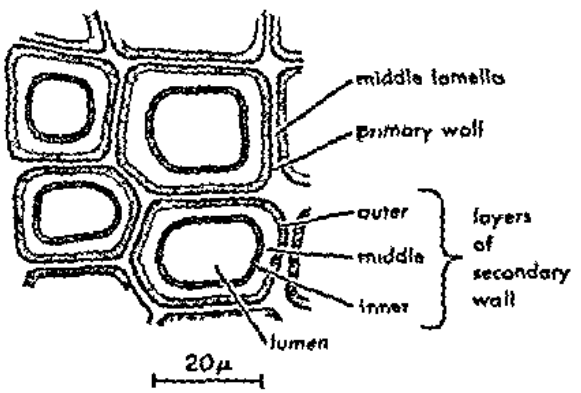


Fig 1 *Diagram of transverse section of typical wall structure in cells with secondary wall deposition*

However, in some cells, for example, epidermis and collenchyma, they are thickened and more anisotropic (*see* COLLENCHYMA, EPIDERMIS, PLANT) The primary walls of contiguous cells are cemented together by an intercellular substance which is optically isotropic and constitutes the middle lamella (layer)

Secondary walls are deposited inside the primary walls of many types of cells after enlargement has ceased (Fig 1) Secondary walls therefore grow in thickness but not in surface area In mature cells they are usually thick, strongly anisotropic and structurally complex Many cells with secondary walls (some fibers, tracheids, and vessel elements) have no protoplasm at maturity (*see* XYLEM)

Pits. Primary pit fields are groups of surface depressions found in some primary walls (Fig 2) Sieve areas in the phloem (food conducting cells) can be regarded as specialized primary pit fields (*see* PHLOEM) Pits a common feature of secondary walls, are cavities formed where secondary deposition has failed to occur and the primary wall remains uncovered The form and arrangement of



F , , ,ıograph of the cellulose skeleton o ı parenchyma cell from an oat coleophile showing a primary pit field and a longitudinal rib

pits in secondary walls, like the structure of the walls themselves are complex and specific to individual types of cell and species Two main types of pit are found, simple pits in phloem fibers and some parenchyma cells (*see* PARENCHYMA), and bordered pits, in which the secondary wall arches over the pit cavity, commonly in xylem cells such as tracheids (Fig 3) A pit in a secondary wall may or may not occur over a primary pit field in the underlying primary wall Pits in adjacent walls of neighboring cells normally coincide to form pit pairs

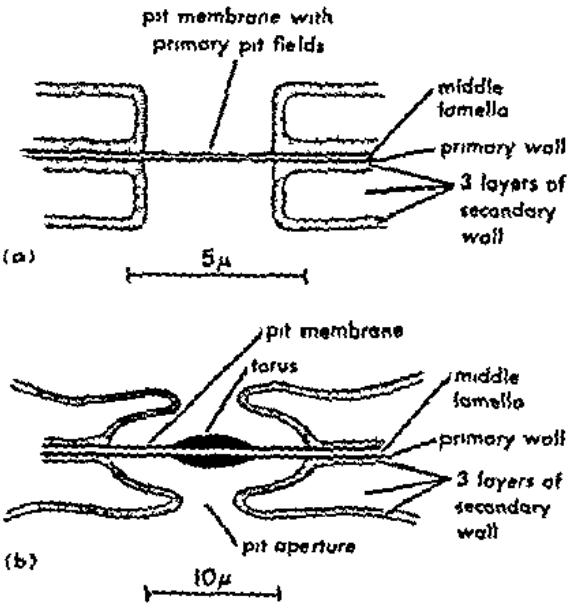


Fig 3 *Diagrams of sections of (a) simple pit pair and (b) bordered pit pair*

Plasmodesmata. These structures are generally believed to be strands of cytoplasm passing from the protoplast of one cell to that of the adjacent cell (*see* CELL PROTOPLAST) Numbers of plasmodesmata always penetrate primary pit fields but they occur elsewhere in the wall as well (Fig 4)

Chemical constitution Chemical constituents of some typical walls are listed in the table

Cellulose This substance is so named because it is the basic constituent of most plant cell walls On a dry weight basis, it forms about one fourth of primary walls and one half or more of secondary walls, fibers such as ramie and flax and cotton hairs are composed of almost pure cellulose (*see* COTTON FLAX RAMIE) Cellulose occurs as microfibrils which in the electron microscope appear as flattish ribbons 100–200 angstroms wide and roughly half as thick and of indeterminate length Within the microfibril the cellulose molecules composed almost exclusively of long straight chains of glucose residues are in a nearly parallel arrangement *It is this order and the parallel arrangement* of cellulose microfibrils within walls which cause walls to be optically anisotropic and to give the characteristic x ray diffraction pattern of cellulose Native cellulose has a tensile strength equivalent to that of mild (soft low carbon) steel and because of its physical strength and form acts as a framework within the wall providing the cell and the whole plant with mechanical support Cellulose is closely associated in the wall with other components most *of which occur as amorphous encrusting substances* around and between individual microfibrils and in laminated walls between layers of microfibrils

Pectic substances These are polymers of galacturonic acid residues or their derivatives The middle lamella is believed to be composed largely of calcium and magnesium pectates Protopectin is the form in which pectic materials occur in walls it is insoluble in water and is probably a high molecular weight form of pectin the water soluble material *found in plant extracts Little protopectin* is found in secondary walls it occurs mainly in primary walls but in widely varying amounts The pectic content of the walls of young oat coleoptiles is about 1% Pectic substances are reported to constitute 44% of the walls of some collenchyma cells

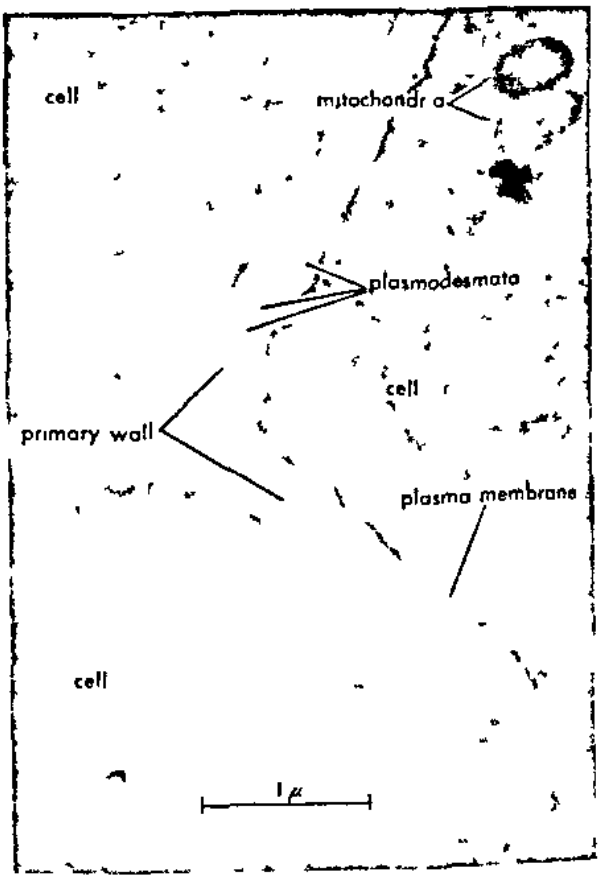


Fig 4 Electron micrograph of a thin section of the outer epidermal wall of an oat coleoptile showing plasmodesmata

and to be in a molecularly ordered form Apple and citrus fruits are rich in pectic substances particularly at maturity Because of their gel forming properties pectic substances are assumed to provide walls with their plasticity and extensibility For highly extensible walls in which the pectic content is low it is possible that these substances act *in a manner analogous to that of plasticizers* in synthetic plastics It has been suggested that plant growth substances affect walls by controlling the pectic substances in them (*see* PLANT HORMONES)

Hemicelluloses These are polymers mainly of sugar residues such as galactose mannose xylose

Chemical constitution of typical plant cell walls*

Predominant type of wall	Primary		Primary and secondary		Secondary		
	Oat coleoptile	Sunflower hypocotyl	Typical straw (stem)	Grass (leaves)	Temperate deciduous wood	Temperate deciduous tension wood	Conifer wood
Cellulose	25	38	43	27	50	60	55
Pectic substances	Less than 1	16		1			
Hemicelluloses	52	8	36	29	25	20	15
Lignin		8	18	12	25	20	30
Wax	1						
Protein	10		2				
Ash			5	14			

* Values shown are approximate average percentages by dry weight

and arabinose or mixtures of these uronic acid residues may also be present Although comparatively little is known of their function these materials are widely distributed in all types of walls With pectic substances they form the major portion of primary walls mannans galactans and particularly xylans are major constituents of secondary walls The molecular chains of hemicelluloses are usually randomly arranged in the wall In the cell walls of ivory nut and date seed however mannan chains are sufficiently well organized to yield an x ray diffraction pattern and to appear as microfibrils in the electron microscope In some algae a mannan entirely replaces cellulose as the microfibrillar component of the wall (*see* ALGAE)

Gums A heterogeneous group of substances containing uronic acid and sugar residues gums occur as exudates of the bark leaves or roots of plants Mucilages are related compounds which occur as coatings on seeds Some algae notably the seaweeds contain in their walls polysaccharides such as agar alginic acid and carrageenin which when extracted form rigid gels in water

Lignin A class of complex polymeric materials containing aromatic rings lignin is the most important noncarbohydrate constituent of walls It supplies rigidity and occurs mainly in hard mature tissues such as tracheids and fibers of wood and straw Its amount varies from a few per cent in the woods of some deciduous trees to over 50% in conifers Lignin is deposited toward the outside of the secondary wall and largely in the middle lamella and primary wall as a complex matrix between the other constituents The secondary walls of hardwoods are generally less lignified than those of softwoods in



Fig 5 Electron micrograph of a fragment of the secondary wall of ramie

Cutin suberin and waxes These are the most important fatty substances in walls They serve largely to make the peripheral parts of the plant impermeable to water Cutin and suberin are closely related and are high polymers of fatty acids Cutin which is a continuous protective layer over the surface of all aerial parts is isotropic In addition to the cuticle the epidermal walls of many plants contain a cutinized layer which is anisotropic Suberin occurs in walls of cork cells of the periderm or outer bark (*see* PERIDERM) Waxes have comparatively short chain molecules and occur in crystalline form in primary walls where they are closely associated with the cellulose microfibrils and in secondary epidermal walls in association with the cutinized layer Waxes are responsible for the 'bloom' on fruit leaves and stems

Protein A complex organic substance protein is found in small quantities particularly in primary walls The most important fraction represents enzymes associated with the physiological functioning of primary walls *See* CELL (BIOLOGICAL)

Callose This substance is widely distributed in cell walls but little is known of its structure or function Reports have described it as a polysaccharide of glucose and as proteinaceous It occurs abundantly in sieve (phloem) areas where it encases the connecting strands of protoplasm it has also been reported in primary pit fields hairs pollen tubes and fungal mycelia *See* FLOWER (BOTANY) It may be a normal constituent of some walls, but its amount is often increased by wounding

Other cell wall materials Chitin replaces cellulose as the microfibrillar component of some fungal walls (*see* FUNGI) Calcium carbonate forms outgrowths called cystoliths in the cells of the epider

skeletons in diatoms (*see* DIATOM)

Detailed structure of primary walls In thin primary walls the cellulose microfibrils usually form a somewhat disordered array about a common direction which in elongating cells is transverse to the long axis of the cell Part of the disorder is caused by expansion of the wall during cell enlargement This type of structure is found in walls of hair cells such as cotton and in some parenchyma cells It is modified in many parenchyma cells by the presence of longitudinal ribs Thickened primary walls are usually multilayered walls of epidermal cells in oat coleoptiles and the thickened walls of some collenchyma cells as in celery are composed of distinct layers of longitudinal mi



Fig 6 Photomicrograph of a transverse section of conifer tracheids in polarized light showing bright inner and outer layers of the secondary walls.

crofibrils embedded in and alternating with layers of noncellulosic materials In developing fibers of *Asparagus* the microfibrils occur in thin layers with the microfibrillar direction changing markedly between successive layers A different arrangement of microfibrils is found in the alga *Nitella* where they are oriented transversely to the cell axis with little angular dispersion

Detailed structure of secondary walls In contrast to primary walls secondary walls are composed of cellulose microfibrils in a highly ordered parallel arrangement (Fig 5) In tracheids as in wood fibers and some vessels three layers can be distinguished in the wall the inner and outer are thin and birefringent (characterized by double refraction) in transverse section, the middle layer varies in thickness between early and late woods and is less birefringent in transverse section (Fig 6) The differences in birefringence are accounted for by the differences in arrangement of the cellulose microfibrils in the inner and outer layers, the microfibrils are well oriented and lie on flat helices (spirals) In the middle layer the microfibrils are less well oriented and lie on a steeper helix (Fig 7) As deposition of secondary wall proceeds, the relative amount of cellulose increases so that in the final wall the region nearest the lumen (cell cavity) is richest in cellulose whereas noncellulosic materials particularly lignin are concentrated toward the outside of the wall The structure just described is modified in cells of reaction woods (tens or [illegible]

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addition to the normal three layers of the secondary wall, may replace the normal inner layer, or may replace both the normal middle and inner layers The secondary walls of some other cells are similar to those in tracheids except that the angles of the microfibrillar helices may differ and individual layers may themselves be laminated In mature cotton hairs, for example, the middle layer is of the latter type

The secondary wall of the alga *Valonia* is composed of many fine lamellae of parallel microfibrils whose direction changes regularly from one lamella to the next This general type of crossed lamella structure is found in some secondary walls of higher plants for example, in the outer layer of the secondary wall of conifer tracheids In higher plants, there is a tendency for some of the microfibrils to associate laterally to form bands, giving the wall a cross band appearance

CELL WALL GROWTH IN PLANTS

Initation of a new wall at cell division occurs during division of the cytoplasm (*see* MITOSIS) The first partition to appear is the cell plate (Fig 8*a*) Its origin and nature are not fully understood but it appears to be an accumulation of semifluid substances which coalesce, centrifugally dividing the protoplast into two approximately equal parts (*Fig 8b*) Pectic substances may be present in the

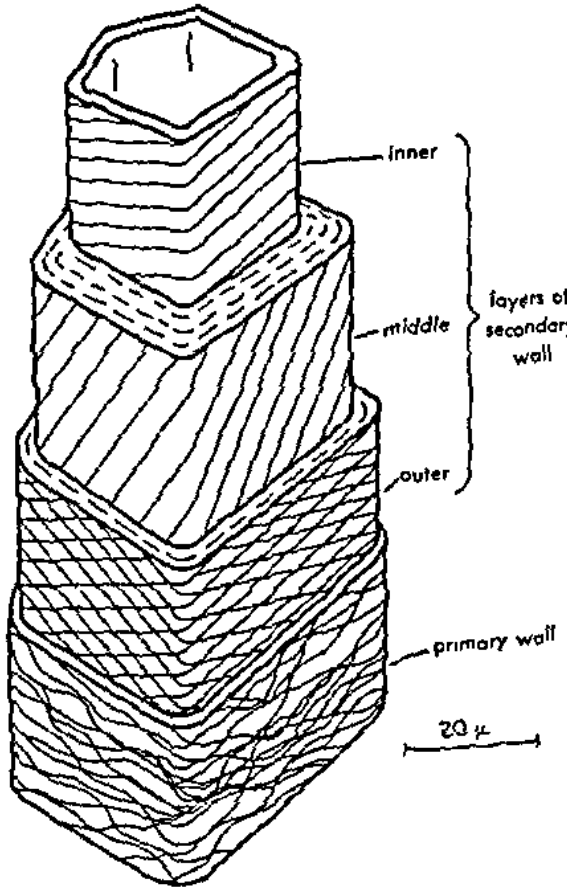


Fig 7 Schematic diagram of the wall of a normal tracheid

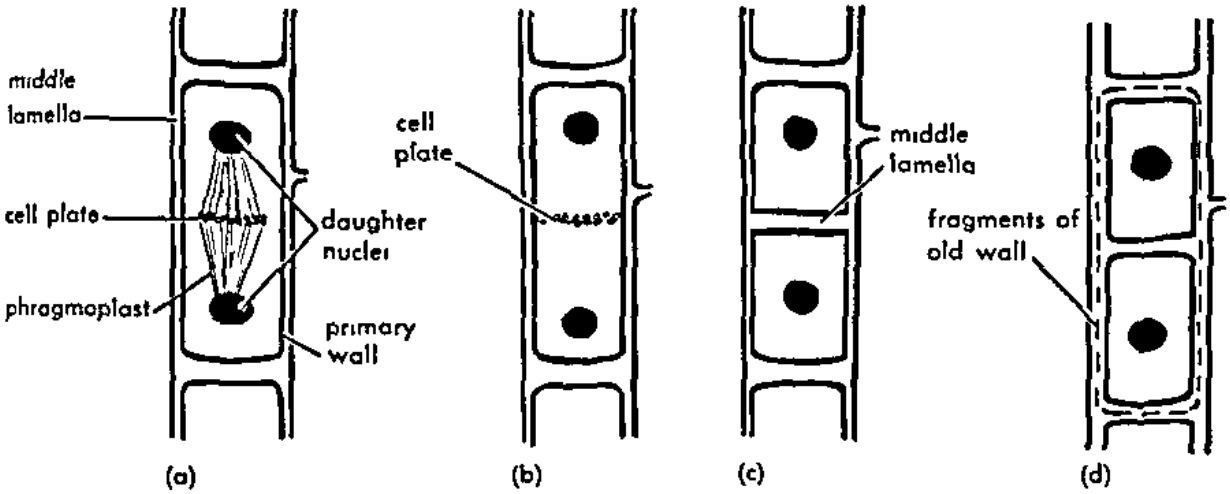


Fig 8 Diagram of initiation of new wall at cell division (a) Cell plate formation (b) Cell plate divides cytoplasm in two (c) New primary walls formed and joined to the old Middle lamella around daughter cells made continuous by rupture of old primary wall (d) Alternative possibility to (c), daughter cells entirely surrounded by new walls

cell plate and form the new middle lamella on both sides of which new primary walls are presumably deposited The new middle lamella may make contact with the walls of the surrounding mother cell by joining with the old primary wall at the periphery of the new lamella (Fig 8c) Another possibility is that completely new primary walls are deposited by the protoplast around each daughter cell and as these new cells enlarge the old primary wall of the mother cell fragments and blends with the new wall (Fig 8d) In lower plants and in pollen and endosperm development in higher plants where cells divide by furrowing centripetally new walls arise in the cleavage furrows which develop inwardly from the old walls of the mother cell and divide the protoplast into two or more parts (cells)

Cell elongation. This phase of cell development is often extensive, epidermal cells in oat coleoptiles may elongate 150 times at a rate of about 20 μ per hour (*see* PLANT GROWTH) The primary walls of enlarging cells grow correspondingly in surface area but without commensurate thinning In some cases as in developing conifer tracheids bast fibers and root hairs the wall extends in localized regions of the cell only such as at the tips, while deposition of secondary wall is proceeding elsewhere in the cell In general however growth proceeds uniformly throughout the primary wall The classical explanations of wall growth are by apposition that is deposition of new material onto the interior surface of the wall and by intussusception the insertion of new material into the existing fabric of the wall Growth of walls of the type found in some hair and parenchyma cells is satisfactorily explained by the multinet model (Fig 9) In this new microfibrils are continually deposited in a transverse direction on the interior of the wall Elongation of the cell draws the microfibrils already deposited into a longitudinal direction thereby creating a series of closely associated interpenetrating nets of microfibrils and accounting for the angular dispersion observed in the microfibrils of these walls Apposition occurs in some thickened primary walls but often it alone cannot account for their growth There is evidence that precursors of pectin hemicelluloses and cellulose, the high molecular weight constituents of these walls, are able to diffuse from the cytoplasmic surface and polymerize in the body of the wall itself Diffusion of precursors may be helped to some extent by plasmodesmata Where plasmodesmata penetrate epidermal walls they may also facilitate the passage of waxes and fatty acids to the outside of the epidermis where formation of the cutin occurs

Evidence suggests that deposition of new material in primary walls does not promote cell enlargement but only compensates for thinning of the wall caused by extension In promoting cell elongation plant growth substances are believed to influence among other reactions the metabolism of primary walls It seems most likely that these substances increase the plasticity of the walls enabling turgor pressure to extend the wall and enlarge the cell (*see* PLANT WATER RELATIONS OF)

Basing their theories on other evidence however some investigators hold that cellulose molecules cannot be stretched and that cell wall elongation is the result of bipolar growth of the microfibrils that make up the primary cell wall network Opposition to the bipolar growth theory stems from the feeling that difficulties in explaining the extensibility of cell walls are due to the inadequacy of the stretching experiments

Growth of secondary walls This growth is most probably by apposition of noncellulosic substances notably hemicelluloses, and cellulose microfibrils in a highly ordered arrangement, onto the existing primary wall The arrangement of microfibrils in the secondary wall is often markedly different from that in the adjacent primary wall There is some evidence that secondary thickening commences in the vicinity of plasmodesmata and primary pit fields

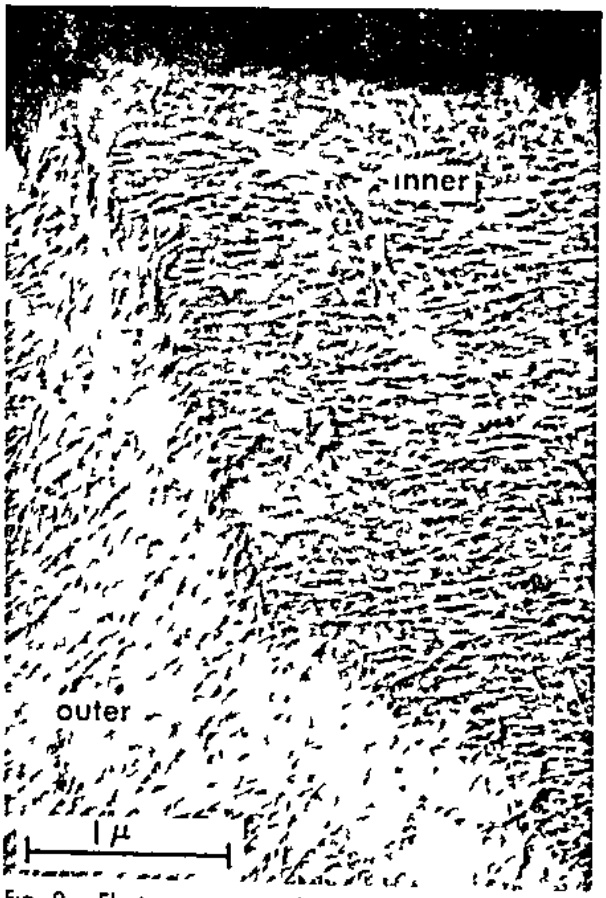


Fig 9 Electron micrograph of fragment of cellulose skeleton of a young cotton hair to illustrate multinet growth The wall has folded over and the microfibrils can be seen to be predominantly transversely oriented on the interior of the wall but forming a network on the outside The few microfibrils oriented almost longitudinally on the interior are the beginnings of the secondary wall

The mode and extent of development of secondary walls vary in different types of cell and plant In the xylem for example the secondary walls of the first formed tracheary elements develop as series of rings (annular thickening) or helices (helical thickening) whereas in elements formed later the thickenings may have a ladderlike appearance (scalariform thickening) or may completely envelop the cell and be interrupted only by pits Lignification of secondary walls is probably brought about by the diffusion of raw materials from the cytoplasm to the region of the middle lamella where they are built up into a matrix of lignin

Factors governing detailed structure of walls The number of layers in the secondary wall of cotton hairs can be correlated with the intervals of dark and light during their growth and it has been suggested that a similar correlation may exist for the numerous much finer layers in the walls of some algae In reaction woods tracheid and fiber walls are modified in response to physical stress The exact causal relationships between wall structure and environmental factors in these instances are not clear Attempts have also been made to explain the orientation of cellulose microfibrils in walls in terms of simple physical forces such as pressure and tension acting on the wall but here again the manner in which stress directly influences microfibrillar arrangement is not clear The multiplicity and intricacy of structures in walls differing often between contiguous cells suggests rather that wall formation is mainly an expression of specific cellular differentiation and that control of wall structure resides in the cell itself and is affected only indirectly by the environment The relationship between the cytoplasm and the wall of the plant cell has not been studied in detail However in xylem cells the annular or helical thickenings of the secondary wall appear to develop according to a pattern of increased density in the cytoplasm and it has been suggested that this cytoplasmic pattern may also control the helical arrangement of microfibrils within these thickenings [STB]

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Cellobiose

A disaccharide not known to exist free in nature but which is obtained by partial hydrolysis of cellulose It consists of two D glucose units joined by a 1→4-β D-glucosidic linkage and is chemically named 4-*O* β D glucopyranosyl D glucose It is most often isolated from cotton or filter paper which has been simultaneously acetylated and acetolyzed by acetic anhydride and sulfuric acid The product cellobiose octaacetate crystallizes well and may be converted to cellobiose by saponification of the acetyl groups with barium methoxide in methanol Cellobiose may be made directly from cellulose by enzymatic cleavage with various enzymes such as one from *Aspergillus niger* It is digestible and can be produced synthetically by chemical means *See* CELLULOSE, MALTOSE [RLWH]

Cellophane

A thin transparent sheeting or film made of viscose a solution of cellulose treated with caustic soda and carbon disulfide Treatment of the viscose in an acid bath regenerates the cellulose in a modified form About 75% of the cellophane produced in the United States is used in wrapping food products *See* CELLULOSE DERIVATIVES [CCO]

Cell surface differentiation

The specialization or modification of cell surfaces The surfaces of cells vary greatly and epithelial cells provide excellent examples of such differentiation

Specialization of the free surface The free surfaces of epithelial cells may be smooth or modified in various ways to serve more efficiently the functions of protection absorption secretion or transport

Cuticle An extracellular layer that forms a protective covering for an epithelial sheet is called a cuticle It is a product of the underlying cells and

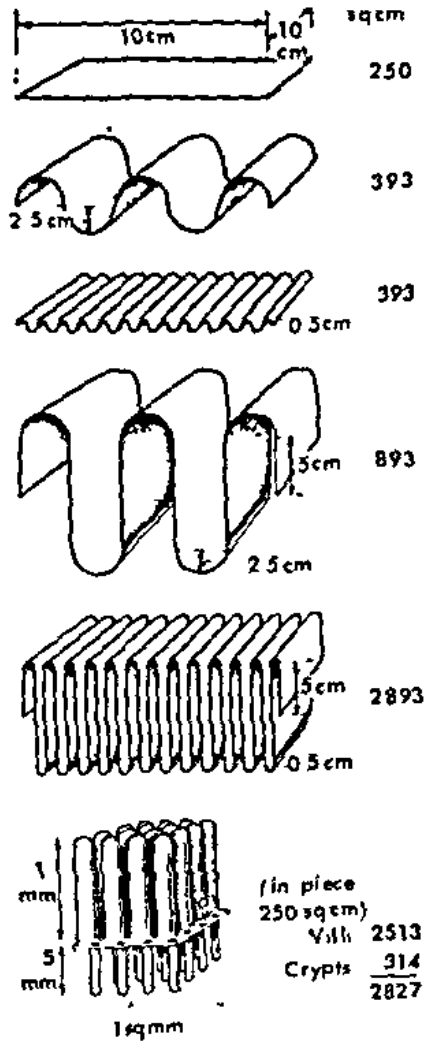


Fig 1 Diagram showing the relative increase in area produced by corrugation or plication of a surface and by the formation of villi and crypts. (From H S D Garven, A Students Histology, E S Livingstone Ltd, 1957)

may consist of separate polygonal areas, each corresponding to the surface of a cell, or the contiguous areas may fuse to form a continuous sheet True cuticles are uncommon among the tissues of vertebrates, the best examples being found in the integument of nematodes and annelids and in the exoskeleton of arthropods At the submicroscopic level of organization cuticle consists of a highly ordered framework of collagenous or chitinous fibers embedded in a matrix which in some instances is heavily impregnated with calcium salts *See* ANNELIDA, ARTHROPODA, NEMATODA

Brush border The light microscope reveals on the surface of many absorbing epithelia a vertically striated, refractile border This is not an extracellular layer but a specific modification of the superficial protoplasm called a striated or brush border In electron micrographs it is found to consist of numerous slender projections of the cell surface, closely packed in parallel array These filiform processes now commonly called microvilli are very uniform in size, measuring 80–100 millimicrons (mμ) in diameter and 0.5–1 0 microns (μ) in length Each is limited by an extension of the plasma membrane of the cell and has a fine granular content which is continuous below with the apical cytoplasm of the cell Typical examples of this type of border are found on the intestinal epithelium and on the cells of the proximal convoluted segment of the nephron In both of these sites the cells are actively engaged in fluid transport and the specialized border is interpreted as a device for increasing the area of active surface Figure 1 shows the relative amplification of surface that can be achieved by corrugation, plication, and the formation of villi and crypts It is estimated that a single cell of intestinal epithelium may bear 3000 microvilli, and 1 mm² of mucosa as many as 200 000,000 In the brush border of renal epithelium there are, in addition, slender crypts or canaliculi that arise in the clefts between the microvilli and extend downward into the cytoplasm Here, both evagination and invagination of the plasma membrane have been used to achieve approximately a tenfold increase of surface area

Stereocilia Long slender, nonmotile processes such as are found on the epithelium of the ductus epididymis are called stereocilia They are similar to microvilli in their fine structure, but reach a length of several microns Instead of forming a continuous border of parallel processes, the stereocilia of each cell tend to be matted together in a brushlike tuft The significance of these structures in relation to the function of this epithelium is unknown

Cilia Hollow organs such as the trachea and the oviduct, are often lined by ciliated epithelium (Fig 2) The cilia are processes, much larger than microvilli, that execute rapid whiplike movements serving to transport a film of mucus across the

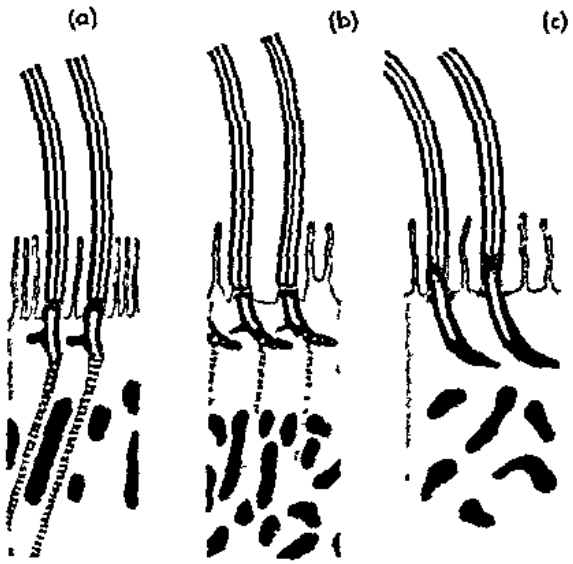


Fig 2 Diagrammatic vertical sections through pairs of cilia in ciliated epithelia (a) Mollusk (b) Frog (c) Man The cilia emerge through a striated border of microvilli Their hollow basal bodies vary in shape from species to species The cross-striated rootlets are vestigial or absent in mammalian ciliated ep

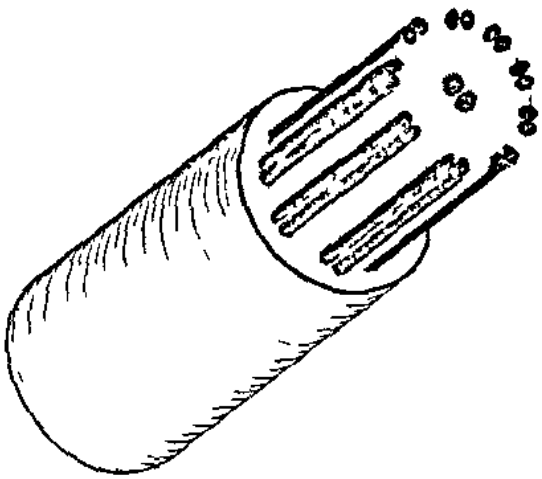


Fig 3 Extended diagram of a segment of the shaft of a cilium showing the arrangement of longitudinal fibrils nine double fibrils around two single fibrils

epithelium or to create currents in the fluid bathing its surface There may be 100–200 cilia per cell They originate from refractile basal corpuscles, arranged in rows just beneath the free surface The cylindrical shaft of a cilium is 7 12 μ long about 0 2 μ in diameter and is closely invested by an extension of the cell membrane In its interior is a bundle of 11 fibrils that arise from the wall of the basal corpuscle and run longitudinally through the cilium over its entire length The fibrils are arranged in a constant pattern with 9 uniformly spaced around a central pair (Fig 3) The fibrils are of two kinds Those of the outer row appear double in cross section but the two components are fused together and are usually considered as a unit a double fibril The two in the axis of the cilium are separate single fibrils The same number and disposition of fibrils are found in cilia throughout the plant and animal kingdoms The basal corpuscles are hollow bodies which have the basic structure of a centriole but vary in shape from species to species In some ciliated epithelia one or more cross striated rootlets take origin from each basal corpuscle and extend downward into the cytoplasm The longitudinal fibrils in the cilium are apparently the contractile elements, whereas the rootlets are anchoring structures stabilizing the basal corpuscle *See* CENTRIOLE

Specializations of contact surfaces. The contact surfaces of epithelial cells may be plain or may have interdigitating processes and other devices for mutual attachment

Desmosomes Adjoining cells of the stratified squamous epithelium of the epidermis are not in contact over their entire surface, but are covered instead with numerous short processes that *make* contact with similar projections from the surface of neighboring cells These connections were formerly called intercellular bridges in the belief that they constituted open communication from cell to cell (Fig 4*a*) In electron micrographs it is apparent that the processes are closed and where they meet end to end the opposing membranes are thickened and reinforced by a condensation of dense material in the subjacent cytoplasm (Fig 4*b*) Fine tonofilaments converge upon the process and terminate in this dense cytoplasmic substance The apposition of two such specializations on the surfaces of neighboring cells forms a bipartite connecting body called a desmosome or adhesion plate

In gingival and lingual stratified squamous epithelia, pricklelike processes are lacking Instead the cell surfaces are corrugated and fit together so that the ridges of one occupy the grooves of the other Here the desmosomes are randomly scattered over the interlocking surfaces

Terminal bars In many simple columnar epithelia, specializations called terminal bars are found just beneath the free border on the surfaces of contact between cells (Fig 5*a*). Seen from above in stained preparations they appear as thick dark lines outlining the cell boundaries They were once believed to be local accumulations of an intercellular cement substance, but they have now been shown by electron microscopy to be similar to desmosomes in their fine structure However, rather than small plaques, they are long bands that extend the full width of the cell (Fig 5*c*). Desmosomes may occur elsewhere on the contact surfaces of the cells, but terminal bars are found only near the free surface Both are considered to be devices for maintaining cell cohesion

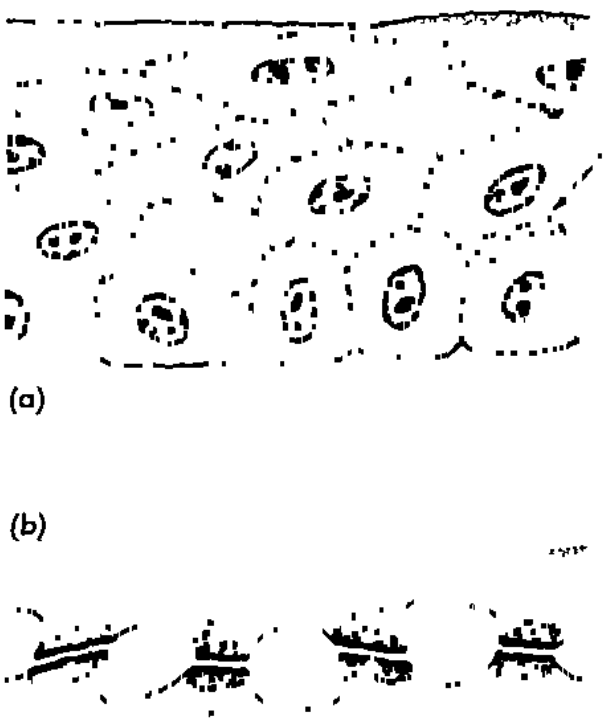


Fig 4 (*a*) Diagram of epidermal stratified squamous epithelium as seen with the light microscope (*b*) The structure of the desmosomes at end to end junctions of the processes on adjoining epithelial cells as revealed by the electron microscope For orientation, see rectangle indicated by arrow I

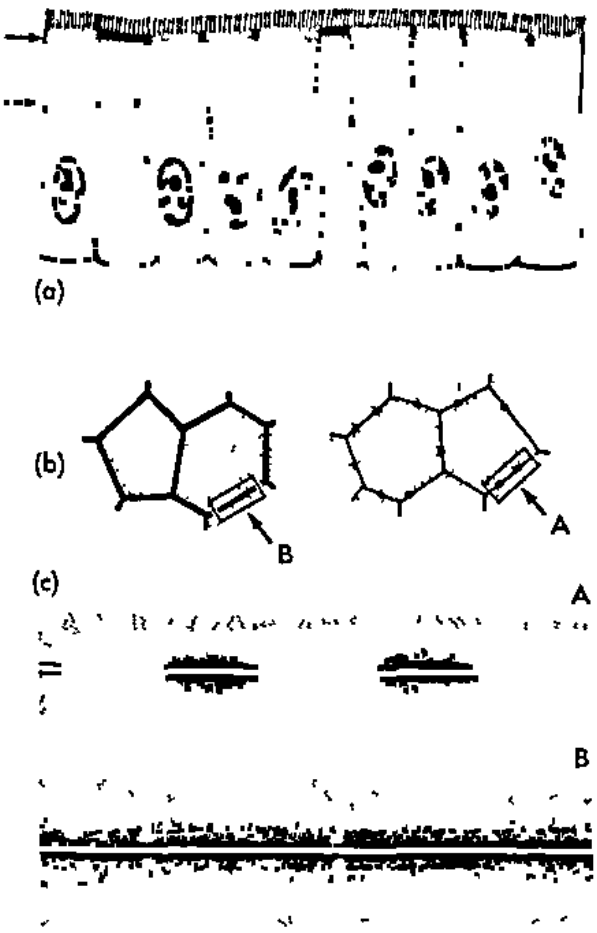


Fig 5 (a) Diagram of simple columnar epithelium of the intestine as seen in vertical section with the light microscope Terminal bars appear as dense bands or dark oval bodies just beneath the striated border Desmosomes elsewhere on the contact surfaces appear as small dots (b) In horizontal section at the levels indicated by the arrows in (a) terminal bars are dense bands outlining the cell boundaries whereas desmosomes are localized plaques (c) In electron micrographs terminal bars B resemble desmosomes A in their fine structure, but differ in their shape being bands that extend the full width of the cell For orientation, see rectangles indicated by arrows in (b)

Intercalated disks In cardiac muscle where the cellular units meet end on the surfaces are deeply interdigited Stout processes on one cell fit into depressions of complementary form in the other and most of the surface of both cells is specialized in the same manner as at desmosomes and terminal bars of epithelia Here the myofilaments terminate in the condensation of cytoplasm in much the same manner as the tonofilaments end at the desmosomes of epidermis *See* CELL (BIOLOGICAL), EPITHELIUM

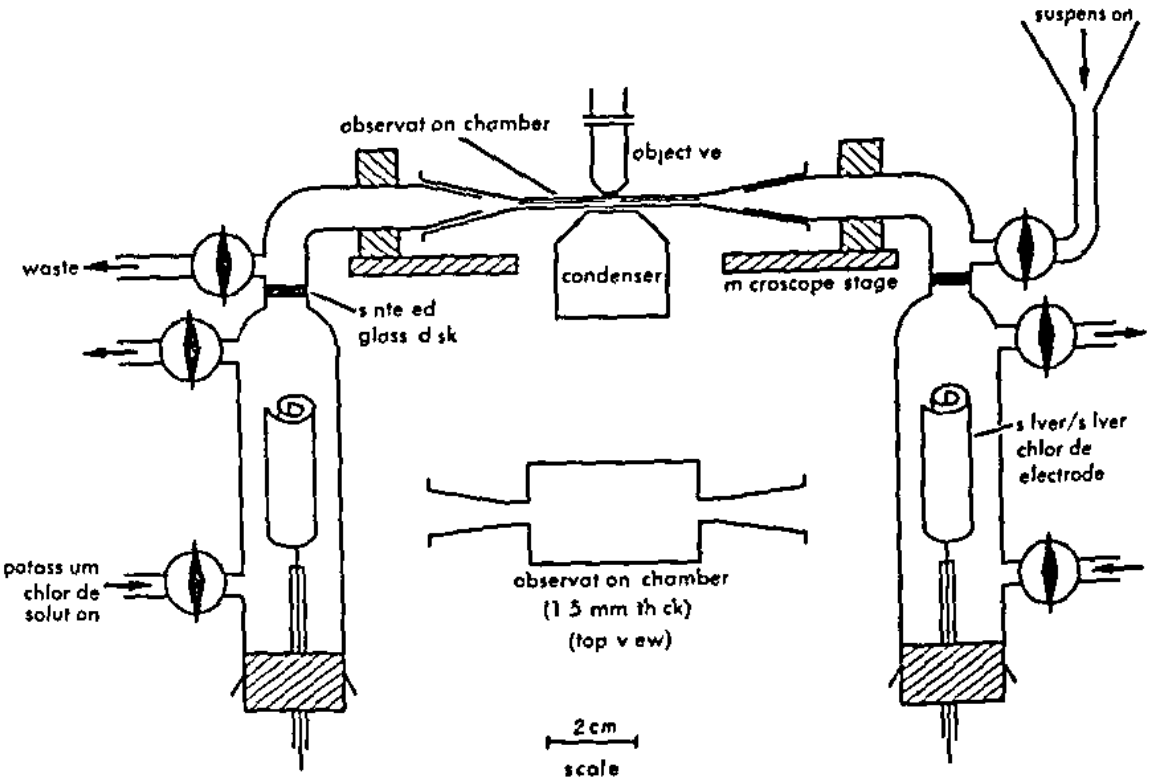
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Cell-surface ionization

All living cells suspended in aqueous salt solutions at neutral pH values possess a negative charge The charge is due partly to the dissociation of ionogenic or charged groups (carboxyl, amino, and others) in the cell surface and partly to ions absorbed from solution Studies of the charge carried by bacteria give information regarding the nature of the components in their surfaces, these studies have been used to measure the frequency distribution of bacterial variants in a mixed population and can assist in the selection of material for vaccine production The occurrence and nature of tumor cells and the selection of yeasts for brewing have been studied electrophoretically *See* BIOLOGICALS

Electrophoretic mobility When an electric field is applied between electrodes placed in a cell suspension the cells migrate generally toward the positive electrode This migration can be observed under a microscope in a microelectrophoresis apparatus (see illustration) The electrophoretic mobility, $\bar{v}$ (velocity per unit field strength), is measured by timing cells across a fixed distance in the observation chamber under a known field strength In this method the mobility of individual cells of varying shape and size can be measured with minimal cellular disorganization Migration occurs because charged groups and ions adsorbed on the surface produced a nonuniform distribution of ions in solution at the cell liquid interface This distribution is generally expressed in terms of the ζ potential (volts) which may be calculated from the mobility, $\zeta = 4\pi\eta\bar{v}/D$, where η and D are the viscosity and dielectric constant, respectively, of the medium The surface charge density (esu/cm^2) can be calculated from ζ

Variation of charge. Factors which may affect the charge of cell surfaces are of three types (1) biological factors—in bacterial and yeast cells, such things as sex strain, age growth conditions presence of capsules or fimbriae, virulence, and toxicity, in mammalian cells such things as species type or tissue normal or pathological conditions and the like, (2) nature of suspension medium that is, ionic strength, pH presence of dyes drugs or surface active agents in the medium, and (3) chemical or enzymatic treatment of the surface It is often possible to correlate alteration of charge with changes in the nature or number of ionogenic groups in the surface and hence with a particular biological property Such a correlation is justified only if the variation of charge is measured in media of different physical properties An absolute value of the charge under standard conditions of test is without value, the charge carried by particles with ionogenic and nonionogenic surfaces under the same conditions may be identical However, variations of charge with changes in the nature of the medium are completely different With living cells lowering the pH of the medium at constant ionic strength produces a lowering of the negative value of the ζ potential, at low pH values, charge reversal may occur This change results from the decreased dissociation of acidic groups which may be characterized from the dissociation constant pK of the surface Simultaneously there is an increased ionization of



M croelectrophores s apparatus

groups At extreme pH values surface and possiblv cellular disorganization must be investigated When the salt concentration of the suspension medium is increased biological and nonionogenic surfaces behave similarly The charge density concentra tion curve is a typical Langmuir adsorption iso therm indicating adsorption of anions from solu tion *See* Adsorption

Ionogenic groups can be characterized by the binding properties of a series of cations Their order of effectiveness in reversing the charge of the particles is known as a charge reversal spec trum The spectra for various cells can be com pared with spectra of model systems with known ionogenic surface groups Alteration of charge in the presence of anionic surface-active agents can reveal the presence of lipid and protein in the s irface Mild chemical treatment to inactivate specific groups for example diazomethane for carboxyl results in marked changes of charge Enzymatic treatments for example using the en zyme trypsin mav produce changes in the charge *See* Enzyme Lipid Protein

Bacteria Most strains show slight if any varia tion of charge density during growth Any drastic alterat on of charge always occurs during the pe riod of active cell division returning to the normal value during the stationary phase as in hemolytic streptococci Little alteration of charge generally results from changes in nutrition Growth in the presence of some drugs for example *Aerobacter aerogenes* in crystal violet results in the formation of a resistant strain with different charge char acteristics The pK values of the surfaces of *Esch erichia coli* (29) and *Aerobacter aerogenes* (30) obtained from ζ pH studies are the same as those for a large number of polysaccharides, strongly suggesting that carboxyl and not phosphatid c groups (pK = 1 8) are present on the cell surface Charge-reversal spectra lead to the same general conclusions Treatment of *Escherichia coli* K12 in aqueous suspension at pH 4 5 with gaseous diazo-methane results in an 80% decrease of charge when measured at pH 7 0 Assuming that all the surface carboxyl groups have been esterified the number of such groups is about 8×10^5 per cell Spores of *Bacillus subtilis* treated with *p* tol iene sulfonyl chloride in aqueous suspension show a 25% increase in negative charge this is attrib ted to the blocking of amino groups

Yeasts In suspensions of pH greater than 2 3 yeast cells carry a negative charge Various strains of *Saccharomyces cerevisiae* and *S carlsbergensis* have such low charges that ion binding is small the composition of the wall determining the charge In some strains the charge is due to combined phosphate in the cell wall and in others to protein The nature of the growth medium has a pronounced effect on the charge

Blood cells The major components on the eryth rocyte surface are phospholipid in nature prote n and cholesterol may also be present near the s r face Of sheep blood cells lymphocytes exhibit an isoelectric point at pH 2 5 (that pH at which there is a zero charge) in contrast to erythrocytes and polymorphonuclear leukocytes which are damaged at low pH values Charge reversal spectra indi cate that the predominant groups are phosphate on erythrocytes carboxyl on polymorphonuclear leukocytes and both phosphate and amine on

lymphocytes and platelets *See* BACTERIA BIOPHYSICS BLOOD COLLOID ELECTROKINETIC PHENOMENA STREAMING POTENTIAL YEAST

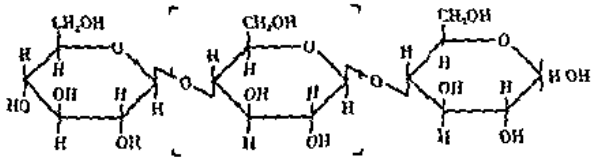
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Cellulose

The principal polysaccharide in land plants It forms the skeletal structure of the cell wall hence the name cellulose and it occurs together with polysaccharides and hemicelluloses derived from other sugars such as xylose arabinose and mannose In the woody parts of plants cellulose is intimately mixed and sometimes covalently linked with lignin Wood normally contains 40–50% cellulose 20–30% lignin and 10–30% hemicelluloses as well as mineral salts proteins and other biochemical compounds

Cellulose is a polymer of β D-glucose units which are linked together with elimination of water to form chains of 2000–4000 units



Except for the β orientation of the glucosidic linkage between glucose units cellulose is chemically identical with starch amylose *See* STARCH

Uses Commercial celluloses are evaluated on the basis of their content of α cellulose which is that portion of the pulp insoluble in 17.5% sodium hydroxide solution All the material extractable from a pulp by the 17.5% solution is β and γ celluloses β Cellulose is that portion of the material which is precipitated when the alkaline extract is acidified and γ cellulose is the name given to the portion remaining in solution after acidification Both β and γ cellulose contain in addition to lower molecular weight cellulose molecules a variety of hemicelluloses Pulps of low α cellulose content are used for paper making and pulps of higher α cellulose content (88 96%) are required for the preparation of cellulose derivatives and for rayon manufacture

Cellulose of high chemical purity for research purposes is readily prepared from cotton by dewaxing with organic solvents and by extraction by boiling in a 1% sodium hydroxide solution The resulting cellulose is almost entirely free from other components and is one of the purest readily available polysaccharides

In addition to degradation under hydrolytic conditions the cellulose molecule is cleaved by photooxidation and in alkaline solutions by oxygen and various other oxidants In oxygen free alkali the molecule undergoes a slow degradation in which one end unit after another is removed as isosaccharinic acid

High molecular weight cellulose is used for making cellophane viscose and acetate rayon Both high molecular weight and lower molecular weight celluloses may be used for making other derivatives

Natural occurrence Cellulose occurs within plant cell walls mainly in the form of fine fibrils which are visible under the optical microscope In both the primary wall and the thick secondary cell wall these fibrils are arranged side by side to form layers or lamellae and are normally inclined at an angle to the fiber axis The electron microscope shows that the fibrils are composed of still finer microfibrils or micellar strings The microfibrils are thought to consist of numerous nearly parallel cellulose molecules which are so exactly ordered at places that they form crystalline regions called crystallites or micelles The micelles are interspersed by amorphous regions where the cellulose chains are less ordered and may even be tangled Most heterogeneous reactions of cellulose occur slowly in the crystalline regions but take place rapidly in the lower density amorphous regions where the looser packing of cellulose chains permits easier penetration of the reagent molecules Thus acidic hydrolysis of cellulose which takes place by splitting of the β D-glucosidic linkages occurs first in the amorphous regions During the hydrolysis of the amorphous regions in wood or textile fibers progressive weakening occurs In the later stages a powder may be formed which has a very high crystallinity because of the predominance of surviving micelles Eventually all the micelles are hydrolyzed to D-glucose Accessibility of cellulose for reaction is important in the preparation of derivatives of cellulose such as the acetate and is normally improved by use of a swelling agent which expands the crystalline lattice and so permits reagent to penetrate to all cellulose molecules *See* CELL WALLS IN PLANTS

Preparation Commercial cellulose may be obtained from cotton linters but is produced mainly from woods particularly pine and spruce by pulping procedures designed to remove lignin and other noncellulosic constituents In addition to mechanical and semimechanical processes which separate wood fibers for use in paper manufacture there are three chemical pulping processes in wide commercial use the kraft soda and sodium sulfite processes The most frequently used is the kraft or sulfate process in which logs are debarked

sodium hydroxide alone is used in the cooking liquor In the sodium sulfite process wood chips are cooked in a calcium bisulfite solution containing a large excess of free sulfur dioxide and lignin

are converted to soluble lignosulfonates Pulps obtained from any of the three chemical digestions may be subjected to later purification stages in which they are treated alternately with chlorine and with alkali *See* PAPER AND PAPER PRODUCTS

Derivatives Cellulose nitrate (nitrocellulose or guncotton) is prepared by the direct esterification of cellulose with nitric acid in the presence of sulfuric acid Lower nitric acid esters are used to make coating lacquers collodion and photographic film

Cellulose acetate is prepared by reaction of cellulose with acetic anhydride and acetic acid in the presence of sulfuric acid Cellulose acetates in different degrees of esterification are used in the making of acetate rayon Mixed esters of cellulose esterified with acetic acid and other low molecular weight aliphatic acids such as butyric acid are used for making clear tough moldable plastics

Cellulose propionate is used for making colored plastics for such products as colored telephones

Cellulose xanthate is produced by a reaction of soda cellulose (prepared by treating cellulose with strong sodium hydroxide solution) with carbon disulfide The product viscose can be spun into rayon or cast into cellophane by extruding the viscose dissolved in alkaline solution into an acid bath where the xanthate is decomposed and the insoluble cellulose regenerated High strength viscose rayons are used for tire cords *See* PLASTICS FABRICATION

Methylcellulose is manufactured by reaction of soda cellulose with methyl chloride The incompletely etherified derivative is used as a thickening suspending and stabilizing agent

Ethylcellulose is prepared by the reaction of soda cellulose with ethyl chloride and is used for many of the same purposes as methylcellulose

Hydroxyethylcellulose is manufactured by the reaction of cellulose with ethylene oxide and is used for thickening and sizing

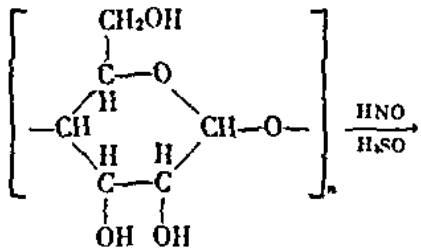
Carboxymethylcellulose is the incomplete ester resulting from the action of chloroacetic acid on soda cellulose It is used as a thickening suspending and stabilizing agent but in greatest volume as an additive to detergents for the prevention of soil redeposition on fabrics *See* CARBOHYDRATE CELLOBIOSE FIBER MAN MADE HEMICELLULOSE POLYSACCHARIDE [C N R B L WH]

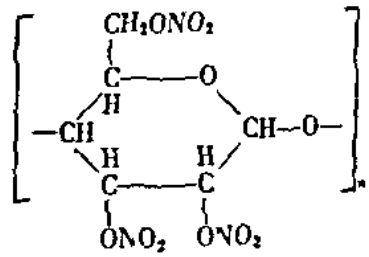
Cellulose derivatives

Compounds produced by treating cellulose with nitric acid or acetic anhydride There are several *high polymers available* in nature cellulose starch and other carbohydrates silk wool casein and other proteins natural rubber and various *gums* *See* CARBOHYDRATE FIBER NATURAL PROTEIN RUBBER

Cellulose derivatives such as cellulose nitrate and *cellulose acetate are* of special interest These *two derivatives were* developed in the 1850s and 1860s Use of the products required the development of new methods of fabrication (molding extrusion and spinning) stabilization to light and aging and plasticization Although the modified polymers can be considered to be semisynthetic their development represents the beginning of modern plastics technology and polymer science

Cellulose nitrate is prepared by treating cellulose such as cotton fiber or purified wood pulp with a mixture of nitric and sulfuric acids





Cellulose trinitrate

The trinitrate (gun cotton cordite) is explosive If the nitration is not allowed to proceed to completion products averaging the dinitrate or the mononitrate in composition may be obtained The dinitrate has been used extensively for lacquers films and fibers and the mononitrate for plastics and lacquers The original success of cellulose nitrate as a plastic material was based on the discovery that camphor acted as a plasticizer The composition known as celluloid was used for many years for collars combs and other articles More recently additional materials have been found to function as plasticizers The phosphate esters are effective and also reduce the burning rate of the composition Because of its tendency to burn and to become colored by the action of light cellulose nitrate has been replaced to some extent by newer materials However the high impact strength and low cost of the product make it useful for tool handles and mallets and in certain lacquer formulations

Cellulose acetate prepared by the action of acetic anhydride on cellulose is widely used in fibers (acetate rayon) and films and for molded articles such as telephones *See* CELLULOSE PLASTICS FABRICATION [J A M L M H]

Cement

In its broadest meaning any substance that acts as a bonding agent for materials *In its more* restricted sense and particularly if it is unqualified and used in connection with construction and engineering, the word almost always means hydraulic cement since this is by far the most important

cement used at the present time For information about other cementing materials *see* ADHESIVE ASPHALT AND ASPHALTITE CLAY COMMERCIAL EPOXY RESIN GLUE, MUCILAGE

Hydraulic cements are produced by burning an intimate mixture of finely divided calcareous and argillaceous materials and grinding the resulting clinker to produce a fine powder The calcining process produces calcium silicates and calcium aluminates that react chemically with water to form a hard stonelike mass When mixed with sand coarse aggregate and water these cements produce mortars and concretes *See* CONCRETE MORTAR

There are many hydraulic cements each with its particular merits and uses The principal ones used in construction and engineering are portland cement of which there are a number of modifications and types (*see* PORTLAND CEMENT) air entraining portland cement (*see* AIR ENTRAINING PORTLAND CEMENT) masonry cement a mixture of portland cement with lime and other materials to produce (with sand) a smoother more adhesive mortar than is obtainable with portland cement alone natural cement a naturally occurring argillaceous limestone calcined and pulverized is slower setting and less uniform in quality than portland cement and is sometimes mixed with portland cement to obtain special qualities aluminous cement also called high alumina cement which consists mainly of aluminates rather than silicates of calcium and is characterized by quick strengthening and high resistance to sulfate attack oil well cement which is any portland cement suitable for cementing oil wells and may be either regular portland cement or portland cement modified with special retarders mainly to prevent too rapid setting under the high heat and pressure encountered at great depths slag cement which is finely divided material consisting essentially of water quenched granulated blast furnace slag and hydrated lime used in masonry mortars and in portland cement requiring high sulfate resistance and portland pozzolan cement which contains up to 50% pozzolan to make the cement less costly and improve some of its qualities

The specific characteristics properties and uses of most of these various cements are described in the specifications by the American Society for Testing Materials and the American Petroleum Institute

In its mineral surveys the U S Bureau of Mines reports the annual production of cement In 1957 world wide production was estimated at 1 443 993 000 bbl (376 lb/bbl) 309 756 000 bbl was produced in the United States Of this total production 289 097 000 bbl or 93% was portland cement and air entraining portland cement and the production of all other types of hydraulic cement was 20 659 000 bbl [W LE]

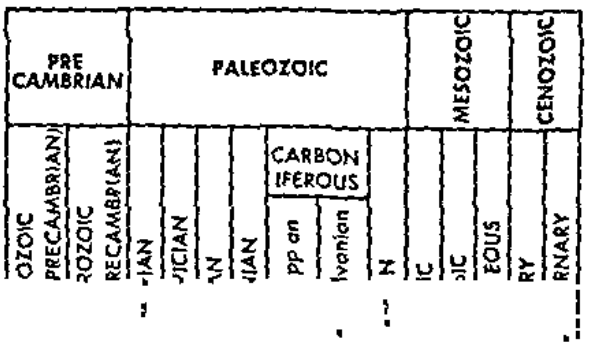
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Cement asbestos

A building material composed of asbestos fiber and cement formed under pressure into dense monolithic sheets Flat sheets are used for walls ceilings siding and partitions Corrugated sheets can be used without other covering for roofs having a slope of at least 3 in vertical to 12 in horizontal Corrugated sheets are also employed as a deck for flat roofs The surface is smoothed with a layer of insulating board or granular cork and asphalt and topped with a built up roofing Cement asbestos sheets are fire-resistant durable easily applied and equally well adapted to exterior and interior use [C S C]

Cenozoic

The latest major division (era) of geologic time extending from the beginning of the Tertiary (end of Mesozoic) to the present or Recent It is characterized particularly by (1) the rapid development of mammals and birds grasses higher types of flowering plants and certain groups of invertebrate animals (2) development of the modern configuration of the continental land masses (3) great volcanic activity and (4) widespread continental glaciation The term Cenozoic is also applied to all rocks formed during the same time but no unit term such as era is used for the rocks The generally unconsolidated sedimentary rocks contain plant and animal remains which are the primary bases for identification of Cenozoic age Under normal conditions Cenozoic sedimentary materials were deposited on older rocks and unless disturbed by earth movements of some kind still retain this position Some Cenozoic igneous rocks (extrusive) rest on older rocks but others (intrusive) may occur in or below older rocks



The term Cenozoic also written Caenozoic and Kainozoic was originally proposed by J Phillips in 1841 to replace the term Tertiary In modern usage Cenozoic includes not only Tertiary but also later (Quaternary) deposits

The Cenozoic Era is now generally divided into two divisions of unequal length the older Tertiary Period which is relatively long and the younger Quaternary Period which is relatively short. Rock

formed during the Tertiary Period are classed as the Tertiary System and those of the Quaternary Period as the Quaternary System The terms Tertiary and Quaternary are holdovers from earlier geological nomenclature when rocks were classed in four divisions Primary (oldest) Secondary Tertiary and Quaternary Primary and Secondary have long been obsolete but Tertiary and Quaternary are firmly fixed as a part of geologic nomenclature throughout most of the world Quaternary is separated from Tertiary because of the apparent emergence of man and relics of his presence and the widespread development of glaciers in polar latitudes *See* QUATERNARY TERTIARY

The Cenozoic is the apogee of mammals birds and flowering plants on the land and of pelecypods and gastropods in the sea Archaic forms have been progressively replaced with more advanced forms in each of these groups but the groups themselves have managed to maintain their ascendancy throughout the Cenozoic Era *See* PALEOBOTANY PALEONTOLOGY [A H CH G E M]

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Centaurus

The Centaur in astronomy one of the most magnificent of the southern constellations Two first magnitude navigational stars Alpha and Beta Centauri mark the right and left front feet respectively of the centaur The former is Rigil Kentaurus or simply Rigil Kent and the latter Hadar Rigil Kent is the third brightest star in the whole sky fainter than only Sirius and Canopus The line joining Rigil Kent and Hadar points to the constellation Crux (the Southern Cross) Thus they are also called the Southern Pointers in contradistinction to the northern pointers of the Big Dipper *See* URSA MAJOR *see also* CONSTELLATION [C S Y]

Center of gravity

A fixed point in a material body through which the resultant force of gravitational attraction acts The resultant of all forces or attractions produced by the earth s gravity on a body constitute its weight This weight is considered to be concentrated at the center of gravity in mechanical studies of a rigid body The location of the center of gravity for a body remains fixed in relation to the body regardless of the orientation of the body If supported at its center of gravity a body would remain balanced in its initial position Coordinates as for an aircraft are conveniently chosen with origin at the center of gravity *See* RESULTANT OF FORCES *see also* GRAVITY [N S F]

Center of mass

That point of a material body or system of bodies which moves as though the system s total mass existed at the point and all external forces were applied at the point The earth moon system moves in the sun s gravitational field as though both masses were located at a center of mass some 3000 miles from the earth s geometric center The function of the center of mass concept is to permit analysis of the motion of an entire system as distinguished from that of its individual parts

Consider a system of mass M composed of n bodies with masses m_1 m_2 m_n and radius vectors r_1 r_2 r_n measured from some common reference point Separate the force on each body into internal and external components ${}^{i}f$ and ${}^{e}f$ The motion of the jth body is given by

$$m_j \frac{d^2 r_j}{dt^2} = {}^{e}f_j + {}^{i}f_j \tag{1}$$

The sum of the motions of all bodies is

$$\sum_j m_j \frac{d^2 r_j}{dt^2} = \sum_j {}^{e}f_j + \sum_j {}^{i}f_j \tag{2}$$

By Newton s third law $\sum_j {}^{i}f_j$ is zero and the sum of the external forces acts as a single resultant force

$$\sum_j {}^{e}f_j = F \tag{3}$$

Define a point with radius vector R such that

$$MR = \sum_j m_j r_j \tag{4}$$

Then

$$\frac{d^2}{dt^2}(MR) = \frac{d^2}{dt^2}\sum_j m_j r_j = \sum_j m_j \frac{d^2 r_j}{dt^2} \tag{5}$$

and by substitution from Eq (2),

$$\frac{d^2}{dt^2}(MR) = F \tag{6}$$

$$\frac{d^2 R}{dt^2} = \frac{F}{M} \tag{7}$$

This equation an expression of Newton s second law states that the center of mass at R moves as though it possessed the total mass of the system and were acted upon by the total external force

A simplification of the description of collisions can be obtained by using a coordinate system which moves with the velocity of the center of mass before collision For a discussion of this *see* COLLISION *see also* RIGID BODY DYNAMICS [J P H]

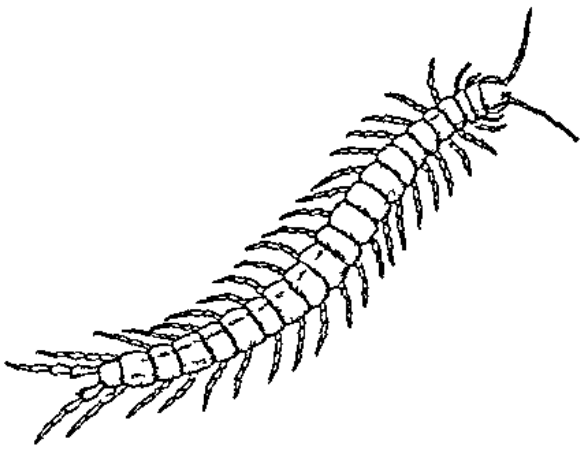
Center of pressure

A point on a plane surface through which the resultant force due to pressure passes Such a surface can be supported by a single mounting fixture at

its center of pressure For example a water gate in a dam can be supported by a single shaft at its center of pressure For a nonvertical plane surface submerged in a motionless liquid the center of pressure is vertically below the centroid of the volume of liquid above the surface For a vertical submerged surface the distance from the surface of the liquid to the center of pressure is y_p given by $y_p = I/y_c A$ where A is the area of submerged surface y_c is the distance below liquid surface to the centroid of area and I is the moment of inertia of area A about the intersection line of the vertical surface with the liquid surface *See* CENTROIDS OF AREAS AND LINES, MOMENT OF INERTIA [N S F]

Centipede

Any member of the subclass Chilopoda class Myriopoda phylum Arthropoda There are about 2000 species of centipedes mostly tropical but some occur throughout the United States



Centipede (subclass Chilopoda) (*From T I Storer and R L Usinger General Zoology 3d ed McGraw Hill 1957*)

Centipedes have poison claws but only a few of the larger forms in the southwestern United States are large enough to inflict damage to humans A few of the tropical species are dangerous Most centipedes are useful because they feed primarily on insects They differ from the superficially similar millipedes in that they have only one pair of legs per segment The paired poison claws located just back of the head are used to paralyze their prey The American species are mostly brown orange yellow or reddish in color Most species live under rocks bark and fallen trees

The fragile long legged house centipede *Cermatia (Scutigera) forceps* is often trapped in the sink or bathtub It is completely harmless

Sexes are separate Some species lay eggs whereas others produce living young The young resemble the adults but may have fewer segments These animals as well as millipedes are frequently called thousand legs or thousand legged worms *See* MILLIPEDE MYRIAPODA [J D B]

Central force

A force whose line of action is always directed toward a fixed point The central force may attract or repel The point toward or from which the force acts is called the center of force If the central force attracts a material particle the path of the particle is a curve concave toward the center of force If the central force repels the particle its orbit is convex to the center of force Undisturbed orbital motion under the influence of a central force satisfies Kepler s law of areas *See* CELESTIAL MECHANICS [R L D]

Central heating

The use of a single heating plant to serve a group of buildings facilities or even a complete community through a system of distribution pipework that feeds each structure or facility Central heating plants are basically of two types steam or hot water High temperature hot water under pressure is being used increasingly because of its considerable advantage over steam

Benefits Advantages of a central heating plant over individual heating plants for each building or facility in a group include reduced labor cost lower fuel cost and simpler maintenance Even though a central plant may require a 24-hour shift of operators the total number of employees can be substantially less than that required to operate and maintain a number of individual plants

Firing efficiencies of 85 93% dependent upon such factors as fuel boiler and plant design are usual with large central heating plants Corresponding efficiencies for small individual heating boiler plants average 60–70% Fuel in bulk quantity has a lower unit cost and single handling for one large plant as distinct from multiple handling for many small plants saves appreciably in labor and transportation

Maintenance costs on a single central plant are considerably lower than the aggregate of those for a number of small plants

The disadvantages of a central heating plant concern primarily the maintenance of distribution pipework particularly with steam systems Corrosion of drainage lines may shorten their life This problem does not arise with hot water installations

Design Heat load requirements are calculated by the addition of the following for each individual building or facility (1) winter heat losses (2) domestic water heating requirements (3) industrial or other additional heat requirement To the sum of these for all buildings or facilities must be added the system distribution heat losses

To the total of the above a diversity factor of 70–80% is applied because not all heat loads peak simultaneously Winter heat loss due to weather conditions must be taken at its maximum Water heating and industrial requirements will vary throughout the daily cycle Distribution losses must

be proportioned to the maximum figure for winter losses The individual characteristics of each system must be considered in the diversity factor usage

Divergencies between winter and summer loads must be calculated Distribution losses will be less for summer than for winter because the heat load carried through the distribution system is smaller An average figure may be 10–20% of the heat load carried

Individual boiler sizing should allow the best arrangement to meet load variations as between individual 24-hour peaks and summer and winter loads Standby capacity is essential

Fuel selection usually oil coal or gas will depend on local conditions and costs taking into account labor and firing efficiencies to be expected with each fuel

Distribution pipework sizing follows normal practice using suitable pressure drops with allowance for load variations and diversity factors as indicated Such factors apply particularly to main distribution headers as distinct from branches Numerous commercial forms of preinsulated waterproofed and structurally self sufficient conduits are available for underground distribution mains

Economics The economics for each system must be individually figured The following represent general averages

First cost per boiler horsepower	
Steam	$630–870
High temperature hot water	$500–700
Operating cost per 1 000 000 Btu	
Steam	$1 00–2 00
High temperature hot water	$0 90 1 60

In general hot water is more economical in installations of 30 000 000 Btu/hour or more

The following factors directly affect each plant's economics (1) system type such as low pressure steam high pressure steam hot water high temperature hot water and so on (2) fuel used as coal gas or oil (3) labor costs and conditions (4) type and occupancy of buildings or facilities served and (5) terrain

Boiler plant Both high pressure (125 psi saturated) and low pressure (15 psi saturated) steam plants are used although the former is the more common Both types follow conventional design Boilers may be either water tube or smoke tube dependent on the rate of load cycling Feed water and firing auxiliaries are of conventional type Chemical treatment of feed water is usual

Either conventional hot water heating plants or high temperature hot water plants dependent on size are used Design and components are conventional for each Hot water circulation due to losses in the distribution pipework should be at maximum temperature pressure limitation Circulation through the distribution system is by centrifugal pump with standby equipment being furnished High temperature hot water installations may operate in the 400 500°F range

Fuel handling firing, and control arrangements also follow conventional design Capacity of fuel storage should be on a minimal 3-4 week basis Coal oil or gas are equally suitable as fuels their individual choice being dependent upon local conditions and economics

Physical size of plant will depend on type and fuel used A rule of thumb may be taken as 2 5 ft² of floor area per boiler horsepower This does not include fuel storage space

Distribution systems. Both overhead and underground pipework is used for distribution although the latter is more usual except for industrial plants Overhead mains must be strongly supported insulated and weatherproofed Underground mains must be insulated and carefully waterproofed particularly in damp areas They must be structurally adequate Steam distribution requires proper drainage of mains and often pumped return of condensate when gravity flow is not practical In municipal distribution systems in larger cities where steam is used it is frequently considered uneconomical to return the condensate to the central boiler plant as pumping costs become excessive over large distances For a plant serving a small community or medium sized facility however this does not apply

When one of the commercial forms of prefabricated conduit is used proper cover must be arranged in depth of excavation to give adequate protection against surface loads Granulated plastic minerals which harden on application of heat with high insulating value are also used around buried distribution mains for insulation and waterproofing purposes Generally this usage effects considerable economies in first cost

Heat sales Various methods of heat sale are in use where central plants service public communities or facilities With steam distribution steam meters to each individual building or facility served are usual and a utility type of sliding scale rate per pound of steam sold is charged The use of condensate measuring meters is in general not recommended because of their inaccuracy

For hot water distribution a combination meter measuring both water flow and temperature differential between supply and return mains may be used This measures directly Btu per hour furnished In certain cases where a constant temperature differential between supply and return water mains is maintained metering may be by flow only although this is naturally not very accurate *See* BOILER FEED WATER, COMFORT CONTROL, FURNACE (STEAM GENERATING), STOKER

[J K M P]

Central nervous system

The division of the nervous system comprising the brain and spinal cord

The brain is contained in the cranium and is covered by membranous sheaths the meninges which protect the brain and provide support for the passage of blood vessels into the brain The

meninges surround the spinal cord and provide similar functions as the cord traverses the spinal canal formed by the vertebrae *See* BRAIN

The brain is composed of several subdivisions such as the cerebral hemispheres and cerebellum which are concerned with higher orders of nervous activity such as thought motor control coordination and reception of sensory stimuli Other segmental structures the midbrain pons and medulla oblongata comprise the brain stem These are segmental because they retain connections by means of 12 pairs of cranial nerves with the original embryonic segments in which they developed Other specialized associative integrative and relay centers are also present in the brain stem

The spinal cord consists of white and gray matter the former being bundles of nerve fibers from the body the latter being largely composed of groups of nerve cell bodies The cord is both anatomically and functionally integrated in that 31 pairs of spinal nerves pass to successive body levels from between adjacent vertebrae The right and left halves of the cord are mirror images of each other as are the brain halves Each half is concerned primarily with the nerves and fibers of the same side but crossing over of nerve tracts is characteristic In addition the anterior portion of the cord contains mostly motor components whereas the posterior or dorsal portion is sensory in nature *See* AUTONOMIC NERVOUS SYSTEM NERVOUS SYSTEM VERTEBRA [E G ST]

Centrifugal force

A fictitious outward force on a particle rotating about an axis usually considered to be equal and opposite to the centripetal force (*see* CENTRIPETAL FORCE) Consider a mass M tied by a string of length R to a pin at the center of a smooth horizontal table and whirling around the pin with an angular velocity of ω radians per second The mass rotates in a circular path because of the centripetal force $F_c = M\omega^2R$ which is exerted on the mass by the string If in addition an equal and opposite force the so called centrifugal force acted on the mass the net force would be zero and in accordance with Newton s first law of motion the mass would continue moving in a straight line

On the other hand to an experimenter in a windowless circular laboratory that is rotating smoothly about a centrally located vertical axis no object remains at rest on a smooth surface all such objects move outward toward the wall of the laboratory as though an outward centrifugal force were acting An outside observer would realize that the inward force which the experimenter in the rotating laboratory must exert to keep the object at 'rest does not keep it at rest but furnishes the centripetal force required to keep the object moving in a circular path However to the rotating experimenter this outward centrifugal force is real The concept of an outward centrifugal force may be used to expla

See CENTRIFUGATION

Centrifugal pump

A machine for moving fluid by accelerating it radially outward More fluid is moved by centrifugal pumps than by all other types combined The smooth essentially pulsationless flow from centrifugal pumps their adaptability to large capacities easy control and low cost make them preferable for most purposes Exceptions are those in which a relatively high pressure is required at a small capacity or in which the viscosity of the fluid is too great for reasonable efficiency

Centrifugal pumps consist basically of one or more rotating impellers in a stationary casing which guides the fluid to and from the impeller or from one impeller to the next in the case of multistage pumps Impellers may be single suction or double suction (Fig 1) Additional essential parts of all centrifugal pumps are (1) wearing surfaces or rings which make a close-clearance running joint between the impeller and the casing to minimize the backflow of fluid from the discharge to the suction (2) the shaft which supports and drives the impeller and (3) the stuffing box or seal which prevents leakage between shaft and casing

Characteristics The rotating impeller imparts pressure and kinetic energy to the fluid pumped A collection chamber in the casing converts much of the kinetic energy into head or pressure energy before the fluid leaves the pump A free passage exists at all times through the impeller between the discharge and inlet side of the pump Rotation of the impeller is required to prevent backflow or draining of fluid from the pump Because of this only special forms of centrifugal pumps are self priming Most types must be filled with liquid or primed before they are started

Every centrifugal pump has its characteristic curve which is the relation between capacity or rate of flow and pressure or head against which it will pump (Fig 2) At zero pressure difference maximum capacity is obtained but without useful work As resistance to flow external to the pump increases capacity decreases until at a high pressure flow ceases entirely This is called shut off head and again no useful work is done In between these extremes capacity and head vary in a fixed relationship at constant rpm Input power generally increases from a minimum at shut off to a maximum at a capacity considerably greater than that at which best efficiency is realized The operating design point is set as close as practical to the point of best efficiency Operation at higher or lower speed results in a change in the characteristic curves with capacity varying directly with the speed and head varying as the square of speed Since the power required is proportional to the product of the head and capacity it varies as the cube of the speed These relations are essentially constant as long as viscosity of the fluid is low enough to be negligible

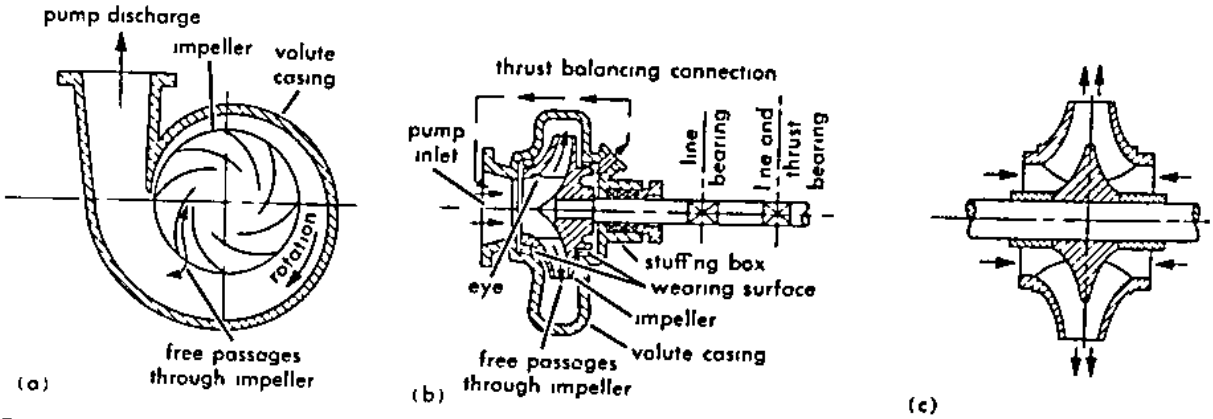


Fig 1 Centrifugal pump (a) Section across axis of single section volute pump (b) Section along axis of single section volute pump (c) Double suction impeller

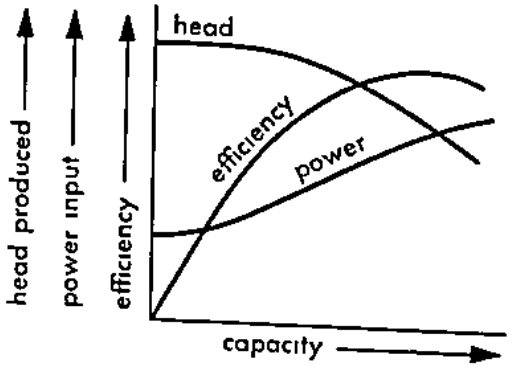
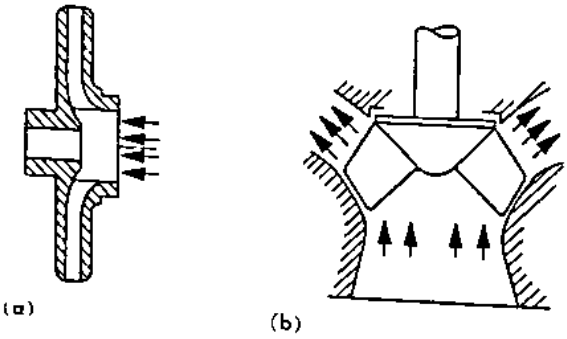


Fig 2 Typical characteristics of centrifugal pump at constant speed of rotation



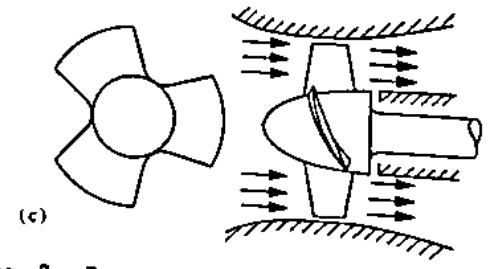


Fig 3 Types of impeller (a) Centrifugal for low speed (b) Mixed flow for intermediate speed (c) Axial flow or propeller for high speed

practical rotating speed Impellers and pumps are commonly classified as (a) centrifugal (b) mixed flow and (c) axial flow or propeller (Fig 3) There is a continuous change from the centrifugal impeller to the axial flow impeller For maximum practical head at small capacity, the impeller has a large diameter and a narrow waterway with vanes curved only in the plane of rotation As the desired capacity is increased relative to the head the diameter of the impeller is reduced the width of the waterway is increased and the vanes are given a compound curvature For higher capacities and less head the mixed flow impeller is used It discharges at an angle approximately midway between radial and axial For maximum capacity and minimum head the axial flow or propeller type impeller is used

Capacity Specific speed is used to identify the place occupied by an impeller in this range of form or type The narrow, purely radial discharge impeller is at the low end of the specific speed scale while the axial flow impeller is at the high end The highest pump efficiency is obtainable at a specific speed of approximately 2000 when the capacity is expressed in gallons per minute (gpm), or 94 when the capacity is expressed in cubic feet per second (cfs) Specific speed $N_s = NQ^{1/2}H^{3/4}$ where N is rpm H is head, in feet, and Q is capacity in gpm or cfs

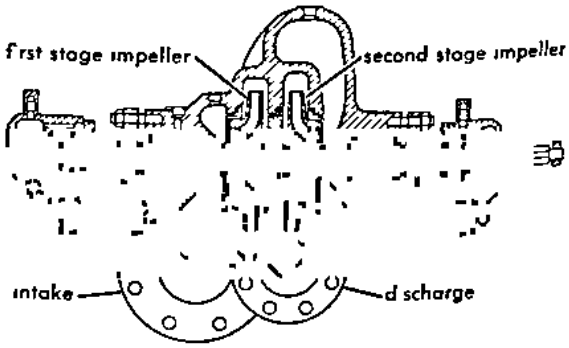


Fig 4 Two stage horizontally split casing pump

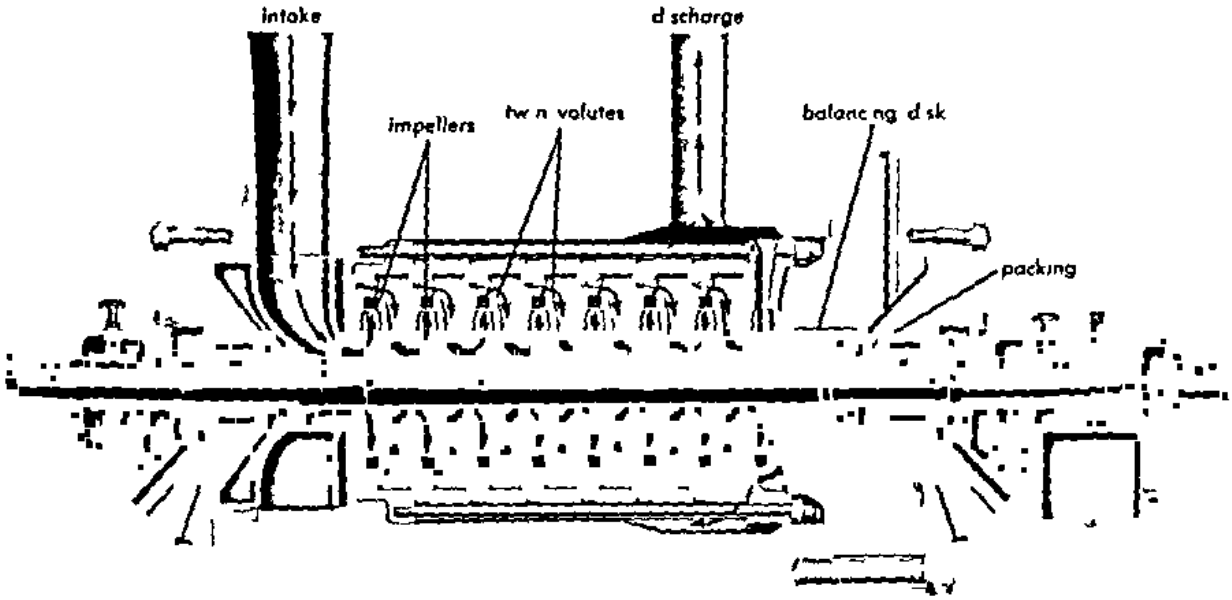


Fig 5 High pressure multistage centrifugal boiler feed pump

Since the highest efficiency is obtained at a medium specific speed theoretically an optimum speed of rotation may be calculated for any head and capacity Such a selection must be adjusted for practical considerations Because most pumps are driven directly by electric motors available motor speeds govern operating speeds to a large extent For small capacities a lower specific speed is usually necessary The low limit is set by casting limitations for long vanes and extremely narrow impellers by the hydraulic losses from flow through the small passages and by the friction of a large disk rotating in the fluid At the other end of the scale for large capacities and low heads high specific speed is necessary to keep the driver speed as high as practical In large pumps the head per stage may be limited by mechanical considerations At common motor speeds single-stage pumps are limited to heads of about 600 feet per stage However at higher speeds heads up to about 2000 ft per stage have been attained in multistage boiler feed pumps

Cavitation limits also play a major part in limit

Since the static pressure in a closed stream of fluid drops as velocity is increased there is a limiting velocity at which the absolute pressure approaches the vapor pressure of the fluid Beyond this partial vaporization occurs and the subsequent collapse of these pockets of vapor causes noise vibration and ultimately destruction of the surrounding walls This form of vaporization in a moving stream of fluid is called cavitation Higher operating speeds require higher suction pressure over the vapor pressure spoken of as a net positive suction head

Multistage pumps When the required head exceeds that practical for a single stage pump several stages are employed Figure 4 shows a typical two stage pump with single suction impellers mounted back to back to obtain an approximate balance of the hydraulic thrust developed by pressure acting on the greater area of the back side of the impeller A modern high pressure multistage centrifugal pump enclosed in a forged steel barrel with all the single-suction impellers facing in the same direction is shown in Fig 5 In this design axial thrust is balanced by a rotating disk mounted at the high pressure end of the pump Leak off from this balancing device which is piped back to suction pressure serves also to reduce practically to suction pressure the load on the stuffing box packing or seal at this end of the pump Pumps of this type are built with four to ten or more stages depending on the speed pressure and capacity desired

Another widely used type of multistage pump is the vertical turbine or deep well pump The details of design and the choice of an impeller of relatively high specific speed are the result of a drastic limitation of the outside diameter required to fit inside drilled well casings Pumps of this type are built with as many as 20 or 30 stages for high lifts from relatively small-diameter wells Pumps with this same arrangement are built with a closed bottom cylindrical housing with the inlet connected near the top of the housing for applications at moderate head and limited net positive suction head The cylindrical housing or can is then located in a pit or dry well with suction and discharge connections near ground or floor level *See* PUMP PUMPING MACHINERY [E F W]

Centrifugation

The separation of mixtures such as immiscible liquids or solids in liquids by means of centrifugal force Much of the centrifugation terminology

in common usage is not standardized for example sugar crystals are spun dry in a centrifugal nitrocellulose is wrung dry in a wringer and textiles are spun dry in an extractor All these terms describe the identical operation of introducing solids and liquid into a basket and rotating the basket at high speeds to remove liquid from the solids

A centrifugal generally refers to the centrifugal filter type of equipment that retains solids (cake) on a screen or filter cloth placed inside a perforated basket and passes liquid (filtrate) through the deposited bed of solids and the perforations in the basket A centrifuge is a rotating device that subjects materials held in it or passed through it to centrifugal force and achieves a separation because of the difference in the densities of the components in the mixture A hydrocyclone is a cylindrical conical chamber into which a stream of fairly high velocity is introduced along a tangent The resultant bending of the stream into a circular cyclonic path subjects the stream to centrifugal force and achieves a centrifugal separation of the components of the feed stream

Centrifugal force results from the resistance of a body to a change in direction An automobile turning a sharp corner at high speed tends to lean because the automobile resists the sudden change in direction The higher the speed and the shorter the radius of turning the greater the tendency of the car to overturn

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and resist turning corners The resulting resistance of the liquid and solids to the change in direction generates centrifugal force which may be expressed mathematically by the equation

$$\text{Centrifugal force} = 14.2 \times 10^{-6}\, DN^2 = 0.75\,(V^2/D)$$

where centrifugal force is expressed as multiples of the force of gravity D is the diameter of bowl in inches N is the number of revolutions per minute (rpm) and V is the peripheral speed of the bowl in feet per second (fps)

Centrifugal bowls must withstand the stresses (self stress) imposed by centrifugal force on the

a safe speed which is the average design speed for steel bowls The larger diameter centrifugals operate at somewhat lower surface speeds because in addition to the self stress of rotation the bowls must also support the load of relatively large volumes of liquids and solids held in the bowl

The major types of centrifugal operations are summarized in Table 2 In addition to these many special centrifugals have been developed such as laundry centrifugals to dewater clothes and textile centrifugals to process threads and yarns

Table 1 Comparison of bowl diameter and centrifugal force

Bowl diameter in	Velocity rpm	Centrifugal force multiples of gravity	Bowl surface speed fps	Type of centrifugal
¼	230 000	190 000	250	Ultracentrifuge
1¾	33 000	27 000	258	Laboratory tubular
4	14 300	11 600	250	Commercial tubular
12	4 800	4 000	250	Disk centrifuge
18	3 200	2 600	250	
18	1 900	970	150	Continuous solid bowl
24	2 400	2,000	250	
24	1 400	670	150	Batch centrifugals
48	1 200	980	250	
48	710	340	150	Large centrifugals

Table 2 Typical centrifugal operations

Centrifugal	Type of feed	Gravity equivalent	Centrifugals
Filtration	Slurries	Draining	Perforated baskets continuous solid bowl
Separation	Immiscible liquids	Decantation	Tubular and disk centrifuges
Clarification and classification	Solids in liquid	Settling	Tubular and disk centrifuges continuous solid bowl

Centrifugal filtration This may be compared to gravity draining of water from a slurry of wet sand placed on a porous screen Excess surface water drips from the sand until it is only damp to the touch In the centrifugal filter a slurry is introduced into a rapidly rotating basket and solids are retained on a porous screen Centrifugal force separates the liquid from the solids much more effectively than is possible with gravity draining and the final cake is almost dry to the touch

Centrifugal separation An oil and water mixture placed in a jar and left undisturbed will separate into a floating oil layer and a lower water layer Depending upon the difference in specific gravities of the lighter oil and the heavier water and the tendency of the mixture to form an emulsion the separation may be completed rapidly or slowly by the force of gravity Many mixtures of immiscible liquids form emulsions (cream in whole milk for example) that require many hours of gravity settling to separate The centrifuge multiplies the effect of gravity and achieves the separation of most immiscible liquids in a few seconds or minutes Further some mixtures that cannot be separated by gravity settling may separate readily in a centrifuge

Centrifugal clarification Solid particles can be removed from liquids merely by allowing the liquid to stand quietly in a settling tank The smaller the

solid particle the longer the time required for complete clarification The velocity of settling of a particle is given by Stokes law

$$\text{Velocity of settling of spherical particles (gravity)} = \frac{D^2\rho g}{18\eta}$$

$$\text{Velocity of settling of spherical particles (centrifugal force)} = \frac{D^2\rho\omega^2 r}{18\eta}$$

where D is the diameter of the particle ρ is the density of the particle g is the force of gravity η is the viscosity of the fluid ω is the angular velocity of the centrifugal and r is the radius of the centrifugal

Thus, the centrifugal replaces g (gravitational force) with $\omega^2 r$ (centrifugal force) and the higher settling velocity of centrifugal clarification reduces the time of settling from hours to minutes

Centrifugal classification This may be viewed as a special case of centrifugal clarification in that complete clarification is purposely not achieved According to Stokes law large diameter particles settle faster than small diameter particles If insufficient settling time is provided in the centrifugal the smaller diameter particles will not settle and will remain suspended in the liquid discharged from the centrifugal Larger particles will settle to the bowl wall and will be removed

The basic types of centrifugal equipment are summarized below

Centrifugal filters	*Centrifuges*
batch perforate basket top suspended	ultracentrifuge bottle or test tubes
batch perforate basket underdriven	tubular bowl
automatic batch horizontal	disk bowl
automatic batch underdriven	hydrocyclones
continuous pusher type	
continuous screen conveyor type	
continuous solid bowl conveyor type	

Centrifugal filters The suspended basket batch centrifugal has a large basket (20–60 in in diameter) which hangs from the top drive head An electric or hydraulic motor provides several rotational speeds—an intermediate speed for introducing slurry onto the basket until a full load is obtained followed by high speed dewatering of the cake and finally slowing the basket to 50 rpm for plowing the cake from the basket Operator attention is required during feeding to ensure uniform distribution of solids in the basket thereby preventing an unbalanced load which will cause the basket to swing back and forth

The underdriven batch basket centrifugal has a relatively large basket (diameter of 20–60 in) housing and drive motor suspended from three stationary columns The solids are collected and spun dry in the same manner as in the top suspended basket machine but they are manually shoveled out of the stationary basket at the end of the batch cycle

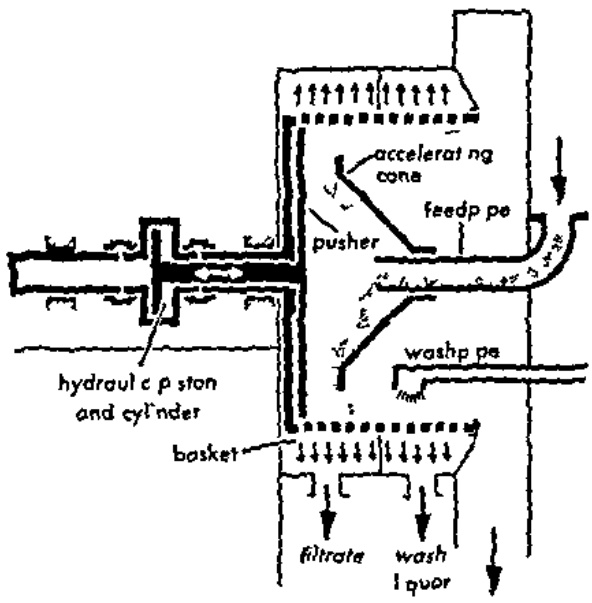


Fig 1 Pusher type centrifugal

Batch automatic centrifugals have been developed to eliminate the hand labor associated with the batch centrifugals described above The horizontally mounted centrifugal rotates at constant speed throughout the entire cycle Various valves actuated by pneumatic controls and electrical timers control the feed cake rinse spin and unload operations Approximately 2 ft^3 of cake is collected from a slurry during the feed portion of the cycle and is washed dried and unloaded in 30–90 sec Relatively coarse free-draining crystals are readily processed on this type of centrifugal

The underdriven batch centrifugal has also been made automatic Solids are plowed by a hydraulically operated unloader and are dropped through openings in the bottom of the basket A cycle programmer controls the various portions of the cycle to provide for intermediate speed feeding high speed spinning, and very low speed unloading Hydraulic drives are used to obtain flexibility of speeds and rates of acceleration and deceleration required for the various process applications

Three continuous centrifugals have been developed (1) pusher or ter Meer type (2) screen conveyor type and (3) solid bowl conveyor type The pusher type (Fig 1) has a horizontally mounted perforated basket into which a slurry is introduced through a rotating acceleration cone Liquid is thrown through the holes in the basket leaving the solids retained on the inner wall of the basket The reciprocating pusher forces the solids to travel along the basket where dewatering washing and final dewatering take place before the solids are pushed over the edge of the basket into the dry solids housing

The conveyor type centrifugal has been produced in a variety of sizes shapes, and special designs The basic parts are a rotating solid bowl or per

forated screen basket with an internal screw conveyor turning at a slightly different rotational speed to scrape the settled solids from the basket wall and transport them to the discharge outlet

The solid bowl conveyor centrifuge may have a cylindrical conical bowl A liquid pool forms on the inside of the bowl and solids contained in the original feed stream are settled through the liquid pool to the bowl wall The clear liquor spills over the filtrate outlets which act as a dam to hold the liquid pool The settled solids are moved along the bowl wall by the screw conveyor and pushed uphill out of the pool and up the draining beach to the solids discharge outlets

Centrifuges An ultracentrifuge is a small diameter extremely high speed centrifuge that develops exceedingly high centrifugal force Generally used in research work it consists of a small rotor about ½ in in diameter or smaller with a transparent window A sample placed in the rotor is observed through a suitable microscope arrangement *See* ULTRACENTRIFUGE

Bottle centrifuges are batch units that is the mixture to be separated is poured into small bottles or test tubes which are then placed in position in the rotor assembly Rapid spinning of the rotor assembly generates centrifugal force to make various separations—clarification or classification of solids in liquids or mm

The tubula
bowl suspend
ing housing at the top of the machine Feed enters at the bottom of the bowl through a stationary nozzle that injects the feed into the bowl proper The spinning bowl causes the feed to rotate as it moves

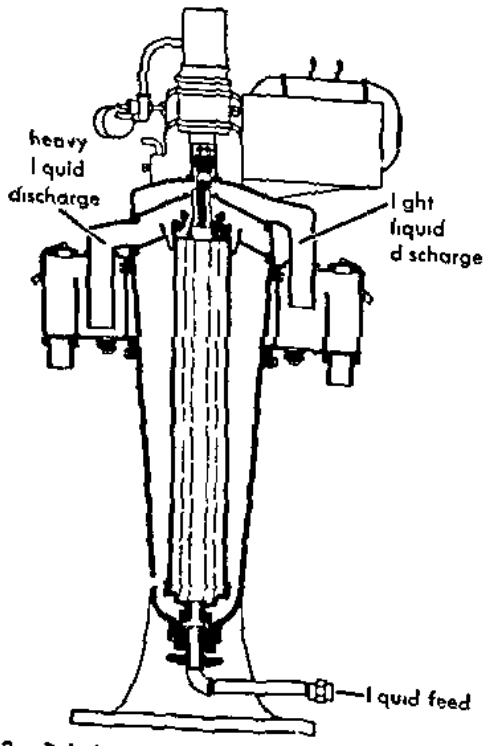


Fig 2 Tubular bowl centrifuge

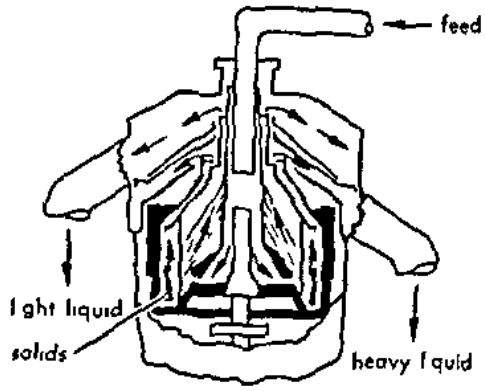


Fig 3 Disk centrifuge

up the bowl wall, thereby subjecting the liquid to centrifugal force.

The disk centrifuge bowl is relatively large in diameter (12–30 in) and has a set of disks that separate the liquid into thin layers to create shallow settling chambers Feed enters at the center line of the rotating bowl and is accelerated by fins or channels at the bottom of the disk stack assembly before it is introduced into the bowl proper The heavy liquid separates quickly and settles to the bowl wall Light liquid with some of the heavy liquid entrained as small drops enters the outside of the disk stack and flows up the sloped surfaces to the central portion of the disks The entrained drops of heavy liquor are separated in the shallow layers between the disks and settle back to the bowl wall Any solids contained in the feed are also settled to the bowl wall

Hydrocyclones achieve separations by injecting a relatively high velocity liquid stream into a cyclone much the same as a dust collector cyclone for removing solids or mists from a gas The stationary hydrocyclones eliminate the mechanical rotation problems of the centrifuge The high inlet velocity is obtained with standard pumps Rather crude separations that is, removal of relatively large heavy solids from liquids can be obtained in 4 in diameter and larger cyclones with approximately 30–60 psig pressure drop across the cyclone The more difficult separations of small particles from liquids or the separation of two immiscible liquids require small diameter cyclones A 10 mm diameter (0 4 in) unit can remove 1 to 5 micron particles from liquids with a pressure drop of 40 psig *See* SEPARATION (MECHANICAL) [J E F]

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Centrifugation (biology)

Many different types of centrifuges are used by biologists for various purposes The modern biologist frequently has recourse to standard chemical techniques involving the use of centrifuges, hence this article discusses only biological methods

One simple use for a centrifuge is to concentrate the material being investigated For example a bi

ologist interested in examining or studying the microscopic fauna of a pond or stream can facilitate his search for protozoa rotifers or other tiny organisms by centrifuging relatively large samples of pond or stream water The organisms will pass to the bottom of the centrifuge tube or bottle to form a relatively concentrated mass of material

Cellular studies. Often cells or parts of cells are separated by centrifugation Blood cells are commonly separated from the plasma in which they are suspended by centrifuging whole blood after it has been suitably treated with an anticoagulant In modern biology and biochemistry there is frequently a need to separate out constituent parts of cells Cells are broken either by homogenization or by freezing and thawing and then by centrifuging at different speeds or in media of different specific gravities Thus it is possible to separate nuclei or granules of one sort or another from the rest of the cellular material Figure 1 shows a preparation of rat liver nuclei obtained in this way

Students of cell physiology sometimes want to know the specific gravity of cells or parts of cells One way of determining this is with the aid of a centrifuge If the cells nuclei or granules are centrifuged in media of varying specific gravity then it is only necessary to determine the conditions under which cells or parts of cells move neither centripetally nor centrifugally Such determinations usually must be made rapidly so as to minimize any possible change in specific gravity during the course of the measurement Varying concentrations of sucrose are convenient media for use in such determinations for physical tables commonly list the specific gravity of different concentrations of this substance However polymers such as polyvinylpyrrolidine (PVP) offer the advantage that they are less likely to have an effect in altering the specific gravity of the cell or cell constituent When a solution of a polymer is used it is necessary to determine the specific gravity of various concentrations for these values are not listed in physical tables

The centrifuge can also give information as to the relative specific gravity of different parts of a cell Fat or lipid inclusions typically move centripetally forming a cap of fatty material at the light end of the cell But not all lipids have a low specific gravity for phospholipids have a specific gravity greater than that of water and they may pass to the heavy end of the cell In both plant and animal cells the nucleus is typically light in comparison with the cytoplasm and in centrifuged cells it can be seen just under the fat cap (Fig 2) Within the nucleus the nucleolus is relatively heavy and it moves centrifugally However it does not always move to the extreme centrifugal end of the nucleus for there may be granular material within the nucleus which is even heavier than the nucleolus

For many years embryologists have used centrifuges to study the effect of centrifugal force on the processes of development These studies have tended to show that different types of granules in the cytoplasm have different functions and contain



Fig 1 Rat liver nuclei obtained by homogenization and differential centrifugation (Norman G Anderson)

different enzyme systems If egg cells are centrifuged immediately before fertilization or at various times after fertilization but before the first cleavage the resultant shifting of granules causes an uneven distribution of granular material in the various cells of the developing embryo As a result there may be cells which are tightly packed with granules and other cells almost completely lacking in granular material If the granules are as important as is commonly supposed such a disturbance in granular distribution should disturb the normal course of development In some perhaps in most cases it apparently does not

When cells are strongly centrifuged the light granules pulling centripetally and the heavy granules pulling in the opposite direction tend to break the cell in two This can readily be accomplished in some sea urchin eggs although in other types of eggs in which the outer membranes are relatively tough no such breakage occurs When breakage does occur the centripetal or lighter fragment contains the nucleus the heavier fragment is without a nucleus Both fragments can be fertilized and both can also be made to begin their development by treatment with suitable parthenogenetic agents The information gained from studies of such fragments has important theoretical implications The enzymic content of the two fragments is a matter of some interest

Cell surface tension A knowledge of the force required to break a cell in two can give information concerning the tension at the surface of a cell This quantity is the sum of the surface tension of the cell and the elastic tension of the cell membrane The method is similar in its reasoning to

drop weight method of measuring surface tension When a spherical egg cell elongates into a cylinder of radius a and then is pulled into two halves the tension T around the circumference $2\pi a$ of the elongating cylinder acting in each direction is equal to the sum of the opposing pulls of the two halves Thus

$$2\pi a2T = cg(w_1 + w_2)$$

in which c is the centrifugal force in gravities g the gravity constant w_1 the volume of the heavy half times the difference between its specific gravity and that of the surrounding medium and w_2 is a similar quantity for the light half Figure 2*a* shows a sea urchin egg being pulled into two fragments by centrifugal force

Physical properties of protoplasm In the study of the physical properties of protoplasm the centrifuge has played an important role Protoplasm is a highly complex colloid consisting of various macromolecular constituents with large numbers of granules or other inclusions suspended in it and constituting a part of it The colloidal state of this complex mixture is subject to sudden and marked changes and it is influenced both by the processes normally occurring within the cell and also by exposure to various factors of the environment Sol gel changes are believed to accompany various aspects of cell activity and the protoplasm can indeed change from sol to gel and back again in a short space of time *See* PROTOPLASM

Viscosity and Stokes' law To obtain information about the nature and behavior of the protoplasmic colloid it is necessary to know its viscosity and how this viscosity changes Ordinarily in studying a colloid in a test tube or beaker gross viscosity changes are easy to observe Merely by tilting a beaker it is possible to determine whether the colloid within the beaker is a sol or a gel No such observations are possible for the colloid or colloids contained within a tiny cell However it is possible to determine the viscosity of protoplasm with the aid of a centrifuge One standard method of measuring the viscosity of a fluid is to determine the speed of movement of a small sphere through the fluid Stokes' law states that when a sphere is pushed through a liquid its speed v varies directly with the propelling force W and inversely with the radius of the sphere a and the viscosity of the fluid η Thus

$$W = 6\pi\eta av$$

If the sphere falls under the influence of gravity then the force acting on it is its apparent weight times the gravity constant g In a cell granules sometimes fall under the influence of gravity but their rate of fall is slow at best Hence if one is to use Stokes law for the measurement of protoplasmic viscosity it is ordinarily necessary to use forces greater than gravity These can be obtained with a centrifuge The apparent weight of the sphere which is falling or being moved is the volume of the sphere times the difference between its

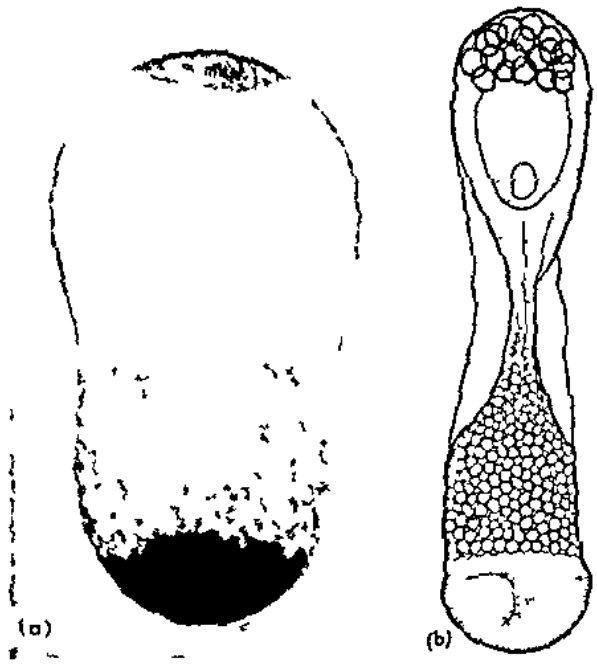


Fig 2 (*a*) A sea urchin egg (*Arbacia*) in the process of being pulled into two fragments by centrifugal force (*from* L V Heilbrunn *An Outline of General Physiology* 3d ed , Saunders 1952) (*b*) Nereis egg showing zones of stratification (*from* D P Costello *Fertilizability of nucleated and non-nucleated fragments of centrifuged Nereis eggs* J Morphol 66 103 1940)

specific gravity σ and the specific gravity of the fluid ρ By substituting in the above equation proper values for the force exerted by gravity and multiplying this by c, the centrifugal force in terms of gravity, the following equation is obtained

$$4/3\pi a^3(\sigma - \rho)cg = 6\pi\eta av$$

and solving for η

$$\eta = \frac{2cg(\sigma - \rho)a^2}{9v}$$

Limitations of Stokes' law There are various limitations to the use of Stokes' law The most important of these is that the law was derived for a single sphere If there are many spheres moving simultaneously the movement of any one sphere or all of them, will be slowed Therefore it is necessary to introduce a correction The one commonly used is the Cunningham correction q which is introduced into the denominator of the above equation for η To calculate q the following equation is used

$$q = \frac{4b(b^5 - a^5)}{(b - a)^2(4b^4 - b^3a - 6b^2a^2 - ba^3 - 4a^4)}$$

In this equation, a is the radius of one of the spheres and b is best taken as three fourths of the distance between adjacent spheres

When the hyaline (nongranular) protoplasm is not viscous and when the concentration of granules is not high the movement of granules is suff

rapid that an appreciable distance is covered in only a few seconds at a centrifugal force of about 2000 times gravity A series of tests is made and the number of seconds required to move the granules through a half a third or any reasonable fraction of the cell diameter is determined Because the time required is often short a hand centrifuge is preferable for with an electric centrifuge some seconds are required before a constant speed is attained The specific gravity of the granules can be determined by [illegible]

granular concentration known the specific gravity of the fluid through which the granules travel can be estimated by a simple arithmetical calculation

Other centrifugal methods There is another way in which the centrifuge can be used to determine the viscosity of the hyaline protoplasm of a cell After the granules have been moved they return to their original position by Brownian movement The rate of such movement along a given axis was calculated by Einstein and his equation can be used to calculate the viscosity In using Einstein s equation it is not necessary to know the specific gravity of the granules but merely their size and how long it takes for them to travel a given distance

It is of some interest to know not only the viscosity of the hyaline protoplasm but also the viscosity of the entire protoplasm granules and all Knowing the viscosity of the hyaline protoplasm and also the concentration of granular material one can calculate the viscosity of the entire protoplasm with the aid of an equation for the viscosity of a suspension Einstein developed such an equation but it does not hold if the concentration of granules is high as is usually the case in protoplasm A more recent equation is that of R Simha in which

$$\eta_s = \eta_0 (1 + a_1 c + a_2 c^2 + a_3 c^3 + \quad)$$

In this equation η_s is the viscosity of the suspension η_0 the viscosity of the suspension medium (the hyaline protoplasm in this case) c the concentration of suspended particles a_1 a constant (the value of which is taken as 2 5) a_2 and a_3 other constants The value of a_2 is not certain and different authorities prefer different values varying from 7 to 14 the value for a_3 is not ordinarily important Another way of determining the viscosity of the entire protoplasm is possible if there are granules or inclusions of markedly different sizes Thus in the egg of the sea urchin *Arbacia* there are many small colorless granules and relatively few red pigment granules which are much larger By using the Stokes law equation for these larger granules the viscosity of the entire protoplasm can be measured the values obtained are similar to those obtained by calculation In the common protozoan *Paramecium* the movement of food vacuoles under the influence of centrifugal force can be used to determine the viscosity of the protoplasmic suspension It is also possible to measure the viscosity of the entire protoplasm by determining the speed with which a nucleus moves through it under a given centrifugal force

In many marine egg cells and also in the common ameba *Amoeba proteus* the interior protoplasm is surrounded by a stiff cortex In the marine eggs one can determine the rigidity of this cortex by determining the amount of centrifugal force necessary to dislodge granules from it In making such measurements one must be sure that the granules one is observing are really in the cortex

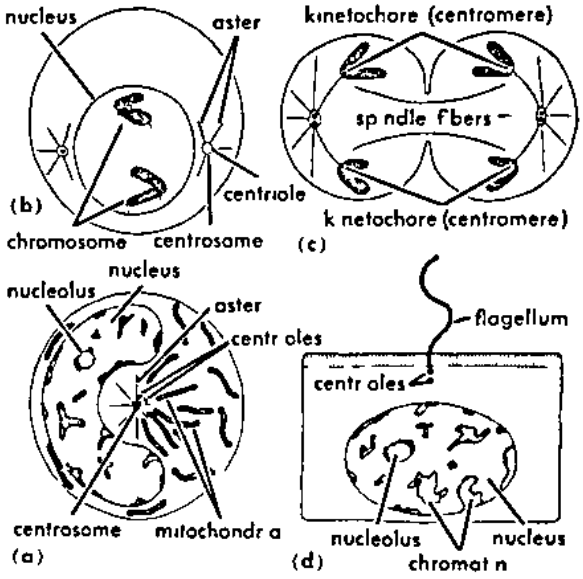
Viscosity changes In most studies of protoplasmic viscosity the interest lies not so much in obtaining absolute values but rather in knowing how the viscosity changes during the activity of the cell how it changes as the temperature varies or if the cell is exposed to different types of radiation or to one chemical or another In such studies of relative viscosity it is not necessary to know the specific gravity or the sizes of the granules However it is essential that neither the specific gravity of the granules nor their size change during the course of the experiment Many drugs have a marked effect on protoplasmic viscosity and the centrifuge method has provided reliable data on the effect of such drugs on the protoplasmic colloid [L V H]

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Centriole

A minute cell organelle found at the poles of astral mitotic spindles at the bases of cilia and flagella and in specific locations in other cells of animals and lower plants

Location and nature The term was originated for two small bodies within the single centrosome which were found to persist in interphase and to separate to determine spindle orientation at the next cell division Centrioles are very small bodies near the limit of resolution of the light microscope (0 2 μ) stainable with basic dyes and only rarely visible in living cells A pair of closely adjacent centrioles occurs in each metazoan cell at interphase in a characteristic location which is supposed to be determined by physiological relationships For example in unpolarized cells such as leukocytes the centrioles lie in the center of the main mass of cytoplasm or within a small nuclear indentation whereas in polarized epithelial cells the centrioles are in the center of the apical pole of the cell If the cell divides the centrioles move to opposite sides of the nucleus in prophase and the mitotic spindle develops with a centriole at each pole In this stage or slightly later each centriole gives rise to two From its strict interphase position and its behavior during mitosis early observers were led to consider the centriole of organizing center for the cytoplasm



Centrioles and centrosomes of animal cells (diagrammatic) (a) Leukocyte at interphase (nondividing stage) an aster and centrosome occupy the approximate center of the cytoplasm two centrioles are eccentrically located in the aster adjacent to the centrosome mitochondria near the aster are oriented radially to its center the centrosome centriole region (b) Late prophase of mitosis the two centrioles each within a centrosome and aster are at opposite sides of the nucleus and mark the location of the poles of the metaphase spindle which will form when the nuclear membrane breaks down (c) Early telophase each centriole has divided the centrosome-centriole region is connected with the spindle spherules of the chromosomal kinetochores (centromeres) by the spindle fibers (d) A flagellated cell a flagellum is connected to one of the two centrioles

which seems most plausible in the case of animal cells such as leukocytes endocrine epithelial cells and spermatocytes in which no organization is imposed by the relation to adjacent cells blood supply or direction of absorption or secretion Commonly in such cells the mitochondria are oriented radial to the centrioles the Golgi region and small vacuoles (rosette) surround the centrioles and in some spermatocytes even the nucleus is influenced so that chromosome ends are oriented toward the centriolar region (idiozomal area)

Function A major role for the centriole is perhaps more clearly evident in its function as a blepharoplast or center from the vicinity of which a flagellum or the axial filament of the spermatozoan develops because this is a process in which no other cell organelles seem to be implicated The extension of this view to include the hypothesis that the basal bodies of cilia arise by multiplication of centrioles is less well substantiated although some sort of involvement of the centriolar material is suggested by the finding that cilia flagella and axial filaments are morphologically very similar in electron micrographs *See* CELL SURFACE DIFFERENTIATION

Centrioles and chromosomes A relationship between the centrioles and the chromosome cycle is indicated by the correlation in division time of the nucleus and centrioles and by the similarity in size and staining properties of the centriole and the spindle spherule (centromere) of the chromosome from which the spindle fiber develops This comparison has been strengthened by observations suggesting that in atypical spermatogenesis the spindle spherules become detached from chromosomes and transformed into fully functional centrioles *See* SPERMATOGENESIS

The centrioles have also been compared to chromosomes as self duplicating bodies, derived by a single division from the previous generation Whether this is their only mode of origin has been disputed largely because centrioles appear only during stages which precede the formation of flagellated male germ cells in certain ferns This discrepancy has not been reexamined in the light of the finding that the centriolar material can probably arise from the centromeric substance of the chromosomes

Size and shape Centrioles are so near the limit of the resolving power of the light microscope that as a rule their exact shape cannot be demonstrated they seem to be merely black dots Some of the largest centrioles however have been noted to be rodlike bodies and observations with the electron microscope indicate that the centriole is generally in the form of a short hollow cylinder the wall of which can be resolved into a ring of nine parallel smaller rods arranged exactly like the fibrils in cilia *See* CELL (BIOLOGICAL) CELL STRUCTURES CENTROSOME, CHROMOSOME MITOSIS

[A W P]

Centripetal force

The force needed to produce the radial acceleration required to keep a body or particle moving in a circular path (*see* ACCELERATION) This force has the same direction as the radial acceleration (sometimes called the centripetal acceleration) which is toward the center of rotation and may be computed by the application of Newton's second law of motion That is the centripetal force F_c required to keep a particle of mass M revolving in a circular path of radius R with an angular velocity ω or linear speed v as in the figure is

$$F_c = Ma_r = Mv^2/R = M\omega^2 R$$

where the centripetal acceleration a is $v^2/R = \omega^2 R$

For example a small heavy body tied to a stout cord can be whirled by hand in a circular path

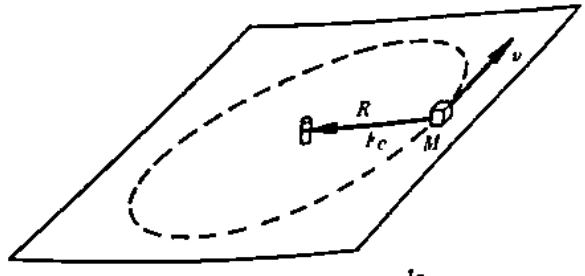


Illustration of centripetal force in circula

which is nearly horizontal To anyone who tries this experiment it is evident that an inward centripetal force must be exerted upon the rotating body In the case of a car rounding a curve the force is furnished by the friction between the roadway and the tires For a rotating disk such as a grinding wheel the particles near the periphery of the wheel are given the necessary acceleration by cohesion with adjacent particles nearer the center of rotation *See* CENTRIFUGAL FORCE [C E H]

Centrode

The path traced by the instantaneous center of a plane figure when it undergoes plane motion If a plane rigid body is constrained to move in its own plane but is otherwise free to undergo an arbitrary translational and rotational motion it is found that at any instant there exists a point called the instantaneous center about which the body is rotating The path that this instantaneous center traces out in space as the motion unfolds is called the space centrode Although the instantaneous center need not lie within the body the path that it would trace out in the body were that body sufficiently extended is called the body centrode The motion may therefore be specified when the two centrodes are given by allowing one curve to roll without slipping along the other [H C C]

Centroids of areas and lines

Points positioned identically with the centers of gravity of corresponding homogeneous thin plates or thin wires Centroids are involved in the analysis of certain problems of mechanics for example the phenomenon of bending

Centroids by integration The centroid of plane area A is point C (Fig 1) Coordinates x and y of C as referred to the indicated X and Y coordinate axes are

$$\bar{x} = \frac{\int x\,dA}{\int dA} \quad \text{and} \quad \bar{y} = \frac{\int y\,dA}{\int dA} \tag{1}$$

Similarly the centroidal coordinates of plane curve L are

$$\bar{x} = \frac{\int x\,dL}{\int dL} \quad \text{and} \quad \bar{y} = \frac{\int y\,dL}{\int dL} \tag{2}$$

In the e equations x and y are the coordinate locations of infinitesimal area element dA and infinitesimal line element dL respectively

Centroids by summation Whether or not the above integrals can be evaluated approximate values of x and y may be determined by summation (Fig 2) To this end area A is divided as shown into n finite elements whose areas ΔA_1 ΔA_n contain center points P_1 P_n Coordinates x y of the centroid of area A are then approximately

$$\bar{x} = \frac{x_1 \Delta A_1 + \quad + x_n \Delta A_n}{\Delta A_1 + \quad + \Delta A_n}$$

and

$$\bar{y} = \frac{y_1 \Delta A_1 + \quad + y_n \Delta A_n}{\Delta A_1 + \quad + \Delta A_n}$$

In analogous fashion equations for the centroid coordinates of a planar line L are in summation notation

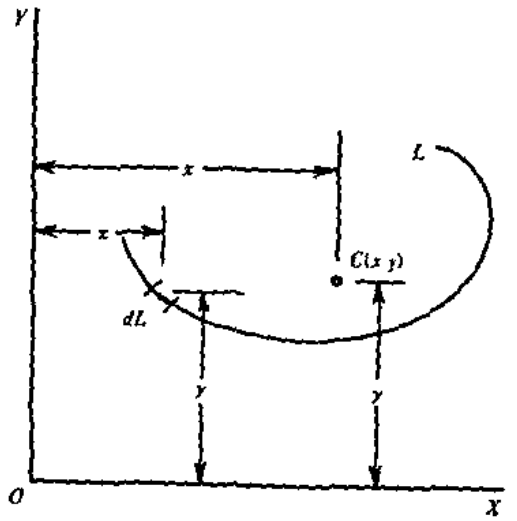
$$\bar{x} = \frac{\sum_{i=1}^{n} x\,\Delta L_i}{\sum_{i=1}^{n} \Delta L_i}$$

and

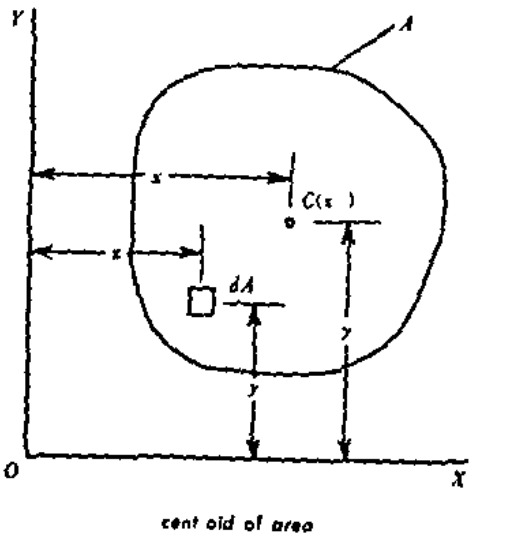
$$\bar{y} = \frac{\sum_{i=1}^{n} y\,\Delta L_i}{\sum_{i=1}^{n} \Delta L_i}$$

Accuracy of the method increases as the number of elements increases

Principle of symmetry The centroid of a geometrical figure (line area or volume) is at a point on a line or in a plane of symmetry of the figure



centroid of line



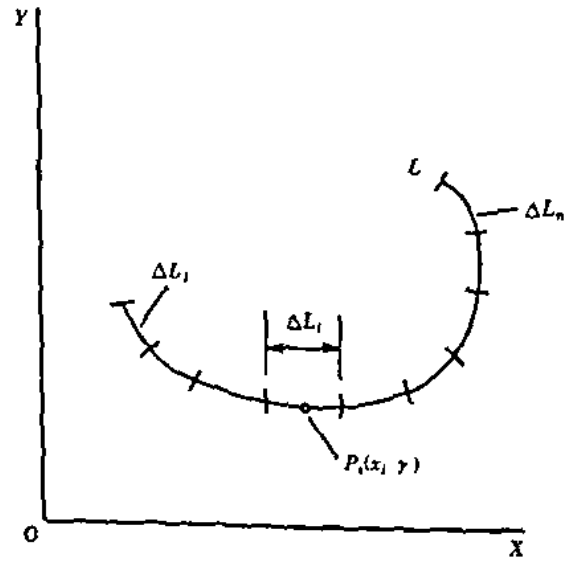
centroid of area

Fig 1 Notation of integral equations for

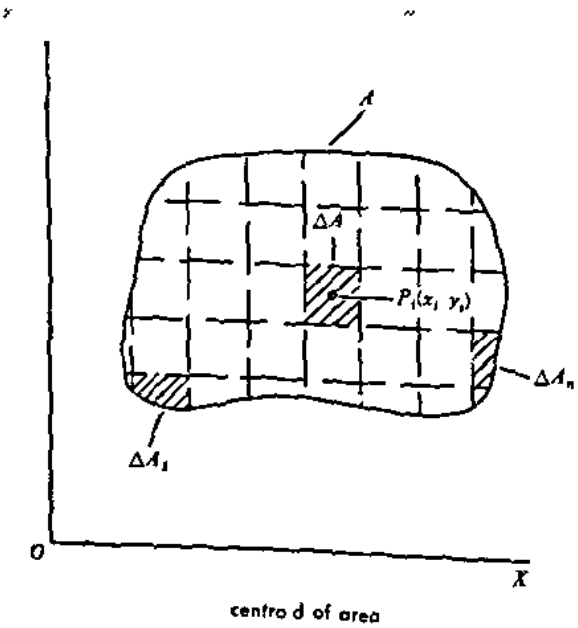
A plane figure is symmetrical about a straight line if the figure may be decomposed into pairs of equal elements so that each pair is in reflected position about a point on the line If every such pair is reflected in the same point it is the point of symmetry of the figure

Lines LL are lines of symmetry (and contain the centroids) of both the perimeter and area of the outlined shapes (Fig 3) Point C is the point of symmetry (and the centroid) of the figure (Fig 4)

Surface and volume of revolution By the following theorems stated by Pappus of Alexandria (Greek mathematician third century A D) a knowledge of the centroids of plane curves and plane areas may be employed to determine respectively, surface areas of revolution and volumes of revolution



centroid of line



centroid of area

Fig 2 Determination of centroids by summation

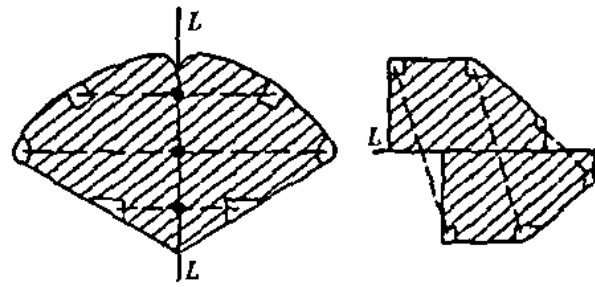


Fig 3 Plane areas symmetric about a line

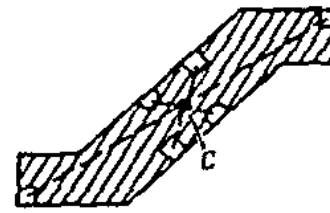


Fig 4 Plane area symmetric about a point

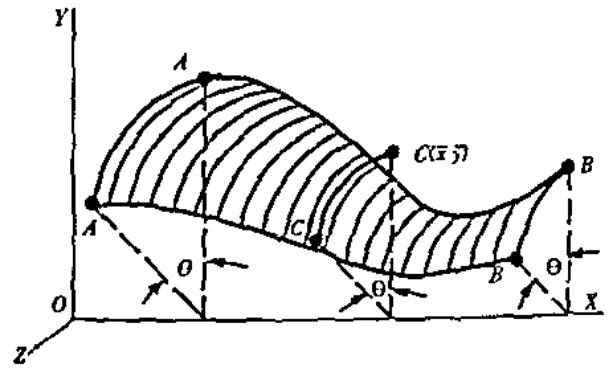


Fig 5 Use of centroid of a line to find area of a surface of revolution

Pappus' theorem of surface area is that the area of a surface generated by rotating a plane curve about a nonintersecting line in its plane is the product of the length of the curve and the arc length traveled by its centroid (Fig 5)

Area S of the shaded surface generated by rotating plane curve AB of length L an amount θ radians about the X axis from position AB in OXY to position $A'B'$ is $S = y\theta L$ where $\bar{y}$ is the centroidal coordinate of curve AB referred to the OXY coordinate plane and $y\theta = \widehat{CC'}$ is the arc length traveled by its centroid

Pappus' theorem of volume is that the volume of a solid generated by rotating a plane area about a nonintersecting line in its plane is the product of the area and the arc length traveled by its centroid

See CENTER OF GRAVITY, MOMENT OF INERTIA, SURFACE AND SOLID OF REVOLUTION [NSF]

Centrosome

The region of cytoplasm located at the center of an aster, either at the poles of the mitotic figure or in the approximate center of the cytoplasm in some cells at interphase The centrosome either surrounds or is adjacent to the centrioles and these two terms are often used interchangeably In the strict sense, however the centrosome is a transitory structure, believed by some to be merely an artifact

of staining or fixation Much broader significance is given to the centriole Synonyms for centrosome are central body centrosphere and attraction sphere *See* CENTRIOLE MITOSIS [A W P]

Centrospermales

An order of the plant subclass Dicotyledoneae characterized in general by basal or free central placentation (ovules attached at bottom of the cell or to a free column arising from the bottom) There are eight families with 411 genera and approximately 6000 species Economically most of these are of little importance The goosefoot family (Chenopodiaceae) has a world wide distribution Many species are weeds some are ornamentals and a few (beets spinach swiss chard quinoa) are food plants The amaranth family (Amaranthaceae) is characterized by a crowded inflorescence and flowers with dry chaffy bracts The basella family (Basellaceae) is a small tropical group of mostly climbing herbs Species of the pokeweed family (Phytolaccaceae) occur most abundantly in the tropics and subtropics The four o clock family (Nyctaginaceae) is a mostly tropical and subtropical group with a few ornamentals (four o clock and bougainvillea) The carpetweed family (Aizoaceae) is mainly a South African group usually characterized by fleshy leaves The pink family (Caryophyllaceae) is the largest and occurs primarily in the North Temperate Zone Distinguishing characteristics are opposite leaves free central placentation and notched petals Many are grown as ornamentals including pinks carnations baby s breath and sweet william and there are many weeds such as chickweed spurry sandwort and corn cockle *See* BEET QUINOA SPINACH *see also* DICOTYLEDONEAE EMBRYOPHYTA PLANT KINGDOM [P D S]

Cephalaspidomorphi

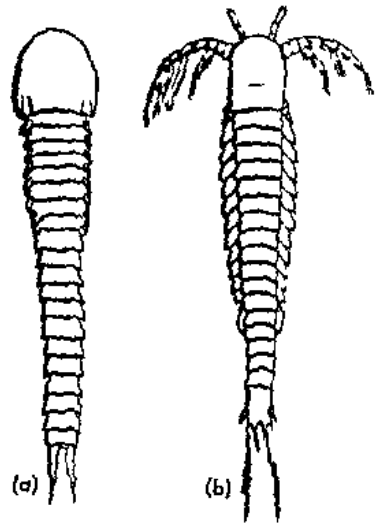
A subclass of the Agnatha The Cephalaspidomorphi are considered by some authorities to include three orders the Osteostraci Anaspida and Cyclostomata Other specialists consider the Cyclostomata to be a subclass equal in rank to the Cephalaspidomorphi Members of both the Osteostraci and Anaspida are known only as fossils whereas the cyclostomes are represented by the lampreys and hagfishes *See* AGNATHA ANASPIDA CYCLOSTOMATA (CHORDATA) OSTEOSTRACI [C B C]

Cephalobaenida

An order of the class Pentastomida in the phylum Arthropoda This order includes pentastomids with 6 legged larvae In the adult the mouth is anterior to the hooks The genital pores, in both sexes occupy an anterior position on the abdomen The family Cephalobaenidae includes three genera *Cephalobaena* has equal hooks at the end of finger like appendages the parapodia The posterior end of the body is bifid *Raillietella* has lobes at the base of the hooks The anterior pair of hooks is the smaller In *Megadrepanoides* the anterior hooks are larger and the posterior hooks have accessory spines These animals are parasitic in snakes lizards and toads The family Reighardiidae contains the single genus *Reighardia* with one species which is parasitic in the air sacs of gulls and terns The terminal segment of this species is bifid and the hooks are small and equal A proboscis and parapodia are lacking *See* PENTASTOMIDA [H R H]

Cephalocarida

A subclass of the Crustacea that was erected in 1955 to include the newly described form *Hutchinsoniella macracantha* Sanders This animal is at least as primitive as any other known crustacean either living or fossil It appears closely related to the basal crustacean ancestral stock since the other subclasses can be readily derived from a cephalocaridlike form despite the fact that each subclass is a sharply circumscribed group At the same time *Hutchinsoniella* uniquely shares morphological features with the long extinct trilobites and thus it serves as a bridge between the Paleozoic trilobites and the modern Crustacea *See* CRUSTACEA TRILOBITA [H L S]



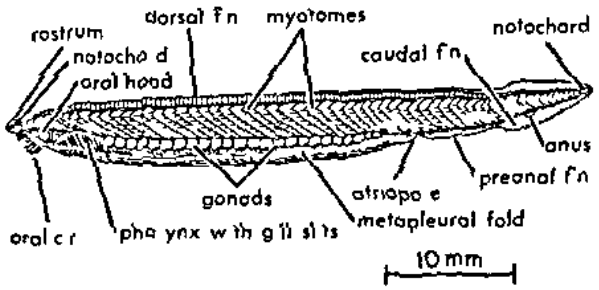
(a) The extant *Hutchinsoniella macracantha* (b) The middle Devonian fossil *Lepidocaris thyrensis* (After Scourfield)

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Cephalochordata

A subphylum of the phylum Chordata comprising the lancelets or amphioxus They are also known as the Leptocardii Lancelets are small fishlike animals not exceeding 80 mm in length They burrow in sand on the ocean bed or in estuaries in tropical and temperate regions throughout the world Only two genera are recognized *Branchiostoma* with 23 species and *Asymmetron* with 6 species

Morphology The structure of the lancelet is based on the same fundamental plan as all other



Drawing of the European lancelet *Branchiostoma lanceolatum* (*After J E Webb from Proc Zool Soc London 127 131 1956*)

chordates but there is neither head nor paired fins The skeletal rod of the back or notochord extends the entire length of the body The animal is thus pointed at both ends a feature to which the name amphioxus refers and lanceolate in form hence the names lancelet The mouth lies at the base of an oral hood fringed with sensory projections or cirri and opens into a capacious pharynx occupying over half the length of the body The body wall in the pharyngeal region is perforated on each side by a large number of elongated gill slits This delicate branchial basket is protected by two folds of tissue the metapleural folds which grow down on either side of the body and joining midventrally form a sac into which the gill slits open The cavity of this sac is called the atrium and opens to the exterior through a posterior atriopore The circulatory system resembles that of a fish but there is no heart and the blood is colorless The excretory system is quite unlike that of higher chordates and consists of nephridia situated above the pharynx with ciliated cells similar to those of the Platyhelminthes and the annelid worms Lancelets are either male or female The gonads are segmentally arranged pouches arising from the metapleural folds and discharging into the atrium

Nutrition Feeding in lancelets is by a ciliary or filter feeding mechanism Water is taken in through the mouth passed through the gill slits into the atrium and thence out through the atriopore The water current is maintained by the beating of cilia on the gill bars Microorganisms and organic debris on which the animal feeds are strained off by the gill bars onto a mucous string the endostyle and transported by cilia back to the intestine for digestion

Life history The adults burrow in rather coarse sand or shell gravel and usually lie with the mouth open at the surface of the sand They select by trial and error sands of high permeability with rounded grains coated with microorganisms and free from organic decay The selection of the optimum sand deposit available results in the congregation of large numbers of lancelets in small areas for spawning The egg develops into a larva not

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larva is bottom living but later becomes planktonic Metamorphosis to the symmetrical adult form takes place after about 11 12 weeks of life The young adult sinks to the bottom and swims actively until a suitable sand in which it can burrow and remain undisturbed is found Some species complete the life cycle in a year and death evidently occurs after spawning but others may live 3 or 4 years and spawn annually In some species metamorphosis occurs late and comparatively large larvae with 20–30 gills are formed At one time specimens of this type were placed in a separate genus *Amphioxides* but these are now generally regarded as larvae of either *Branchiostoma* or *Asymmetron*

Importance The importance of lancelets lies chiefly in their being one of the most primitive chordates However lancelets are eaten by the Chinese and there are lancelet fisheries at Amoy Lancelets are also being used as indicator organisms to assist in tracing the pattern of ocean currents on which their distribution appears to depend [J E.WE]

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Cephalopoda

A group of exclusively marine animals constituting the most advanced class of the Mollusca The class contains about 150 genera and 650 species of living forms ranging in size from the pygmy squid *Idiosepius pygmaeus* with a total length of 17 mm to the giant squid *Architeuthis princeps* over 50 ft



Class Cephalopoda Loligo squid Sepia cuttlefish *Nautilus* pearly nautilus *Argonauta* paper nautilus *Octopus* octopus Variously reduced (*From T I Storer and R L Usinger General Zoology 3d ed McGraw Hill 1957*)

in length and the largest known invertebrate In Paleozoic and Mesozoic times representatives of the class were numerous far exceeding the present species, and were represented by the nautiloids ammonoids and belemnoids Today the class contains only a single nautiloid *Nautilus* the octopuses squids and cuttlefishes *See* CEPHALOPODA FOSSILS

Taxonomy The cephalopods show great variation in form and structure and their systematics is incompletely known Several systems of classification are in use The older classification of Tetrabranchia and Dibranchia is common in text books among specialists a later system with various modifications is more favored These classificatory systems follow

Class Cephalopoda	
Subclass Tetrabranchia	Subclass Nautiloidea
Order Nautiloidea	Subclass Ammonoidea
Order Ammonoidea	Subclass Coleoidea
Subclass Dibranchia	Order Belemnoidea
Order Belemnoidea	Order Sepioidea
Order Decapoda	Order Teuthoidea
Suborder Myopsida	Suborder Myopsida
Suborder Oegopsida	Suborder Oegopsida
Order Vampyromorpha	Order Vampyromorpha
Order Octopoda	Order Octopoda
Suborder Cirromorpha	Suborder Cirromorpha
Suborder Incirrata	Suborder Incirrata

Morphology The cephalopods differ greatly from the rest of the Mollusca The molluscan organ of locomotion the foot has moved forward and surrounds the mouth and is subdivided into eight or more appendages which sometimes are contractile and in all but *Nautilus* are provided with suckers The symmetry is bilateral and except in *Nautilus* the external shell has disappeared It has been replaced by an internal shell which is coiled and chambered in *Spirula* thick and chalky in *Sepia* thin and chitinous in *Loligo* vestigial and in two parts in *Octopus* and absent in *Idiosepius* The fragile external shell of *Argonauta* is not homologous but serves as an egg case

As a result of the forward movement of the foot the digestive tract is U shaped and the viscera form a hump contained within a fleshy mantle in which the gills are also suspended The mantle is bulky and rounded in the Octopoda slender and pointed in the Decapoda Fins are found in widely divergent forms but the main means of locomotion is the funnel found beneath the head During rapid movement water enters the mantle cavity and is violently ejected through the funnel the animal moving posteriorly from the force of the jet

Digestive system The digestive tract consists of a pair of chitinous beaks a multitoothed radula two pairs of salivary glands the posterior of which may contain a powerful poison sometimes fatal to man a long esophagus a large stomach a rectum and an anus The latter usually is protected by winglike flaps

Circulatory system The circulatory system is of the closed type which is unusual in the Mollusca except in *Nautilus* where it is partly lacunar In the others sinuses are absent as a rule The blood contains a blue respiratory pigment hemocyanin Three hearts are present a systemic and two branchial hearts one at the base of each ctenidium or gill *See* RESPIRATORY PIGMENTS

Nervous system The nervous system is particularly well developed and is centralized in the head where the nerve centers are contained in a cartilaginous cephalic capsule Rapid locomotion by the contraction of the mantle walls generally has been accomplished in the decapods by the giant dorsal axons These are highly developed in the swift moving squids such as *Loligo* and *Ommastrephes gigas* The latter species is the source of the largest known nerve fibers important in medical research In *Architeuthis* the giant axons are missing The cephalopodan eye is large and complex except in *Nautilus* in which it is a simple pit It is not equaled among the invertebrates and in some respects is superior to the vertebrate eye

Coloration Cephalopods change their colors with great rapidity by the alternate contraction or expansion of chromatophores of different colors overlying the pearly iridocyst Each chromatophore consists of a pigment containing contractile sac which when expanded by nerve innervation displays its particular color but when contracted is nearly invisible *See* CHROMATOPHORE

Reproduction The sexes are separate and the genitalia highly developed The males usually have an arm modified for transference of spermatophores to the female This hectocotylus may be capable of being cast off as in *Tremoctopus* where it is left within the mantle cavity of the female The eggs are either released free in the water as in *Vampyroteuthis* or attached to the bottom or to large objects and in some cases such as the *Octopus* are brooded over by the female

The eggs are telolecithal with large quantities of yolk and cleavage is discoidal There is no typical molluscan trochophore or veliger stage but the young hatch out either as larvae which differ widely from the adults in form and become part of the plankton or as more fully developed young which immediately occupy the adult habitat In some groups such as the Cranchiidae the larvae are weird transparent creatures with stalked eyes stalked heads and slender bodies Development in this group is incompletely known *See* CLEAVAGE EMBRYONIC OVUM

Nutrition Cephalopods feed voraciously upon crustaceans larval and adult fish and cannabalistically upon their own kind Food is obtained by darting out the tentacles or arms and seizing the prey with suckers or in some squids with the clawlike hooks Large portions are bitten out by the beaks and pushed down the esophagus by the ram

ming action of the radula which also functions as a rasping organ

Ecology Cephalopods are numerous in the sea particularly in the bathypelagic regions where they occur in vast shoals They form the most important part of the diet of the sperm whales and are the sole food of many of the smaller toothed whales as well as a major item of food for the larger pelagic fishes They are eaten by man and fished for in many parts of the world A large fishery exists along the coast of Portugal for squids and octopuses are regularly caught in the Mediterranean Japan the foremost producer of seafood in the world is the largest consumer with cephalopods constituting over 65% of its total fisheries They may represent one of the largest nearly untouched food resources in the sea *See* AMMONOIDEA DECAPODA (MOLLUSCA) DIBRANCHIA NAUTILOIDEA OCTOPODA TETRABRANCHIA [G L V]

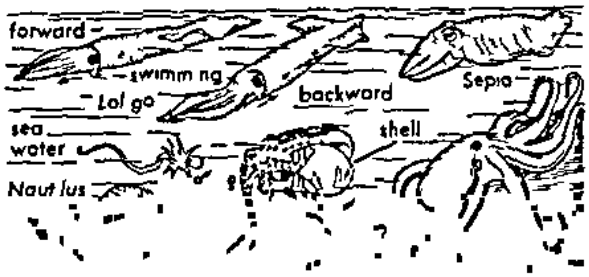
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Cephalopoda fossils

The externally shelled or tetrabranchiate (4-gilled) representatives of the class Cephalopoda including some of the most important and common fossils of the Paleozoic and Mesozoic eras The Nautiloidea a subclass which is named for the vestigial *Nautilus* showed greatest abundance and variety during early and middle Paleozoic time Representatives of this group lived in the seas of the world as recently as some 20 000 000 years ago However *Nautilus* is the only survivor and can be regarded as a restricted living fossil or relic of a biologic unit already extinct The shell of this modern form is similar to some of those in primitive species which lived hundreds of millions of years ago A second subclass the Ammonoidea represents a more vigorous branch This segment included the dominant marine invertebrates of several geologic periods but has been extinct since the end of the Mesozoic *See* LIVING FOSSILS

Nautiloidea When the soft parts of *Nautilus* were first studied over 200 years ago their resemblance to the shells of fossils was based entirely on the anatomy of living *Nautilus* plus similarities of the shell in the fossils Although all members of this class possess hard parts and can therefore be preserved under ordinary circumstances the calcareous external shell is the only common remains of extinct types

These fossils consist of a chambered univalve shell characteristically coiled in a plane The body



Typical fossil cephalopod from the Devonian Period The sutures make a complex pattern where the external shell with growth lines has been removed Actual size

(soft parts) of the animal occupied the outermost part of the coil while gas presumably filled the vacant inner chambers Evidences from the outline of the aperture suggest that fossil forms also possessed a funnel or hyponome through which water was forced to provide propulsion in swimming It is also apparent that at least simple eyes and a group of tentacles existed comparable to living forms The hard parrotlike beaks like those in modern forms can be recognized as fossils

The shell of nautiloids served as a protective external covering as well as a hydrostatic apparatus buoyed by gas in the chambered portion The shell may be thought of as a bilaterally symmetrical hollow cone in fossils straight and curved forms are as common as the coiled species The chambers are also invariably penetrated by a tubular fleshy extension the siphuncle which continues to the tip Such an association of shell characteristics distinguishes the class from all other mollusks

Cephalopod eggs (definitely established as such) have not been found as fossils However in many cases small immature shells may be secured to provide a series of life stages in an individual species Also the inner part or tip end of the shell represents early growth As in modern forms a fairly uniform size was attained by the mature animal within species The usual gross form is about average for mollusks but the largest fossil cephalopods known had a mass nearly as great as the giant squid of the present day seas the entire creature must have weighed several hundred pounds during life

The first known cephalopods of the Cambrian Period possessed relatively small shells and showed a resemblance to the undifferentiated molluscan prototype However within a relatively short time a surprising variety had evolved and most of the nautiloid groups were represented in the Lower Ordovician Tightly coiled nautilicones horn shaped curved cyrtocones egg shaped brevicones and rod shaped elongate orthocones existed as hundreds of species even during this early stage of development The orthocones became most diverse and abundant at this time but diminished in later periods to become extinct in the early Mesozoic Important features used in classification of the orthocones are internal shell structures such as

position and nature of the siphuncle as well as lamellar deposits within the chambers

Ammonoidea This subclass may be defined to some extent by comparison with the ancestral Nautiloidea Even the first of the more highly developed ammonoids which appeared in Early Devonian time show basic similarities to other members of the subclass. One specialization was the relatively small peripheral siphuncle Another primary distinction is the presence in ammonoids of a small bulbous protoconch or initial chamber at the tip end of the shell Such a structure probably served as the larval buoyant gas chamber and suggests that this subclass may have been a more active group of organisms than the nautiloids possibly strong swimmers in the open sea The shells are even more light and delicate than those of the other tetrabranchiates

In primitive ammonoids the edges of the partitions in the chambered part of the shell are simple but these margins became progressively more complex and frilled in advanced ammonoids The trace of this edge known as the suture is exceedingly intricate in some Mesozoic forms Such a meshlike structure served to provide great strength with a minimum of shell material

Suture patterns represent a major basis for classification In addition to a tracing of phylogenetic trends in strata of successive geologic ages the embryonic development of the sutures preserved on inner coils approximates evolutionary progression Other types of variation appeared also and the regular simple spiral evolved repeatedly into a series of highly sculptured shells In a belated attempt at adaptation secondarily uncoiled or irregularly coiled variants appeared in the Cretaceous Period as the entire group approached extinction The largest known ammonoids some 6 or 7 ft in diameter also existed at this time [A K M W M F]

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Ceractinomorpha

A subclass of the Demospongiae This group of sponges includes the orders Dendroceratida Dictyoceratida Haplosclerida Poecilosclerida and Halichondrida Ceractinomorphs constitute a more homogeneous group in contrast to the subclass Tetractinomorpha Spongin is common to the ceractinomorphs Members of this group have an incubated stereogastrula larva *See* DEMOSPONGIAE TETRACTINOMORPHA [C B C]

Ceramic technology

The techniques of making useful products from nonmetallic inorganic earthy materials either the manufacture or the use of the products or both involves high temperatures Ceramic products cover a great range in time from some of the first man made products (pottery bricks from 3000 B C) up through some electrical and magnetic products unknown until a few years ago *See* ABRASIVE, CEMENT CERMET CLAY PRODUCTS ARCHITECTURAL GLASS AND GLASS PRODUCTS LIME (INDUSTRIAL) METAL COATINGS MORTAR PLASTER PORCELAIN PORTLAND CEMENT POTTERY REFRACTORY

The term earthy in the definition implies that ceramic materials are obtained from the earth In some cases such as in the manufacture of brick this is literally true because the raw materials are dug up and processed directly For the higher grades of clayware such as pottery the raw materials are naturally occurring but are usually cleaned and blended before use Thus a potter may use ball clay from Kentucky kaolin from Florida potter's flint (ground silica SiO_2) from Ohio and feldspar from Maine In more recent times greater use has been made of materials which although derived from natural minerals are actually synthesized (such as barium titanate $BaTiO_3$ in electroceramics) or refined (such as aluminum oxide Al_2O_3 in refractories and abrasives) *See* CLAY COMMERCIAL CLAY MINERALS

In Europe the term ceramics is applied only to clay products thus excluding glass cements and abrasives However this classification is breaking down because the new electroceramics which generally contain no clay are regarded as ceramics

Raw materials A list of the most common elements in the earth's crust includes the elements found in ceramic materials and products Because oxygen is the only abundant electronegative element the rest of the elements tend to combine with it Most ceramic materials are oxides either simple such as silica or complex, such as kaolinite the clay mineral

$$Al_2O_3\ 2SiO_2\ 2H_2O \quad \text{or} \quad Al_2Si_2O_5(OH)_4$$

The first way of writing the chemical formula is more common in ceramic technology but it should be understood that it does not imply there is water of hydration in the clay generally the hydrogen forms hydroxyl ions in the crystal structure Although oxide materials are most common the synthetic carbides (tungsten carbide WC) and nitrides (boron nitride BN) are coming into greater use and silicon carbide is already widely used *See* CARBIDE

Because silicon is the most common metallic element silica (SiO_2) is very common in the earth's crust either alone or in combination with other oxides For this reason a great many ceramic materials are silicates Until recently ceramic technology could be thought of as high temperature silicate chemistry however in view of the very large number of ceramic products which have no silica in them the definition is outmoded *See* SILICATE PHASE EQUILIBRIA

In considering the manufacturing operations peculiar to the ceramic industry it is convenient to discuss them first from the point of view of clay working because they were developed for this

terial and then to indicate how these methods have been adapted to materials containing no clay the so called nonplastic materials Furthermore, it is convenient to divide ceramic products into two groups those such as pottery and brick which are shaped or formed before the high temperature treatment (firing) and those such as glass and cement which are shaped afterward Only the first group will be discussed in this article

The methods of mining crushing milling and mixing ceramic materials are similar to those op erations in other industries and are covered in sepa rate articles

The three common ingredients in a ceramic mix (body) are clay potter s flint and feldspar Each plays a specific role The clay when sufficiently wet imparts plasticity or workability to the body The ceramist uses the term plastic in its rheological sense to indicate a material which can be formed into a desired shape without crumbling and which will hold this shape without deforming under its own weight this should be distinguished from the idea of plastic as a synthetic organic material Ball clays impart more plasticity and kaolin or china clays have a whiter color hence both are usually used Potter s flint very finely ground silica is added to decrease the shrinkage which occurs when wet clay dries it also decreases the firing shrink age Feldspar (albite $NaAlSi_3O_8$ orthoclase $KAlSi_3O_8$ anorthite $CaAl_2Si_2O_8$ or a mixture of these) is added so that the body can be fired at a reasonable temperature Such a material with a relatively low melting point added to lower the firing temperature of the body is known as a flux

In a naturally occurring body such as a brick or stoneware clay the filler and flux are found de posited with the clay mineral itself A naturally oc curring material which becomes plastic when mixed with water is called a clay whereas the specific mineral which imparts this property is known as a clay mineral For example kaolin is a type of clay, the main constituent of which is the mineral kao linite

Forming operations Plastic forming of clays is the oldest method and hand molding is the simplest example except for artware hand forming is not important today

Throwing is the first step toward mechanization of the forming operation In it the potter shapes the ware with his hands while the material turns on a wheel or rotating platform again the method is only of m[illegible]

piece (perhaps a plate) by throwing the plastic mass on a plaster of paris mold placing the mold and clay on a rotating wheel much like a potter's wheel and forming the other surface by forcing a template or jigger knife of the desired contour against the clay (Fig 1) The jiggering method has been mechanized and is used in mass produc tion of dinnerware *See* PLASTER OF PARIS

The above methods are sometimes lumped to- gether under the term soft mud forming processes

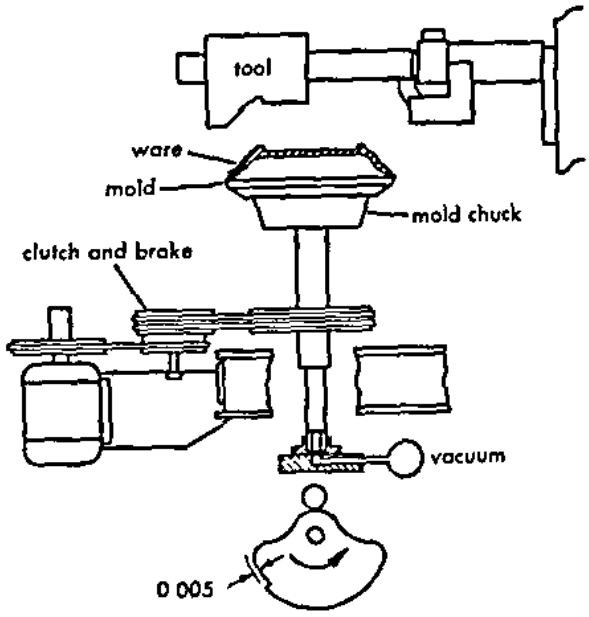


Fig 1 Jiggering tool and cam raised j gger ng ap paratus (*From W D Kingery, ed Ceramic Fabrica tion Processes Technology Press MIT, and Wiley 1958*)

In all of them the average clay body will be mixed with 15–25% by weight of water to make it plastic None of these methods has been adapted to the forming of nonplastics

Pressure methods Extrusion is carried out by forcing the plastic mass through an opening or die in the form of the desired cross section, the con tinuous ribbon which emerges is cut to the desired length For example in making brick the ex truded column is cut to length by a device with rotating wires known as a wire cutter By placing inserts in the die, hollow or cored ware can be made but in any case ware of uniform cross sec tion is produced Very often a single piece of ap paratus is used for mixing the clay with water (pugging) passing it through a vacuum chamber to improve its properties (deairing), and extruding it through the die Because the amount of water used is less than in the soft mud process (about 10–15% by weight), the extrusion method is often called the stiff mud process

Nonplastics are extruded by mixing them with organic materials (plasticizers) which form a mold able mass and then burn or vaporize in the firing operation

Pressing is the forming of a piece by compress ing it in a die or mold the top and bottom faces of which are movable plungers to which force is ap plied The force may be applied mechanically by a screw or lever action or hydraulically the latter permits better control and is used for precision ce ramics A simple type of mold would be a block of metal with a vertical cylindrical hole into which close fitting cylindrical rods are placed, such a mold could be used to produce a simple cylinder or a flat disk (Fig 2)

The pressing of a clay body depends on the fact that a clay with less than enough water to make it



Fig 2 Some complex ceramic shapes which can be formed by dry pressing (American Lava Division of Minnesota Mining and Manufacturing Co)

plastic at atmospheric pressure (usually 5–10% by weight of water) will become plastic at higher pressures One advantage of pressing clayware is that the small amount of water used results in practically no drying shrinkage making dimensional control easier The operation is variously referred to as dry damp dust or power pressing each term seems to be peculiar to one branch of the industry

Plastic pressing of wet clay in plaster molds is a fundamentally different process which is used for some types of ware

Pressing has been widely adapted to nonplastics it is perhaps the most important forming method for these materials Again organic lubricants and binders are added to assist in forming and holding the material together until it is fired

Hydrostatic pressing (sometimes referred to as isostatic pressing) is a special method in which the ware is shaped and subjected to the pressure of a liquid such as glycerin and water in a closed chamber (Fig 3) Developed for nonplastics it is used for special products but not as yet on a mass production basis

Hot pressing is similar to dry pressing except that the die and hence the material in it is heated to a fairly high temperature during the pressing In effect the forming and firing operations are combined It is used for making ceramic cutting tools and other special products Generally the die is made of graphite so that the pressure applied is not as great as can be attained with steel dies in ordinary pressing The high temperature may be obtained by induction or resistance heating of the die or simply by placing the assembly in a furnace

The porous plaster mold withdraws water from the slip by capillary action and builds up a layer of solid clay next to the mold In drain casting used to make hollowware (teapots and washbasins) the excess slip is poured out after a wall of the desired thickness has built up In solid casting the slip is allowed to remain until the entire casting is solid

The casting slip is made by adding a small amount (less than 1%) of a material known as a deflocculant (Na_2CO_3 and Na_2SiO_3 for example) to a clay water mixture (about 25% water) which turns the sticky paste into a pourable slip The process is known as deflocculation because it consists of changing the electrical charges on the clay particles in such a way that they repel and slide past one another instead of adhering as in the sticky paste

Nonplastics of many types are slip cast and this is an important method of forming these materials Deflocculation in this case is usually brought about by adjusting the pH (acidity or alkalinity) of the slip For example finely ground Al_2O_3 can be made into a slip of high specific gravity if the pH is about 3 or 4 (that is slightly acid) Any liquid powder mixture can be made pourable if enough liquid is used The problem is to get a slip with as high a solid content as possible An undeflocculated liquid solid mixture of low solid content is often called a slurry

Fusion casting is an entirely different forming method in which the ceramic material is melted and cast in a mold to solidify just as in metal cast

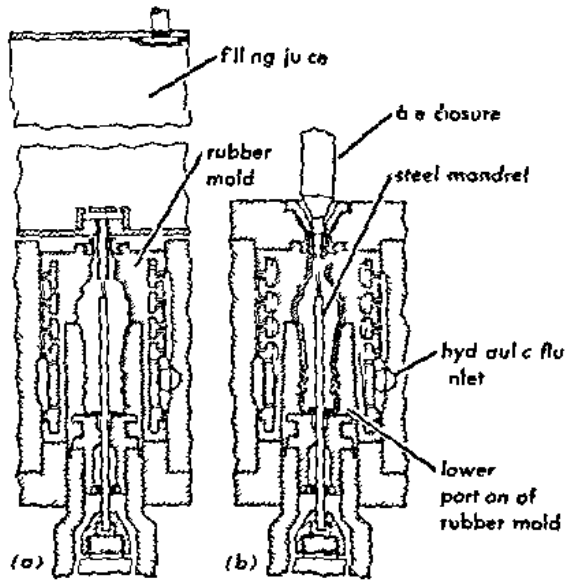


Fig 3 Hydrostatic rubber mold for spark-plug blank (a) being filled with powder and (b) compressed (Champion Spark Plug Co)

ing It is used to make refractory blocks for the construction of glass tanks

Drying and fixing After the forming operation ware is sent to an oven or dryer to remove the water used in forming Care must be used to prevent cracking of the ware by too rapid drying *See* DRYING

After drying the ware goes to the firing operation (*see* KILN PYROMETRIC CONE) The most obvious physical changes in ware after firing are in its size which is generally smaller (firing shrinkage) and in its color which may range from a pure white for high grade ware through cream buff and brown to a red or even nearly black in the case of some brick In clayware and in some nonplastics there is a weight loss The net result of the size and weight changes is usually an increase in density strength and resistance to attack by water *See* SINTERING

The chemical changes taking place during firing of clayware containing fluxes are the loss of water from the clay minerals subsequent conversion to mullite ($3Al_2O_3\ 2SiO_2$) and silica melting of the flux and solution in the flux of some of the other materials Some of the material which is liquid at the firing temperature recrystallizes on cooling but most of it does not and so becomes a glass Thus the fired clayware consists of a silicate glass bonding mullite and silica crystals together with some voids or pores (air spaces) and minor constituents depending on the impurities present

The chemical changes taking place on firing pure oxide or cermet bodies depend on the particular composition and must be studied as individual cases

Electroceramics Ceramics have been connected with electricity since its earliest days a glass rod was first used to generate static electricity and glass was an important part of the famous Leyden jar With the advent of electric power about 1900 porcelain was one of the materials used for insulators even today it is used for high voltage insulators and low voltage switches Glass also is used as an insulator in both power transmission and communications

With the development of radio and its much higher frequencies of alternating current compared to the 60 cycles of power lines it became evident that the power lost in porcelain at radio frequen

ve been using magnesium containing materials as fluxes Typical of these bodies is steatite essentially a mixture of magnesium aluminum and silicon oxides formed from the proper mixture of clay and talc ($3MgO\ 4SiO_2\ H_2O$) Steatite bodies are now widely used in radio equipment as insulators

Another closely related magnesium body is cordierite because of its very low thermal expansion and consequent good thermal shock resistance it was used to make forms for the open type of electric stove element However because it is almost impossible to fire to zero absorption its use has greatly declined

The first ceramic material used as a dielectric (that is as a material to make a condenser) was titania (TiO_2) Because of its high dielectric constant (about 100) and the decrease of the dielectric constant with temperature (a negative temperature coefficient) titania is widely used today for making capacitors *See* CAPACITOR

Out of work on titania grew a host of ultra high dielectric constant ceramics Typical is barium titanate ($BaTiO_3$) which has a dielectric constant of about 2000 This material also has the unusual property that in its ceramic form it can be made piezoelectric by application of a strong dc voltage All previously known piezoelectric materials (that is materials which convert a mechanical deformation into an electric voltage and vice versa) were single crystals and hence very expensive Barium titanate finds wide use in phonograph pickups hydrophones and accelerometers Lead titanate–zirconate $Pb(Ti\ Zr)O_3$ is a newer ceramic piezoelectric which can be used at higher temperatures than barium titanate it exhibits less temperature variation of properties *See* PIEZOELECTRICITY

Parallel to the growth of electrical ceramics there began about 1930 the development of magnetic ceramic materials These are most useful at high frequencies because their high electrical resistivity compared with that of metallic magnet materials results in much lower eddy current losses Magnetic ceramics can be divided into two groups soft and hard the terms referring to their magnetic properties not to their mechanical behavior *See* MAGNETIC MATERIALS MAGNETISM

Soft magnetic ceramics (ferrites) have the type formula $MO\ Fe_2O_3$ where M may be such divalent ions as Cu Ni Co Fe Zn Mg or Mn alone or in combination These substances all crystallize in the spinel structure with the metal ions occupying various positions in the structure *See* SPINEL

Hard magnetic ceramics are typified by barium ferrite ($BaO\ 6Fe_2O_3$) which is similar to the naturally occurring magnetoplumbite ($PbO\ 6Fe_2O$) A great variety of bodies with slightly different composition crystal structure and properties have been developed from this basic composition *See* DIELECTRICS FERRITE INSULATION ELECTRIC

[M C M]

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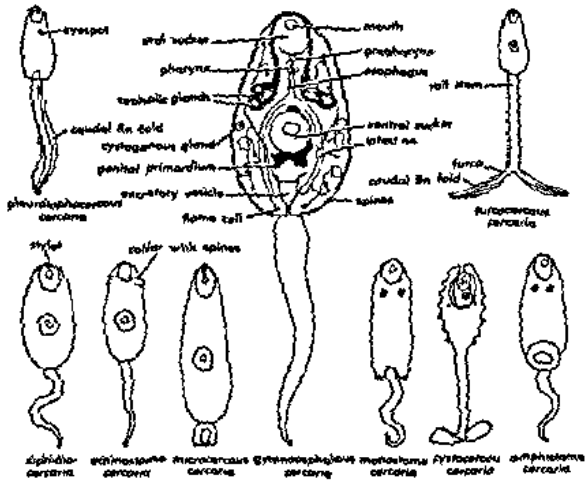
Cerargyrite

A mineral with composition AgCl It crystallizes in the isometric system but crystals usually cubic are rare Most commonly it is in crusts and coatings resembling wax The hardness is 2½ on Mohs scale and specific gravity 5 5 Cerargyrite is colorless to pearl gray but darkens to violet brown on exposure to light It is perfectly sectile and can be cut with a knife like horn hence the name horn

silver Bromyrite AgBr is physically indistinguishable from cerargyrite and the two minerals form a complete series Both minerals are secondary ores of silver and occur in the oxidized zone of silver deposits *See* SILVER [C S HU]

Cercaria

The larval generation which terminates the development of a digenetic trematode in the intermediate host a mollusk or rarely an annelid It becomes the adult fluke after entering the definitive host a vertebrate Access to the vertebrate may be either direct or indirect by entering a second intermediate or vector host which is ingested by the vertebrate (see DIGENEA) The intermediate host is usually aquatic and the cercaria has a tail used in swimming when it escapes from that host but the tail may be inactive reduced or absent and the larva unable to swim When the tail is absent the organism is called a cercariaeum Larvae with unknown life cycles are commonly described and named as species such as *Cercaria microura* or *Cercariaeum helicis*



Various types of cercariae (From R M Cable An Illustrated Laboratory Manual of Parasitology Burgess 1958)

Cercariae vary from less than 0 15 to over 20 0 mm in length Usually they can be obtained by crushing and examining freshly collected snails or by placing them in water to permit the larvae to escape A hand lens or microscope is needed to detect small species

Cercariae are classified into several types based on the structure of the body and tail and also on the pattern of the excretory system The body may have or lack such larval characters as eyespots (ocelli) a stylet in the oral sucker and glands used for penetration and encystment The tail may be forked or not and bear fins setae or other appendages sometimes it is enlarged and may enclose the body The tail is always lost when the larva reaches the next host in the life cycle

The cercaria is important in taxonomy because that stage of closely related trematodes usually is less variable than that of the adult and thus indicates kinships that may be masked in the adult by adaptations to parasitism of the vertebrate host [R M C]

Cereal

Any member of the grass family which produces edible starchy grains usable as food by man and his livestock Common cereals are rice wheat barley oats maize (corn) sorghum and certain millets These are summer or winter annuals Today as in ancient times the cereals provide more food than any other crops Modern breakfast foods made from certain of the grains are also called cereals *See* GRAIN CROPS GRASS CROPS [P P S]

Cereal chemistry

The branch of chemistry concerned with the analysis and characterization of cereals and their constituents In practice most cereal chemistry is related to the milling and baking of wheat Cereals may be divided broadly into food grains such as wheat and rice and feed grains such as corn (maize) grain sorghum oats barley rye and millet although all cereals can serve either as human food or as animal feeds Until late in the nineteenth century the processing of cereals was essentially the same as that used in Biblical times namely grinding between stones With the introduction of modern roller mills the physical and chemical properties of the cereal grains became important and fractions of the cereal grains became available for special uses Chemists were called on to determine the composition of these fractions to establish specifications for those most useful and to devise processes leading to better food feed or industrial use *See* BARLEY CORN MILLET OATS RICE RYE SORGHUM WHEAT

Since starch is the largest component of all cereals much attention has been given to the chemistry of starch in the major crops wheat and corn (*see* STARCH) Protein the next largest component of cereals is especially important in wheat because wheat gluten is unique in producing bread of good texture (*see* PROTEIN) Oil is present in relatively small amounts in cereals and only corn oil is produced in important amounts (*see* FAT AND OIL, EDIBLE) Wheat germ oil is sold for pharmaceutical purposes in relatively small amounts

Milling Dry milling is applied to most cereals for refining or for separating into fractions or constituents such as starch gluten germ and bran Only with corn has an extensive wet milling industry developed Although the effect of moisture content (tempering) is very important in dry milling attempts have been made only recently to apply knowledge of the chemistry of cereals to dry milling processes In 1957 commercial use of a new milling process for wheat was announced By the use of high velocity air streams size reduction

turbo milling employs a combination of impact and particle fluid energy Flours of unusually high protein and low ash content can be made In wet milling corn is steeped in dilute sulfurous acid solution to loosen the hull and soften the gluten Subsequent operations result in a more complete fractionation into starch gluten fiber and oil than is possible with dry milling For example 1½ lb of oil may be recovered in the wet milling of corn whereas only ¼ lb of oil would result from dry milling of the same sample *See* FOOD MANUFACTURING

Chemistry Much of the present knowledge of the chemistry of wheat has come from the four wheat quality laboratories of the U S Department of Agriculture located at Beltsville Md Wooster O Manhattan Kans Pullman Wash and the Grain Research Laboratory Winnipeg Canada

Each laboratory works on the wheats of its area in developing and applying tests to assist wheat breeders and producers Utilization of cereals for food and industrial purposes is studied at the Northern and Western Regional Laboratories of the U S Department of Agriculture in Peoria Ill and Albany Calif respectively The American Association of Cereal Chemists founded in 1914 publishes two journals *Cereal Science Today* and *Cereal Chemistry* a book of analytical methods and a monograph series

Although the largest uses of cereals are for food and feeds industrial uses of cereals particularly corn products are important In many industrial uses cereals have been almost completely displaced by petrochemicals Organic solvents (ethanol butanol acetone) were formerly largely derived by fermentation of grains Beverage alcohol must still be made from agricultural products but for industrial use vast quantities of solvents are synthesized from oil gas or coal sources *See* INDUSTRIAL MICROBIOLOGY

Starch as such or slightly modified by oxidation has found chief industrial use in the sizing of paper and the sizing and finishing of textiles Degradation of starch with heat acid or both produces dextrins whose chief uses are as adhesives either alone or in combination with other materials (*see* AMYLASE) Because starch contains very large molecules varying widely in molecular size and configuration it is evident that widely varying properties are found in starches produced under different conditions and from different sources Although cornstarch is the cheapest and most abundant wheat starch is said to have esse
starch and
specialty s
specificati
ranging from ingredients of oil well drilling muds to dusts for surgical gloves

The starch granule of ordinary corn contains two types of molec
mer
mole

(73%) Waxy corn has practically 100% amylopectin and is grown and processed for food starch uses Geneticists, with the help of cereal chemists have succeeded in breeding corn which contains as much as 70% amylose If starches containing 80-85% amylose can be produced they can be used to make superior self supporting films for packaging and paper coatings which will have wide application *See* CARBOHYDRATE [R T M]

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Cerebral palsy

In the broadest sense any nonprogressive motor disorder caused by brain damage incurred during development Although in common use by both laymen and physicians the term cerebral palsy is nonspecific and includes many kinds of brain damage from various causes In fact few authorities agree on the disorders to be included

Nonprogressive motor disorders such as spasticity paralysis convulsions muscular spasms abnormal reflexes and delayed or abnormal development of speech movement and behavior patterns are characteristic Intelligence is not noticeably altered in over two-thirds of the cases According to published figures cerebral palsy occurs about once in 14 000 births Of those afflicted 14% die in infancy 14% are so damaged that therapy is ineffective and 14% incur only a mild or transient injury and require no treatment Of the remainder half are mentally retarded and half will benefit from appropriate treatment Of those that survive infancy about half are spastics with exaggerated muscle tone and movement One quarter show athetosis or slow involuntary purposeless movements Ten per cent are of the mixed type and 4% display ataxia the failure or irregularity of muscle coordination The final 12% are hemiplegics with variable degrees of paralysis of an arm and leg on the same side

Possible prenatal causes include certain hereditary and congenital defects as well as some maternal diseases such as German measles in early pregnancy Toxemias of pregnancy abnormal or difficult labor and insufficient oxygen before during, or after birth are precipitating causes of brain damage *See* GERMAN MEASLES, PREGNANCY DISORDERS OF

Birth injuries are a major cause of cerebral palsy but this does not necessarily mean obstetrical mismanagement The infant head is subjected to tremendous stresses during labor especially in a first pregnancy a precipitate delivery or when abnormalities of mother or child are already present This stress may cause anoxia edema hemorrhage rupture of brain tissue or other mechanical effects which in turn cause degeneration or death of nervous tissue No regeneration of such tissue takes place and even if nervous tissue damage is slight there is still the chance that a scar may form and cause later difficulty

Skillful obstetrical techniques including major and minor operative procedures and the judicious use of delivery forceps and other special methods have greatly reduced the incidence and severity of damage in many forms of cerebral palsy Other unknown causes and contributing factors are under intensive investigation [F C ST]

Cerenkov radiation

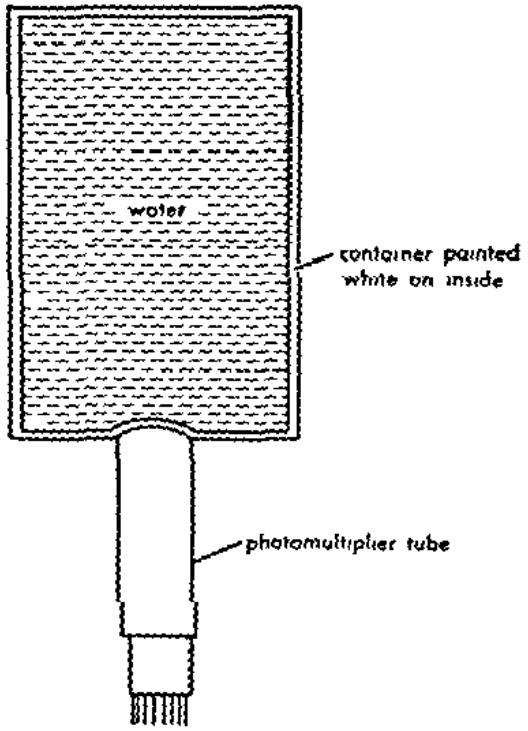
Light emitted by a high speed charged particle when the particle passes through a transparent nonconducting solid material at a speed greater than the speed of light in the material The blue glow observed in the water of a nuclear reactor close to the active fuel elements is radiation of this kind The emission of Cerenkov radiation is analogous to the emission of a shock wave by a projectile moving faster than sound since in both cases the velocity of the object passing through the medium exceeds the velocity of the resulting wave disturbance in the medium This radiation first predicted by P A Cerenkov in 1934 and later substantiated theoretically by I Frank and I Tamm is used both as a signal for the indication of high speed particles and as a means for measuring the energy of these particles in devices known as Cerenkov counters

Direction of emission Cerenkov radiation is emitted at a fixed angle θ to the direction of motion of the particle such that $\cos\theta = c/nv$, where v is the speed of the particle c is the speed of light in vacuum and n is the index of refraction of the medium The light forms a cone of angle θ around the direction of motion If this angle can be measured and n is known for the medium, the speed of the particle can be determined The light consists of all frequencies for which n is large enough to give a real value of $\cos\theta$ in the preceding equation

Cerenkov counters. Particle detectors which utilize Cerenkov radiation are called Cerenkov counters (*see* PARTICLE DETECTOR) They are important in the detection of particles with speeds approaching that of light such as those produced in large particle accelerators and in cosmic rays and are used with photomultiplier tubes to amplify the Cerenkov radiation These counters emit pulses of length less than 10^{-9} sec and are therefore useful in time-of flight measurements when very short times must be measured They can also give direct information on the velocity of the passing particle

Dielectrics such as glass water or clear plastic may be used in Cerenkov counters Choice of the material depends on the velocity of the particles to be measured since the values of n are different for the materials cited By using two Cerenkov counters in coincidence one after the other with proper choice of dielectric the combination will be sensitive to a given velocity range of particles

The counters may be classified as nonfocusing or focusing In the former type the dielectric is surrounded by a light reflecting substance except at the point where the photomultiplier is attached,



Nonfocusing Cerenkov counter using water as the dielectric

and no use is made of the directional properties of the light emitted (*see* illustration) In a focusing counter lenses and mirrors may be used to select light emitted at a given angle and thus give information on the velocity of the particle

Cerenkov counters may be used as proportional counters since the number of photons emitted in the light beam can be calculated as a function of the properties of the material the frequency interval of the light measured and the angle θ Thus the number of photons which make up a certain size pulse gives information on the velocity of the particle

Gas may also be used as the dielectric in Cerenkov counters In such counters the intensity of light emitted is much smaller than in solid or liquid dielectric counters but the velocity required to produce a count is much higher because of the low index of refraction of gas [W B F]

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Ceres

The first discovered asteroid found by G Piazzi at Palermo Sicily on January 1 1801 Its orbit was first computed by C F Gauss and found to fill the gap between the orbits of Mars and Jupiter as predicted by J E Bode

The semimajor axis of its orbit or mean distance to the Sun is $a = 258 \times 10^6$ mi, the eccentricity $e = 0.079$ the inclination of its orbit to the plane of the ecliptic is $i = 10.6°$ and the sidereal period of revolution $P = 1681$ days

Ceres is the largest of the minor planets (though not the brightest) with a diameter of about 4

miles and an estimated mass of 8×10^{23} grams or about 1/10 000 of Earth's mass Its apparent stellar magnitude at mean opposition is +7, at which time it is visible through small telescopes *See* ASTEROID, PLANET [G D V]

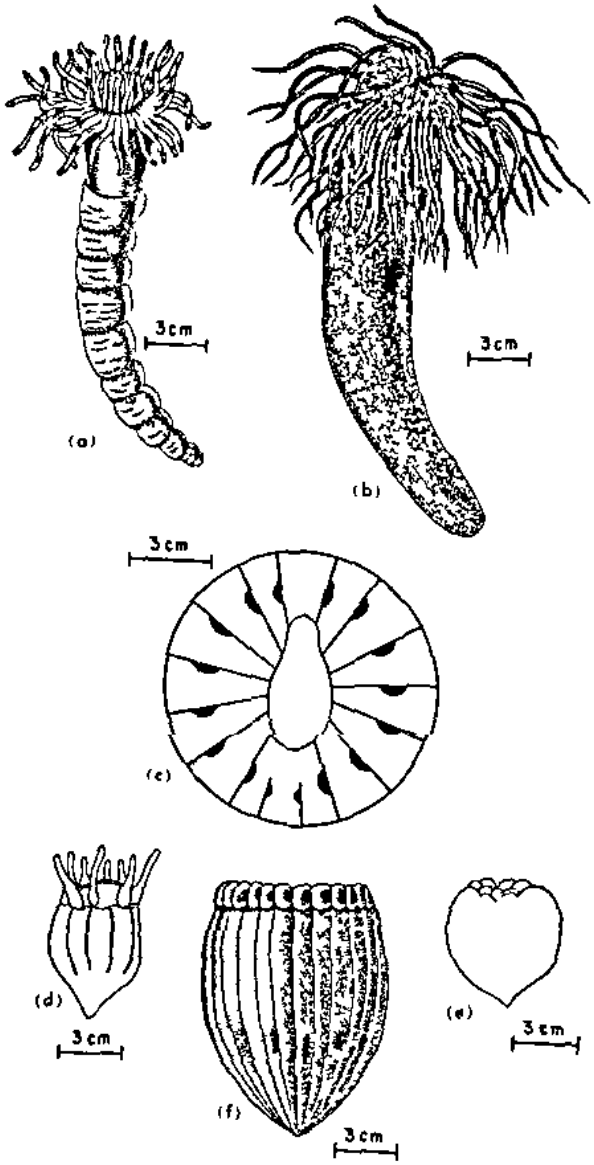
Cerianthería

An order of the Zoantharia (illustration *a, b*), typified by *Cerianthus* which lives in sandy marine substrata The animal is enclosed in a sheath formed by mucus secreted from gland cells of the column ectoderm in which discharged nematocysts sand grains and other foreign objects are embedded

The polyp is a muscular, skeletonless, elongated cylindrical body with a smooth wall Long slender unbranching freely retractile tentacles are arranged in two cycles and consist of smaller labial and larger marginal ones A siphonoglyph termed the hyposulculus is present and a pedal disk is lacking

The mesenteric arrangement is most characteristic (illustration *c*) Mesenteries are arranged bilaterally in couples not in pairs, forming a single cycle All are complete The three most dorsal couples or directives appear first, then the other two appear at both sides of the directives Additional metacnemic couples are added to the ventral intermesenteric space and are arranged in quartets with regard to length The longitudinal muscles are weakly developed in the ventral faces of the mesenteries whose free edges bear filaments and acontialike threads or acontioids, which seem to have an adhesive function

Pelagic larvae (illustration *d f*) known as *Arachnactis, Cerianthula, Otactis, Anactinia,* and others always pass through the cerinula stage with three couples of the protocnemes Life cycles have not been fully investigated *See* ZOANTHARIA [K A]



Cerianthería (a) *Cerianthus solitarius (after Y Delage)* (b) *Pachycerianthus multiplicatus (after O Carlgren)* (c) Mesenteric arrangement *(after F Pax)* (d) *Cerianthula spinifer* larva *(after E Van Beneden)* (e) *Otactis aequatorialis* larva *(after E Van Beneden)* (f) *Anactinia pelagica* larva *(after O Carlgren)*

Cerium

Element number 58 cerium, Ce is the most abundant of the metallic elements of the rare earth group Its atomic weight is 140 13 and the naturally occurring element is made up of the stable isotopes Ce^{136} 0 193%, Ce^{138} 0 250%, Ce^{140} 88 48%, Ce^{142} 11 07% It was discovered in 1803 by M H Klaproth and independently by J J Berzelius and W Hisinger Cerium occurs mixed with other rare earths in many minerals particularly monazite and bastnasite, and it is found among the products of the fission of uranium thorium or plutonium



Although the common valence of cerium is 3 it also forms a series of quadrivalent compounds and is the only rare earth which occurs as a quadrivalent ion in aqueous solution Although it can be separated from the other rare earths in high purity by ion exchange methods it is usually separated chemically by taking advantage of its quadrivalent state Ceric oxide, CeO_2, is the oxide usually obtained when cerium salts of volatile acids are heated CeO_2 is an almost white powder which is insoluble in most acids, although it can be dissolved

n sulfuric acid or other acids when a reducing gent is present The trivalent salts are white and he quadrivalent salts are usually yellow in color The metal is an iron gray color and it oxidizes read ly in air forming a gray crust of oxide In the pure state it is not very pyrophoric but when slightly oxidized or alloyed with iron it becomes extremely pyrophoric Mischmetall an alloy of ce rium is used in the manufacture of lighter flints Cerium has the interesting property that at very low temperatures or when subjected to high pres sures it exhibits a fourth allotropic form face-cen tered cubic which is diamagnetic and 18% denser than the common form For other properties of ce rium metal see RARE EARTH ELEMENTS

Crude mixtures of cerium with other rare earths have found extensive use in industry It is used as a "getter in the metal industry and as an opacifier and polisher in the glass industry and it is one of the main ingredients in Welsbach gas mantles and cored carbon arcs Cerium metal in common with the other rare earths is almost immiscible in molten uranium and can therefore be used as a liquid liquid extraction agent to remove fission products from spent uranium fuel [F H SP]

Cermet

One of a group of composite materials consisting of an intimate mixture of ceramic and metallic components usually in the form of powders These are compacted and sintered in order to obtain certain physical properties not found solely in either of the components

According to the application cermets may be classified as high corrosion resistant materials high temperature resistant high-strength mate rials high strength high wear resistant materials materials for nuclear engineering purposes and materials for special electrical properties

Friction parts and cutting and drilling tools have been successfully made from cermets for many years Certain nuclear reactor fuel elements such as dispersion type elements are also made as cermets Gas turbine parts and jet engine com ponents in cermet composition however have not yet been developed satisfactorily These materials should be corrosion resistant have high tempera ture strength temperature (thermal) shock re sistance and a certain ductility Although it has been possible to develop cermets to satisfy three of these requirements it is not yet possible to satisfy all four of them Ceramic components may be metallic oxides carbides borides silicides nitrides or mixtures of these compounds the metallic components include a wide variety of metals the selection of which depends on the ap plication of the respective cermet Some of the component materials under investigation are shown in the table

One distinguishes basically between four dif ferent combinations of metal and ceramic com ponents the formation of continuous interlocking phases of the metallic and ceramic components

Representative cermets

Class	Ceramic	Metal addition
Oxides	Al_2O_3	Al, Be Co Co Cr Fe stainless steel
	Cr_2O_3	Cr
	MgO	Al Be Co Fe Mg
	SiO_2	Cr Si
	ZrO_2	Zr
	UO_2	Zr Al, stainless steel
Carbides	SiC	Ag Si Co Cr
	TiC	Mo W Fe Ni Co Inconel Hastelloy stainless steel, Vitallium
	WC	Co
	Cr_3C_2	Ni Si
Borides	CrB_2	Ni
	TiB_2	Fe Ni Co
	ZrB_2	Ni
Silicides	$MoSi_2$	Ni Co Pt, Fe Cr
Nitrides	TiN	Ni

dispersion of the metallic component in the ce ramic matrix dispersion of the ceramic com ponent in the metallic matrix and interaction between the metallic and ceramic components

The various reactions taking place between the metallic and ceramic components during fabrica tion of cermets may be briefly classified and de scribed as follows

1 Heterogeneous mixtures with no chemical re action between the components characterized by a mechanical interlocking between the components and without any formation of a new phase no penetration of the metallic component into the ce ramic component and vice versa and no altera tion of either component (Example MgO Ni)

2 Surface reaction resulting in the formation of a new phase an interfacial layer which is not soluble in the component materials The thickness of this layer depends on the diffusion rate tem perature and time of the reaction (Example Al_2O_3 Be)

3 Complete reaction between the components resulting in the formation of a solid solution characterized by a polyatomic structure between the ceramic and the metallic component (Ex ample TiC-Ni)

4 Penetration along grain boundaries without the formation of interfacial layers (Example Al_2O_3 Mo)

One of the most important factors in the selec tion of metallic and ceramic components in cer mets is their bonding behavior Extensive studies in this respect were made by L S Williams and P Murray who distinguish in bonding between surface interaction and bulk interaction In cer mets of the oxide metal type for example these investigators differentiate among three forms of surface interaction macrowetting solid wetting and wetting assisted by direct lattice fit

Two different forms of bulk interaction between metals and ceramics can be distinguished solid solution and formation of chemical compounds

Usually solid solution bonding involves the addi tion or formation within the cermet, of a small

amount of the appropriate ceramic form of the metal constituent, examples of the type of phase involved are provided by the systems Al_2O_3 Cr_2O_3 and NiO MgO for oxides and TaC TiC and NbC ZrC for carbides The systems form continuous series of solid solutions but there are also many suitable systems in which solid solution occurs over a limited range only

Formation of a compound in a bonding phase can best be shown by the examples of spinels having the generalized formula $RO\ R'_2O_3$ where R could for example stand for Ni^{++} Mg^{++} Fe^{++} or Co^{++} and R for Al^{+} Cr^{+++} or Fe^{+++} A great deal of work has been done on the system Al_2O_3 Fe with out achieving the combination of properties required for the high temperature engineering appli cations in view However some other likely combinations involving a spinel bond have not been so fully investigated and may yet yield a satisfac tory cermet material *See* CERAMIC TECHNOLOGY EQUILIBRIUM PHASE INTERMETALLIC COMPOUNDS POWDER METALLURGY [H H H]

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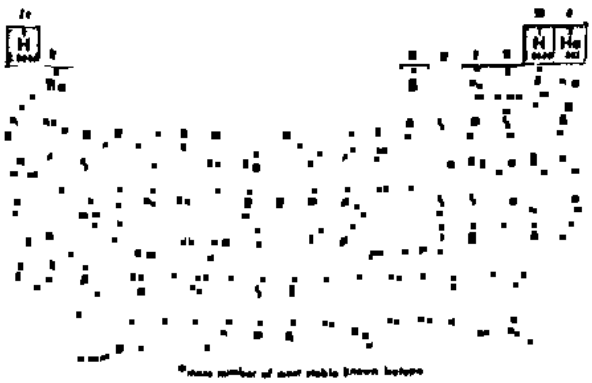
Cerussite

The mineral form of lead carbonate $PbCO_3$ Cerus site is common as a secondary mineral associated with lead ores In the United States it occurs mostly in the central and far western regions Cerussite is white when pure but is sometimes darkened by im purities Hardness is 3¼ on Mohs scale and spe cific gravity is 6 5 Cerussite has orthorhombic sym metry and the same structure as aragonite Crystals may be tabular elongated or arranged in clusters *See* CARBONATE MINERALS [R I H]

Cesium

With an atomic number of 55 and an atomic weight of 132 91 cesium Cs is the heaviest of the alkali metals in group Ia of the periodic table of the elements (except for francium the radioactive member of the alkali metal family) Cesium was discovered by R Bunsen in 1860 by spectroanaly sis and was first isolated by electrolysis in 1881 It is a soft light very low melting metal It is the most reactive of the alkali metals and indeed is the most electropositive and the most reactive of all the elements Little was known of its prop erties because of the relative unavailability and high cost of cesium compounds in the chemical *market In 1958* however cesium salts became available much more readily and at lower prices as by products of lithium chemicals manufacture Knowledge of the properties and reactions of cesium metal should develop accordingly What is known of the chemical behavior of this most reactive metal is intriguing and it seems to offer unusual research possibilities

Uses Cesium metal is used in photoelectric cells, spectrographic instruments scintillation counters radio tubes military infrared signaling lamps and various optical and detecting devices Cesium compounds are used in glass and ceramic production as absorbents in carbon dioxide puri fication plants as components of getters in radio tubes and in microchemistry Cesium salts have been used medicinally as antishock agents after administration of arsenic drugs The isotope ce sium 137 is supplanting cobalt 60 in the treatment of cancer



Occurrence Cesium is not very abundant in the earth's crust there being only 7 parts per million (ppm) of cesium present However this concentra tion still places cesium above beryllium arsenic uranium and boron in abundance There is only about 0 002 ppm of cesium in solution in sea water Detectable amounts are found in plant and animal organisms mineral waters and soils

Like lithium and rubidium cesium is found as a constituent of complex minerals and not in rela tively pure halide form as are sodium and potas sium Indeed lithium rubidium and cesium fre quently occur together in lepidolite ores such as those from Rhodesia Cesium is unlike lithium and rubidium however in that a cesium rich mineral pollucite essentially $2Cs_2O\ 2Al_2O_3\ 9SiO_2\ H_2O$ does occur It is found on the island of Elba in South West Africa and in Manitoba In the United States there are deposits in Maine and South Dakota

Metallurgical extraction Cesium metal is not produced on a commercial scale In the limestone process for the conversion of lepidolite ore to lithium chemicals however a mixed alkali car bonate liquor is obtained by carbonation in a submerged combustion evaporator after the separa tion of the bulk of the lithium values as the hy droxide Filtration after carbonation removes lith ium carbonate and gives a filtrate containing the carbonates of potassium rubidium and cesium The separation of the mixed alkali salts is de scribed in the article on rubidium *See* RUBIDIUM

Cesium metal is generally made by thermo chemical processes The carbonate can be reduced by metallic magnesium or the chloride can be reduced by calcium carbide Metallic cesium vola

Physical properties of cesium metal

Property	Temperature °C	Temperature °F	Metric (scientific) units	British (engineering) units
Density	20	68	1 9 g/cm³	118 5 lb/ft³
Melting point	28.5	83		
Boiling point	705	1301		
Heat of fusion	28 5	83	3 8 cal/g	6 9 Btu/lb
Heat of vaporization	705	1301	*136 cal/g*	*263 Btu/lb*
Viscosity	100	212	4 75 millipoises	2 5 kinetic units
Vapor pressure	278	532	1 mm	0 019 lb/in²
	635	1175	100 mm	7 7) lb/in²
Thermal conductivity	28 5	83	0 041 cal/(sec)(cm²)(°C)	106 Btu/(hr)(ft²)(°F)
Heat capacity	28 5	81	0 06 cal/(g)(°C)	0 06 Btu/(lb)(°F)
Electrical resistivity	30	86	36 6 microhm-cm	

tilizes from the reaction mixture and is collected by cooling the vapor

Physical properties The physical properties of cesium metal are summarized in the table

Chemical properties Cesium reacts vigorously with oxygen to form a mixture of oxides in the same manner as do rubidium and potassium In moist air the heat of oxidation may be sufficient to melt and ignite the metal

Cesium does not appear to react with nitrogen to form a nitride but does react with hydrogen at elevated temperatures to form a moderately stable hydride

Cesium reacts violently with water and even with ice at temperatures as low as −116°C Little is known about the reaction of cesium with carbon but acetylides can be formed from cesium and acetylene.

The reaction with halogens is vigorous and cesium is distinguished among the alkali metals for its ability presumably due to its large ionic radius to form stable polyhalides such as CsI_3

Cesium reacts with ammonia to form cesium amide and with carbon monoxide in the cold at low pressures to give a crystalline compound of indeterminate composition

Cesium in general undergoes some of the same type of reactions with organic compounds as do the other alkali metals but it is much more reactive Thus it adds directly to ethylene to form a brown solid $C_2H_4Cs_2$ whereas the other alkali metals will add only to dienes or to olefins activated by aromatic groups For a discussion of handling techniques *see* SODIUM

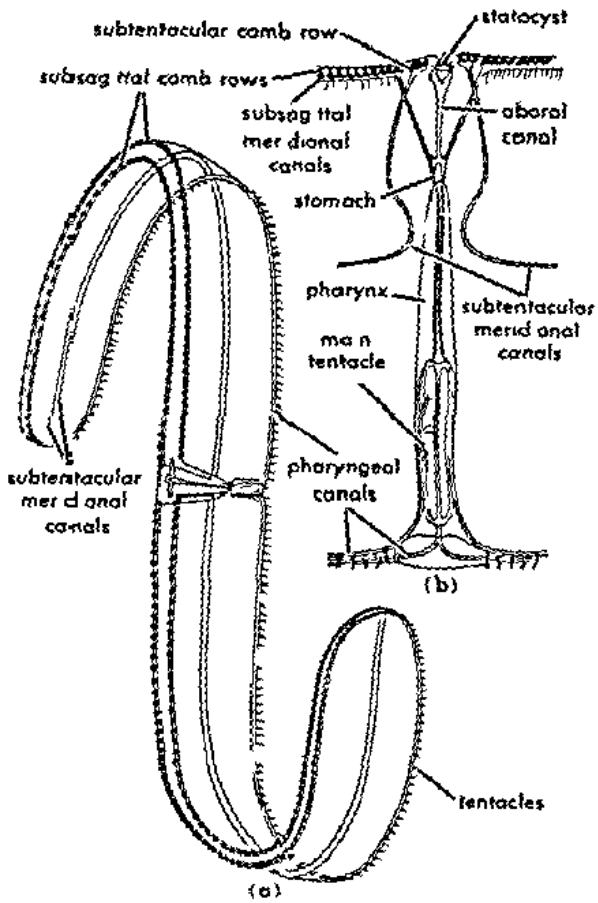
Availability Cesium metal is sold only in very small lots and is generally handled in sealed ampules Total U S production was perhaps 25 pounds per year in 1958 and the price was about *$4 00 per gram ($1800 per pound)* Cesium salts have been reduced in price from several hundred dollars to $15–30 per pound

Principal compounds Cesium chloride is the most important cesium compound The metal is made from the chloride and the chloride is used as a constituent of getter mixtures for vacuum tubes The fluoride carbonate and sulfate are also available and used in small commercial quantities

Analytical methods Cesium can be identified qualitatively by its blue flame The fact that cesium forms an extremely insoluble alum may be used in the quantitative determination of cesium *See* ALKALI METALS [M St]

Cestida

An order of ribbon shaped ctenophores having a very short tentacular axis and an elongated pharyngeal axis The subtentacular ribs consist of a few plates while the subpharyngeal extend over



Cestida (a) *Velamen* sp (b) Central region of *Cestus veneris*

the whole aboral margin of the body The primary tentacles have been replaced by secondary tentacles *Cestum veneris* is a common example *See* CTENOPHORA TENTACULATA [T K]

Cestoda

A subclass of tapeworms including most of the members of the class Cestoidea All species are endoparasites of vertebrates living in the intestine or related ducts

Morphology Like other members of the class the cestodes have no digestive tract or mouth Nutrition presumably occurs by absorption of food through the body surface The body or strobila is usually very elongated and tapelike and frequently divided into segments or proglottids with replication of the hermaphroditic reproductive systems In a few species there is duplication of both male and female organs within a single segment The anterior end is usually modified into a holdfast organ the scolex Since a digestive tract is completely absent the scolex is of solid construction typically highly muscular with sucking depressions and hooks Behind the scolex there is usually a region of undifferentiated tissue termed the neck from which proliferation of new segments occurs In some species a neck is not apparent and segments begin immediately behind the scolex The strobila or chain of segments typically arises by growth and differentiation the smallest and least differentiated segments being nearest to the neck Young segments are always broader than long but as the segments grow in volume they may become square or longer than broad The body is clothed with what has been called a cuticle but it has been shown that this noncellular layer is relatively complex (see illustration) This might be expected since these animals actively absorb such nutrients as carbohydrates and amino acids



The cuticle of *Hymenolepis diminuta* ×21 000 (Electron photomicrograph by A H Rothman)

Nervous system The nervous system consists basically of a pair of longitudinal lateral nerves running through the length of the strobila Additional nerve trunks are frequently present The trunks are connected by a ring shaped commissure in each segment and by thickened commissures a brain in the scolex Although the tapeworms lack special sensory structures such as eyes the body surface is well supplied with sensory nerve endings

Excretory system The excretory or osmoregulatory system consists of protonephridia or flame bulbs which connect ultimately through a system of fine ducts to a pair of longitudinal lateral canals on either side These canals traverse the length of the body

Reproductive system The reproductive systems develop progressively along the strobila the male system usually becoming mature before the female In some forms there are two complete hermaphroditic systems The male and female genital ducts commonly open into a common antrum usually situated on the lateral margin of the segment (*see* CESTOIDEA) The testes are usually small rounded bodies ranging in number from 1 to 1000 but most often about 100 Sperm are carried in a system of ducts to an eversible copulatory organ the cirrus which is frequently armed with spines or hooks The ovary is single commonly having two lobes In the orders other than Cyclophyllidea yolk glands occur as numerous follicles Yolk cells from these glands are gathered in a duct system which enters the oviduct from the ovary The oviduct also receives the vagina and eventually enlarges to form the uterus The uterus begins developing after the gonads and their associated ducts have matured and varies in shape from a simple sac to a ramified network With growth differentiation of the reproductive systems occurs and fertilization occurs in a modified region of the oviduct where the ovum is enclosed with yolk cells in a shell These eggs develop into embryos or oncospheres within the uterus Fertilization may occur within a single proglottid between segments in the same strobila or between proglottids of separate worms Hypodermic impregnation occurs in a few cases The posterior proglottids become distended with embryos In some orders such as the Tetraphyllidae the sexually mature proglottids are shed from the body before significant development of embryos and the free proglottids undergo ripening in the host intestine (*see* TETRAPHYLLIDEA) In most other orders the gravid embryo filled proglottids are shed from the strobila and pass out of the host with or without degeneration of the segment tissue (*see* CYCLOPHYLLIDEA) In the Pseudophyllidea gravid proglottids are retained and the shelled embryos are shed through a uterine pore The growth rates of cestodes show great variation Different

species of the same genus may show marked differences in growth rate and in the time during which a high growth rate without senility is maintained The life of the sexually reproducing tapeworm varies from 4 or 5 days in some pseudophyllideans to 20 or more years in some cyclophyllideans

Larval development The details of larval development are known for only a few tapeworms Cleavage leads to the formation of a 6-hooked embryo the oncosphere which is enclosed in a ciliated embryophore in the Pseudophyllidea Further embryonic development occurs in some other host species Except for Cyclophyllidea two intermediate hosts are usually required for embryonic development. Except for some taeniaoid tapeworms the first intermediate host is always an arthropod while the second is often a fish but may be an invertebrate Invariably the embryo attains entrance to the intermediate host by being eaten and the vertebrate host is infected by eating the intermediate host

The postoncosphere development of all cestodes includes a procercoidlike stage (*see* PSEUDOPHYLLIDEA) In most orders this is followed by the development of a plerocercoid larva in a second intermediate host However considerable modification of this developmental pattern occurs in the Cyclophyllidea in which the postprocercoid development continues in a single intermediate host and the plerocercoid is modified in one of several different ways Other modifications of development in Cyclophyllidea include asexual reproduction of new individuals by budding After differentiation and maturation of the scolex in the larval form growth ceases until such time as the intermediate host is eaten by a vertebrate in which development of the strobila can occur In general the sexual strobilate phase of tapeworms shows considerable specificity with regard to the kind of vertebrate in which development occurs It is rarely known whether this is due in a given case to a failure of contact of worm and host or to a physiological incompatibility In many instances such as the cestodes of birds tapeworms occur in only a single vertebrate host species

Nutrition The nutritional relationships of adult tapeworms have been extensively studied The worms require carbohydrate for growth and reproduction and this requirement is satisfied only from the host ingesta On the other hand nitrogenous nutrients and many micronutrients may be obtained from the body stores of the host deleting such materials from the host's diet has no appreciable effect on the worms In at least one case *Dibothriocephalus* it has been shown that the anemia appearing in some humans harboring the worm is attributable to the absorption of vitamin B_{12} by the cestode The energy metabolism of tapeworms is primarily fermentative In air the rate of oxygen uptake is low and accounts for the oxidation of a small fraction of the carbohydrate metabolized

Phylogeny Most authorities agree that the tapeworms are ancient parasites probably evolving as parasites of the earliest fishes It seems probable that the tapeworms did not evolve from trematodes or other present-day groups of parasitic flatworms Their ancestry may be directly derived from the acoele or rhabdocoele turbellarians and represents a line of evolution which is completely independent of other parasitic flatworms These relationships remain obscure in the absence of any fossil record *See* TURBELLARIA {C P R}

Cestodaria

A subclass of worms belonging to the class Cestoidea Only a few species are known All are endoparasites of primitive fishes The subclass is usually divided into two orders Amphilinidea and Gyrocotylidea These worms differ from the other Cestoidea in being unsegmented in not having the anterior end modified as a holdfast organ and in frequently occurring as parasites of the coelomic cavity rather than the digestive tract Some species have the posterior end modified into a holdfast organ (*see* GYROCOTYLIDEA) The animals are hermaphroditic and sexual reproduction occurs in the vertebrate host The embryo or oncosphere bears 10 hooks instead of the 6 found in other Cestoidea

In the only complete life history known the worm undergoes a period of larval development in an invertebrate When this invertebrate is eaten by the fish host the worm develops to sexual maturity *See* CESTOIDEA {C P R}

Cestoidea

A class of the phylum Platyhelminthes commonly referred to as tapeworms All members are endoparasites usually in the digestive tract of vertebrates The class has been subdivided as follows

Class Cestoidea
- Subclass Cestodaria
  - Order Amphilinidea
  - Order Gyrocotylidea
- Subclass Cestoda
  - Order Proteocephaloidea
  - Order Tetraphyllidea
  - Order Lecanicephaloidea
  - Order Trypanorhyncha
  - Order Diphyllidea
  - Order Pseudophyllidea
  - Order Cyclophyllidea
  - Order Nippotaeniidea

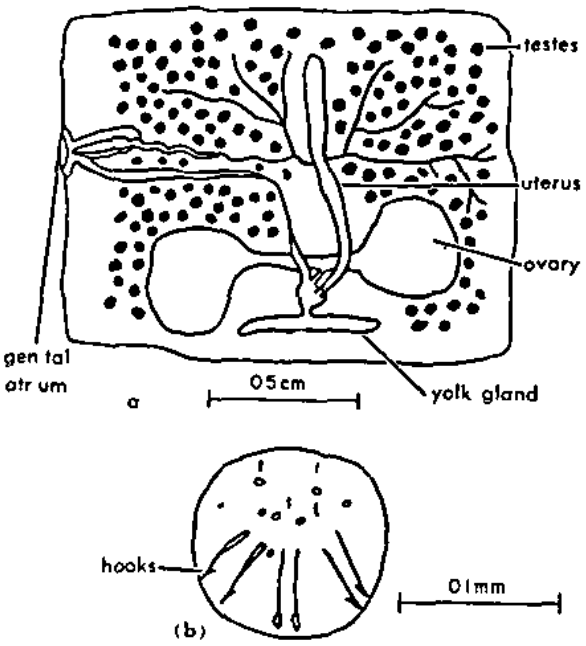
Separate articles appear on each group listed in the classification

Morphology and life history In size the tapeworms range from less than 1.0 mm to several meters in length The class is differentially characterized by the presence of a cuticle rather than a cellular epidermis and by the total absence of a mouth and digestive tract External cilia are never present although the cuticle usually bears minute

projections ranging from 0 1 to 1 0 μ in diameter In most species of the class the body is divided into proglottids each proglottid containing one or two hermaphroditic reproductive systems (illustration *a*) The anterior end is usually modified into a holdfast organ bearing suckers or sucking grooves and frequently armed with hooks Early embry

s

the parental body through a uterine pore or by liberation of the terminal segment from the main body of the worm Further development of the



Cestoidea (a) Sexually mature segment of *Taenia* (b) Oncosphere of a cyclophyll dean tapeworm

worm always occurs within the body of a host most often an invertebrate which commonly ingests the larval form Growth of the larval worm frequently with differentiation of the holdfast organ occurs in this host In some species asexual reproduction by budding occurs Further larval growth and development of the holdfast may require a second host (*see* PSEUDOPHYLLIDEA) Development of the sexual phase from the larva occurs in a different host commonly a vertebrate which acquires the worm by eating the larva or the larva bearing host Growth with strobilation and development of the reproductive systems follows the worm usually remaining in the digestive tract

Nutrition Food materials are presumed to be absorbed through the external surface It has been shown that tapeworms have catalytic mechanisms for the active transport into the body of simple sugars and amino acids Elaboration of digestive enzymes has not been demonstrated The chemical composition of these worms is unique in that polysaccharide and fat represent a much larger proportion of the dry weight than does protein *See* PLATYHELMINTHES [CPR]

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Cetacea

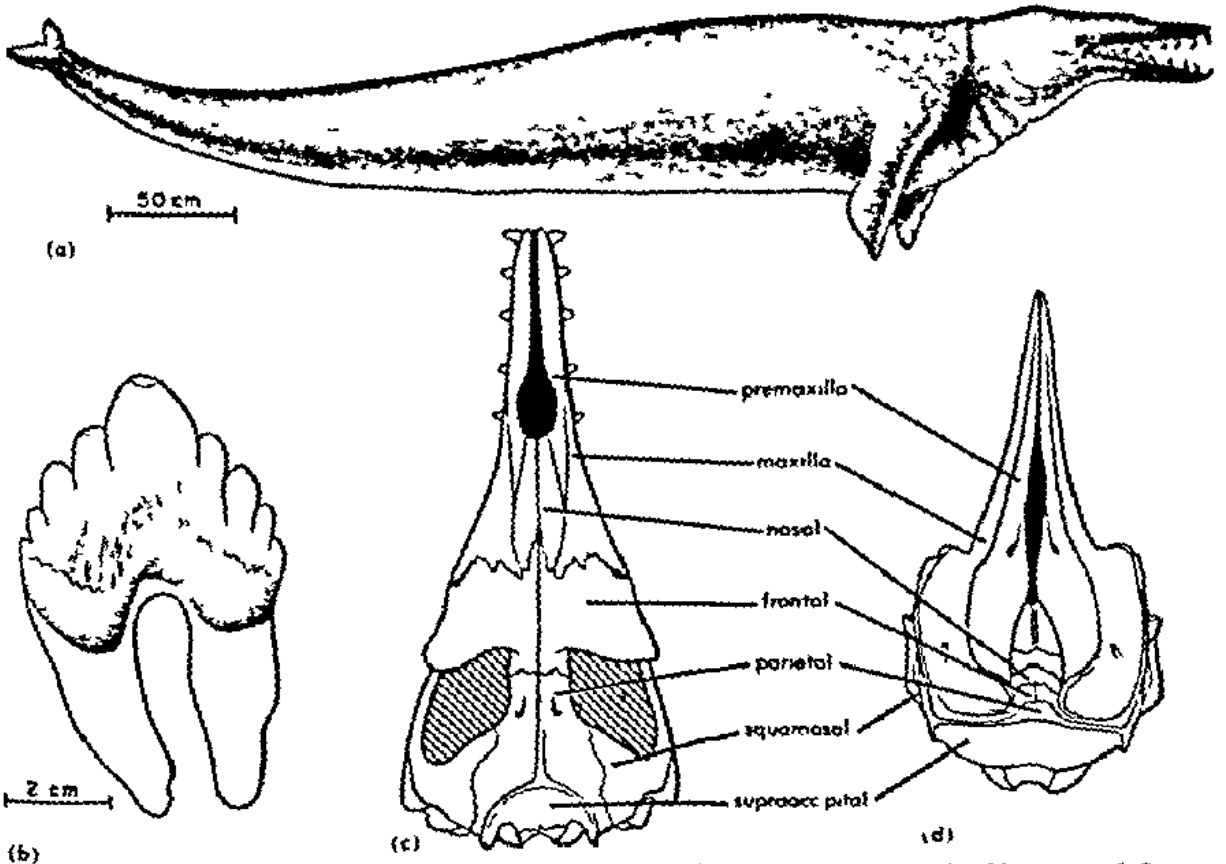
An order of mammals which includes the whales and porpoises All cetaceans are completely aquatic and their extreme adaptation to an aquatic existence makes them the most peculiar and aberrant of all mammals Even the smallest whales are completely helpless on land Fossil whales appeared suddenly in the Eocene as animals already highly adapted to aquatic life and no intermediate forms are known that connect these early whales with the ancestral Cretaceous placentals Consequently the cetaceans stand completely isolated among the mammals

The Cetacea are divided into three suborders The Archaeoceti includes only extinct forms often called the zeuglodonts Although they were true cetaceans the zeuglodonts were more primitive than modern whales particularly in the skull The bones of the face were not telescoped into the back of the skull as in modern whales and the teeth were relatively unspecialized The Odontoceti or toothed whales include most of the modern cetaceans All are predaceous feeding on large-sized prey such as fishes or squids The gigantic sperm whale *Physeter* is the source of sperm oil of commerce The Mysticeti or whalebone whales include only a few types These are completely toothless the teeth being replaced by remarkable baleen plates which are ridges of hardened skin fringed at the edge hanging down from the roof of the mouth and serving as strainers for the plankton on which these huge animals feed The blue whale a whalebone whale that reaches a length of 100 ft and a weight of 150 tons is the largest animal that ever lived *See* CETACEA FOSSILS EUTHERIA WAX ANIMAL AND VEGETABLE [DDD]

Cetacea fossils

This order encompasses a large and long ranging group of aquatic carnivorous or herbivorous marine mammals including the whales porpoises and dolphins The three suborders are related primarily by their adaptation to an aquatic habitat and secondarily by the tendency for telescoping or the overlapping of one cranial bone upon another in the skull Bones involved in this process are joined by squamous or noninterlocking sutures

Archaeoceti Included in the suborder Archaeoceti are large extinct primitive toothed carnivorous forms found in the Eocene of Africa and North America the Eocene and Oligocene of Europe and the early Miocene of New Zealand Some have complete dentitions with sharp serrate reptilelike cheek teeth others have lost the upper third molar The anterior teeth are simple sharp caniniform teeth widely spaced along greatly ex



(a) A restoration of a late Eocene archaeocete from Alabama *Zygorhiza kochi* (by H Hammon) (b) left upper premolar of *Zygorhiza kochii* (c) skull of *Prozeuglodon stromeri* from early Oligocene of Egypt (d) skull of *Dephanodon dividum* from the middle Miocene of Maryland (after R Kellogg 1928 and 1936)

tended maxillaries and lower jaws The bones of the skull maintain their normal relationships for there is little or no telescoping and the anterior nasal openings are not far back on the skull as in later forms Characters in the skull indicate that archaeocetes probably evolved from some unknown pre Eocene creodontlike ancestral stock in North America or Africa

Mysticeti The Mysticeti include the toothless baleen whales (with a whalebone filtering mechanism) from the middle Oligocene and Pliocene into Recent of Europe Miocene into Recent of North America and early Miocene and Pliocene into Recent of South America (presently distributed throughout all oceans) Bones over the brain case are telescoped chiefly from behind The anterior narial openings are well back on the head and the bones comprising the narial passage maintain their normal relationships There are many simple undifferentiated teeth in the embryos but none in the adults Baleen is present in all adults

Odontoceti The Odontoceti are carnivorous toothed whales porpoises and dolphins of present marine waters and are represented in the late Eocene marine deposits of North America with a gap in the record until late Oligocene From that time on they are reasonably well known in marine deposits of most continents Bones over the brain case are telescoped chiefly by an apparent posterior growth of anterior bones. Bones of the narial passage usually depart from their normal relationships narial openings are far back on the head teeth are normally present and supernumerary and baleen is absent [C T J]

Cetane

The common name of the straight-chain alkane n hexadecane $C_{16}H_{34}$ While it has been isolated from vegetable products it is usually prepared by hydrogenation of cetene (hexadecene) obtained by the dehydration of cetyl alcohol Cetyl alcohol is produced by the hydrolysis (saponification) of spermaceti (cetyl palmitate) or more economically by the hydrogenation of ethyl palmitate Pure l cetene may be obtained directly by the pyrolysis of spermaceti

Cetane is the standard reference fuel in determining the ignition quality (cetane number) of diesel fuels The cetane number of a fuel is the percentage by volume of cetane (cetane number 100) in a blend with α-methylnaphthalene (cetane number 0) which matches the ignition properties of the fuel under standardized test conditions in a single-cylinder variable-compression ratio engine

See ALKANE CETANE NUMBER, DIESEL FUEL.

[L.]

Cetane number

A number that indicates the ability of a diesel engine fuel to ignite quickly after being injected into the cylinder In high speed diesel engines, a fuel with a long ignition delay tends to produce rough operation (*see* COMBUSTION CHAMBER)

To determine cetane number of a fuel sample a specially designed diesel engine is operated under specified conditions with the given fuel The fuel is injected into the engine cylinder each cycle at 13° before top center The compression ratio is adjusted until ignition takes place at top center (13° delay) Without changing the compression ratio the engine is next operated on blends of cetane (*n* hexadecane) a short delay fuel and α methylnaphthalene which has a long delay When a blend is found that also has a 13° delay under these conditions the percentage by volume of cetane in the mixture is called the cetane number of the fuel sample [ARR]

Cetyl alcohol

A straight chain primary aliphatic alcohol of 16 carbon atoms found free in feces

$$CH_3(CH_2)_{14}CH_2OH$$

Its ester with palmitic acid comprises 90% of spermaceti, the wax from marine animals *It* is also present in esterified form in wool fat *See* ALCOHOL, LIPID, WAX ANIMAL AND VEGETABLE [HEC, RHC]