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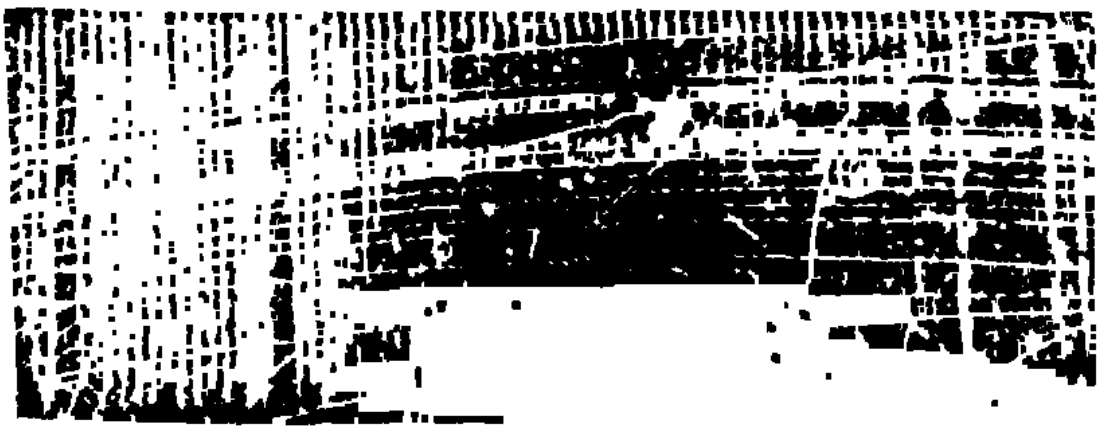
NEW YORK CHICAGO SAN FRANCISCO DALLAS TORONTO LONDON

of Science and Technology

AN INTERNATIONAL REFERENCE WORK

IN FIFTEEN VOLUMES INCLUDING AN INDEX

VOLUME 3 CHA-CYT



(LEFT) Flying fish (*photograph by H Edgerton*)
(RIGHT) Cloud chamber (*Radiation Laboratory, University of California*)

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

CH *Chabazite to Cytoplasmic inheritance*

Chabazite

A mineral belonging to the zeolite family of silicates It crystallizes in the hexagonal system and usually occurs in simple rhombohedral crystals with nearly cubic angles Penetration twins are common There is a poor rhombohedral cleavage Hardness is 4–5 on Mohs scale specific gravity is 2.05–2.15 The luster is vitreous and the color usually white but may be yellow red or pink. Chabazite resembles calcite in its crystal form and cleavage but may be distinguished from it by the lack of effervescence in hydrochloric acid *See* ZEOLITE.

Chabazite is essentially a hydrous calcium sodium aluminum silicate

$$(Ca\backslash a_2)[Al_2Si_4O_{12}]\cdot 6H_2O$$

The ratio of calcium to sodium may vary and potassium is usually present in small amounts Chabazite has been the most widely used natural zeolite for cation-exchange and gas-sorption purposes but synthetic zeolites are now widely employed

Chabazite is a secondary mineral usually found lining cavities in basalt and related rocks It is associated with other zeolites and calcite Notable localities are the Giant's Causeway Ireland Faeroe Islands Trentino Italy and Oberstein Germany In the United States it is found at West Paterson and Bergen Hill, New Jersey and Table Mountain Oregon [C FR C.S HL]

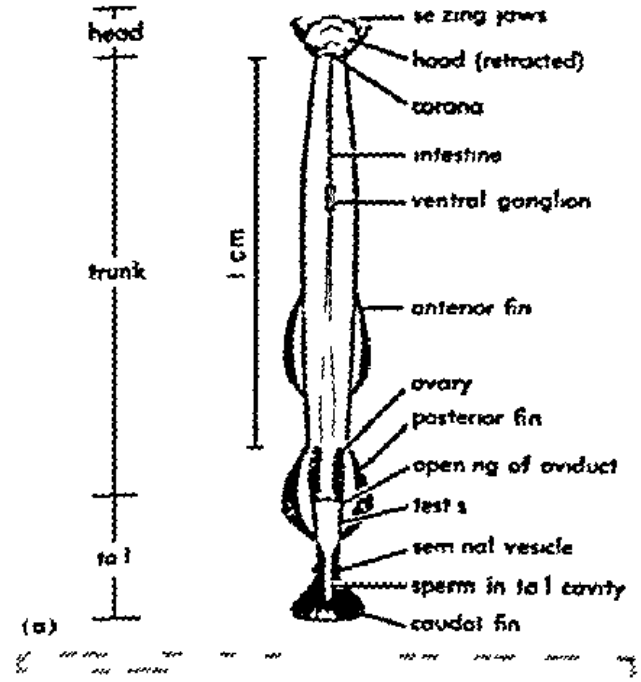
Chaetognatha

A phylum of abundant planktonic arrowworms As adults they range in size from 5 to over 100 mm Their bodies are tubular transparent and divided into three portions, a head trunk and tail The head possesses one or two rows of minute teeth anterior to the mouth and usually 7 10 larger chaetae or seizing jaws on each side of the head One or two pairs of lateral fins and a caudal fin are present In mature individuals a pair of seminal vesicles protrudes from the sides of the tail segment just forward of the caudal fin

Nine genera and about 42 species are recognized by some specialists. Most species belong to the genus *Sagitta* which can be recognized by the presence of two pairs of teeth and two pairs of lateral fins Important diagnostic features for species include the shape and position of the seminal vesicles and the number and arrangement of the anterior teeth

Morphology The body is covered with a thin flexible cuticle secreted by the epidermal cells The head is rounded and is covered by a thin hood of epidermis When drawn forward the hood covers the teeth and jaws and streamlines the anterior end of the body Two small dark eyes are found on the dorsal side of the head. Behind the eyes and forming an irregular loop on the epidermis is a structure called a corona ciliata which is visible only when stained

The nervous system consists of a dorsal ganglion, or brain from which nerves lead to various portions of the head and body A pair of nerves extend pos-



Sagitta enflata (a) Dorsal view (b) ventral head

teriorly from the brain and joins the prominent ventral ganglion which lies just beneath the epidermis

The head musculature is quite complex but the trunk has only six longitudinal bands of muscle which restrict the body to simple lateral movements Arrowworms are unable to constrict their bodies Swimming is accomplished by rapid but brief movements of the caudal fin followed by a quiet period They do not appear to swim much but rather drift passively most of the time

The digestive system is simple A mouth opens ventrally in the center of the head A short esophagus leads to a straight intestine which begins just behind the head and terminates in an anus opening ventrally at the septum separating the trunk and tail segments The intestine is supported by dorsal and ventral mesenteries A large coelom surrounds the intestine

All chaetognaths are hermaphroditic The ovaries are tubular and lie in the trunk segment just ahead of the septum dividing this portion of the body from the tail The eggs in the ovaries increase in size at maturity only a small fraction of eggs maturing and being spawned at one time Alongside the ovary is an oviduct and contained within the oviduct is a narrow sperm duct Fertilization is internal The fertilized eggs are spawned free in the ocean and the young chaetognaths hatch in some instances within 48 hours There is no larval stage

The testes are situated in either side of the tail segment As the sperm mature they break away and often circulate in the tail cavity From time to time some pass through short ducts leading from inside the tail cavity to the seminal vesicles Small quantities of sperm are stored in the ducts prior to discharge

Natural history Chaetognaths are cosmopolitan forms which live not only at the surface but also at great depths however no one species is found in all latitudes and at all depths One of the arctic species *Eukrohnia hamata* may extend to the Antarctic by way of deep water across the tropics A few species are neritic and are not found normally beyond the continental shelf

Their food consists principally of copepods and other small planktonic crustaceans however they are very predacious and will even eat small fish larvae and other chaetognaths on rare occasions The suggestion has been made that they feed on plants as well as animals but this needs more supporting evidence They seize their food with their pointed jaws and aided by the teeth they push it into their mouths Small crustacean larvae eaten one day appeared to be digested by the next

Along the Atlantic Coast of the United States they are most abundant over the continental shelf Numbers of five or more per cubic meter of water are common along the coast farther offshore only a fraction of this number is normally encountered When very abundant they may exceed 100 per cubic meter however this is unusual and often includes many young specimens

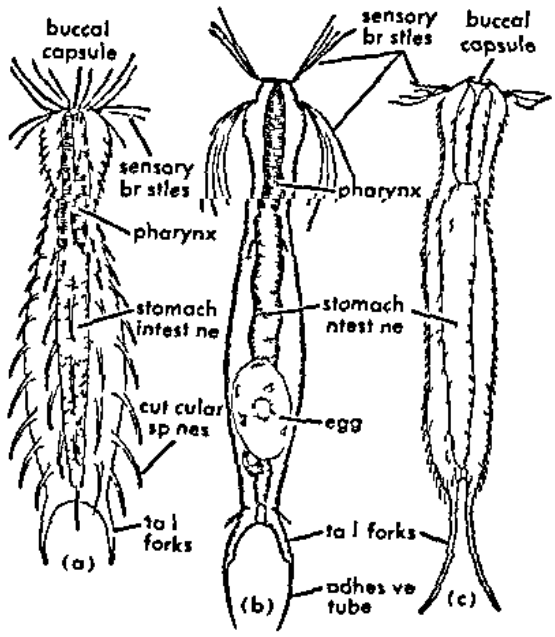
Studies have shown them to be useful as indicator organisms Certain species appear to be associated with characteristic types or masses of water and when this water is displaced into an adjacent water mass the chaetognaths may be used as temporary evidence for such displacement

Their abundance and cosmopolitan distribution in marine waters their little known life history their importance in the food chain both as predators and prey and their value as indicator organisms invite further investigation *See* ANIMAL KINGDOM SEA WATER FERTILITY [E L P]

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Chaetonotoidea

An order of the class Gastrotricha These animals usually have two adhesive tubes connected with the distinctive paired posterior tail forks or toes Paired protonephridia are present Parthenogenetic females deposit cuticular covered smooth or spinous eggs and direct development occurs The young emerge within 1 3 days and are similar to the adult in form A lobed head usually with 3–5 lobes shows ciliary tufts A simple brain with nerve fibers is present and no mastax exists The oral apparatus is variable and sometimes protrusible A



Chaetonotoidea (a) Chaetonotus a freshwater gastrotrich from life (b) Ichthydium (after A Remane 1927) (c) Polymerurus (after J Marcolongo 1914) (From L H Hyman The Invertebrates vol 3 McGraw Hill 1951)

nematodelike pharynx of varying shape connects with a stomach intestine An anterior thickened cuticular plate or cephalion with paired lateral epi and hypopleurions and postoral hypostomion are diagnostic *Chaetonotus Ichthydium Lepido dermella* and *Polymerurus* are well known genera with over 200 species only about 20 of which have been reported from the United States *See* GASTROTRICHA [C E P]

Chagas' disease

A progressive noncontagious insect transmitted disease enzootic and endemic in the Americas and caused by a protozoan *Trypanosoma* (*Schizo trypanum*) *cruzi* Its outstanding features are fever edemas enlargement of the lymph nodes cutaneous manifestations of varied types cardiac abnormali ties and particularly in infants a meningoen cephalitis which often is fatal It is a long lived infection evolving characteristically in acute and chronic phases The presence of immature multi plicative forms of *T cruzi* in the tissues is distinc tive Transmission is effected by winged blood sucking insects of *Triatoma Rhodnius* and related genera (*see* HEMIPTERA) On presumptive evidence the infection is believed to occur in Asia

Extreme variation in severity is correlated with the area reporting In the United States human in fections thus far have been mild Asymptomatic cases occur In the past some of these may have been mistaken diagnoses the true infecting or ganism was probably *T rangeli* now known to have an overlapping area of distribution and some of the same vectors as *T cruzi* but which has not been proven to cause disease

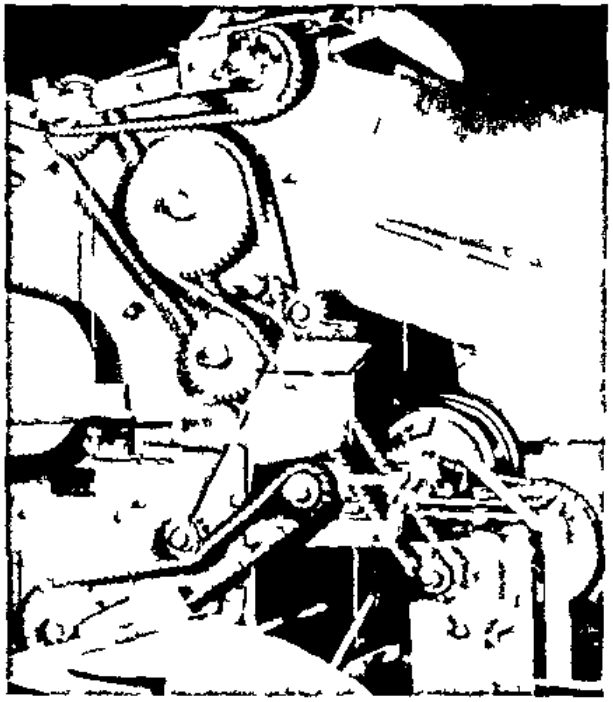
Infection is proved by detection of *T cruzi* in the blood This is done by direct examination by culture by animal inoculation or by the infection of clean insect vectors a procedure known as xenodiagnos s it is presumptive when only im munological reactions are positive In the tissues *T cruzi* occurs w th great frequency in heart muscle and diagnosis is possible from heart sec tions alone although many other organs can be involved Tissue damage may be extensive the intimate mechanism of the tissue destruction is unknown

Treatment is unsatisfactory Control therefore centers on insect proofing of residences and on insect destruct on *See* PARASITOLOGY MEDICAL TRYPANOSOMATIDAE [D W]

Chain drive

A flexible device for hoisting conveying and for transm tt ng power Chains for power transmission are classified as block roller or silent For uses of chain other than in power transmission *see* CONVEYOR

A chain drive consists of an endless chain whose l nks mesh with toothed wheels called sprockets which are keyed to the driving and driven shafts Such drives are particularly well suited for use in



Fg 1 Roller chain dr ve (*Link Belt* Co)

transmissions where the shaft center distance is too short for a belt drive but too long to make practical the use of gears (Fig 1) In contrast to belts chains have no slippage and can be used in applications demanding constant velocity ratios of the driving and driven shafts The chain drive has a higher initial cost than an equivalent belt drive but this is balanced by its compactness For a given capacity the chain is narrower than a belt and the sprockets are smaller than the equivalent pulleys

Types of chain The several types of chain are adapted to particular classes of service Block chain is built up from a series of steel blocks that are connected by side plates and steel pins (Fig 2*a*) It is used in low speed drives and in light ma chines

Roller chain is more efficient than block chain as well as being stronger it is preferred for higher speeds and capacities than block chain (Fig 2*b*) The pitch of a chain is the distance from the center of one link pin to that of the next Chain width is the minimum distance between the link plates Roller diameter is the outside diameter of the roller and approximately equal to five eighths of the pitch For transmission of heavy loads a mul tiple strand chain with two or more chains joined side by side by common link pins may be used (Fig 2*c e*) Double pitch chains are similar to standard roller chains except the l nk plates have twice the pitch of the corresponding standard pitch chain

Leaf or laminated chains are used on counter weight and tension devices on machine tools and textile equipment (Fig 2*f*) They are also used as wrench chains mast chains on lift trucks and for hoist chains in a rcraft

Silent chain drives consist of a series of toothed link plates assembled on joint components in such a manner that articulation occurs between adjoining pitches (Fig 3) The links have straight bearing edges which contact the straight sided teeth of the sprocket In addition to quiet operation the advantages of silent chain drives include high efficiency and adaptability to high speed drives Single flexure silent chains have teeth projecting on one side of the chain Double flexure chains for use where the drive requires sprockets to contact both sides of the chain have teeth projecting on both sides of the chain

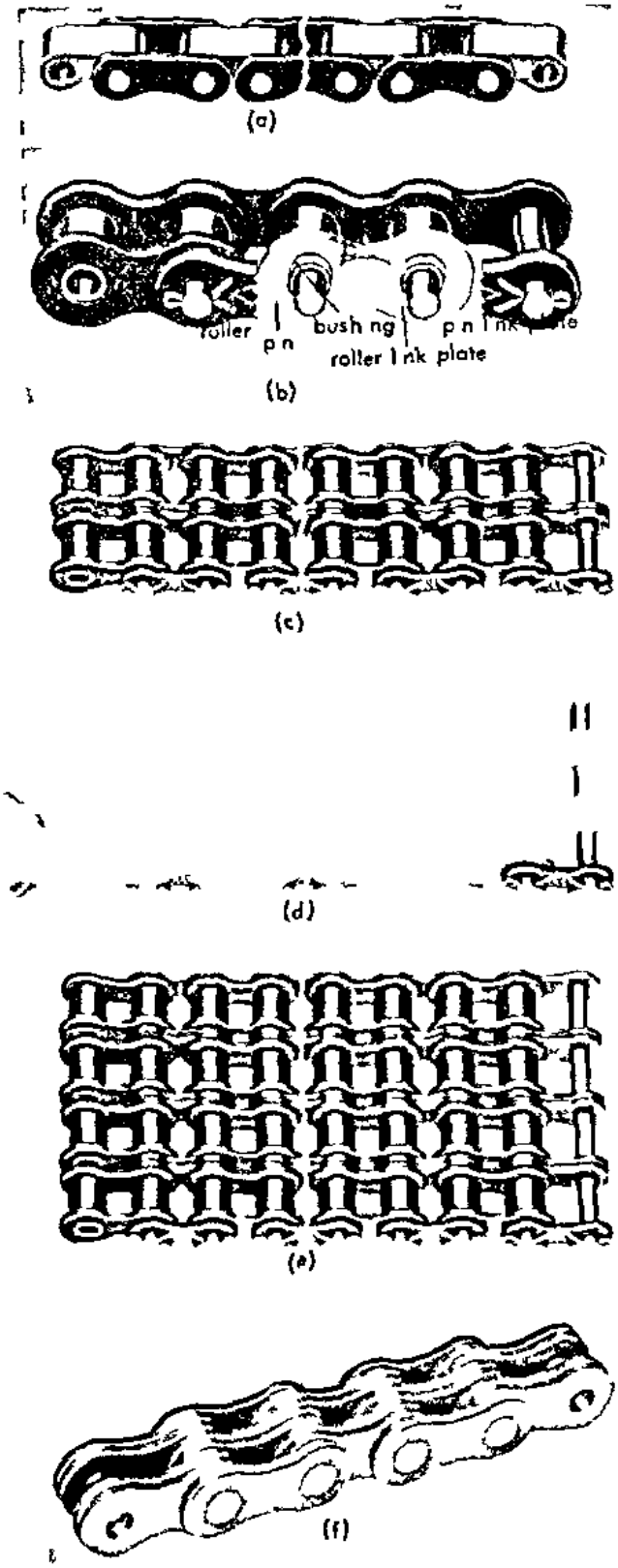


Fig 2 Common types of chain (a) Block chain (b) Roller chain (Diamond Chain Co) (c) Double strand roller chain (d) Triple strand roller chain (e) Quadruple strand link chain (f) Leaf chain (Link Belt Co)

Sprockets Power is transmitted by chains and sprockets which are toothed wheels whose teeth are shaped to mesh with the chain (Fig 4) Cut tooth sprockets—those with the teeth machined to proper form—are the most suitable for use with roller chains While sprockets with fewer than 16 teeth may be used for very slow speeds a minimum of 18 to 24 teeth is desired for higher speed service For speed ratios requiring the larger sprocket to have more than 120 teeth or more than 8 times the number on the smaller sprocket it is usually better to make the speed change in two or more steps

Pitch diameter is the diameter of the pitch circle that passes through the centers of the link pins as the chain is wrapped on the sprocket Since the chain pitch is measured on a straight line between the centers of adjacent pins the chain pitch lines form a series of chords of the pitch circle The bottom diameter is the diameter of the circle tangent to the curve at the bottom of the tooth space The caliper diameter is the same as the bottom diameter for a sprocket with an even number of teeth for one with an odd number it is the distance from the bottom of one tooth gap to that of the most nearly opposite tooth gap

The sprocket tooth form—the outline of the working surface on which the roller runs—must in general satisfy the following conditions (1) smooth engagement of the sprocket and chain (2) distribution of the load so that each tooth engaged with the chain carries its share of the load and (3) normal elongation of the chain The tooth profile—the outline of the tooth as projected on a plane through the sprocket axis and the center of the tooth—must be proportioned to provide proper

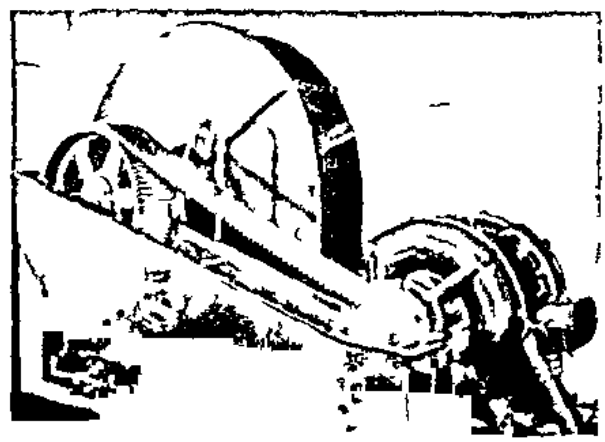


Fig 3 Silent chain drive (Link Belt Co)

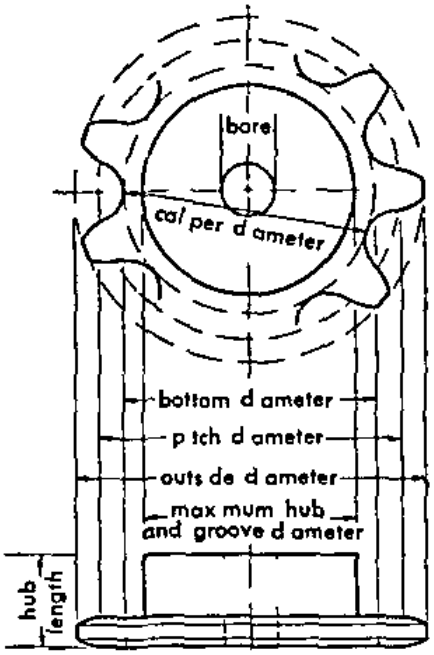


Fig 4 Characteristics of sprocket for roller chain

clearance between the roller link plates With multiple strand chains the transverse pitch—the axial distance from the center of one tooth profile to that of the next—must be specified Sprockets for double pitch chains may be single cut (those having the number of effective teeth equal to the number of actual teeth) or double cut (those having the number of effective teeth equal to one half that of the actual teeth) With an odd number of teeth each tooth on a double cut sprocket will engage the chain only on every other revolution [RCF]

Bibliography Association of Roller and Silent Chain Manufacturers *Design Manual for Roller and Silent Chain Drives* 1955 American Standards Association *Transmission Roller Chains and Sprocket Teeth* ASA Standard B29 1 1950

Chain reaction, chemical

A chemical reaction in which many molecules undergo chemical reaction after one molecule becomes activated In ordinary chemical reactions every molecule that reacts must first become activated by collision with rapidly moving molecules and the number of these violent collisions per second is so small that the reaction is slow After a chain reaction is once started it is not necessary to wait for more collisions with fast molecules and thus the chain reaction is fast

Photochemical reactions A typical chain reaction is the photochemical reaction between hydrogen and chlorine which is described by the following reactions

$$\begin{aligned} Cl_2 + light &\rightarrow Cl + Cl \\ Cl + H_2 &\rightarrow HCl + H \\ H + Cl_2 &\rightarrow HCl + Cl \\ Cl + H_2 &\rightarrow HCl + H \end{aligned}$$

The light absorbed by a chlorine molecule dissociates the molecule into chlorine atoms these in turn react rapidly with hydrogen molecules to give hydrogen chloride and hydrogen atoms The hydrogen atoms react with chlorine molecules to give hydrogen chloride and chlorine atoms The chlorine atoms react further with hydrogen and continue the chain until some other reaction uses up the free atoms of chlorine or hydrogen The chain stopping reaction may be the reaction between two chlorine atoms to give chlorine molecules or between two hydrogen atoms to give hydrogen molecules Again the atoms may collide with the walls of the containing vessel or they may react with some impurity which is present in the vessel only as a trace

The length of the chain that is the number of molecules reacting per molecule activated is determined by the relative rates of the competing reactions namely the chain propagating reaction and the chain stopping reactions In the chain reaction just described 10^6 molecules of hydrogen chloride may be formed by the photodissociation of 1 chlorine molecule

In photochemical chain reactions the length of the chain can be determined by measuring the number of photons of light absorbed that is the number of molecules activated and dividing by the number of molecules which react chemically

Thermal reactions In thermal reactions the length of the chain may sometimes be estimated from a knowledge of the intermediate steps and the kinetics involved The presence of a chain reaction can often be proved by adding a trace of an inhibitor such as nitric oxide If the reaction is slowed down greatly by a very small amount of a substance which reacts with the chain propagating units the reaction involves a chain While the inhibitor is being consumed in this way the reaction is slow After an induction period the inhibitor is consumed and the rapid chain reaction then takes place

Chain reactions are erratic and are reproduced with difficulty in different laboratories because they depend so much on the presence and concentration of accidental impurities which act as inhibitors

In many chemical reactions particularly organic reactions at elevated temperatures the chains are carried by free radicals which are very reactive fragments of molecules that have unshared electrons such as $\cdot CH_3$ $\cdot C_2H_5$ $\cdot H$ and $\cdot OH$ The thermal decomposition of propane is a typical free radical chain which follows the reactions

$$\begin{aligned} C_3H_8 &\rightarrow CH_3 + C_2H_5 \\ CH_3 + C_3H_8 &\rightarrow CH_4 + C_3H_7 \\ C_3H_7 &\rightarrow CH_3 + C_2H_4 \\ CH_3 + C_3H_8 &\rightarrow CH_4 + C_3H_7 \end{aligned}$$

One molecule of propane is decomposed into free radicals $\cdot CH_3$ and $\cdot C_2H_5$ which then react with more propane to give the product methane and a free radical $\cdot C_3H_7$ which decomposes into $\cdot CH_3$ and the product ethylene The $\cdot CH_3$ reacts with more propane and continues the chain The chain is terminated by collision of the free radicals with

the wall or with each other in reactions such as

$$\cdot CH_3 + \cdot C_3H_7 \rightarrow C_4H_{10}$$

Thus it is possible to obtain products of higher molecular weight as well as products of lower molecular weight The fact that these higher mo lecular weight products are found supports the theory of free-radical formation and chain reac tions

Certain oxidations in the gas phase are known to be chain reactions The carbon knock which oc curs at times in internal combustion engines is caused by a too rapid combustion rate caused by chain reactions This chain reaction is reduced by adding tetraethyllead which acts as an inhibitor

The polymerization of styrene to give polystyrene and the polymerization of other organic materials to give industrial plastics involve chain reactions The spoilage of foods the precipitation of in soluble gums in gasoline and the deterioration of certain plastics in sunlight involve chain reactions which can be minimized with inhibitors *See* ANTI OXIDANT CATALYSIS CHAIN REACTION NUCLEAR FREE RADICAL INHIBITOR (CHEMICAL) KINETICS (CHEMICAL) PHOTOCHEMISTRY [F D]

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Chain reaction, nuclear

A succession of generation after generation of acts of nuclear division such that the neutrons set free in the nuclear disruptions of the *n*th generation split the fissile nuclei (U^{233} U^{235} Pu^{239}) of the $(n+1)$st generation The first few neutrons ordi narily come from the natural or spontaneous fission of admixed U^{238} or Pu^{240} or from other nuclear reactions *See* FISSION NUCLEAR

The ra [illegible] in the (r as the [illegible] whether k is greater than 1 equal to 1 or less than 1 the chain reaction is said to be divergent self sustaining or convergent and requires at least a mass of fissile material greater than equal to or less than the critical mass *See* CRITICAL MASS

The circumstance of several neutrons being given off in fission permits in principle a multiplication factor as high as $k = 2$ or more in a sufficiently large mass of metallic U^{235} or Pu^{239} An atomic bomb and a runaway power reactor are distin guished not only by very different values of $k - 1$ (several tenths vs 0 01) but also by the time be tween one generation and another (10^{-8} sec vs 10^{-3} sec in order of magnitude) *See* ATOMIC BOMB REACTOR PHYSICS [J A W]

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Chalcanthite

A mineral with the chemical composition $CuSO_4$ $5H_2O$ Chalcanthite commonly occurs in blue to greenish blue triclinic crystals or in massive fi brous veins or stalactites Fracture is conchoidal and luster is vitreous Hardness is 2 5 on Mohs scale and specific gravity is 2 28 It has a nauseat ing taste and is readily soluble in water It dehy drates rapidly in dry air to a greenish white pow der

Chalcanthite is a secondary mineral associated with gypsum melanterite brochantite and other sulfate minerals found in copper or iron sulfide de posits It is also found in mine workings

Although deposits of commercial size occur in arid areas chalcanthite is generally not an impor tant source of copper ore Its occurrence is wide spread in the western United States [E C T C]

Chalcedony

A fine grained fibrous variety of quartz, silicon di oxide The individual fibers that compose the min eral aggregate usually are visible only under the microscope A number of subvarieties of chalced ony have been recognized on the basis of color dif ferences and some have been valued since ancient times as semiprecious gem materials Carnelian is translucent and of a deep flesh red to clear red color in the most prized kinds Carnelian grades into sard which is of an orange brown to reddish brown color Both types are pigmented by admixed finely divided iron oxide Chrysoprase is an apple green type colored by a compound of nickel Chal cedony sometimes contains dendritic enclosures re sembling plants or trees Chalcedony of a black to red brown color containing manganese or iron has been called mochastone and a green type com posed of intertwined filaments and hairs resem bling moss has been called moss agate *See* GEM, QUARTZ

Chalcedony usually occurs as crusts with a rounded mammillary or botryoidal surface The hardness is 6 5–7 on Mohs scale The specific grav ity is 2 57 2 64 In relatively pure types the color ranges from colorless or milky white to pale shades of blue gray or yellow The mineral is trunslucent and the luster is waxy to weakly vitreous Chalced ony ordinarily contains 90–98% SiO_2 with the bal ance water together with varying amounts of iron oxide aluminum oxide and other impurities

Crusts of chalcedony generally are composed of fairly distinct layers concentric to the surface Agate is a common and important type of chalced ony in which successive layers differ markedly in color and degree of translucency In the most com mon kind of agate the layers are curved and con centric to the shape of the cavity in which the ma terial formed The successive layers of chalcedony and agate usually differ in their permeability to solutions and much of the colored agate sold com mercially has been artificially pigmented by dyes or inorganic chemical compounds *See* AGATE [C F R]

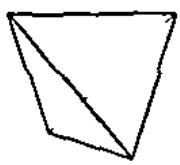
Chalcocite

A mineral having composition Cu_2S Chalcocite crystallizes in the orthorhombic system (l elow 105°C) but crystals are rare and small usually

with hexagonal outline as a result of twinning Most commonly the mineral is fine grained and massive with a metallic luster and a shining lead gray color which tarnishes to dull black on exposure It is imperfectly sectile the hardness is 2 5 (Mohs scale) and specific gravity is 5 7 Chalcocite is an important copper ore formed principally as a supergene mineral in the enriched zones of sulfide deposits as at Miami Morenci and Bisbee Arizona It also occurs in veins with other copper minerals as at Butte Montana Fine crystals have been found in Cornwall England and at Bristol Connecticut *See* BORNITE CHALCOPYRITE COPPER [C S HU]

Chalcopyrite

A major ore mineral of copper with composition $CuFeS_2$ Chalcopyrite crystallizes in the tetragonal crystal system but crystals are usually small with disphenoidal faces resembling the tetrahedron It is usually massive with metallic luster and a brass yellow color often with a bronze or iridescent tarnish The hardness is 3 5 (Mohs scale) and the specific gravity is 4 2 Chalcopyrite is a so-called fool s gold but it is brittle and thus may be distinguished from sectile gold It is distinguished from pyrite the most common and widespread fool s gold by its lesser hardness pyrite cannot be scratched by the knife



Pseudotetrahedral crystal of chalcopyrite with spheno dal faces (*From C S Hurlbut Jr Dana s Manual of Mineralogy 16th ed Wiley 1952*)

Chalcopyrite is the most widely occurring of the primary copper ore minerals and many of the secondary copper minerals have been derived by its alteration *It* is an original constituent of igneous rocks and occurs in pegmatite dikes contact metamorphic deposits and metallic veins It is often disseminated through large masses of pyrite and pyrrhotite making them serve as low grade copper ore A few of the notable localities where chalcopyrite is the chief copper ore are Cornwall England Freiberg Germany and Rio Tinto Spain In the United States it is mined at Butte Montana Jerome Arizona and Ducktown Tennessee *See* CHALCOCITE COPPER PYRITE [C S HU]

Chalk

A variety of limestone formed from pelagic or floating organisms that is very fine grained porous and friable It is white or very light colored and consists almost entirely of calcite The rock is made up of the calcite shells of microorganisms partially cemented by structureless calcite The most conspicuous are the Foraminifera *Globigerina* and *Textularia* Also present are remains of floating algae rhabdoliths and coccoliths some sponge spicules and radiolaria In some chalk remains of microorganisms constitute more than one third of the rock

The best known chalks are those of the Cretaceous exposed in cliffs on both sides of the English Channel The Selma (Cretaceous) chalk of Alabama Mississippi and Tennessee and the Niobrara chalk of the same age in Nebraska are well known deposits in the United States Chalk is used for cements powders (as soft abrasives and polishers) crayons and fertilizers *See* CRETACEOUS FORAMINIFERA FOSSILS LIMESTONE SEDIMENTARY ROCKS [R S]

Chameleon

A common name applied to two unrelated groups of lizards the Old World chameleons of the family Chamaeleontidae and some American lizards of the family Iguanidae



The New World chameleon *Anolis carolinensis* length to 6 in (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

The Old World chameleons are found in extreme southern Europe southern Asia and are most abundant in Africa These lizards are famed for their ability to change color a feat accomplished by the expansion and contraction of different types of pigment cells in the skin this is a trait shared by many wholly unrelated animals but best known in the chameleons They are sluggish arboreal lizards with a prehensile tail and with the digits highly modified for grasping limbs They possess a remarkably protrusile tongue which they can flick out sometimes as far as half their body length to pick up insects with its sticky tip

The American chameleons belong to the large genus *Anolis* common in tropical America and the West Indies *A carolinensis* the only United States species is especially characteristic of the southern pine forests It is a slender long legged arboreal lizard skilled at jumping and climbing It varies in color from green to brown the shade apparently depending more upon its emotions than its environment *See* SQUAMATA [J D B]

Chamois

A goatlike antelope *Rupicapra rupicapra* native to the mountains of Europe and Asia Minor but now well established in New Zealand Chamois are agile graceful animals Bucks average about 65 lb does are much smaller Both sexes have short erect horns sharply curved in and down at the tips short tails and are covered with long outer hairs and thick underfur they are reddish brown in summer darker in winter Chamois are good game animals and their flesh is



The chamois *Rupicapra rupicapra* length 45 in (*From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd*)

flavor They are the original source of chamois skin but their numbers are now so depleted that most commercial chamois comes from domestic goat skins *See* ARTIODACTYLA [J D B]

Channel, open

A natural or man made covered or uncovered conduit in which liquid (usually water) flows with its top surface bounded by the atmosphere Typical open channels are rivers streams canals flumes reclamation or drainage ditches sewers and water supply or hydropower aqueducts

Open channel flow is classified according to steadiness a condition in relation to time and to uniformity a condition in relation to distance Flow is steady when the velocity at any point of observation does not change with time if it changes from instant to instant flow is unsteady At every instant if the velocity is the same at all points along the channel flow is uniform if it is not the ... f...

... Flow occurs from a higher to a lower elevation by action of gravity If the phenomenon is short wall friction is small or negligible and gravity shapes the flow behavior Gravity phenomena are local they include the hydraulic jump flow over weirs spillways or sills under sluices and into culvert entrances

If the phenomenon is long friction shapes the flow behavior Friction phenomena include flows in rivers streams canals flumes and sewers in their usual concepts ... ... empirical equations which reflect observed facts Models are sometimes used to show flow patterns and to measure forces for projection to full scale By the laws of dynamic similarity friction phenomena are reproduced to a chosen scale if the model and prototype have the same Reynolds number gravity phenomena the same Froude number (*see* DYNAMIC SIMILARITY) Where gravity and friction play commensurate roles a combination of a Froude number model study and an analytical friction study may be desirable

From the laws of mechanics the instantaneous dynamic relation in all open flow hydraulics is expressed per pound for a given length in a direction such as the direction of flow by

$$\begin{pmatrix}\text{Gravity}\\ \text{work}\end{pmatrix} - \begin{pmatrix}\text{resistance}\\ \text{work}\end{pmatrix} = \begin{pmatrix}\text{change in}\\ \text{specific energy}\end{pmatrix}$$

The specific energy per pound at a point is the depth of flow plus the kinetic energy there In uniform flow there is no change in depth or velocity from point to point and therefore no change in specific energy per pound hence

$$\text{Gravity work} - \text{resistance work} = 0$$

In varied flow where the specific energy is constant in time but changes from point to point the channel is assumed to be composed of a succession of short lengths in each of which flow is uniform the length depth rate of flow computation goes stepwise from one short length to the next until the desired length has been traversed Depending upon the channel characteristics and the precision required the stepwise computation may be made arithmetically or by methods of the calculus An example is the backwater curve

In variable flow the change in specific energy occurs in both time and distance Hence in each short length of the whole consideration is required of continuously changing resistance and of storage because the rate of flow in at one end will be more than that out at the other Electronic computers facilitate the calculations otherwise even with

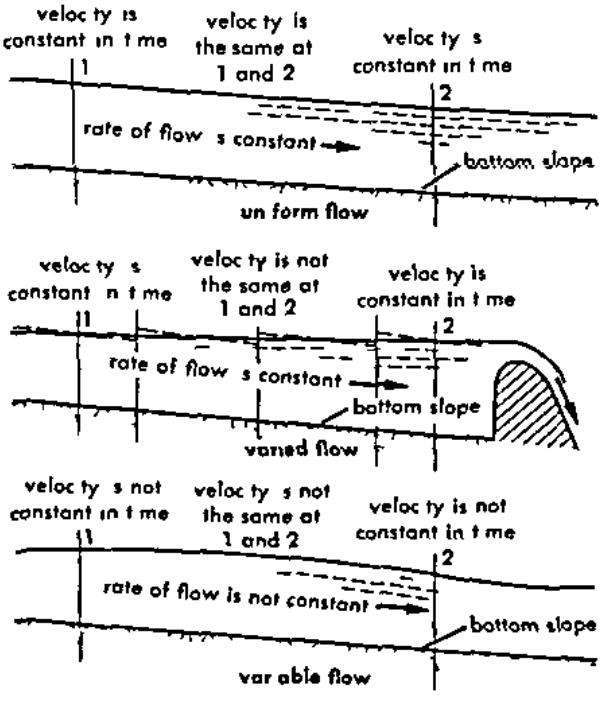


Fig 1 Three types of flow in open channels

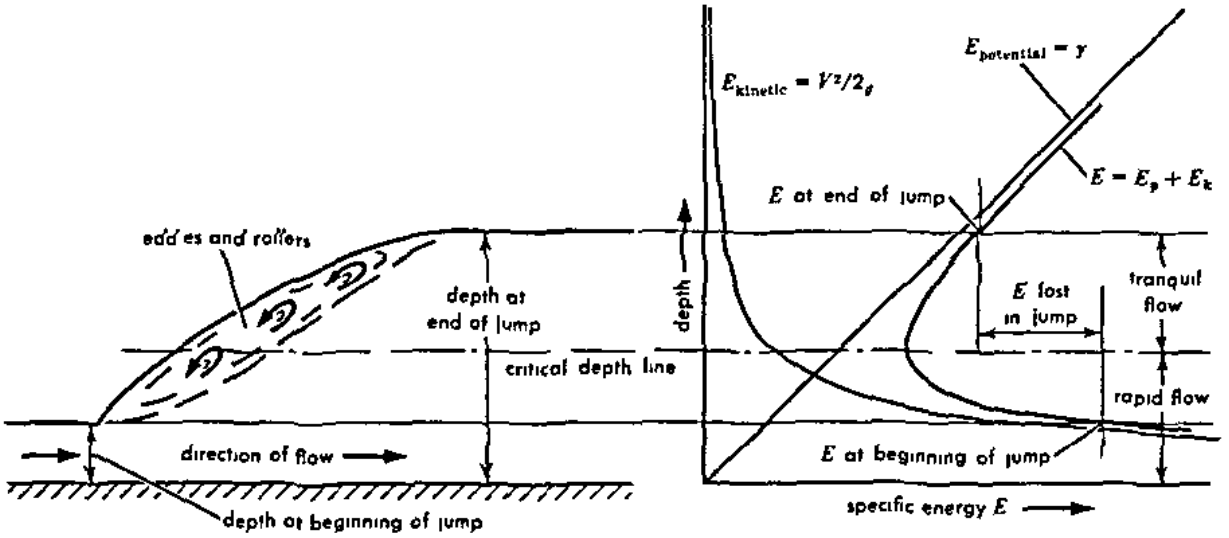


Fig 2 Depiction of hydraulic jump and graphical accounting for its energy transition

simplifying assumptions, the solution requires much time An example is flood flow in a river

Uniform flow at a given rate in a cross section of given shape and wall roughness occurs at a greater depth and lesser velocity if the bottom slope is small (mild) and at a lesser depth and greater velocity if the bottom slope is large (steep) At one intermediate slope (critical), the given flow occurs at a depth (critical) at which the specific energy content per pound is a minimum, this flow is critical, its Froude number is unity Flow at greater than critical depth occurs with more than the minimum specific energy content, this flow is tranquil, its Froude number is less than unity In flow at less than critical depth, the specific energy content is also more than the minimum, this flow is rapid, its Froude number is greater than unity

Hydraulic jump. If design conditions or natural circumstances require flow to change from rapid to tranquil state the transition will involve a hydraulic jump This is a local phenomenon in which the specific energy content changes abruptly from low potential and high kinetic to high potential and low kinetic (Fig 2) Usually the wall friction is negligible, but in the transition some energy goes into the creation of eddies and rollers which break up and dissipate their mechanical energy as heat Thus a jump usefully converts energy from a high kinetic to a less eroding, high potential form

Stream gaging. Methods of gaging depend upon the size of the channel and the conditions at the site Flow in small streams is measured by means of weirs or similar calibrated devices (see FLOW MEASUREMENT) Large streams are gaged by means of velocity measurements taken at many points laterally and vertically in a measured cross section A calibrated current meter is generally used The relation between discharge and stage (water level on a fixed gage) depends upon the steadiness of flow If flow is uniform or varied a single curve exists, if variable as in time of flood the curve is

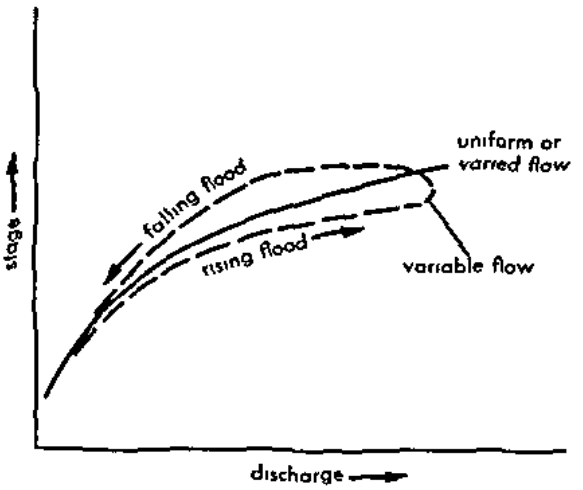


Fig 3 Relation between flow or discharge and water level or stage depends on nature of flow

hairpin shaped (Fig 3) Complete study of a stream requires simultaneous determination of the slope of the water surface, dimensions of cross sections, and distribution of velocities See HYDRAULICS [W A]

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Characteristic curve

A curve that shows the relationship between two changing values A typical characteristic curve is that which shows how the changes in the control grid voltage of an electron tube affect the anode current When three variables are involved, a family of characteristic curves is frequently drawn, with each curve representing one value of the third variable Other common examples of curves include speed torque characteristics of motors, frequency-gain characteristics of amplifiers, and voltage

perature characteristics of thermocouples The curves are produced by making a series of measurements and plotting the results

With appropriate electronic circuits the measurements can now be made automatically and fast enough so that the entire characteristic curve can be made visible on the screen of a cathode ray oscilloscope *See* OSCILLOGRAPH OSCILLOSCOPE CATHODE RAY RECORDING INSTRUMENTS GRAPHIC [J MR]

Charadriiformes

An order of birds of world wide distribution most members of which live near water Sixteen living families are usually recognized but some authorities combine certain of these The order contains both large well known families and small families of limited distribution Among the latter are the pantropical jacanas (Jacanidae) the seed snipe (Thinocoridae) of southern South America the sheathbills (Chionididae) of subantarctic islands and the crab plover (Dromadidae) of the shores of the Indian Ocean Better known members of the order include the shorebirds gulls terns and auks

Members of the plover and sandpiper families (Charadriidae Scolopacidae) have been popular game birds in many countries but only the common snipe (*Gallinago gallinago*) and woodcock (*Philohela minor*) are now hunted legally in North America Several species of these two families perform remarkable migrations notably the trans pacific flights of the golden plover (*Pluvialis dominicus*) and the bristle-thighed curlew (*Numenius hitiensis*) The longest known migratory flights are those of the arctic tern (*Sterna paradisaea*) a member of the family Laridae which also includes the familiar gulls

In two small families the painted snipe (Rostratulidae) and phalaropes (Phalaropodidae) the roles of the sexes are reversed males being less brightly colored than the females and responsible for care of eggs and young

The Alcidae a family predominately of northern coasts contains such groups as the murres guillemots puffins auklets and auks, including the extinct flightless great auk (*Pinguinus impennis*) *See* AVES [K C P]

Charcoal

A porous solid product containing 85–98% carbon produced by heating carbonaceous materials such as cellulose wood peat and coals of bituminous or lower rank at 500–600°C in the absence of air Chars or charcoals are rendered more porous and more efficient for sorption by heating in air carbon dioxide or steam at 900°C for a brief period Those prepared from cellulose or wood are soft and friable and are used chiefly for decolorizing solutions of sugar and other foodstuffs and in treatment of water supplies to remove objectionable tastes and odors Those prepared from the shells of nuts and from coal are dense hard carbons used in gas masks and in chemical manufacturing for many types of separations of mixtures of compounds The sorptive properties of chars result from a very large internal surface The selectivity of the sorption can be modified by mixing additives to the char and by controlling the partial pressure or concentration of components the temperature of the mixture and (in liquids) the acidity or polar environment *See* ACTIVATED CARBON, ADSORPTION CARBON, COKE, DESTRUCTIVE DISTILLATION, PYROLYSIS WOOD CHEMICALS [H H ST]

Charge, electric

A basic property of elementary particles of matter One does not define charge but takes it as a basic experimental quantity and defines other quantities in terms of it The early Greek philosophers were aware of the fact that when amber was rubbed with fur both the amber and the fur if carefully insulated had properties after the rubbing that they did not have before (for example the amber attracted the fur after but not before) these new properties were later said to be due to 'charge' The amber was assigned a negative charge while the fur was assigned a positive charge

According to modern atomic theory the nucleus of an atom has a positive charge because of its protons and in the normal atom there are enough extranuclear electrons to balance the nuclear charge so that the normal atom as a whole is neutral Generally when the word charge is used in electricity it means the unbalanced charge (excess or deficiency of electrons) so that physically there are enough 'nonnormal' atoms to account for the positive charge on a positively charged body or enough unneutralized electrons to account for the negative charge on a negatively charged body

The rubbing process mentioned 'rubs' electrons off the fur onto the amber thus giving the amber a surplus of electrons and it leaves the fur with a deficiency of electrons *See* ELECTROSTATICS

In line with the previously mentioned usage the total charge q on a body is the total unbalanced charge possessed by the body For example if a sphere has a negative charge of 1×10^{-10} coulomb it has 6.24×10^{8} electrons more than are needed to neutralize its atoms The coulomb is the unit of charge in the mks system of units *See* COULOMB COULOMB'S LAW ELECTRICAL UNITS

The surface charge density σ on a body is the charge per unit surface area of the charged body Generally the charge on the surface is not uniformly distributed so a small area ΔA which has a magnitude of charge Δq on it must be considered Then σ at a point on the surface is defined by

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta q}{\Delta A}$$

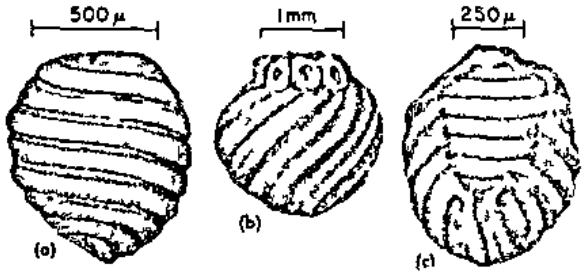
The subject of electrostatics concerns itself with properties of charges at rest while circuit analysis electromagnetism and most of electronics concern themselves with the properties of charges in motion *See* CAPACITANCE [R P WI]

Charles' law

A thermodynamic law, also known as Gay Lussac's law, which states that, at constant pressure, the volume of a fixed mass or quantity of gas varies directly with the absolute temperature Conversely, at constant volume, gas pressure varies directly with absolute temperature J A Charles and J L Gay Lussac independently discovered the relation for an ideal gas This experimentally determined relation is a useful and close approximation *See* GAS [F H R]

Charophyta

A group of small aquatic plants that have been limited to fresh and brackish water environments since the Early Devonian period The charophytes range from a few inches to several feet in height and live entirely submerged in quiet or slowly moving bodies of alkaline to mildly acidic water Their calcareous remains are widely distributed in nonmarine shales and limestones, and the group is useful in stratigraphic subdivision and paleoecological interpretation of these strata Modern forms provide an important source of food for wild fowl



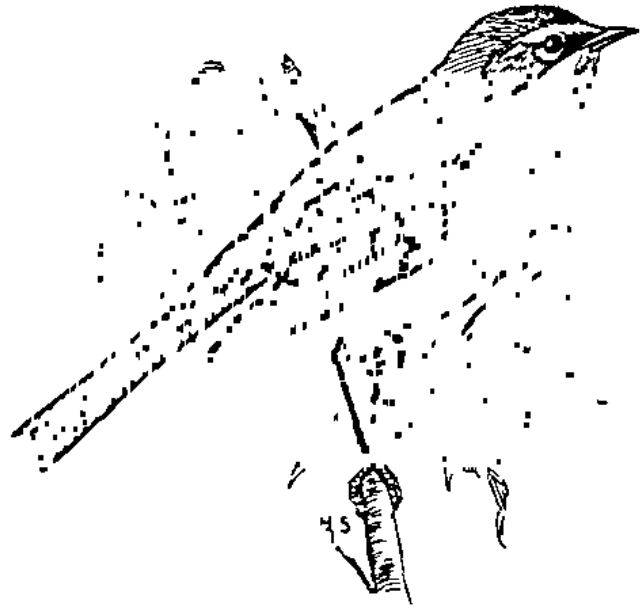
Charophyte gyrogonites (a) Charales (b) Trochili scales (c) Clavatoraceae

Charophyta are generally classified with the green algae, but their reproductive organs, antheridia and sporophydia (unfertilized oogonia), are so specialized that some systematists consider them a separate group Classification of fossil forms is based chiefly on the gyrogonites (see illustration), the small, approximately 1 mm diameter, calcified portions of the sporophydia Devonian and Mississippian gyrogonites are either sinistrally spiraled (Paleocharaceae), dextrally spiraled (Trochiliscales), or vertically ribbed (Sycidiales) Pennsylvanian to Recent gyrogonites are composed of five sinistrally spiraled units (Charales) An important group in the middle Mesozoic (Clavatoraceae) had the sporophydia enclosed in utricles of calcified spine cells *See* ALGAE, PALEOBOTANY [R E P]

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Chat

The yellow breasted chat, *Icteria virens*, is the largest member of the wood warbler family The chat strongly resembles an oriole A little over 7 in long, it is distinguished by olive green coloring above, a bright yellow breast and throat, a



The yellow breasted chat, *Icteria virens*, length to 7½ in (*From E L Palmer Fieldbook of Natural History, McGraw Hill, 1949*)

white belly, white "spectacles" and a long tail The chat is a bird of the underbrush and frequents blackberry thickets, brushy field borders, and similar areas It has a distinctive song of unusual, often harsh and explosive sounds which it frequently delivers as it hovers in the air or, more commonly, as it moves through a dense thicket or a tree top *See* PASSERIFORMES [J D B]

Cheese

There are many varieties of cheese, all produced in the following general manner Raw or pasteurized milk is clotted by acid, by rennet or by both (*see* RENNIN) The curd is cut and shaped into the special form of the cheese with or without pressing Salt is added, or the cheese is brined after pressing

All varieties of cheese, except processed cheese, are produced by a lactic acid fermentation This fermentation is initiated by the addition of a culture of lactic acid bacteria (starter culture) to the milk The souring of the curd prevents the growth of bacteria that will cause a putrefaction of cheese protein Moreover it favors the expulsion of the whey and the fusion of the curd particles Fresh cheese (cottage or cream cheese) does not require any ripening and it is sold soon after it is made Other varieties of cheese are cured or ripened to obtain the desirable consistency, flavor, and aroma The flavor and aroma of cheese are obtained by a partial breakdown of milk proteins and fat by the

action of microbial, milk, and rennet enzymes In hard varieties of cheese (Cheddar, Gouda, Edam, Emmentaler or Swiss, Provolone) this is done by the microorganisms in the interior of cheese, in semisoft or soft cheeses (Limburger Camembert, Roquefort) by the organisms on or in contact with the surface of cheese *See* MILK

CHEESE MICROBIOLOGY

Starter cultures. Lactic acid starter cultures are of great importance in the cheese-making process Different types of lactic acid bacteria are used depending upon the kind of cheese The starter (both single and mixed strains of bacteria are used) must convert all milk sugar left in the curd into lactic acid within a reasonable time Several factors are known that may prevent this such as the occurrence of natural inhibitors in milk, the presence of chemicals used for the disinfection of utensils, antibiotics and bacteriophages Some antibiotics (for example nisin) which affect the activity of the starter culture may be produced by microbes in the milk Others may be excreted into the milk by cows treated for a particular disease, this happens for example if penicillin is used to treat mastitis Bacteriophages or phages are viruses which lyse sensitive bacterial cells and produce new phage particles Phage particles active against *Streptococcus lactis* are sperm shaped *See* ANTIBIOTIC, BACTERIOPHAGE, STREPTOCOCCUS

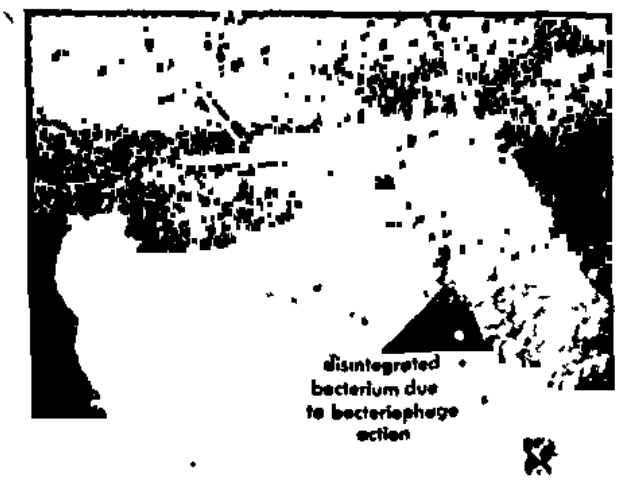


Fig 1 Electron photomicrograph of *Streptococcus lactis* attacked by bacteriophages

By the action of phage particles the activity of the starter culture is slowed down or totally inhibited This causes insufficient souring and thus spoilage of the cheese Phage may get into the milk with infected starter cultures or through contamination with phage-carrying dust particles Phage multiplication is influenced by such factors as temperature, pH, and calcium content of the medium Phage outbreaks cause serious economic losses They can be controlled by rigorous hygienic handling of starters, by culture rotation or by culturing starters in calcium free media Attempts to isolate phage resistant strains have not met with success

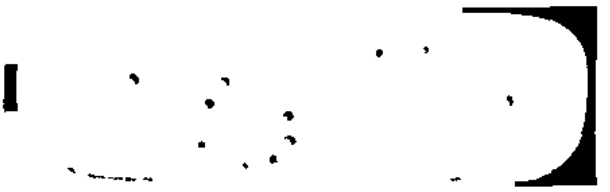


Fig 2 Gouda cheese Normal eye formation

Flora of cheese. Cheeses of the hard type contain lactic acid streptococci and other bacteria present in the starter Moreover, they contain all the microorganisms originally present in the raw milk or pasteurized milk The types of bacteria most important for the curing process are the lactobacilli, micrococci, and propionic acid bacteria They, together with the enzymes of rennet and milk break down the proteins to peptides and amino acids hydrolyze the milk fat to fatty acids, and frequently produce carbon dioxide gas which gives the holes or eyes to the cheese During the ripening process, the structure of cheese is greatly changed

In semisoft and soft cheeses the lactic acid originally produced by the starter is broken down afterward by molds, yeasts and bacteria on the surface The same flora decomposes the protein and the fat to a much greater extent than in hard cheeses As a result, strong flavors are produced and the structure of the cheese becomes much softer For the production of blue veined cheese, needles are pushed into the interior to bring the molds, added during the manufacturing of the cheese into contact with air they need for growth The blue color is the color of the mold spores The red color on the surface of some soft cheeses is caused by *Brevibacterium* (*Bacterium*) *linens* and micrococci To get a good surface growth, the soft cheeses must be cured in a high humidity environment such as in caves or air conditioned rooms

Defects of cheese. In hard cheeses an abnormal gas formation is a problem It can occur at almost any stage of manufacture or ripening Early gas production (blowing) is nearly always caused by coliform bacteria Late blowing may be caused by propionic acid bacteria or more often by butyric



Fig 3 Late blowing in Gouda cheese



Fig 4 Blowing of process cheese

acid bacteria (*Clostridium tyrobutyricum*) Milk is often contaminated with *Cl tyrobutyricum* by the feeding of bad quality silage Gas formation can be prevented in most cases by the addition of nitrate or of an antibiotic such as nisin Other defects of hard cheeses are excessive acidity various off flavors discolorations and the presence of white particles Soft cheeses are sometimes spoiled by improper development of the surface flora or contamination with atypical molds

Process cheese This type is made by blending cheeses of different ages melting the ground mixture with the aid of emulsifying salts such as citrates and polyphosphates and packing the hot viscous cheese mass in sealed containers (tins paper board foil plastic) Few bacteria other than spore formers survive the heat treatment No substantial growth of the flora takes place in well preserved process cheese but spoilage may occur by anaerobic sporeformers *Cl sporogenes* causes putrefaction and slit openness *Cl tyrobutyricum* causes blowing of tins and packages Factors such as acidity and salt content are highly important in controlling spoilage In addition the antibiotic nisin is very effective [J W P]

CHEESE MANUFACTURE

Because of different environmental conditions various methods of making cheese have developed There are about 18 distinct varieties of cheese and over 400 different names The commonly recognized varieties are brick caciocavallo Camembert Cheddar cottage cream Edam Emmentaler Gouda Gruyere Holstein Limburger Neufchatel Parmesan Roquefort sapsago Scanno and Trappist

Ripened cheese In commercial manufacture in the United States a culture of the desired bacteria is added to clarified pasteurized milk Usually rennin is introduced to facilitate whey separation It also functions during the ripening of the cheese Curd shrinkage and its separation from the whey is brought about by the developed lactic acid the action of the rennin enzyme and the application of heat If low moisture cheese is desired the curd is cut into small cubes and acid is developed early in the process the curd is heated to a fairly high temperature and is subjected to a relatively high pressure The opposite of these conditions will pro

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pending on the variety being made

Ripening a critical part of cheese making results in breaking down the rubbery texture of the fresh curd to a softer smoother and less plastic body During ripening the desired flavor characteristics of a particular variety are developed The composition of the curd and the conditions under which it is held determine the nature and extent of the enzymic action responsible for body and flavor changes

The chemical changes taking place during cheese ripening have to do in part with a breakdown of the lactose to lactic acid volatile acids and alcohol From lactic acid are formed acetic acid propionic acid and carbon dioxide The protein in the cheese is hydrolyzed to form proteoses peptones peptides and amino acids The amino acids may be broken down to amines and carbon dioxide The extent of protein breakdown determines the character and nature of the finished cheese In fully ripened Limburger the protein breakdown is nearly complete but in Cheddar cheese only about one-third of the protein is changed

Hydrolysis of cheese fats may yield volatile butyric caproic caprylic and capric acids In making Roquefort cheese the molds that are introduced into the curd produce lipase which hydrolyzes the fat and the fatty acids are further oxydized by the molds in part to methyl ketones substances responsible for the characteristic flavor and aroma of this cheese

For ripening most hard cheeses the desired environment favors activity of the microorganisms and enzymes within the cheese itself and discourages surface growth For soft cheese varieties such as Limburger the growth of organisms at the surface

not require surface ripening are usually protected against surface evaporation and contamination by

veloped by the growth of starter and by adding rennet The curd is separated from the whey by cooking and then is drained and salted

smooth firm body Pimentos or fruit such as pine apple may be added

These cheese making processes are completed within 24 hours Creamed cottage cheese usually contains 4% fat Cream cheese contains a minimum of 33% fat and a maximum of 55% moisture A small amount of gum is sometimes added to cream cheese to improve the body These cheeses contain about 1% salt

Cream cheese The cold pack method of manufacturing cream cheese follows

1 Milk is standardized with cream to a fat content of about 15% pasteurized by heating to 62 8°C for 30 min cooled to 48 9°C, and homogenized at 1500 lb pressure About 2 3 lb of a good starter and 0 33 oz of a properly diluted rennet extract are added to 1000 lb of milk

2 When the pH is 4 5–4 4 the curd is stirred and heated to 46 1 51 7°C in 45–60 min

3 The heated curd is placed in muslin bags and stacked in stainless steel cheese vats for drainage

4 After sufficient drainage the curd is dumped into a mixer and 1% salt is added

Cheddar cheese Cheddar cheese was originally made from raw milk The more modern procedure involves the use of pasteurized milk

1 The milk is set at 30°C with 0 5–1 0% starter A small amount of cheese color is added

2 Usually after about 45 min the acidity test shows an increase of 0 01% and 2 5–4 0 oz of rennet per 1000 lb milk is added to firm the curd in 25–30 min

3 When properly firmed the curd is cut into 0 25-in cubes and heated slowly to 37 8–38 9°C. The combined effect of heat acid and rennin determines the rate at which the whey separates from the curd Slow stirring is continued for 10–15 min after the maximum temperature is reached to prevent the curd from matting When the curd is properly firmed the whey is removed

4 As the whey drains away the curd begins to mat The two long slabs of curd one on each side of the vat are cut into blocks and occasionally turned to facilitate draining When the whey has reached an acidity of 0 4–0 45% the curd is ready to be milled

5 The matted curd is cut with a curd mill into pieces about 2 in long and ½ in square After milling 1.5% salt is added

6 The salted curd is placed in metal hoops and put in a cheese press under pressure to cement the small particles together

7 After removal from the hoops the cheese is placed in a cool dry room for 3 or 4 days to form a surface rind It is then dipped into melted paraffin and placed in the curing room

Steps 4 and 5 have been mechanized The whey is drained continuously then the curd is hydraulically pressed into one large block where it is held while desired acidity develops The laborious manual cheddaring operation is replaced by this step

variation in the conventional procedure is known as the Ched o-Matic system It produces a cheese equal in quality to that made by the conventional method and reduces both the production time by 1 hour per vat and the cost by 1 cent per pound

Some Cheddar is made with a plastic film coating instead of a rind Cheese treated in this manner is made into rectangular blocks and prepared in small packages for consumer use

The cheese may be cured at 0–4 4°C for 3–4 months and then placed at a lower temperature for further curing Ordinarily a minimum of 1 year is required to develop the flavor and body characteristic of good Cheddar cheese

The Federal standard in the United States for Cheddar cheese is a minimum fat content of 50% of solids and a maximum moisture content of 39%

Swiss cheese (wheel) The Federal standards for Swiss cheese specify a minimum of 43% milk fat in the dry matter and a maximum of 41% moisture To obtain the desired fat to total milk solids ratio it is usually necessary to standardize the fat by removing a portion of cream from the whole milk to be used

1 Special copper kettles holding 2500 lb of milk are used for setting the milk A small amount of starter is added to each kettle as follows 0 5–2 lb *Lactobacillus* 0 5–2 lb of *Streptococcus thermophilus* and 0.5–2 oz of *Propionibacterium shermanu*

2 The milk is warmed to 31 1–34 4°C and 1.5–3 0 oz of rennet diluted 40 times with cold water per 1000 lb of milk is added The curd should be firm enough to cut in about 20 min Movement of the milk in the kettle is stopped as soon as the rennet is mixed with the milk

3 The curd is cut with a special device called a Swiss-cheese harp Within 5 min after the curd is cut it is harped by moving the harp to and fro with an elliptical motion This is continued until the particles are slightly larger than a grain of wheat This is usually completed in 15 min from the time of cutting

The curd is then "foreworked" by operating the mechanical stirrer for 30 min or less This causes the curd particles to shrink as the whey is expelled and become firmer

4 After foreworking the curd is slowly cooked in the kettle to 48 9–53°C. Usually 30 min is required for this step The curd is stirred constantly during cooking and for about 1 hour after the steam is turned off in the kettle This is termed "stirring out." When the curd is sufficiently firm and crumbly it is ready to be dipped

5 For dipping the curd a large coarsely woven cloth supported at the edge with a flexible steel strip is used The cloth is passed under the entire mass of curd without breaking the curd or turning it over The metal strip is then removed and the edges of the cloth are brought together and tied The bag of curd is hoisted free of the kettle and the whey is permitted to drain into the kettle

6 The drained bag of curd is lowered into a circular stainless steel hoop on a drain table The curd is forced gently into the hoop and the edges

of the cloth are folded over the top Pressure is applied from above by a screw press In about 5 min the curd is ready to be dressed

7 At definite intervals the cheese is redressed and turned This requires about 9 hours Then the cheese is left in the press overnight without dressing except for a flat layer of burlap on the top and bottom

The temperature in the manufacturing room is kept at 21 1–23 9°C to prevent the interior of the cheese which at time of dipping is 48 9–50°C, from cooling too rapidly

8 After remaining in the press overnight the cheese is removed from the hoop and placed in a brine tank in a 12 8°C room in which the relative humidity is 80–85% The brine is a 23% solution of sodium chloride in water After 2–3 days the cheese is placed on a shelf in the cold room for 7 10 days

9 To cure the cheese the wheels each weighing about 175 lb, are placed in a warm room) 20–23 3°C 80–85% relative humidity) Two or three times a week the cheese is turned over and salt is rubbed into the surface As ripening progresses, the eye formation typical of Swiss cheese begins The rate of eye formation indicated by the amount of bulging can be regulated to some extent by the shelf location in the curing room and the amount of salt worked into the surface of the cheese If the curing proceeds too rapidly the wheel is kept on the cooler lower shelf and more salt is applied To the discriminating cheese buyer the size and distribution of the eyes are very important

After 4–6 weeks the cheese will have risen sufficiently and the wheel is returned to the cold room graded and sold At least 6 months is necessary to develop the desired Swiss flavor During this time a thick rind forms on the surface

Several modifications of the traditional procedure have been developed These involve such changes as setting the cheese in rectangular vats and processing the curd into small square blocks and curing it without rind

Limburger cheese Limburger is usually made from pasteurized milk A small amount of lactic starter 0 1–0 2% of the volume of milk and rennet sufficient to set the curd in 40 min are added The setting temperature is 32 8 35 6°C The curd is cut into ½ in cubes stirred for a short time and placed in perforated rectangular metal frames for pressing and draining When sufficiently firmed the curd is cut into 1 to 2 lb blocks

Salt is rubbed into the surface of the curd and the blocks are stored at 15 6–20°C 90–95% humidity They are rubbed daily with dry salt to close openings on the surface and to distribute evenly the ripening microorganisms which grow abundantly in the room A reddish slime soon develops on the surface After about 2 weeks the blocks of curd are wrapped in parchment and foil and stored at 10°C and the ripening is continued The cheese is ready for market in 6–8 weeks

The Federal standard in the United States requires a minimum of 50% fat in the solids and a maximum moisture content of 50% The finished cheese will contain 1 5–3 0% salt

Blue cheese The original of the blue cheese group is probably Roquefort which is made from sheep's milk in southern France The use of the term Roquefort is copyrighted by French manufacturers A similar type of cheese is made from cow's milk and called by different names such as blue, bleu Stilton (English), and Gorgonzola (Italian) The English and the Italians sometimes use goat's milk also in making blue cheese

The composition of these cheeses varies but in general they contain 30–32% fat 41–43% water and 4–5% salt The U S Federal standard is a minimum fat content of 50% of the solids and a maximum moisture content of 46%

Manufacturers of the various types of blue cheese have different methods of processing In the United States pasteurized homogenized milk is ordinarily used From 2 to 3% lactic culture and from 3 to 4 oz rennet per 1000 lb milk are added The setting temperature is 30°C When the curd reaches the proper firmness in 1–2 hours it is cut separated from the whey salted (1 0–1 5%) and put into metal hoops 8½ in in diameter and 3½ in high The time of adding the spores of *Penicillium roqueforti* varies Some cheese makers add them at the time of salting some mix them with the curd when filling the hoops and a few add the mold to the milk before curdling

The spores are prepared by growing the mold on cubes of sterile whole wheat bread After the mold growth is sufficiently developed the bread cubes are dried and powdered The amount needed for inoculation is 2 4 g/1000 lb of milk

The hoops are placed on a draining rack without pressure and are turned occasionally to facilitate drainage of the whey and matting of the curd The drainage takes place at room temperature The next day the cheese is removed from the hoops and salted in a 8 9°C room with a relative humidity of 80–90% The salting is done either by dipping in brine or by the application of dry salt and is continued for about 1 week or 10 days

After drying for 2–3 days the cheese may be paraffin coated and then punctured with long needles to admit the air needed for mold growth and to permit carbon dioxide to escape Cheese not coated with paraffin develops a slimy surface growth which must be removed occasionally This results in a loss of about 7–8% of the cheese The cheeses are stored on their sides at a temperature of 8 9–12 2°C and 95 98% humidity

After about 3 months the cheeses are cleaned wrapped in foil and stored for an additional 1 2 months or until the desired flavor and body are obtained The proteinase formed by *Penicillium roqueforti* is active at pH 5 3–7 0 with its optimum activity at about pH 6 0

Process cheese Process cheese is a term applied to those cheese products that have been heated and packed into sealed containers The term unqualified by any variety name is understood to mean process Cheddar cheese

A wide variety of materials can be used in making the cheese Usually aged and unaged cheeses of the same or different varieties are blended to obtain a mild but distinct flavor The cheese is trimmed comminuted and then heated The mixture is heated to at least 65 6°C for 30 min and run into glass tumblers plastic containers or foil lined cartons which are sealed to exclude air

Sodium citrate and disodium phosphate are added to dissolve the protein and emulsify the fats High test sweet cream nonfat dry milk solids and water may be added to produce a cheese with a desired total solid to fat ratio

Packaging processed cheese increases its keeping time Blending cheeses of different ages results in a more uniform product Mixing different cheese varieties provides an almost limitless number of blends Additional substances such as fruits and spices may be added at the time of mixing and pathogenic microorganisms may be destroyed during the heating process

The following standards in the United States have been established for pasteurized process cheese products (1) in pasteurized process cheese made of cheese cream emulsifying material salt and acid not more than 40% moisture and not less than 50% fat must be present (2) in pasteurized process cheese food in which additional solids from milk skim milk cheese whey or whey albumin are used the moisture content must not exceed 44% (3) in pasteurized process cheese spread which contains the same basic ingredients as pasteurized process cheese sweetening agents and not more than 0 8% of stabilizer the moisture content must not exceed 60% and the fat content must be at least 20% [PHT]

Bibliography E M Foster F E Nelson M L Speck R N Doetsch J C Olson *Dairy Microbiology* 1957 G P Sanders *Cheese Varieties and Descriptions* USDA Handbook 54 1953 G P Sanders H E Walter and R T Tittsler *General Procedure for Manufacturing Swiss Cheese* USDA Circ 851 1955 A L Simon *Cheeses of the World* 1956 L L Van Slyke and W V Price *Cheese* 1949

Cheilostomata

An order of the ectoproct Bryozoa having 82 families and 649 genera and subgenera (R Bassler) Extending from the Middle Jurassic to the present it is the dominant bryozoan order today The colonies exhibit various growth forms including crusts free lamellae or reticulate fronds The Cheilostomata are divided into two suborders by some authorities on the basis of the presence of an ascus or compensatory sac which functions in the extension or retraction of the polypide The suborder Anasca lacks an ascus the ascus is present in the suborder Ascophora

The zooecia are mostly short boxlike and arranged side by side and serially with walls touching Walls may be membranous or chitinous but in most species they are calcareous The frontal wall is sometimes beautifully sculptured a diagnostic feature The lateral and distal walls are perforated permitting communication between body cavities of neighboring zooids Mesenchymatous strands extend through these perforations Each zooid has a hydrostatic apparatus consisting of either a flexible membranous frontal area or a special compensation sac (Fig 1) depending upon the species This regulates the internal body cavity pressure during the retraction or protrusion of the polypide Tentacles are extruded or withdrawn

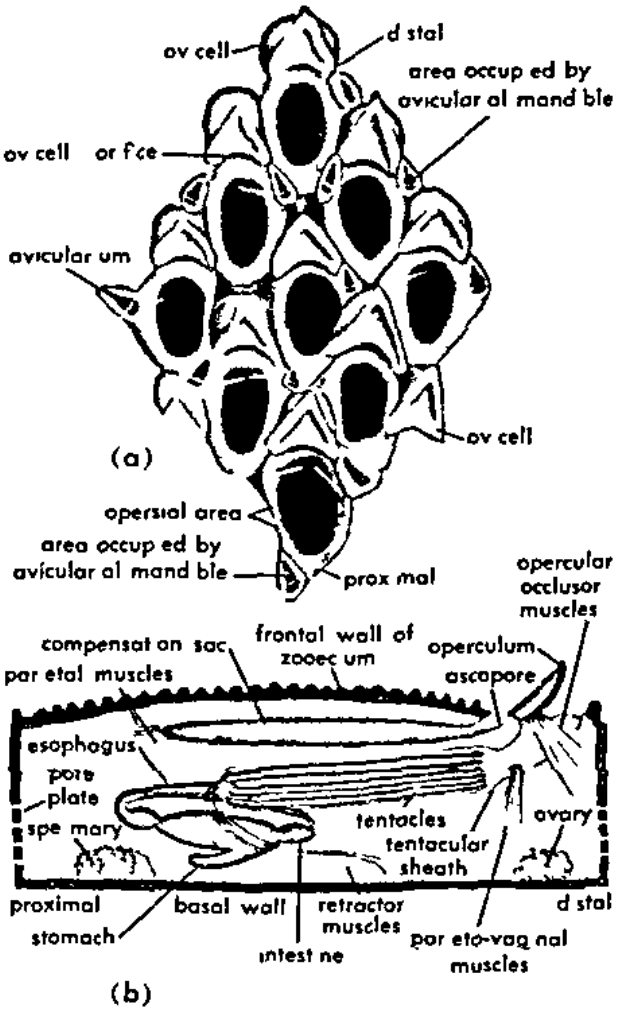


Fig 1 Cheilostome morphology (a) Portion of *Callopora aurita* colony showing the calcareous skeleton of nine ovicelled zooecia *Callopora* is an encrusting bryozoan of the Anascan *Membranipora* type Anascans lack a compensation sac but the frontal membrane plays the hydrostatic role (b) Cut-away diagram lateral view of a single ascophoran type zooid Ascophoran cheilostome Bryozoa with a compensation sac

through the zooecial orifice which is closed by a hinged operculum in a drawbridge fashion (Fig 2) Many species have special chambers the ovicells or ooecia which are internal or external for the incubation of larvae Only one larva occurs in each ovicell Polymorphism or presence of several types of individuals such as gonozooids autozooids kenozooids avicularia and vibracula are common but

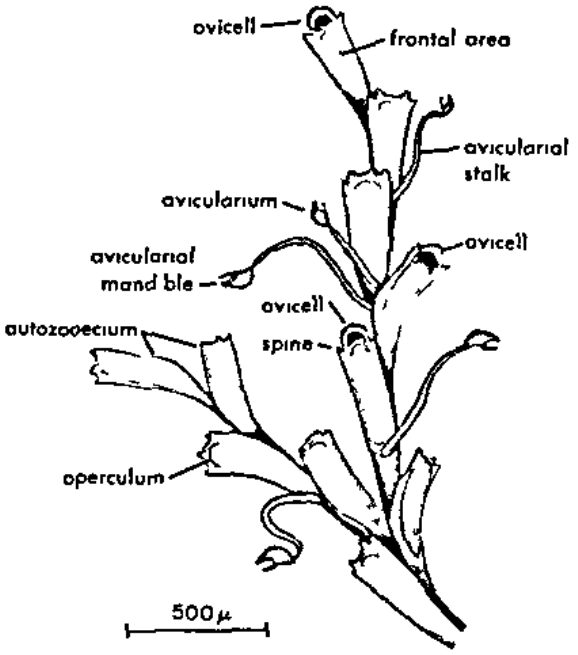


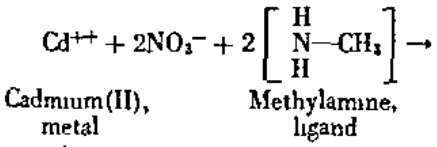
Fig 2 *Bugula abyssicola*, a chitinous, dendritic, anascan cheilostome

not all types occur in each species *See* BRYOZOA, BRYOZOA FOSSILS [M D RO]

Chelation

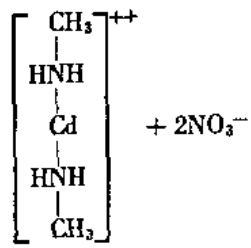
A chemical process involving the formation of a heterocyclic ring compound which contains at least one metal cation (or hydrogen ion) in the ring Metal chelate compounds are a subdivision of the broader group of complex substances known as Werner coordination compounds *See* COORDINATION CHEMISTRY

The process of Werner complex formation can be illustrated by the reaction in water solution between cadmium nitrate, $Cd(NO_3)_2$, and methylamine



Cadmium(II), metal cation

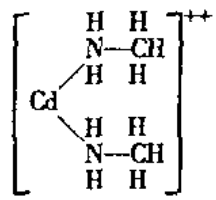
Methylamine, ligand



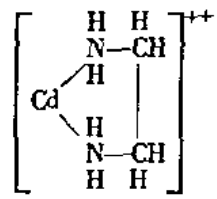
Bismethylamine cadmium(II) complex metal cation

Structural information first interpreted properly by Alfred Werner in 1891 indicates that the metal cation (M^{++}) is joined directly to the nitrogen of the amine molecule The molecule ion or group bound to the metal cation is known as a ligand Current electron theory assumes that the bond between ligand and cation is formed by the free electron pair on the donor atom of the ligand (that is, the nitrogen of the methylamine). The electron pair may be represented by a pair of dots or by a line joining metal and donor atom, as in the equation above The entire process is referred to as coordination, and the electron pair gives rise to a coordinate bond Since two methylamine molecules are bound to the Cd^{++}, the complex is known as a bismethylamine cadmium(II) ion If three methylamine molecules were bound the complex would be trismethylamine cadmium(II) The symbol (II) following the cadmium indicates that the metal ion carries a formal positive electric charge of two into complex formation

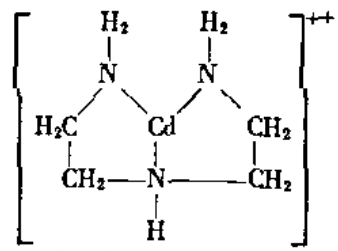
Ethylenediamine, $H_2NCH_2CH_2NH_2$, may be regarded in a formal sense as a molecule resulting from the linkage of two methylamine molecules through elimination of hydrogen between the two *methyl groups Coordination of both nitrogen atoms* to the same metal cation then would give a heterocyclic ring If a chelating agent (group which forms a chelate) has two points of attachment it is known as a bidentate ligand, if it has three, as in $H_2NCH_2CH_2NHCH_2CH_2NH_2$ it is tridentate, if four, it is quadridentate All chelating agents must be at least bidentate, tridentate agents give fused rings Even hexadentate ligands, giving multiple fused rings are known



Bismethylamine cadmium(II) complex, monodentate ligand nonchelated structure



Ethylenediamine cadmium(II) complex, bidentate ligand, one chelate ring

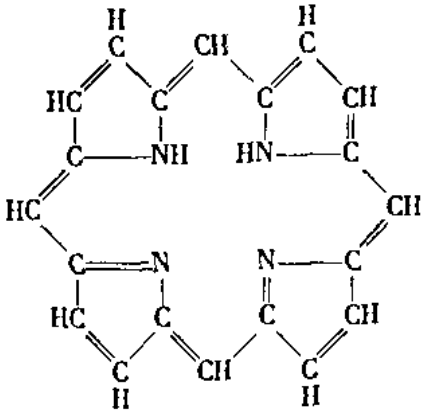


Diethylenetriamine cadmium(II) complex, tridentate ligand two fused chelate rings

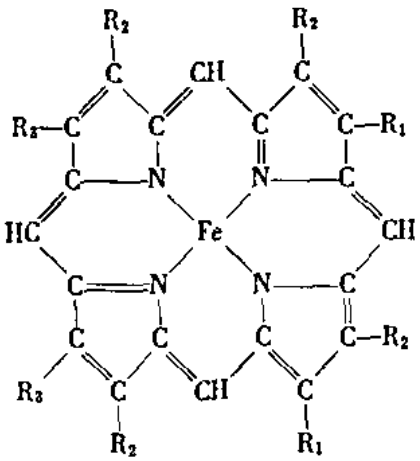
Because many of the functional groups of organic chemistry can form coordinate bonds to metal cations producing biologically active complexes chelate compounds are found in the border region be

are chelate compounds derived from the tetradentate porphin structure The metal phthalocyanines are synthetic chelate compounds of extraordinary

stability, and they are porphyrinlike in structure Furthermore, synthetic chelates which absorb and desorb oxygen reversibly, as does hemoglobin, have been prepared in the laboratory



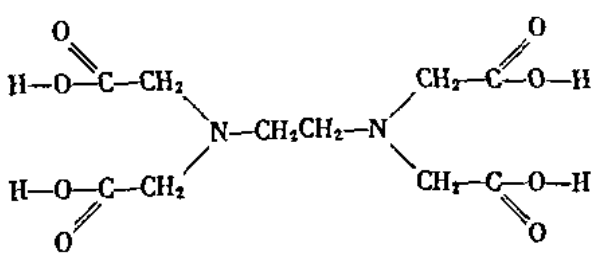
Porphin
tetradentate
chelating agent



R_1 = [CH=CH$_2$]
R_2 = [CH$_3$]
R_3 = [CH$_2$CH$_2$COOH]

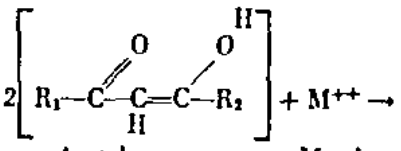
Hemin,
tetradentate
chelate of iron(II)

A rapidly developing body of experimental evidence indicates that chelation may be important in the pharmacological action of certain drugs and the use of chelating agents to remove certain toxic cat ions such as lead and plutonium from the body is now widely recognized in medical practice The ability of chelating agents to reduce the chemical activity of certain metal cations has found exten sive application in many areas of science For ex ample, the hexadentate chelating agent, ethylene diaminetetraacetic acid or EDTA,



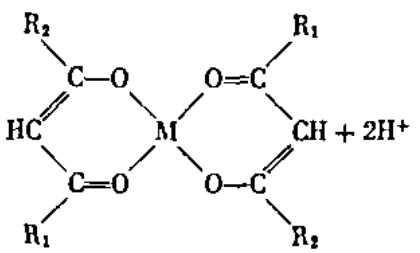
has found a wide commercial market Chelating agents of related type have been used in biological systems to produce metal ion buffers By proper se lection of a chelating agent, free metal ion concen tration can be maintained at a relatively constant level in a predetermined range, just as relatively constant hydrogen ion concentration can be main tained in a conventional hydrogen ion buffer system Furthermore, certain chelating agents change color according to the metal ion concentration in a man ner completely analogous to the pH dependent color changes observed with acid base indicators, these agents serve as metal ion indicators in analytical chemistry The solubility of many chelates in or ganic solvents permits their use in solvent extrac tion for the separation of metals The separation of zirconium and hafnium one of the oldest and most difficult separation problems in inorganic chemis try can be effected by using thenoyl trifluoroace tone as the chelating agent Finally, many commer cial dyes are chelate compounds

One of the most striking properties of chelate ring compounds is their unusual stability In this respect they resemble the aromatic rings of or ganic chemistry For example β diketones in the enol form can lose a hydrogen ion and coordinate with a metal cation to give a 6-membered ring of unusual stability



Acetylacetone
enol form,
H(acac)

Metal
cation



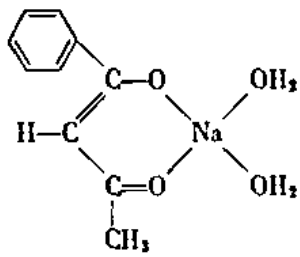
Metal acetylacetonate,
M(acac)$_2$

Beryllium acetylacetonate boils without decomposi tion at 270°C, and G T Morgan reported that

of coordination compounds containing simpler mo nodentate ketones such as acetone Since about 1940 both theoretical and practical considerations have focused attention on the factors which con tribute to chelate stability It is convenient to list such factors under three headings (1) those re lated to the nature of the metal cation, (2) those related to the nature of the ligand and (3) those peculiar to the formation of the heterocyclic ring

Role of metal in chelate stability. The ability to form chelate complexes is common to many metal cations Although the small, highly charged cations generally form the most stable complexes, chelates of even the large alkali and alkaline-earth ions are known The dihydrate of sodium benzoyl acetone is considered to be a chelate of the probable formula shown, since the properties of the

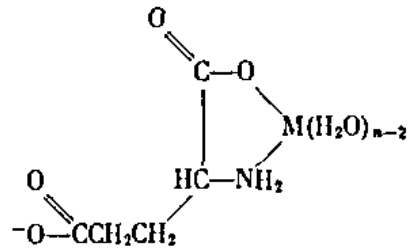
use ethylene-diaminetetraacetate in water softening because of its ability to form stable chelates with Ca^{++}, Mg^{++}, *and* Fe^{++}



Sodium benzoylacetone

Since nitrogen, oxygen and sulfur serve as the actual electron donor atoms in a majority of chelating agents, it is of interest to seek a relationship between the donor atom and the type of metal acceptor atom with which it combines A large majority of the chelates of Li^+, Na^+, K^+, Rb^+, Cs^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Al^{3+}, Ga^{3+}, In^{3+}, Tl^{3+}, Ti^{4+}, Zr^{4+}, Th^{4+}, Si^{4+}, Ge^{4+}, and Sn^{4+} contain oxygen as at least one of the donor atoms It may be furnished as an acid, alcohol, ether ketone or other group These ions coordinate less frequently through two nitrogen or sulfur atoms Cations of other metals such as vanadium, niobium, tantalum, molybdenum and uranium, and the cations Be^{2+}, B^{3+}, and Fe^{3+} show a preference for oxygen as the donor atom, but they may coordinate through nitrogen, sulfur, or phosphorus under proper conditions Cr^{3+}, Fe^{2+}, and the platinum metals show increasing preference for coordination through nitrogen as opposed to oxygen while Cu^+, Zn^{++}, Ag^+, Au^+, Cu^{2+}, Cd^{2+}, Hg^{++}, V^{3+}, Co^{3+}, and Ni^{2+} show a marked preference for nitrogen and sulfur as the donor atoms The ions of the latter group retain the ability to coordinate with oxygen in even greater degree than do the ions of the first group but their tendency to form bonds through nitrogen is so great that it exceeds their oxygen bonding propensity

It must be recognized that broad generalizations such as the above will have many exceptions particularly in intermediate regions On the other hand such generalizations indicate clearly that attempts to arrange elements in the order of their chelating ability can be of significance only when cations of comparable type are selected Thus the stabilities of the alkali metal, the alkaline earth, and the rare-earth chelates decrease as the charge on the cation decreases or as the size of the cation increases For example, the glutamic acid chelates of the metals in group IIa of the periodic table



become less stable as the M^{2+} ion gets bigger in the order Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+} The symbol n denotes the coordination number of the metal ion, the number of nearest donor atoms around it The relationship between ion size and chelate stability is of major importance in the separation of the rare earth and transuranium elements by ion exchange processes The selectivity of the ion exchange column is increased by the use of appropriate chelating agents in the eluting liquid

Arranging the other metal cations in order is somewhat less satisfactory Metal chelates of several substituted β diketones decrease in stability in the order

$$Hg^{++} > (Cu^{++}\ Be^{++}) > Ni^{++} > Co^{++} > Zn^{++} > Pb^{++} > Mn^{++} > Cd^{++} > Mg^{++} > Ca^{++} > Sr^{++} > Ba^{++}$$

Decreasing stability of chelates

If one restricts stability comparisons to bivalent metals of the first transition series, the following order is obtained

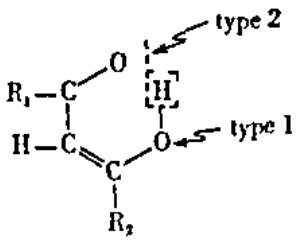
$$Cu^{++} > Ni^{++} > Co^{++} > Fe^{++} > Mn^{++}$$

Decreasing stability of chelates

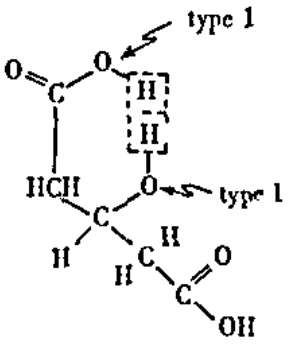
This latter listing of stabilities appears to be valid for virtually all chelating ligands

Role of ligand in chelate stability. Two general types of groups give rise to coordinate bonds between ligand and metal These are (1) primary acid groups in which the metal ion can replace an acid hydrogen, and (2) neutral groups which contain an atom with a free electron pair suitable for bond formation If two groups either from class 1 or 2 or from both classes are present in the same molecule in such positions that both groups can form bonds with the same metal ion, a chelate ring may be formed For example, in acetylacetone, groups of type 1 and 2 are present, in citric acid two groups of type 1 are present, and in ethylenediamine, two groups of type 2 are found

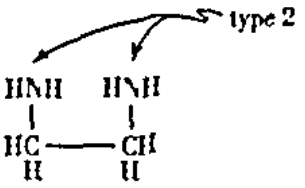
In general anything which increases the localization of negative charge on the donor atom increases its ability to coordinate to a metal atom Since a hydrogen ion is bound to a ligand by an electron pair in groups of type 1, an increase in electron density on the donor atom will increase the ability of the donor to bind either hydrogen ion or metal cation The ability of a ligand to bind hydrogen ion is frequently referred to as its basic strength It is not surprising then that, for ligands of rather similar type, an increase in ligand basic strength in



Acetylacetone



Citric acid



Ethylenediamine

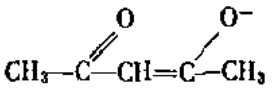
plies an increase in its metal chelating ability A number of research workers have indicated this relationship by plotting the log of the equilibrium constant for the process

$$HKe \rightleftharpoons H^+ + Ke^- \qquad K_1 = \frac{[H^+]\,[Ke^-]}{[HKe]}$$

against the log of the equilibrium constant for the process of chelate dissociation

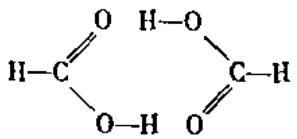
$$MKe \rightleftharpoons M^+ + Ke^- \qquad K_2 = \frac{[M^+]\,[Ke^-]}{[MKe]}$$

Ke is the chelating anion for example

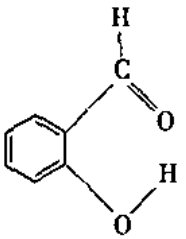


The latter equilibrium constant is referred to as the instability constant of the metal chelate MA (Its reciprocal is the stability constant for the chelate)

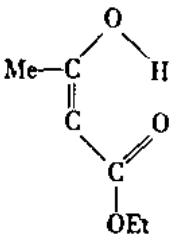
For the organic chemist the analogy between the hydrogen cation and the metal cation is even more clearly drawn Rings formed through a proton are now referred to as chelates thus formic acid dimerizes through hydrogen bond chelation to give the formula



and the properties of salicylaldehyde acetoacetic ester and many other organic compounds are al tered by internal chelate ring formation involving hydrogen bonds (*see* HYDROGEN BOND)

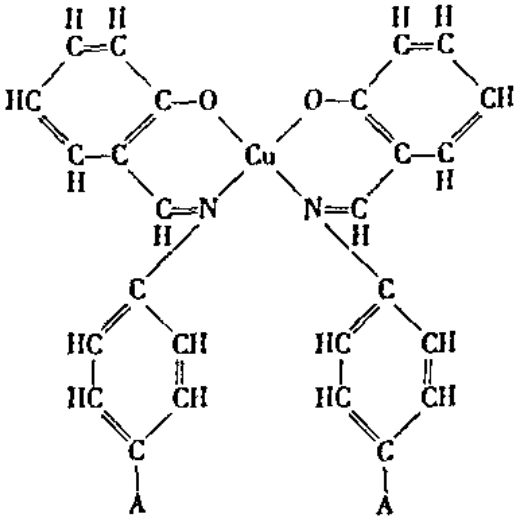


Salicylaldehyde chelate

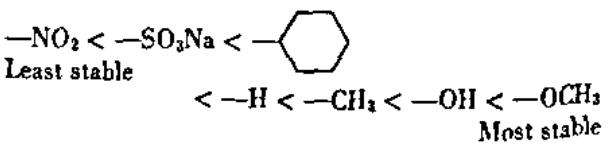


Acetoacetic ester chelate

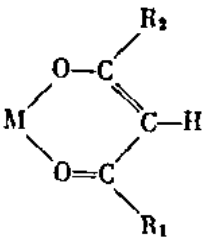
The role of ligand structure on chelate stability may be illustrated by studies which have been con ducted on compounds of the type



where A represents an electron attracting group In general it was found that with an increase in the electron attracting power of the group A elec trons were pulled away from the nitrogen atom resulting in both lower base strength and lower chelating ability for the ligand As A is changed successively through the groups listed below che late stability increases in the order



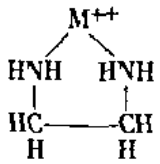
Similar studies on substituted β diketone chelates of the type



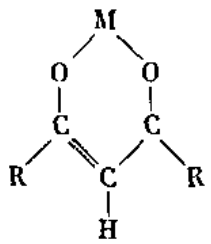
showed that if R_1 were changed from a methyl group to an electron withdrawing trifluoromethyl group the stability of the resulting chelate is

greatly decreased In general all molecular charge effects such as inductive and resonance effects which can be invoked to shift charge in an organic molecule will influence chelate stability, and all the usual advantages and problems of modern dav theoretical organic chemistry are found in any discussion of the relationship between ligand structure and chelate stability

Role of ring closure in chelate stability The stability factors discussed above are applicable to coordination compounds generally not to chelates alone On the other hand a number of stability factors may be considered to apply uniquely to chelates because of their ring structure These will be of immediate concern The most obvious variable in this category is ring size a factor which is uniquely determined by the position of the donor atoms in the chelating ligand When the groups are present in such a position as to form a 5 or 6-membered ring the resulting complex is most stable although 4- 7 8-membered and even larger rings are known The existence of 3-membered rings has not been established Hydrazine H_2NNH_2 which might in theory form a 3-membered chelate ring appears to be monodentate The 4-membered rings are frequently strained While 5 membered rings are very common and are formed preferentially by saturated organic ligands ligands containing two double bonds tend to form 6-membered structures If only one double bond is present 5- or 6 membered rings may form 5 membered saturated rings are illustrated by ethylenediamine-metal chelates and the unsaturated 6-membered units by the metal acetylacetonates



Ethylenediamine chelate saturated 5 membered ring



Acetylacetonate chelate unsaturated 6 membered ring

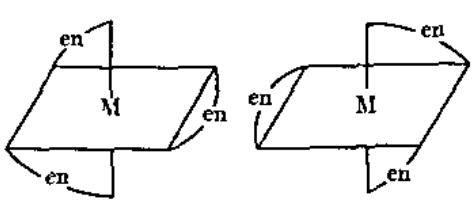
Rings of 7 or more members though comparatively uncommon are well established As the length of the chain between the two donor atoms increases so does the tendency of the ligand to form polymetallic complexes Under such circumstances the two donor atoms on the same chelate molecule coordinate with different metal atoms rather than with one thus a polymeric chain may result rather than a ring structure

$$M^{+}—NH_2CH_2CH_2CH_2CH_2NH_2—M^{+}$$

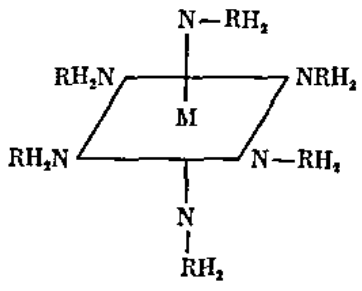
The fact that chelate complexes are usually more stable than comparable nonchelate structures has been called the chelate effect It is at least partly attributable to the fact that simultaneous rupture of both bonds holding the ligand to the metal is highly improbable and if only one bond breaks there is a good probability that the broken bond will reform before the second bond is ruptured As the chain length between the two donor atoms increases the chance for reformation of the second bond declines thus large rings usually show a decrease in stability On the other hand in fused ring systems formed by polydentate ligands such as ethylenediaminetetraacetic acid the probability that at least one bond will reform before all bonds are ruptured results in increased complex stability When the bonding atoms are rigidly positioned around the metal by the organic framework as in the porphins the resulting increase in stability is unusual It has been reported that the copper phthalocyanin complex with a completely interlocked ring system is stable in the vapor phase near 500°C

Finally steric hindrance the clashing of groups on two coordinated ligands will result in a reduction of chelate stability If clashing is severe with a cation of given size and bond arrangement complex formation may be completely impeded whereas another ion of different size and bond arrangement may be able to chelate with the ligand in question This phenomenon has been used to provide selective analytical reagents

Chelate compounds are differentiated from their nonchelate analogs by several properties besides high stability Although not all chelates are volatile by any means the existence of low boiling metal acetylacetonates and related structures is noteworthy If the coordination number of the metal cation for the oxygen atoms of the acetylacetone (that is the number of nearest oxygens around the cation) is equal to twice the ionic



Chelate complexes optical isomers



Nonchelate, optically inactive

charge of the cation the resulting acetylacetonate is volatile thus beryllium with a charge of 2 and a coordination number of 4 forms an acetyl acetonate which boils at 271°C aluminum with a charge of 3 and a coordination number of 6 forms an acetylacetonate which boils at 314°C If the coordination number of the central cation is less than twice the ionic charge nonvolatile saltlike complexes are formed Thus titanium with a charge of 4 and a coordination number of 6 gives a saltlike acetylacetonate of the form $[Ti(acac)_3]_x$

Isomerism of all types so important in organic chemistry is of major concern in chelation particularly to the biologist since desired biological properties are frequently restricted to a particular chelate isomer Ring formation may result in optical activity in cases where analogous nonchelate structures are inactive Thus the ethylenediamine chelate structures are optical isomers whereas the analogous methylamine complexes are optically inactive *See* CHEMICAL BINDING COMPLEX COMPOUNDS EQUILIBRIUM CHEMICAL STEREOCHEMISTRY STERIC EFFECT (CHEMICAL REACTIONS)

[R W P]

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Chelicerata

A subphylum of the phylum Arthropoda which includes the classes Merostomata Pycnogonida and Arachnida The first pair of ventral appendages the chelicerae is modified as pincers The body or opisthosoma usually consists of the cephalothorax and abdomen except in the Acarina in which these body parts are fused The cephalothorax is unsegmented in all but the solpugids or sun spiders In the solpugids six somites are present Four pairs of legs are common to most members of this group however some species of the pycnogonids or sea spiders have five or more pairs Locomotor appendages occur only in the Merostomata Respiratory structures include lung books gills and tracheae The sexes are usually separate with a single sex opening located anteriorly on the abdomen Fertilization is mostly internal and most species lay eggs Chelicerates are chiefly terrestrial and predaceous *See* ARACHNIDA MEROSTOMATA PYCNOGONIDA *see also* ARTHROPODA [C B C]

Chelonia

An order of the Reptilia including the turtles terrapins and tortoises This order is also known as the Testudinata The group first appeared in the Triassic and its representatives are among the commonest fossils from that time on Members of the order are most frequently found in fresh water streams lakes and ponds or in marshy areas However a number of strictly terrestrial species are known and several are marine Turtles occur on all the major continents and continental islands in tropic and temperate regions The marine forms are basically tropic in distribution but some individuals stray into temperate waters

Families of the Chelonia

	Common name	Number of species	Distribution
Suborder Pleurodira			
Family Pelomedusidae		14	Southern Africa Madagascar South America
Family Chelidae		32	Australia New Guinea South America
Suborder Cryptodira			
Family Dermatemydidae		1	Southern Mexico Guatemala Honduras
Family Chelydridae	Snapping mud and musk turtles	25	North Middle and South America
Family Cheloniidae	Hawksbill loggerhead and green turtles	5	Tropic and subtropic oceans
Family Dermochelyidae	Leatherback turtle	1	Tropic and subtropic oceans
Family Testudinidae		132	All continents except Australia only a few forms in South America
Family Carretochelyidae		1	New Guinea
Family Trionychidae	Soft-shelled turtles	14	North America Asia central and southern Africa

The largest carapace length attained by living forms is around 8 ft in the marine leatherback turtle *Dermochelys* which weighs 1500 lb Members of the large land tortoise group *Geochelone* reach lengths of 4 ft and weights of about 560 lb The smallest living species is probably the stinkpot *Kinosternon odoratus* of eastern North America which attains a maximum length of 4½ in The longevity of turtles is well known with many captive tortoises having lived 50–60 years and others estimated to be as old as 150 years

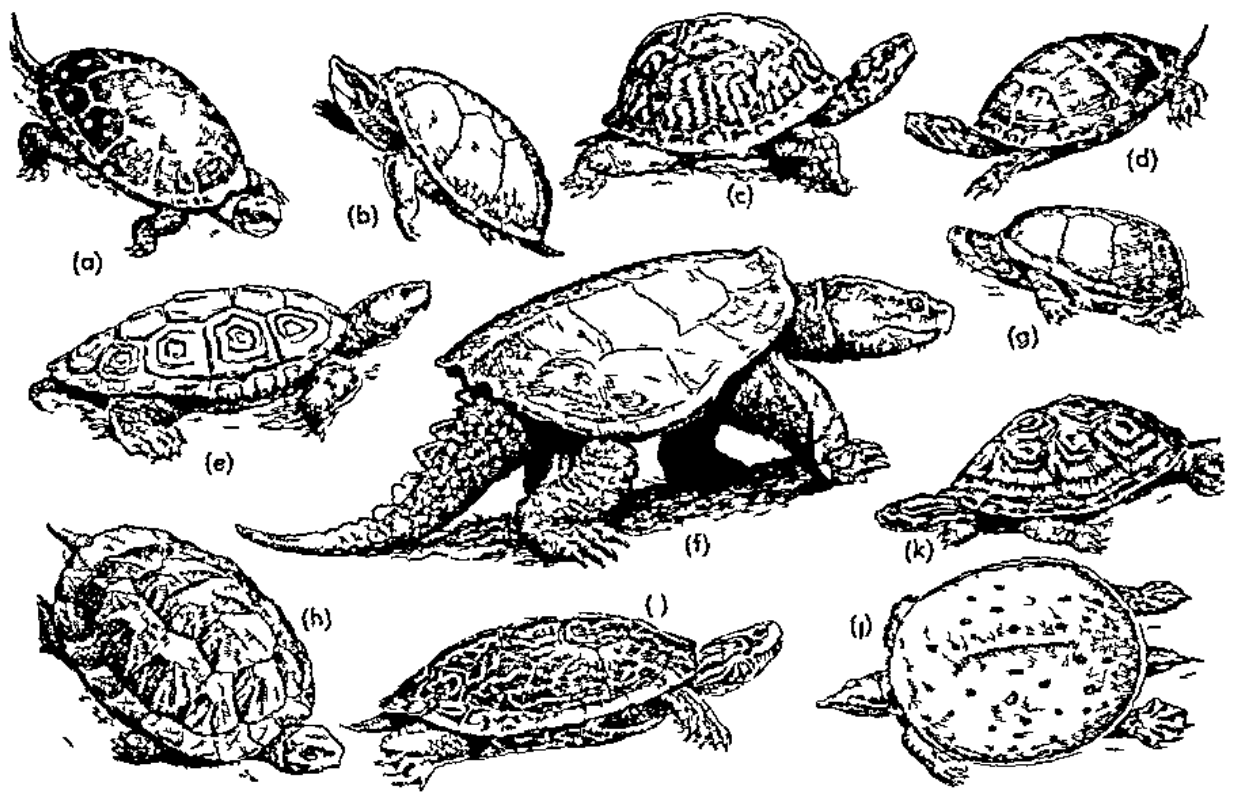
Taxonomy The living turtles are usually divided into two major groups the suborders Pleurodira and Cryptodira based upon the structure of the head and neck Both lines are thought to be evolved from primitive forms placed in the suborder Amphichelydia (Triassic to Eocene) This latter group differs most markedly from recent species in having elongate neural spines on the neck vertebrae so that the neck is not retractible into the shell Correlated with the lack of retractibility the skull is not *emarginated to make room for attachment of muscle* from the cervical region The pleurodires on the other hand have spines on only the most posterior cervicals and the head is retractile laterally The skull is emarginate In the cryptodires the cervical spines are uniformly reduced the skull is usually

emarginate and the head is folded directly back to within the shell. In several cryptodires, most notably in the marine turtles, the neck is secondarily nonretractible because of a reduction in the shell and the skull is nonemarginate.

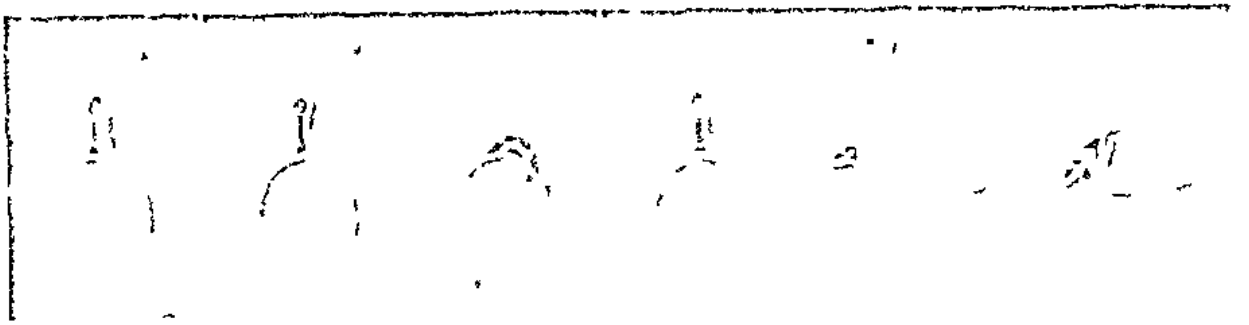
The following classification indicates the principal groups and distribution of the approximately 225 living species of the order. *See* TURTLE.

Morphology. The Chelonia differ from all other vertebrates in possessing a hard bony shell which encompasses and protects the body. The shell is made up of a dorsal portion, the carapace, and a ventral segment, the plastron, connected by soft ligamentous tissue or a bony bridge. The carapace is composed of the greatly expanded ribs and dorsal vertebrae overlain by a series of enlarged dermal ossifications and an outer covering of tough skin or horny scales. The plastron is similarly arranged with remnants of the interclavicle, clavicles, and gastralia fused with dermal ossifications and covered by skin or scales. Other peculiarities associated with the shell include the fusion of the ribs to the vertebrae and the reduction of trunk muscles, the presence of the pectoral girdle completely inside the ribs (found in no other animal), the highly modified short, thick humerus and femur, and the lungs attached dorsally to the shell. In addition, living turtles differ from the tuatara, snakes, lizards, and crocodilians in having an anapsid skull, no true teeth but horny beaks on the jaws, an immovable quadrate, and a single median penis in males. Teeth were present in ancient primitive turtles.

The rigid bony shell of turtles imposes upon them a basic body plan subject to relatively little variation. Turtles are always recognizable as such, and the principal obvious differences between them are in the shell, shape, limbs, head, and neck. The general outline of the shell is variable but in most forms it is moderately high arched and covered with epidermal scales. In some of the tortoises, like *Geochelone*, the shell is very high, being as high as broad. In the soft-shelled turtles, Trionychidae, and the saxicolous African tortoises, *Malacochersus*, the shell is greatly depressed to a thin, almost plate-like form. No scales are present on the shells of the families Dermochelyidae, Carettochelyidae, and Trionychidae, which are covered by thick skin. The majority of turtles have limbs more or less adapted to aquatic or semiaquatic life, with moderate to well developed palmate, webbed feet. However, in strictly terrestrial forms, such as the tortoises, the limbs are elephantine, with the weight of the body being borne on the flattened sole of the feet. The marine turtles and the river turtle *Carettochelys* of southern New Guinea have the anterior limbs modified into paddlelike flippers used to propel them through the water at a rapid rate.



Common United States turtles. (a) Spotted turtle, *Clemmys guttata*. (b) Stinkpot, *Kinosternon odoratus*. (c) Box turtle, *Terrapene carolina*. (d) Painted turtle, *Chrysemys picta*. (e) Diamondback terrapin, *Malaclemys terrapin*. (f) Common snapping turtle, *Chelydra serpentina*. (g) Mud turtle, *Kinosternon subrubrum*. (h) Wood turtle, *Clemmys insculpta*. ( ) Map turtle, *Graptemys geographica*. (i) Spiny soft-shelled turtle, *Trionyx spiniferus*. (k) River terrapin, *Pseudemys floridana*. (From J. J. Shomon, ed., *Virginia Wildlife*, 1[illegible])



Characteristics of turtle suborders

Physiology Associated with the tendency of most turtles toward a life in or near water is the auditory apparatus Even though an ear drum is present hearing is adapted to picking up sounds transmitted through the water or substratum although there is recent evidence that airborne sound can be heard Vision is also important and turtles have color vision Sounds are produced by many species through expulsion of air through the glottis Respiration is by means of the rather rigid lungs which are inflated and deflated by a series of special muscles Several species with aquatic habits have special vacularized areas in the mouth or cloaca which act as auxiliary respiratory devices and make possible gaseous exchanges when the turtle is submerged in water Most forms emit highly pungent

and diurnal and territoriality is unknown in the order

Reproduction The courtship patterns of various turtles are distinctive In general aquatic forms mate in the water but tortoises breed on land The male mounts the female from above and fertilization is internal Sperms may be stored in the cloacal region of the female for extended periods before fertilization Because of the presence of the large median penis in males the sexes of many species *can be distinguished by the longer and broader tail* of the male In addition in many forms the plastron of the male is concave while in the female it is moderately to strongly convex No doubt the characteristic of the female is associated with the spatial requirements for egg production and storage All turtles lay shelled eggs which are buried in sand or soil in areas where females congregate The shell is calcareous in most forms but the marine turtles have leathery shells Eggs are rather numerous as many as 200 being laid by a single individual in some species they are highly valued as human food Incubation takes from 60–90 days and the little turtle cuts its way out of the shell with a small horny egg caruncle at the end of the snout

Nutrition Turtles feed on all types of organisms Aquatic species may eat algae higher plants mollusks crustaceans insects or fishes terrestrial forms are similarly catholic in tastes Most species are omnivores but some have very specialized diets The edges and internal surfaces of the horny beaks of these reptiles are frequently denticulate and modified to form specialized mechanisms adapted to handle particular food items [J M S]

Chemical binding

The fundamental fact of chemistry is that elements such as oxygen hydrogen carbon and iron can combine to form compounds such as water methane and iron oxide with properties completely different from those of their components The description of this in terms of atomic theory is that atoms of the elements attach themselves to each other to form molecules This property that atoms possess of joining together to form molecules is known as chemical binding

Atoms contain electric charges—a small positively charged nucleus surrounded by a cloud of moving negatively charged electrons All chemical binding is caused by the mutual attractions and repulsions of these electric charges Other types of forces—gravitational magnetic nuclear—have negligible direct effect The electric forces are governed by Coulomb's law (*see* COULOMB'S LAW) On the other hand the motions and distributions of the electrons in the atoms are controlled by the laws of quantum mechanics

Chemical bonds are very strong To break one bond in each molecule in a gram mole of material *will typically require an energy of many tens of* kilocalories per mole Most of the energy used by man is chemical energy derived from changing chemical bonds in food or fuel

It is convenient to classify chemical binding into several types although all real cases are mixtures of these idealized limiting cases all of which are purely electrical

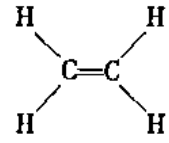
Ionic binding This is the simplest type of binding in which one or more electrons are transferred completely from one atom to another thus converting the neutral atoms into electrically charged ions These ions are approximately spherical in shape and attract one another because of their opposite charges The ions are drawn together until their spherical electron clouds sufficiently interpenetrate and repel one another to balance the force of attraction Molecules can consist of two or more such ions Many inorganic crystals can be considered as giant molecules made up of ions Thus common salt sodium chloride consists of a lattice of Na^+ ions

(positive sodium) each surrounded by six Cl ions (negative chlorine) and vice versa *See* IONIC CRYSTALS

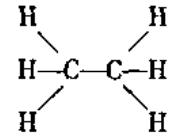
In a purely ionic compound or crystal the ions pack together in a geometrical arrangement which minimizes the total energy Since unlike charges attract and like charges repel each other the positive ions will normally be next to negative ions and vice versa The radii of ions are characteristic of the element and of the charge Negative ions (anions) are usually larger than positive ions The number of negative ions surrounding a positive ion (cation) is mainly determined by the ratio of the radii of the two ions Thus a small cation will not be surrounded by as many negative ions as will a larger cation The number of positive ions surrounding a negative ion is largely governed by the importance of maintaining a local balance of positive and negative charge Ions act as if the attractive and repulsive forces have no specific directional properties The number of charges on an ion is called the electrovalence of the element Sodium for example normally carries a single positive charge in its ionic compounds and thus has an electrovalence of +1 Chlorine in most inorganic compounds is an ion with one negative charge hence it has an electrovalence of −1 Many elements can form several different ions Thus iron commonly occurs as ferrous iron Fe^{++} or as ferric iron Fe^{+} and so often displays electrovalencies of either +2 or +3 Since completely filled electron shells are especially stable the ionic state which gives completed shells is for many elements the most stable one

Covalent binding This is another limiting type of chemical binding Here each atom of a bound pair contributes one electron to form a pair of electrons which move in such a manner as to increase the density of electric charge in the space between the two atoms The negative charge in the region between the two atoms attracts the two positive nuclei This type of bond is also called an electron pair bond because its essential feature is the formation of a pair of electrons which spend much time in the region between the two atoms These two electrons have their spins pointing in opposite directions in other words they are paired If this were not the case the two electrons could not both have a low kinetic energy (which is important for the stability of the molecule) and also spend much time in the region between the two atoms This requirement of pairing is a consequence of the fundamental principles of quantum mechanics and particularly of the Pauli exclusion principle *See* EXCLUSION PRINCIPLE

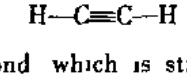
The number of covalent bonds which an atom can form is called the covalence and is governed by the detailed electron configuration of the atom (*see* ELECTRON CONFIGURATION) The meaning of the historical word valence has been gradually modified so that it now usually refers to the electrovalence or the covalence of an atom An extremely important case is that of carbon In most of its compounds carbon forms four covalent bonds When these connect it to four other atoms the directions of the bonds to these other atoms will normally make angles of about 109° to one another unless the attached atoms are crowded or constrained by other bonds In other words covalent bonds have preferred directions However to preserve the idea that carbon forms four bonds it is necessary to introduce the notion of double and triple bonds Thus in ethylene C_2H_4 the structure is written



where all the lines denote covalent bonds the double line connecting the carbon atoms being a double bond This idea has physical reality because such double bonds are distinctly shorter almost twice as stiff and require considerably more energy to break completely than do single bonds However they do not require twice as much energy to break as a single bond so it is energetically advantageous for a molecule to open one component of a double bond and add two atoms for example H_2 adds to C_2H_4 to form ethane

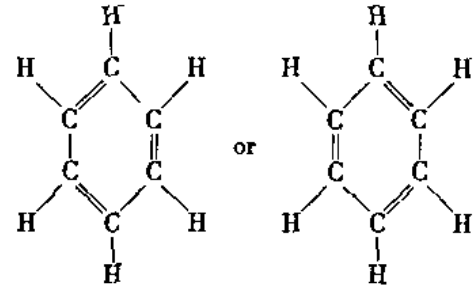


Similarly acetylene is written as



with a triple bond which is still shorter than a double bond A carbon carbon single bond has a length close to 1.54×10^{-8} cm whereas the triple bond is about 1.21×10^{-8} cm long

In many compounds the rules for writing bond formulas are not unique For example benzene C_6H_6 can be written in the two forms



Physical evidence proves that all six C—C bonds are equivalent so neither formula can be correct Quantum mechanical arguments show that the correct picture is a blend of the two in which the bonds have many properties intermediate between those of double and single bonds but in which the whole molecule displays an additional stability This phenomenon which has been called resonance occurs whenever the structure is such that two or

more different bond formulas can legitimately be drawn for the same geometry *See* RESONANCE (MOLECULAR STRUCTURE)

Many substances have some bonds which are covalent and others which are ionic Thus in crystalline ammonium chloride NH_4Cl the hydrogens are bound to nitrogen by electron pairs but the NH_4 group is a positive ion and the chlorine is a negative ion On solution in water ionic crystals normally undergo dissolution into their separate ions

Both electrons of a covalent bond may come from one of the atoms Such a bond is called a coordinate or dative covalent bond or semipolar double bond and is one example of the combination of ionic and covalent binding Actually the electron pair does not have to be symmetrically located in any case so all degrees of mixing of ionic and covalent character may occur

The *hydrogen* bond is a special type of bond in which a hydrogen atom links a pair of other atoms (*see* HYDROGEN BOND) The linked atoms are normally oxygen fluorine chlorine or nitrogen These four elements are all quite electronegative a fact which favors a partially ionic interpretation of this kind of binding

Metallic binding This is a third type of chemical binding which is exemplified in the common metals There are several ways of looking at this binding but perhaps the simplest is to consider the crystal as consisting of positive ions of the metallic element immersed in a sea of electrons The attraction of the positive ions for the electrons holds the crystal together Some of the electrons are free to move about the whole crystal of the metal and this is what makes the metal an electrical conductor For further details on metallic binding *see* CRYSTAL STRUCTURE

Van der Waals forces Although many crystals are giant molecules whose atoms are completely linked together by strong ionic or covalent bonds oth[illegible]

together by what are called van der Waals or dispersion forces Although these forces are electrical in nature they are too weak to be considered as true chemical binding The picture is as follows The electrons in the cloud of negative electricity in a molecule are in rapid motion and the charge distribution may therefore be thought of as fluctuating in time At any instant the distribution in a given molecule may be quite unsymmetrical so that an electric dipole moment results even though there need not be any average dipole moment This dipole [illegible]

in the second molecule in such a way as to produce an instantaneous induced dipole moment in the second molecule The interaction of the two dipole moments namely the original instantaneous one in the first molecule and the induced one in the second will result always in a net but rather weak attractive force between the two molecules This force will then bring the molecules together until the repulsion of their electron clouds for one another keeps them at an equilibrium distance of separation *See* CHEMICAL STRUCTURES INTERMOLECULAR FORCES MOLECULAR STRUCTURE AND SPECTRA QUANTUM CHEMISTRY VALENCE

[E B W]

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Chemical compounds

Substances composed of two or more elements which do not vary in composition from sample to sample and which have fixed and definite physical properties such as density and refractive index The elements in compounds cannot be separated by simple physical or mechanical means but only by chemical treatment When compounds are formed from their elements heat is generated or absorbed These properties distinguish them from mixtures

For example if iron filings and sulfur powder are [illegible]

and the individual particles of each element are distinguishable under a magnifying glass If iron filings and sulfur are heated together a chemical reaction takes place and a new substance is formed iron sulfide with properties totally different from those of the elements iron and sulfur *See* DENSITY ELEMENTS (CHEMICAL) MIXTURE REFRACTION OF WAVES

Chemical compounds are formed in fixed and definite proportions by weight from their elements, and they obey the laws of chemical combination *See* DEFINITE COMPOSITION LAW OF EQUIVALENT WEIGHT INORGANIC CHEMISTRY MULTIPLE PROPORTIONS LAW OF ORGANIC CHEMISTRY [T C W]

Chemical dating

Determination of the relative or absolute age of minerals and of ancient objects and materials by measurement of their chemical composition By inference this method of age determination may be extended to the dating of geological formations and to the dating of geological and human events Most of the observational methods for dating geological formations and events such as that based on the order and thickness of rock strata are reliable only for obtaining relative or sequence dates This is true also of analogous methods for dating artifacts and human events for instance the method based on the depth at which objects are buried in the soil Most of the chemical methods however yield approximate absolute dates involve fewer assumptions and are less likely to result in large errors They are exceeded in accuracy only by the method of tree ring counting (*see* DENDROCHRONOLOGY)

Unfortunately these methods are applicable only to the direct dating of a few minerals and a few kinds of ancient objects and materials

There are three distinct types of chemical dating methods (1) those using the proportion of some stable element as an index of the age of an ancient object or material (2) those using the ratio of the proportion of a decomposition product of radioactivity to the proportion of the residual radioactive element or elements still present and (3) those using the proportion of a radioactive isotope, measured by its present activity as an index of the age of an ancient object or material The most important is the carbon 14 method which depends on a measurement of the present activity of carbon isolated from objects or materials of organic origin (see RADIOCARBON DATING) The most widely used method of the second type depends on the determination of the ratio of the proportion of radiogenic lead to the proportion of residual uranium thorium or both in minerals which contain one or both of these radioactive elements (see GEOCHRONOMETRY) Only methods of the first type will be discussed in detail here

Fluoride method The oldest and least reliable method is based on the increase in the fluorine content of bones with increase in time elapsed since they were buried in the soil This increase is due to contact of the bones with ground water containing fluoride ion and the consequent partial replacement of the phosphate of the bones with fluoride Unfortunately this method involves great uncertainties, such as unknown variations in the volume of ground water coming into contact with the bones and unknown variations in the fluoride content of the water It must therefore be used with great caution and is usually applicable only where all conditions appear to have been fairly constant over long periods as in caves

Chemical composition of coins Another method limited in its application to certain historical times and to certain regions is based on systematic differences in the composition of the metal of ancient coins of certain classes The Greek bronze coins struck from about the middle of the fourth century B C to about the end of the first century A D constitute one such class In these coins the proportion of tin progressively decreases with time a decrease which is accompanied by a progressive and relatively greater increase in the proportion of lead A traditional mint practice of melting worn coins with additional lead to produce metal for new coins is believed to be the chief cause of this systematic change in composition The additional lead makes up for the copper and tin lost during the wearing of the coins Either the proportion of tin the proportion of lead or the ratio of the two proportions as determined by conventional analytical methods is the index to time of manufacture

The Roman brass coins struck from the end of the first century B C. to the end of the second century A D constitute another class of datable coins In these coins the proportion of zinc decreases progressively with time of manufacture The chief cause of this change appears to be the selective loss of zinc by volatilization during the melting of worn coins Since brass of only relatively low zinc content could be made by the cementation process then used and since metallic zinc was unknown this loss of zinc could not be compensated by the addition of new metal The silver coins of the Roman Empire struck from about the middle of the first century A D to about the middle of the third century A D constitute still another class of coins datable from their composition In these the silver content regularly decreases with time of issue because of progressive debasement

Though coins of the last two classes in contrast to Greek bronze coins may be closely dated from their inscriptions, the chemical method is useful for dating the illegible coins frequently found in excavations Since such coins are often found closely associated with other objects in graves and in the ruins of ancient buildings, the burial dates of these other objects may frequently be inferred from the dates of the coins [E R C]

Chemical energy

In most chemical reactions heat is either taken in or given out By the law of conservation of energy the increase or decrease in heat energy must be accompanied by a corresponding decrease or increase in some other form of energy This other form is the chemical energy of the compounds involved in the reaction The rearrangement of the atoms in the reacting compounds to produce new compounds causes a change in chemical energy This change in chemical energy is equal numerically and of opposite sign to the heat change accompanying the reaction

Most of the world's available power comes from the combustion of coal or of petroleum hydrocarbons The chemical energy released as heat when a specified weight often 1 g of a fuel is burned is called the calorific value of the fuel *See* FUEL

Depending on whether the pressure or volume of the system is kept constant differing quantities of heat are liberated in a chemical reaction The heat of reaction at constant pressure q_p is equal to minus the change in the chemical energy at constant pressure ΔH called the change in the enthalpy the heat of reaction at constant volume q_v is equal to minus the change in the chemical energy at constant volume ΔE called the change in the internal energy *See* ENTHALPY INTERNAL ENERGY THERMOCHEMISTRY

It is not possible to measure an absolute value for the chemical energy of a compound only changes in chemical energy can be measured It is therefore necessary to make some arbitrary assumption as a starting point One such assumption would be to take the chemical energies of the free atoms as zero and measure the chemical energies of all elements and compounds relative to this standard If this were done all ch- en-

would then be negative quantities Heat is given out when all elements and compounds are formed from their atoms Since chemical energy can l e re garded as a form of potential energy it is interest ing that the formation of chemical bonds is always accompanied by a decrease of potential energy The reason in qualitative terms at least lies in the quantum theory When chemical bonds are formed between atoms for example in the formation of a chlorine molecule from two chlorine atoms elec trons are shared between the two atoms and this electron sharing produces a lowering of the poten tial energies of the shared electrons and thus a lowering of the potential energy of the molecule relative to the free atoms

Although it would be more fundamental to take the chemical energies of the separated atoms as zero in practice it is more convenient to take a more arbitrary starting point and to assume that the chemical energies of the elements are zero For precision the standard states of the elements at 25°C and 1 atm pressure are chosen Thus in the case of carbon the chemical energy of graphite not diamond is said to l e zero Thus oxygen gas at 25°C and 1 atm and liquid water at 25°C and 1 atm are taken as the standard states Graphite at 25°C and 1 atm is taken as the standard state with zero enthalpy of formation and diamond then has a definite enthalpy value *See* ENERGY SOURCES THERMODYNAMICS (CHEMICAL) [T C W]

Chemical engineering

The branch of engineering concerned primarily with the application of chemistry physics and mathematics in the manufacturing processes of modern industry More precisely defined in the 1954 constitution of the American Institute of Chemical Engineers it is the application of the principles of the physical sciences together with the principles of economics and human relations to fields that pertain directly to processes and process equipment in which matter is treated to effect change in state energy content or composi tion Thus chemical engineering might well be called process engineering

The manufacturing processes of chemical and allied industries can usually be resolved into co-ordinated series of unit physical operations and unit chemical processes—steps that are similar in principle if not identical in many applications Hence in recent years chemical engineering has become a unifying influence as the common de nominator of the technology of industries as ap parently diverse as chemicals cosmetics petroleum paint paper soap sugar plutonium perfumes nuclear reactors rockets and guided missiles

The unit operations involve the application or removal of some form of energy in the contacting separation transport and conditioning of materials by physical means with or without any chemical changes taking place (*see* UNIT OPERATIONS)

The unit processes on the other hand result in chemical changes in composition character and properties of materials and are most often effected or controlled by temperature and pressure changes catalysis intimacy of mixing and other physical phenomena (*see* UNIT PROCESSES)

Unit operations

fluid flow	size reduction
heat transfer	mixing
evaporation	filtration
drying	sedimentation
distillation	centrifugation
sublimation	materials handling
crystallization	mass transfer operations
solvent extraction	gas absorption
adsorption	

Unit processes

oxidation	sulfonation
reduction	halogenation
pyrolysis	hydrolysis
electrochemical proc	*polymerization*
esses	industrial microbiology
nitration	ion exchange

The unit-operation concept first introduced by William H Walker and Arthur D Little at the Massachusetts Institute of Technology in 1915 had revolutionary influence on chemical engineering education in the United States Prior to that time most so called chemical engineering curricula com bined purely descriptive courses in industrial chem istry with smatterings of mechanical electrical and civil engineering Today an average 4-year under graduate course in an American university will de vote 25–30% of its credit hours to chemistry 30% to chemical and other engineering 20% to physics and mathematics and 20–25% to cultural and humanistic studies

Since about 1950 there has been a growing re alization that the unit operations and unit processes are not in themselves the true scientific fundamen tals of chemical engineering Rather they are merely applications of more basic principles that underlie all of science and technology There is an evident trend therefore toward greater em phasis on the so-called engineering sciences such as thermodynamics fluid dynamics kinetics and mass momentum and energy transfer Likewise advances in solid state physics and more exact mathematical knowledge of physical and chemical rate processes are leading to new disciplines in chemical engineering Yet for many years to come the practice of chemical engineering will remain both an art and a science

The National Science Foundation and the U S Bureau of Labor Statistics estimated in 1954 that there were approximately 40 000 practicing chemi cal engineers in the United States Since then their number has increased by approximately 2000 grad uates each year Of these about 80% have com pleted 4-year courses 15% have master s degrees and 5% doctorates More than 90% of all chemical engineers are employed by industry predominantly in manufacturing enterprises

The chemical manufacturing industries provide employment for about 40% of these chemical engineering graduates petroleum refining is second with almost 20% and process equipment and machinery employ about 6% The remainder is divided among such chemical process industries as plastics rubber pulp and paper drugs nonferrous metals glass and ceramics paint and varnish soap inedible oils and fats explosives leather food synthetic fibers and textile processing

Because of his broad scientific and engineering training, the chemical engineer is often called upon to translate the results of laboratory research into large scale commercially successful manufacturing operations Thus it is not surprising that a recent survey of the profession found 31% of chemical engineers in the United States engaged in research and development Next in importance was production and maintenance accounting for 28% Design and construction followed with 13% management and administration with 10% sales and technical services with 5% and the remainder was in governmental laboratory and consulting work teaching and other occupations But no matter what his function the value of the chemical engineer s contribution to industry is measured by its economic results

Of prime importance is the growing role of the chemical engineer in the technical management of the chemical process industries When human and technical resourcefulness are combined with administrative ability these qualities have led to major executive responsibilities in some of the world s largest and most progressive industrial enterprises But whether in plant or laboratory in the drafting room or executive offices the chemical engineer s most important contribution is in the successful commercial development and operation of chemical processes to yield new and better products at ever lower cost

Noteworthy chemical engineering achievements in recent years have included the commercial manufacture of nylon and other truly synthetic fibers the extraction of bromine and magnesium from sea water the creation of a self sufficient synthetic rubber industry the production of petrochemicals and superfuels from petroleum and natural gas high energy fuels and propellants for rockets and missiles and antibiotics by fermentation In a large measure the wartime success of the atomic bomb project and subsequent developments for the control and use of nuclear energy in the civilian economy are achievements of chemical engineering [S D K]

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Chemical fossils

A term applied in a figurative sense to chemical substances in the sedimentary deposits of the geologic past that prove the former presence of living organisms Chief of these are amino acids of which proteins are formed Alanine leucine glycine proline valine lysine porphyrins and many others have been identified in fossil shells and bones and also in black shales in concretions that show no organic structures and in petroleum Such derivatives of proteins are among the best evidences for the organic origin of petroleum *See* PALEOBIOCHEMISTRY PETROLEUM (ORIGIN)

[C O D]

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Chemical fuel

Most of the fuels used in combustion engines and power plants are fossil fuels such as coal petroleum and natural gas or fuels readily derived from these by various refining or separation processes Where a high flame temperature or a large mechanical impulse is needed special fuels usually obtained by synthetic chemical procedures are used These chemical fuels have higher heats of combustion per unit volume of the gaseous combustion products than those from fossil fuels Thus for high flame temperatures of the order of 5000°C gaseous cyanogen N≡C—C≡N and oxygen may be used Derivatives of the boron hydrides are being manufactured on a large scale for use as high energy fuels

For rocket propellants both a high heat release per unit volume and a large volume of gaseous combustion products per unit weight of fuel plus oxidant are desired An ideal but presently impractical rocket fuel would be atomic hydrogen Various types of liquid and solid propellant fuels and oxidants have been used One of the most efficient liquid propellant systems consists of liquid hydrogen as fuel and liquid fluorine as oxidant Other liquid propellant chemical fuels and oxidants are listed below

Oxidant	*Fuel*
Liquid oxygen	75% ethyl alcohol 25% water
Liquid oxygen	Liquid hydrogen
Liquid oxygen	Liquid ammonia
80% hydrogen peroxide 20% water	50% methyl alcohol 30% hydrazine
Red fuming nitric acid	Aniline
90% nitric acid 10% sulfuric acid	Vinylisobutyl ether

Solid propellant fuels and oxidants are in many cases more suitable for rockets than the liquid types In the double base solid propellants the chief constituent is a colloidal mixture of nitrocellulose and nitroglycerine no separate oxidant being used The solid mixture is extruded or cast into the desired shape Many of the solid propellants contain alkali perchlorates or alkali nitrates as oxidants and ethylene oxide or an organic polymer (such as rubber) or a thermosetting plastic (such as phenol formaldehyde or phenol furfuraldehyde) as fuels *See* BORANE FUEL METAL BASE FUEL PROPELLANT [H H ST]

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Chemical microscopy

The application of the microscope to the solution of chemical problems Because the microscope is essentially an aid in seeing minute detail its use is indicated wherever fine structure is of interest or small objects are to be identified counted measured or investigated

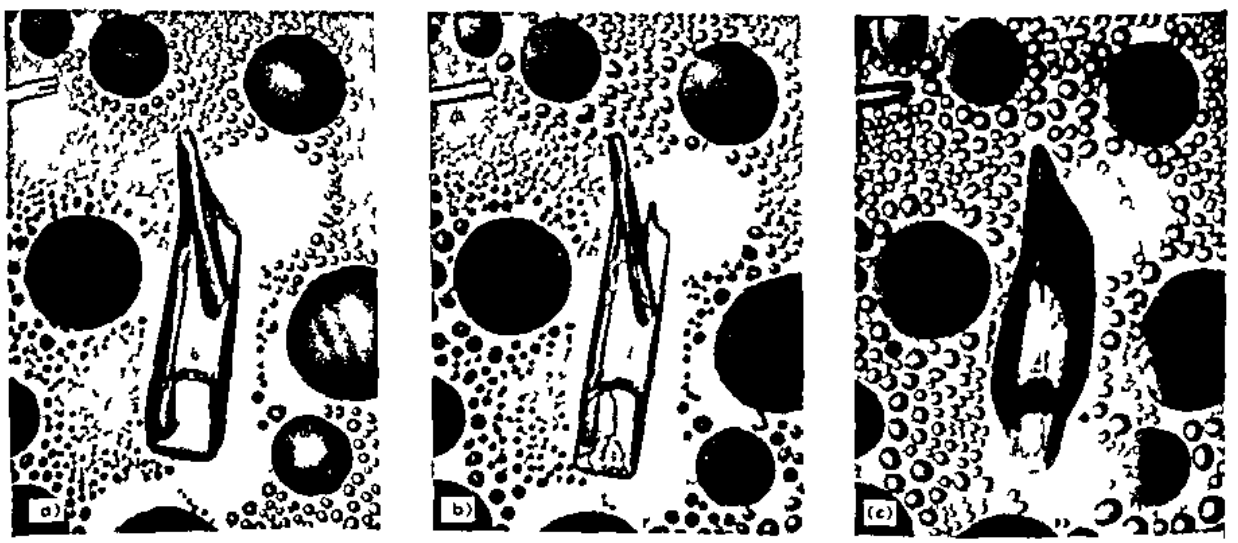
Most used for general chemical work is a simple petrographic stand with graduated rotating stage coarse and graduated fine adjustment draw tube focusing substage swing out condenser polarizer in graduated rotating mount slide in analyzer slot for compensators Bertrand lens with iris diaphragm centerable objectives with magnifications from 2 5 to 20× keyed in cross hair eyepieces and micrometer eyepieces with adjustable eye lenses The microscope is best mounted in a low table so that the stage is on a level with the table top A quick change from transmitted light to reflected light should be possible *See* MICROSCOPE

The microscope becomes indispensable if fine structures provide the means of identification as in the investigation of plant and animal matter and drugs It is equally important in the investigation of small parts of apparatus and machines of corrosion effects and in the general study of metals alloys and other materials of construction since the suitability for a given use is frequently determined by the fine structure

By use of the polarizing microscope both minerals and a large number of inorganic and organic substances may be identified on the basis of their optical behavior

If the microscope is equipped with heating and cooling stages which permit accurate determination of the temperature of that part of the preparation located in the field of the microscope it is possible to observe melting points freezing points and other transition temperatures of particles crystals or fragments of about 1 μg mass The determination of the melting point combined with the observation of the refractive index of the melt which may be carried out in a simple manner with the use of glass powders suffices for the identification of many organic substances The very sharp melting points of eutectic mixtures with added known substances will usually permit the identification of an organic substance The illustration shows the behavior of 2 phenylquinoline-4-carbonic acid near its melting point The field contained several rhombohedral crystals which melted at 199°C to form the large drops visible in the photomicrographs The small droplets stem from the condensation of vapors At 205°C and 208°C. the rectangular crystals of the modification which is stable at high temperature grow at the expense of the melt The large crystal at the center has consumed 2 or 3 large drops The melting of the rectangular crystals starts at 213°C.

Quantitative data may be obtained by counting particles and droplets under the microscope as well as by the measurement of distances and areas in the microscopic image or on the photomicrograph Particle size distribution particle ratios



The behavior of 2 phenylquinoline 4-carbonic acid at (a) 205 (b) 208 and (c) 213°C (*From L Kofler and A Kofler, Mikromethoden 1948*)

and the percentage composition of alloys and rocks may be derived from such observations

Finally the microscope serves for the observation and measurement of small specimens such as dust particles corrosion specks inclusions and irregularities in the appearance of materials With the aid of various auxiliary apparatus and mechanical manipulators the microscope makes possible lengthy investigations with small objects and the study of their physical and chemical behavior *See* MINERALOGY PETROGRAPHY QUALITATIVE CHEMICAL ANALYSIS THERMOANALYSIS [A A B P]

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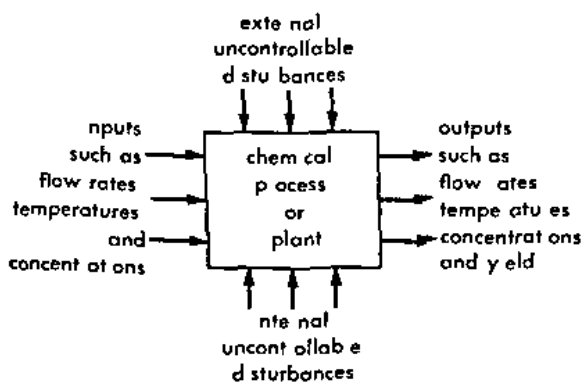
Chemical process control

The branch of chemical engineering that deals with the quality of performance or the behavior of chemical process systems Proper control permits the operation of process plants under the desired conditions of high productivity and quality in spite of transients and instabilities and commensurate with economic factors In many cases suitable control is the only means of operating a chemical process in a profitable manner or with a suitable quality product

Design The adequate design of a chemical process control system requires a knowledge of instrumentation as applied to the particular process something about the physics and chemistry of the process itself and a clear and concise idea of the performance or desired conditions which the control is to achieve

A conceptual discussion of the problems associated with control of a chemical process can be made with the aid of Fig 1

The chemical process represented schematically by the box is subject to two types of uncontrollable disturbances those external to the process itself such as changes in the environment and feed conditions to the system and those changes internal to the process itself The second type can include variations in such items as catalyst activity and heat transfer coefficients which affect the physics and chemistry of the process The inputs may be flow rates temperatures or concentrations of reactants or components of the process the outputs may be flow rates temperatures concentrations or the yield or conversion attained by the process



Fg 1 Generalized chem cal process

The process control system must be designed in such a way that the inputs can be changed in a predetermined manner to compensate for the effect of the external disturbances The output of the process thus remains constant within narrow limits The limits on the output are determined by some optimization relationship based upon technical or economic considerations The type of disturbances the complex phenomenon associated with specifying the yield requirements and the need to maintain the specifications on the output irrespective of the disturbances distinguish chemical process control from the more standard servomechanism type control For a discussion of servomechanism control *see* CONTROL SYSTEMS

Operation Even in the absence of external disturbances the control system must compensate for the internal disturbances In effect these internal variations in the chemical process mean that the optimum behavior of the process changes with time The control system even in the absence of external disturbances must thus track and maintain the process at or near the moving optimum output This is referred to as static optimization

If both types of disturbances occur continuously the control system must track or locate the optimum output limits and manipulate the inputs to the process in such a way as to compensate for the external disturbances and also to follow the desired optimum This is referred to as dynamic optimization On a relative time scale the internal type of disturbance is usually slow in affecting the chemical process outputs whereas the external type of disturbance leads to very rapid changes Thus the dynamic optimization requires a more sophisticated type of control scheme than the corresponding static optimization

Chemical process control systems may be classified as either open loop or closed loop A visualization of the two types follows from consideration of a simple steam jacketed heat exchanger with the temperature of the outlet fluid controlled at a constant value by manipulation of the steam pressure In open loop control a knowledge of the fluid flow rate the inlet fluid temperature and the steam pressure are required By use of these data a pressure regulator in the steam line is adjusted to obtain the desired outlet fluid temperature This can be effective only for a very stable process with almost no disturbances Closed loop control however uses the concept of feedback The outlet fluid temperature is measured and compared with the desired temperature the deviation is then fed back to the pressure regulator to minimize this difference Figure 2 shows a schematic arrangement for the closed loop control of this simple process

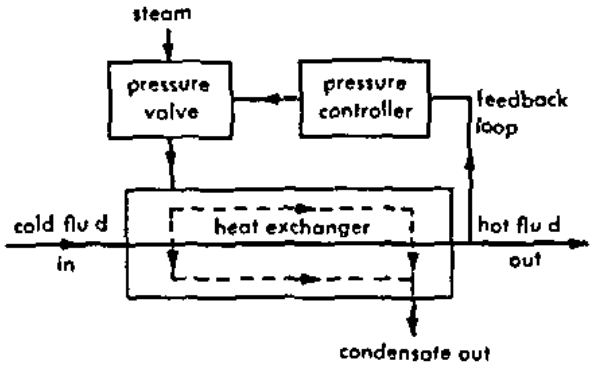


Fig 2 Closed loop control of a heat exchanger

The use of closed loop or feedback control may however introduce oscillatory and unstable conditions in the control scheme Most chemical processes that permit a detailed control analysis are large in size and basically stable in operation Stability is herein taken to mean that a small input disturbance will cause the process to move to a new stable point of operation instead of oscillating or running away Because of the severe time lags associated with the feedback loops of large processes the correction feedback signal may tend to establish an overcorrection proportional to the time lags The system becomes over corrected in first one direction and then the other with a sustained oscillation resulting If this oscillation increases in magnitude the entire system may become unstable and run away The consequences of such a runaway process may be quite serious In fact it may lead to burning out of catalyst and catalyst tubes or the complete shut down of the process

Computers A distinct advantage of closed loop control of a large process is that a high speed digital or analog computer can be inserted in the feedback path in place of human beings The computer could look at the output values compare them with the desired states and then proceed to adjust the control variables to obtain the desired optimum output of the chemical process Because the machines operate at such tremendous speeds this manipulation of the control sequence can be done very often and can be based upon all the possible knowledge of the chemistry and physics of the process itself In addition the computer can be used as a data reporter or logger by printing or graphing the conditions of the process at selected time intervals The chemical industry is presently undertaking detailed investigations of the possibility of such techniques

Computations In order for any form of control to be achieved it is necessary to find a means of predicting the process behavior under the action of typical disturbances Unfortunately this is not always possible and in many cases only the most fragmentary description can be given for a chemical process In those cases where the knowledge of the physics and chemistry is adequate a model called the process dynamics can be constructed The actual description may take a number of forms lumped ordinary differential equations or distributed partial differential equations may be used In terms of ease of usage the former are preferred but the latter may be necessary in many complicated processes For a discussion of closed loop and open loop control *see* CONTROL SYSTEMS

A lumped parameter representation leads to the use of transfer functions as a convenient shorthand notation for linear systems Linearity is taken to mean that the process can be described by means of linear differential equations Of particular importance is the fact that many processes of interest to the chemical industry can be represented simply by a transfer function made up of a delay time and a first order time constant When chemical reaction occurs such a simple representation usually is not adequate and the transfer function must be determined experimentally This can be done by imposing a known and well defined disturbance on one of the inputs of the process and measuring the response of the system The most useful input disturbances or forcing functions are impulses step functions and steady state sine waves in concentration or temperature Standard computational techniques can be used to obtain the transfer function of the chemical process under these conditions After the transfer function is known it is possible at least theoretically to predict the dynamic behavior of the process to any input disturbance Unfortunately it is almost impossible to subject a large chemical process plant to these standard disturbances because of the possibility of creating an unstable system or leading to an off quality output Therefore it is necessary to analyze the effect of small random inputs which will not lead to the undesirable features of large scale disturbances The problems associated with constructing a dynamic model from such an analysis poses some very severe computational difficulties

If the process is not linear there are no simple computational dynamic models The dynamic behavior can be predicted but present day control techniques cannot handle such models In the case of very small external disturbances the nonlinear model can be linearized and handled as if it were linear Such a representation may however be very dangerous to use

After a suitable model has been developed for the chemical process or plant an over all systems design must be made This includes specifying the dynamics of the necessary measuring elements the controlling elements and the process The measuring elements may be thermocouples gas chromatographs mass spectrometers or the like the controlling elements may be valves or pressure regulators *See* CHEMICAL ENGINEERING INSTRUMENTATION LINEAR PROGRAMMING [L L]

Chemical structures

Much of chemistry is explainable in terms of the structures of chemical compounds The understanding of the structures of chemical compounds hinges

very strongly on the understanding of the electronic configurations of the elements The union of atoms and therefore the formation of compounds from the elements is associated with interactions among the extranuclear electrons of the individual atoms Electronic interactions among atoms may occur in either of two ways electrons may be transferred from one atom to another or they may be shared by two (or more) atoms The first type of interaction is called electrovalence and results in the formation of electrically charged monatomic ions The second covalence leads to the formation of molecules and complex ions *See* CHEMICAL BINDING

FORMATION OF IONS

A number of relationships among the electronic structures of the elements are important in determining the properties of ions

1 Only the outermost shell of electrons is of significance in compound formation This is commonly called the valence shell and the electrons contained within it are called the valence electrons

2 The maximum number of electrons encountered in the valence shell of any single isolated atom is eight

3 In the case of transition elements the electrons in the *d* subshell of the penultimate (next outermost) shell are often of importance in compound formation so that special consideration must be given this complicating factor This subshell of electrons is considered as essentially a part of the valence shell Consequently it must be realized that rules (1) and (2) are rigorously true only for the representative elements not the transition elements

4 The number of valence electrons and their subshell assignments are given by the arrangement of the elements in the long form of the periodic table The elements in any vertical family of the periodic table have the same valence electron configuration

a The elements of group Ia H Li Na K Rb Cs and Fr are characterized by single valence electrons in *s* subshells The configuration is ns where n refers to the quantum number identifying the valence shell ($n = 1$ for H 2 for Li 3 for Na) Those in group IIa are characterized by two electrons in filled *s* subshells that is the configuration is ns^2 The elements of groups IIIa IVa Va VIa VIIa and the inert gases contain successively from one to six valence electrons in the *p* subshell in addition to two *s* electrons Consequently it is simply true that the electronic structures of the elements of the a subgroups of the periodic table have numbers of valence electrons equal to the numbers of the vertical periodic groups to which they belong Further the first two valence electrons must be assigned to an *s* subshell The configurations of the valence shells of the elements boron through neon are B $2s^22p^1$ C $2s^22p^2$ N $2s\ 2p^3$ O $2s\ 2p^4$ F $2s^22p^5$ Ne $2s^22p^6$

b The elements of the b subgroups of the periodic table differ from those of the a subgroups as a result of the significance of *d* electrons in the penultimate electron shells The elements of groups IIIb through the triads of group VIII are characterized by electronic configurations containing two valence electrons in the *s* subshell (of the valence shell) and progressively more electrons in the *d* subshell of the penultimate electron shell This is shown as follows Sc $3d^14s^2$ Ti $3d\ 4s^2$ V $3d^34s$ Cr $3d^54s^1$ Mn $3d^54s^2$ Fe $3d^64s^2$ Co $3d^74s^2$ Ni $3d^84s^2$ As a result of the similar energies of ns and $(n-1)d$ electronic states some irregularities occur among the electronic configurations of these elements Groups Ib and IIb are characterized by a complete *d* subshell (penultimate) and one and two electrons in the *s* subshell of the valence shell for example Cu $3d^{10}4s^1$ Zn $3d^{10}4s^2$ *See* ATOMIC STRUCTURE AND SPECTRA

Ionization potential Positive ions are formed by the removal of valence electrons and negative ions result from the addition of electrons to the neutral atom The complete analysis of the energy relationships determining the formation of compounds composed of ions is complex however a few aspects of the problem are directly related to the electronic structures of the isolated atoms The energy required for the removal of an electron from a neutral atom is measured by the ionization potential and relates to the equation

$$M(g) \rightarrow M\ (g) + e$$

A second ionization potential indicates the amount of energy required to convert the unipositive ion into the dipositive ion and the successive removal of the remaining electrons may similarly be related to ionization potentials *See* IONIZATION POTENTIAL

From the relative values of the ionization potentials, it is concluded that the more active metals of groups Ia IIa and IIIa may more easily be converted into positive ions than the succeeding elements The valence electrons are more easily removed than are the electrons in energy levels below the valence shell Along with the accumulated evidence of chemical compositions of large numbers of known compounds these observations lead to the conclusion that typical positive ions will be formed by the removal of all of the valence electrons of the metallic elements of the a subgroups of the periodic table The resulting ions are called inert gas type ions because they have the electronic configurations of the inert gases preceding the respective elements in the periodic system As a consequence of the increasing amounts of energy (ionization potentials) required to remove successive electrons from ions monatomic positive ions that are highly charged do not exist among chemical compounds under the usual conditions of temperature and pressure The most highly charged ions of any apparent significance are tripositive (Table 1) A number of the actinide elements form

Table 1 Inert gas type ions, listed by periodic group*

Ia	IIa	IIIb	IIIa	Va	VIa	VIIa	Inert gas
Li^+	Be^{2+}		B^{3+}			H^-	He
Na^+	Mg^{2+}		Al^{3+}	N^{3-}	O^{2-}	F^-	Ne
K^+	Ca^{2+}	Sc^{3+}		P^{3-}	S^{2-}	Cl^-	Ar
Rb^+	Sr^{2+}	Y^{3+}			Se^{2-}	Br^-	Kr
Cs^+	Ba^{2+}	La^{3+}			Te^{2-}	I^-	Xe

* The horizontal rows contain isoelectronic series of ions and the corresponding inert gas

tetrapositive monatomic ions, U^{4+} Th^{4+} and Pu^{4+} *See* PERIODIC TABLE

Typical ions In addition to positive ions of the inert gas type two other electronic configurations recur with some regularity among chemical compounds The elements of groups Ib (Cu, Ag Au) and IIb (Zn, Cd Hg) may lose their valence electrons forming ions having 18 electrons (instead of 8) in their outermost electron shells These ions are generally called pseudoinert gas type ions (Table 2)

Table 2 Pseudoinert gas and helium type ions

Pseudoinert gas type ions			Helium type ions		
Ib	IIb	IIIa	IIIa	IVa	Va
Cu^+	Zn^{2+}	Ga^{3+}	(Ga^+)	(Ge^{2+})	As^{3+}
Ag^+	Cd^{2+}	In^{3+}	(In^+)	Sn^{2+}	Sb^{3+}
Au^+	Hg^{2+}	Tl^{3+}	Tl^+	Pb^{2+}	Bi^{3+}

In addition elements of the groups IIIa, IVa and Va give evidence of forming ions in which only the electrons from the *p* subshell are lost leaving two electrons in the *s* level of the valence shell These are summarized in Table 2 under the heading Helium type ions

The addition of an electron to a neutral atom with the resulting formation of a negative ion may be associated with the evolution of energy (the electron affinity)

$$M(g) + e \rightarrow M\ (g)$$

mation of highly charged negative ions The known, monatomic negative ions are formed by the addition of the number of electrons necessary for the atom to attain an inert gas electronic configuration (Table 1) and no monatomic negative ions are known to have a charge more negative than 3— *See* ELECTRONEGATIVITY

Simple ions are usually associated with the attainment of favorable electronic configurations A reaction leading to the formation of a compound (composed of simple ions) from the elements in

for example,

$$Na^{\cdot} + \cdot\ddot{\underset{\cdot\cdot}{Cl}}: \rightarrow Na^+, :\ddot{\underset{\cdot\cdot}{Cl}}:^-$$

$$Ca: + \cdot\ddot{\underset{\cdot\cdot}{O}}: \rightarrow Ca^{++}, :\ddot{\underset{\cdot\cdot}{O}}:^{--}$$

$$3Li^{\cdot} + \cdot\ddot{\underset{\cdot\cdot}{N}}\cdot \rightarrow 3Li^+, :\ddot{\underset{\cdot\cdot}{N}}:^{3-}$$

Born Haber cycle. Two principal limitations to the occurrence of electrovalent substances deserve mention The actual occurrence of such a reaction depends on a number of factors, among which the over all energy relationships occupy a position of major importance The energetics of salt formation are simply indicated in the Born Haber cycle which summarizes the several transformations which may be considered as a part of the salt forming reaction In the example given in Fig 1, the formation of a halide salt of a univalent metal is involved Because all the terms contributing to the heat of formation of the solid salt are endothermic except the lattice energy and the electron affinity it is clear that stable salts will occur in those instances where the sum of these exothermic quantities compensates sufficiently for the endothermic quantities The alkali metals are associated with relatively small sublimation energies and ionization potentials so that the formation of simple electrovalent salts should be greatly favored in their case Similarly the alkaline earth metals (except beryllium) are associated with low sublimation energies and ionization potentials It may be concluded that the alkaline earth elements should also be characterized by the ready formation of simple salts

The second factor limiting the occurrence of electrovalent salts is best explained in terms of an example The lattice energy of sodium chloride is 180 4 kcal/mole Because AgCl has the same arrangement of atoms in the solid and because Ag^+ is only slightly larger than Na^+ (1 13 A compared with 0 95 A) the lattice energy of AgCl should be quite similar to that of NaCl if both substances are composed of simple spherical ions Further, the lattice energy of AgCl should be smaller because the oppositely charged ions should be separated at slightly greater distances A comparison of the lattice energies may be made from the Born Haber cycle On the basis of this cycle the lattice energy

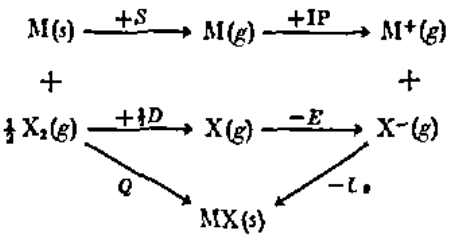


Fig 1 Born Haber cycle for the formation of solid salt, MX,

$$Q = S + IP + \tfrac{1}{2}D - E - U_0$$

where Q = heat of formation of solid salt MX S = sublimation energy of the free metal M IP = ionization potential of the metal D = dissociation energy of the halogen E = electron affinity of the halogen and U_0 = lattice energy of the salt *(The Ohio State University)*

of AgCl is calculated to be 211 0 kcal/mole This result attributes an extra energy equal to 30 6 kcal/mole to the lattice energy of AgCl in excess of the corresponding value for NaCl This contradicts the prediction that the lattice energy of the salt containing the larger ion should be smaller The expected change in lattice energy with cation size is observed in the series of alkali metal halides The anomaly presented in the case of AgCl requires additional assumptions for its explanation This example is not unusual It is commonly observed that the ions in certain salts may not be treated as hard spheres Two closely related explanations have been utilized to account for these facts

It may be assumed that the interaction of the charges of the ions on the electron shells of each other results in the polarization or distortion of the ions Such an interaction would result in induced dipoles or multipoles in the ions The associated attraction then provides an additional contribution to the lattice energy or more generally to the stability of the compound The relative importance of this mutual polarization depends on the nature of the ions Eighteen electron ions such as Ag^+ are much more polarizable than inert gas ions such as Na^+

Alternatively, variations from the behavior expected of simple electrovalent salts may be explained on the assumption that the different atoms for example silver and chlorine are held together by covalent bonds Because silver atoms are expected to show a greater tendency to form covalent bonds than do sodium atoms the explanation suggests the correct relationship between NaCl and AgCl In detail it would probably be assumed that AgCl exists as Ag^+ and Cl^- ions which are held together by both electrovalent and covalent forces *See* IONIC CRYSTALS SOLID STATE CHEMISTRY

The preceding example has been discussed at length in order to illustrate a second principal limitation to the occurrence of simple ions in chemical compounds It simply involves the formation of covalent bonds Experimental methods for the determination of the structures of solid compounds are most effective in showing the relative geometric arrangements of atoms or ions rather than in distinguishing the nature of the bonding forces In those cases where the geometric arrangement of the atoms is not consistent with the expectations based on the assumption of simple ionic structure covalent bonding may be inferred The geometric arrangements of ions in crystals comprises a large area of chemical knowledge

POLYHEDRAL STRUCTURES

Next in order of complexity to structures involving simple monatomic ions are those involving single polyhedral aggregates of atoms The union of neutral atoms to produce an uncharged aggregate results in molecule formation whereas the products of the union of atoms which bear a net charge are called complex ions The concept of coordination polyhedrons is basic to the formulation and systematization of the structures of polyatomic molecules and ions These relatively simple polyatomic aggregates commonly involve the packing together of the united atoms in highly symmetrical polyhedrons The most important polyhedrons of this class are shown in Fig 2 They are the tetrahedron the trigonal bipyramid the octahedron the pentagonal bipyramid and the cube Of these the tetrahedron and the octahedron are by far the most important

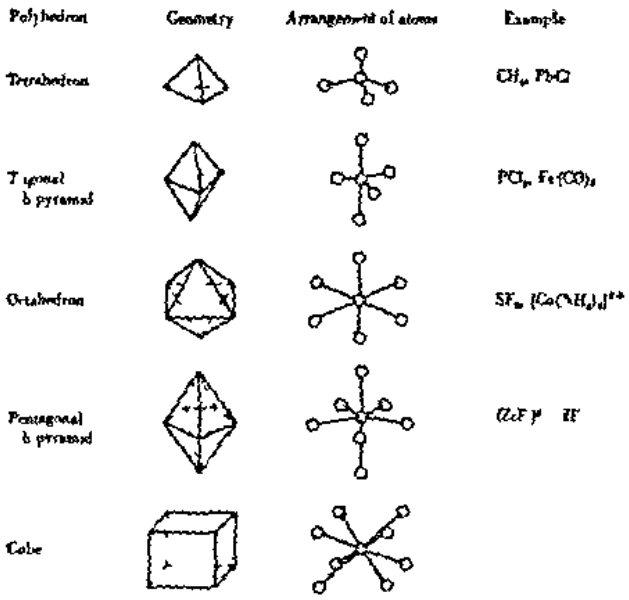


Fig 2 Coordination polyhedrons (*The Ohio State University*)

Coordination polyhedrons The general properties of a coordination polyhedron are summarized in the identification of a central atom which in many cases resides at the center of mass of the polyhedron and the determination of the coordination number of the central atom The coordination number is equal to the number of groups (atoms ions) directly attached to the central atom In the simplest cases the coordination number is also equal to the number of apexes in the coordination polyhedron It is therefore concluded that the tetrahedron may occur among molecules and ions having a coordination number of four the trigonal bipyramid is associated with a coordination number of five, the octahedron with a coordination number of six and the pentagonal bipyramid with a coordination number of seven

Lower coordination numbers are associated with plane polygons rather than polyhedrons, as shown in Fig 3 The coordination number of four may be associated with either a polygon (square plane) or a polyhedron (tetrahedron) Similarly alternative structures exist for the coordination numbers five (tetragonal pyramid) six (trigonal prism), seven (irregular structures) and eight (Archimedean antiprism dodecahedron) however these alternative structures are rare in occurrence

Accounting for these polyhedral and polymer structures has been one of the principal

and triumphs of valency theory Generally, the necessity for the prevalent view that covalent bonds are directed in space has arisen from conclusive demonstration that such polyhedral arrangements of atoms as these are preserved when molecules and complex ions are made to undergo phase changes to dissolve in or crystallize from solvents or even to undergo chemical reactions *See* Co ORDINATION CHEMISTRY

Electrostatic model The simplest correlative de vice which accurately summarizes a very large num ber of such structures and enables the chemist to predict with a good chance of success the geo metric array of the atoms in a compound of known composition is based on an extreme electrostatic model This model or theory represents the bonds in a purely formal way The central atom is con *sidered to be a positive ion having a charge* equal to its oxidation state The groups attached to the central atom (the ligands) are then treated either as negative ions or as neutral dipolar molecules This is illustrated in Table 3 for a series of oxides oxyanions halides and halo complexes The prin cipal *justification for this approach lies in its suc* cessful correlation of a vast amount of information

A number of significant observations related to the formulations of Table 3 should be pointed out There are series of ions or ions and molecules having the same type of *composition differing* only in the nature of the central ion and the net charge on the aggregate Examples are found in the series NO_3^- CO_3^{2-} BO_3^{3-} ClO_4^- SO_4^{2-} PO_4^{3-} ClO_4^- SO_4^{2-} PO_4^{3-} SiO_4^{4-} AlF_6^{3-} SiF_6^{2-} PF_6^- SF_6 ($ClF_6^{+?}$) The numbers of atomic nuclei and of electrons are the same for all the members of each series, consequently these are called isoelec *tronic series* Not only are the several chemical entities in such series isoelectronic but they are usually identical in geometrical structure, that is isostructural

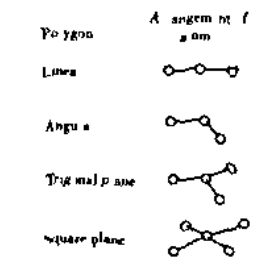


Fig 3 Coordination polygons (*The Ohio State Uni versity*)

It may also be observed that corresponding ions from a given vertical family of the periodic table commonly vary in coordination number A *useful* example is found in N^{5+} and P^{5+} which form NO_3^- and PO_4^{3-} respectively In addition some neutral *molecules expand their coordination* numbers to form stable anionic halo complexes *whereas others* do not Thus, SiF_4 reacts with fluoride ion to form SiF_6^{2-} whereas CF_4 does not form a similar com plex ion The most satisfactory explanation of

Table 3 Formal representation of compounds and complex ions as aggregates of ions

Complex ion or molecule	Constituent ions
NO_2^-	N^{3+}, $2O^{2-}$
NO_3^-	N^{5+}, $3O^{2-}$
CO_3^{2-}	C^{4+}, $3O^{2-}$
BO_3^{3-}	B^{3+}, $3O^{2-}$
ClO	Cl^+ O^{2-}
ClO_2^-	Cl^{3+}, $2O^{2-}$
ClO_3^-	Cl^{5+}, $3O^{2-}$
ClO_4^-	Cl^{7+}, $4O^{2-}$
SO_3^{2-}	S^{4+}, $3O^{2-}$
SO_4^{2-}	S^{6+}, $4O^{2-}$
PO_3^{3-}	P^{3+}, $3O^{2-}$
PO_4^{3-}	P^{5+}, $3O^{2-}$
SiO_4^{4-}	Si^{4+}, $4O^{2-}$
OF_2	O^{2+} $2F^-$
CO_2	C^{4+}, $2O^{2-}$
SO_2	S^{4+}, $2O^{2-}$
SO_3	S^{6+} $3O^{2-}$
NF_3	N^{3+} $3F^-$
CCl_4	C^{4+} $4Cl^-$
BCl_3	B^{3+} $3Cl^-$
ClF	Cl^+ F^-
ClF_3	Cl^{3+}, $3F^-$
BrF_5	Br^{5+}, $5F^-$
IF_7	I^{7+}, $7F^-$
SCl_4	S^{4+} $4Cl^-$
SF_6	S^{6+} $6F^-$
PF_3	P^{3+} $3F^-$
PF_5	P^{5+} $5F^-$
SiF_4	Si^{4+}, $4F^-$
$AlCl_3$	Al^{3+}, $3Cl^-$
BF_4^-	B^{3+} $4F^-$
ICl_2^-	I^+ $2Cl^-$
ICl_4^-	I^{3+} $4Cl^-$
BrF_6^-	Br^{5+} $6F^-$
PF_6^-	P^{5+} $6F^-$
SiF_6^{2-}	Si^{4+} $6F^-$
AlF_6^{3-}	Al^{3+} $6F^-$
ZnI_4^{2-}	Zn^{2+} $4I^-$
$CuCl_4^{2-}$	Cu^{2+} $4Cl^-$
$FeCl_4^-$	Fe^{3+} $4Cl^-$
FeF_6^{3-}	Fe^{3+} $6F^-$

these and many related observations is conveniently formulated in terms of the electrostatic model chosen here

Ionic radii ratios. The necessary condition *for* stability of the coordination polyhedron MA_n requires that the anions A are each in contact with the *central atom* M *As a consequence of this condition* the limit of stability of the structure arises in those cases where the anions are also mutually in contact Larger ligands or anions, would not be in contact *with the* central ion This relationship is usually summarized in terms of the limiting ratio of the ra dius of the cation, r_M, to that of the anion r_A below which the anions would no longer be in contact with the cation Table 4 reports these radius ratios for some of the structures given in Figs 2 and 3 Regardless of the magnitude of r_M/r_A, the linear struc ture satisfies the simple condition for stability How

Table 4 Radius ratios for coordination polyhedrons

Coordination number	Geometric structure	Radius ratios r_M/r_A
3	Trigonal plane	0 155
4	Tetrahedron	0 225
6	Octahedron	0 414
8	Cube	0 732

ever in those cases where r_M/r_A exceeds 0 155 a third group can be stably attached and in general the maximum number of groups which may be associated with a central atom will lead to the most stable chemical species From this it follows that all those cases in which r_M/r_A lies between 0 155 and 0 225 should involve a cation with a coordination number of 3 and not of 2 Similarly in the range $0\,225 < r_M/r_A \leqq 0\,414$ the tetrahedral structure with a coordination number of 4 is expected and an octahedral structure is expected when the radius ratio exceeds 0 414 with the possibility of cubic structures for still larger values of r_M/r_A As pointed out above a number of other structures have been observed in addition to those for which limiting values of the radius ratios are given in Table 4 The square planar structure has been observed in the case of the coordination number of 4 As a consequence of its geometric relationship to the octahedron the square planar structure may occur for the same values of the radius ratio as are required by the octahedron A parallel relationship exists between the trigonal bipyramidal structure (coordination number 5) and the trigonal planar structure (coordination number 3) Because in these cases the radius ratio does not distinguish between the pairs of structures even though both are known to exist it is necessary to find additional factors to explain their occurrence Other complexities could be introduced by extending the treatment properly to include higher coordination numbers

The majority of the structures of the molecules and complex ions containing central atoms or ions of the inert gas and pseudoinert gas types are summarized accurately in terms of the concepts just presented The structures of compounds derived from central ions having unshared pairs of electrons in their valence electron shells require further consideration

It is possible to relate the structures of coordination polyhedrons derived from central ions having unshared pairs of electrons by assuming that the sum of the electron pairs plus ligands determines the total geometry each electron pair being confined to a region in space which might otherwise be occupied by an anion or other ligand Table 5 illustrates the application of these ideas to coordination numbers from 2 to 6 The relationships summarized in Table 5 are presented in more detail in Fig 4 where the structures of H_2S PH_3 and SiH_4 are shown In this figure the electron pairs are represented by the volumes in space in which the electrons have the highest probability of being found Similar treatments are given to molecules and ions derived from the trigonal bipyramidal structure in Fig 5 and to those derived from the octahedron in Fig 6

It may be concluded from the preceding paragraphs that from a knowledge of the electronic structures of the elements the sizes of the ions and the correlations just presented it is possible to predict the geometric structures of binary compounds and complex ions for given central

Table 5 Structures of molecules and complex ions derived from central ions having unshared electron pairs

Total number of ligands plus electron pairs	Coordination polyhedron	Number of unshared electron pairs	Geometry of ligands	Examples
2	Linear	0	Linear	$Zn(CH_3)_2$ $HgCl_2$ CO_2
3	Trigonal plane	0	Trigonal plane	BCl_3 SO_3 NO_2
		1	Angular	SO_2 NO_2 $SnCl_2$
4	Tetrahedron	0	Tetrahedron	CH_4 $SiCl_4$ PCl_4^+
		1	Pyramidal	PCl_3 NF_3 SO_3^{2-}
		2	Angular	OF_2 H_2S BrF_2^+
5	Trigonal bipyramid	0	Trigonal bipyramid	PCl_5 AsF_5
		1	Irregular tetrahedron	SeF_4 $TeCl_4$ BiF_4^-
		2	T-shaped	ClF_3 BrF_3
		3	Linear	ICl_2^-
6	Octahedron	0	Octahedron	SF_6 PF_6^- $Sb(OH)_6^-$
		1	Tetragonal pyramid	IF_5 BrF_5
		2	Square planar	ICl_4^-

and ligands Principal emphasis has been placed on binary halides and oxides and complex oxyanions and haloanions It should be realized that the same treatment may be applied equally well to most polyatomic aggregates containing nontransition ions as central elements In addition the oxyanions and molecular halides of the transition elements may be treated similarly Thus VO_4^{3-} CrO_4^{2-} and MnO_4^- are tetrahedral in structure as are $TiCl_4$ and VCl_4 Also the octahedral fluoro complexes TiF_6^{2-} VF_6^- and FeF_6^{3-} are known Many of the hydrated and ammoniated metallic ions may also be discussed in these terms Among the particularly useful results of these considerations is the prediction of which compounds have electron pairs that might be shared with molecules or ions having the ability to expand their coordination spheres Thus the Lewis acids and bases are predicted from their structures *See* ACID AND BASE

The most significant limitation of the structural discussion just completed is its complete lack of concern with the detailed nature of the chemical bonds uniting the central atom to its ligands in a coordination polyhedron It was pointed out in the discussion of monatomic ions that ions of high charge probably do not exist in chemical compounds and that physical properties of many substances are not explainable in terms of simple electrostatic relationships The quantum mechanical theories of valence provide the more detailed descriptions of the manner of bonding required to overcome these limitations Some classes

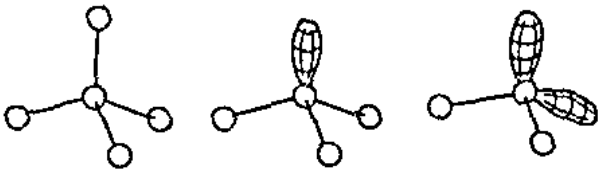


Fig 4 Structures derived from the tetrahedron (*The Ohio State University*)

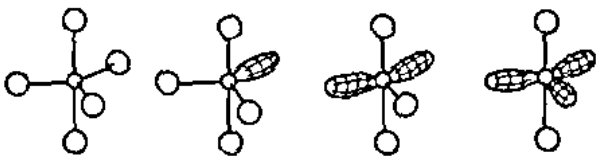


Fig 5 Structures derived from the trigonal bipyramid (*The Ohio State University*)

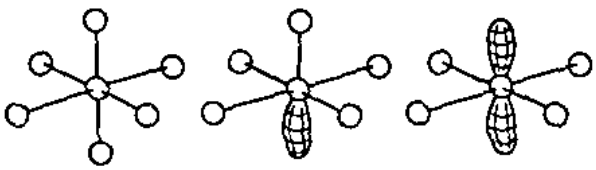


Fig 6 Structures derived from the octahedron (*The Ohio State University*)

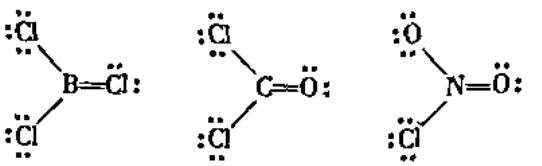
pounds cannot be systematized even from the standpoint of their geometric structures without the use of these more advanced concepts Two major theories exist for the application of the idea of the covalent bond to the structures of chemical compounds It is desirable at this point very briefly to make use of one of these the so called valence-bond concept

Valence bond theory. According to the valence bond theory the principal requirements for the formation of a covalent bond are a pair of electrons and suitably oriented electron orbitals on each of the atoms being bonded The geometry of the atoms in the resulting coordination polyhedron is correlated with the orientation of the orbitals on the central atom The orbitals utilized depend on the energies of the electrons in them In general the order of increasing energy of the electron orbitals is $(n-1)d < ns < np < nd$ It is concluded that a nontransition atom having one valence electron will form a covalent bond utilizing an s orbital In those cases where an unshared pair of electrons may be assigned to the ns orbital as many as three equivalent bonds may be formed by utilizing the three np orbitals of the central atom Because of the orientation of these p orbitals with respect to each other the three resulting bonds should be at 90° to each other This expectation is nearly realized in PH_3 In order to account for four or six equivalent bonds or for that matter, in order to account for all the remaining polyhedral and polyg onal structures, except the angular structure for a coordination number of two (with two unshared pairs of electrons on the cental atom), an additional assumption is necessary. It is assumed that s and p orbitals, s and d, or s, p, and d orbitals may be replaced by new orbitals, called hybridized orbitals These hybridized orbitals are derived from the original orbitals (mathematically) in such a way that the required number of equivalent bonds may be formed In the simplest case, it is shown that s and p may be combined to form two equivalent sp hybridized orbitals directed at 180° to each other Other sets of hybridized orbitals have been shown to be appropriate to describe the bonding in other structures These are summarized in Table 6

Table 6 Geometric structure and hybridized bonding orbitals of central atom

Coordination number	Orbitals	Geometric structure
2	p^2	Angular
2	sp	Linear
3	p^3	Trigonal pyramidal
3	sp^2	Trigonal planar
4	sp^3	Tetrahedral
4	d^2s	Tetrahedral
4	dsp^2	Square planar
5	dsp^3	Trigonal bipyramidal
6	d^2sp^3	Octahedral

Among inert gas ions of the first row of eight elements in the periodic table, there are four orbitals available for covalent bond formation, one $2s$ and three $2p$ Consequently, a maximum of four bonds may be formed This is in general agreement with the existence of the tetrahedron as the limiting coordination polyhedron among these elements for example, BeF_4^{2-}, BF_4^-, CCl_4, NH_4^+ Although only Li^+ deviates from this pattern, having a coordination number of 6 in its crystalline halides these compounds are best treated as simple electrovalent salts In keeping with the limitation of only four orbitals, the formation of double or triple bonds between atoms of these elements reduces the coordination number of the central atom Thus the highest coordination number of a first row element forming one double bond is 3 This is illustrated below

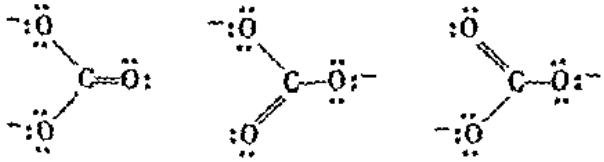


In these and similar examples the geometric array is determined by the formation of three single bonds utilizing sp^2 hybridized orbitals on the central atom and p orbitals on the ligand In general the bonds determining the geometry of a molecule or ion (in this way) are called σ bonds The double bond results from the superposition of a second bond a π bond between two atoms In this example it is seen that the formation of a π bond reduces the number of σ bonds from four to three

thus changing the geometries of the corresponding molecules or ions from tetrahedral to trigonal planar.

The formation of a second π bond (a triple bond or two double bonds) reduces the coordination number of the atom in question still further, resulting in the linear sp set of hybridized orbitals being utilized in σ bond formation. *See* VALENCE.

Resonance. With regard to the nature of doubly bonded compounds, another problem arises when such structures are viewed from the standpoint of valence-bond theory. In the species BCl_3, $COCl_2$, NO_2Cl and many similar substances, nonequivalent bonds are predicted. The doubly bonded oxygen should be closer to the central carbon atom than the singly bonded ones. This is not found to be true experimentally so long as the similar atoms are otherwise equivalent. There is only one observable C—O distance in carbonate, one N—O distance in nitrate, and so on. To account for such facts as these, the concept of resonance must be introduced. If the π bond exists, it must exist equally between the central atom and all the equivalent oxygen atoms. The resonance method of describing this situation is to say that one of the pictorial structures is inadequate properly to describe the substance, but that enough pictorial structures (resonance structures) should be considered to permute the double bond about all the equivalent bonds. The true structure is assumed to be something intermediate to all the resonance structures and more stable than any of them because it exists in preference to any one of them. The resonance structures for CO_3^{2-} are shown below.



See RESONANCE (MOLECULAR STRUCTURE).

Applications of valence bond theory. The valence-bond theory may be utilized to systematize structures involving unshared pairs of electrons in a manner very similar to that utilized above (Table 5 and Figs. 4–6). According to this view, the hybridized orbitals of the central atom determine a total polyhedral structure, but either bonds or unshared electron pairs may make use of the hybridized orbitals. Thus from Fig. 4, the silicon atom in SiH_4 forms bonds directed toward the corners of a tetrahedron by utilizing all four sp^3 hybridized orbitals. In the case of PH_3, the phosphorus atom forms three bonds utilizing three of the same hybridized orbitals, presumably, the fourth orbital is filled by the unshared electron pair.

The remaining elements of the periodic system (except hydrogen and helium) have $(n-1)d$ or nd orbitals available for bond formation in addition to the ns and np orbitals discussed in connection with the first row of eight elements. Along with the increasing values of the radius ratios for their derivatives, the availability of these orbitals accounts for the increased coordination numbers of compounds. The occurrence of such obviously covalent compounds as PF_5, SF_6, and many others is thereby easily understood.

Many of the compounds of transition metal ions may also be explained by utilizing the valence bond concept. The tetrahedral derivatives $TiCl_4$, VO_4^{3-}, CrO_4^{2-}, MnO_4^-, and FeO_4^{2-}, for example, utilize d^3s hybrid orbitals, whereas the central atoms in $CoCl_4^{2-}$ and $FeCl_4^-$ must be attached through sp^3 orbitals because the d orbitals are not available for bonding in these latter cases. Those central ions having two $(n-1)d$ orbitals may form octahedral structures, for example,

$$[Cr(H_2O)_6]^{3+} \qquad [Co(NH_3)_6]^{3+}$$

and

$$[Fe(CN)_6]^{4-}$$

whereas those having available a single $(n-1)d$ orbital may form derivatives having square planar structures, for example $PtCl_4^{2-}$ and $[Ni(CN)_4]^{2-}$. *See* COMPLEX COMPOUNDS.

The relationship between coordination number and the formation of double bonds does not carry over clearly to these elements of atomic number greater than 18. Because none of the coordination polyhedrons commonly encountered would require the utilization of all of the available orbitals on the central atom in σ bond formation, and because just those d orbitals not involved in hybridization (for σ bonds) are favorably disposed toward π bond formation, multiple bonding may at times be present and at other times absent from compounds involving the same coordination number. It follows that the formation of tetrahedral PO_4^{3-}, SO_4^{2-}, and ClO_4^- does not imply the absence of double bonding from the link between the central element and the oxygen.

CONDENSED POLYHEDRAL STRUCTURES

In the preceding discussions of polyatomic molecules and ions attention has been confined to those species in which single coordination polyhedrons effectively account for the geometric structures. Understanding of these species is central to the problem of the structures of chemical compounds, but does not provide an adequate basis for the descriptions of the structures of all or even a majority of the known compounds. Among the largest numbers of structures not covered by these concepts are those in which two or more coordination polyhedrons are united to form a more complex total structure. Large numbers of the compounds involving such condensed polyhedrons fall naturally into the subject of solid state chemistry.

Homologous series. The classic homologous series of compounds in organic chemistry provide useful examples involving the condensation of polyhedrons containing the same central element in the individual units. The structures of the first four members of the series of saturated or aliphatic hydrocarbons are shown in Fig. 7. The formula, C_nH_{2n+2}, represents a large

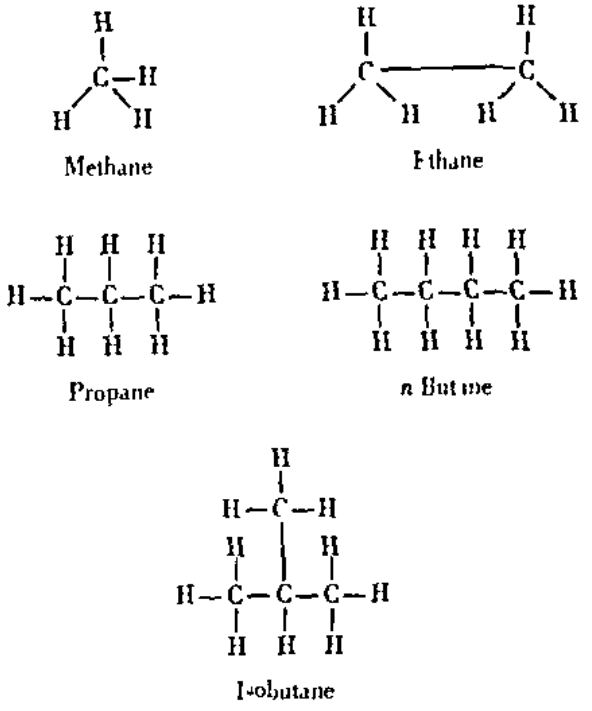


Fig 7 The saturated hydrocarbons (*The Ohio State University*)

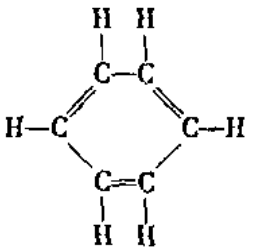
compounds extending from the lowest member methane CH_4 to polyethylene a plastic of economic importance in which n is a very large number The isomerism of the saturated hydrocarbons is easily understood from the example given in Fig 7 Two ways exist for the linking together of these tetrahedrons This gives rise to two molecular forms both of which are stable well known compounds It is an essential part of these structures that each C—C link is linear (because it is merely a σ bond) however when two carbon atoms are linked to a third the C—C—C angle is essentially determined by the bond angle of the central carbon atom (that is the other carbons may be treated as ligands to the first) as shown in Fig 8 The other familiar homologous series of organic chemistry differ from the saturated hydrocarbons in having at least one unique coordination polyhedron of a different type The olefins contain two doubly bonded or unsaturated carbon atoms whose polyhedral structures are trigonal planar and the remainder of the carbons are tetrahedral (Fig 9) As in the case of the aliphatic hydrocarbons the olefins exhibit an isomerism which is associated with the branching of the chain structure In addition the presence of two linked trigonal planar carbon atoms and the fact that the polyhedrons cannot rotate about the double bond gives rise to a different kind of isomerism called cis trans isomerism (Fig 10)

The existence of a predicted isomerism provides one of the most important confirmations of theories of chemical structure In general the polyhedral view of molecular structure as described here has been thoroughly verified by the discovery of the many types of predicted isomerism The first really convincing proof of the tetrahedral structures of saturated carbon atoms involved optical isomerism *See* OPTICAL ACTIVITY

Returning to the problem of condensed polyhedrons,

Alkynes	C_nH_{2n-2}
Primary amines	$C_nH_{2n+1}NH_2$
Carboxylic acids	$C_nH_{2n+1}COOH$
Amides	$C_nH_{2n+1}CONH_2$
Nitriles	$C_nH_{2n+1}C{\equiv}N$

and many other series of organic compounds may be explained in a manner similar to that utilized for the saturated hydrocarbons and olefins In all the substances the carbon atom dominates the structural relationships Many additional types of complex polyhedrons are found among organic compounds The aromatic hydrocarbons are characterized by cyclic arrangements of trigonal planar carbon atoms as shown for benzene below



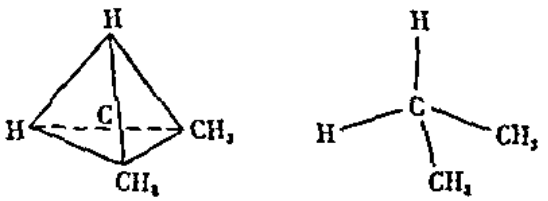


Fig 8 Geometric structure of propane (*The Ohio State University*)

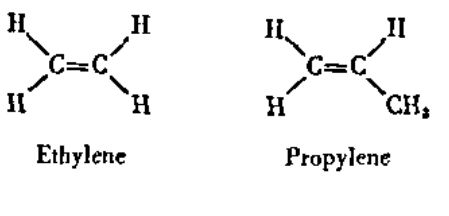


Fig 9 The olefins (*The Ohio State University*)

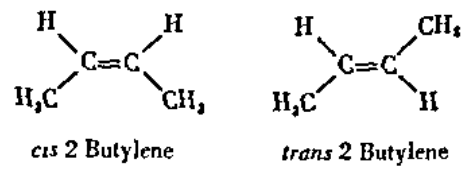


Fig 10 Cis-trans isomerism among olefins (*The Ohio State University*)

The highly symmetrical nature of the benzene molecule is not fully represented by such a structure The figure indicates the presence of three double and three single bonds in the ring It has been shown that the C—C bonds are all the same and consequently, the true structure of the substance must be represented by the resonance structure above and at least one additional resonance structure which interchanges the single and double bonds

Catenation. The property of an element to link to itself, which is so common for carbon, is called catenation Other elements exhibit this property to a lesser extent Nitrogen forms hydrazine, $NH_2—NH_2$ the homolog next higher than NH_3, however, the remaining members of the series N_nH_{n+2} are unknown Similarly, water, H_2O, and hydrogen peroxide, HO—OH, constitute the beginning of a homologous series of which only these two members are known Sulfur appears to approximate the behavior of carbon most nearly in its *proclivity toward catenation A series of sulfanes*, S_xH_2, is known, with x varying from unity to a relatively large number These substances have the structures shown in Fig 11 A number of related homologous series exist the organic sulfides, R_2S_x, the sulfur halides, SCl_2 and S_2Cl_2, the polythiosulfurous acids, $O_3S_x^{-2}$, and the polythionates, $O_3S—S_x—SO_3^{-2}$ The structures of representative members of the latter two series are shown in Fig 12 Catenation occurs to some extent among many other elements, for example phosphorus, silicon, arsenic and germanium

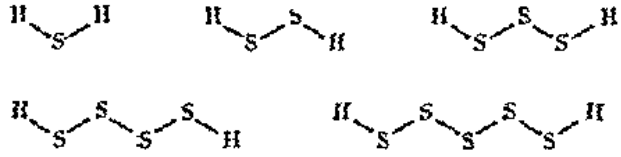


Fig 11 The sulfanes (The Ohio State University)

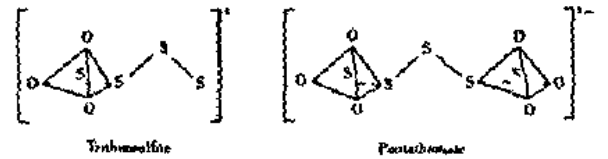


Fig 12 Structures of polythiosulfites and polythionates (The Ohio State University)

Bridge forming atoms. A second type of link is commonly involved in joining coordination polyhedrons into more complex structures This involves the interaction of bridge forming atoms to link other coordination polyhedrons instead of direct union of the central atoms The siloxanes provide examples of this behavior (Fig 13) These interesting and useful substances are related to the silicates in structure

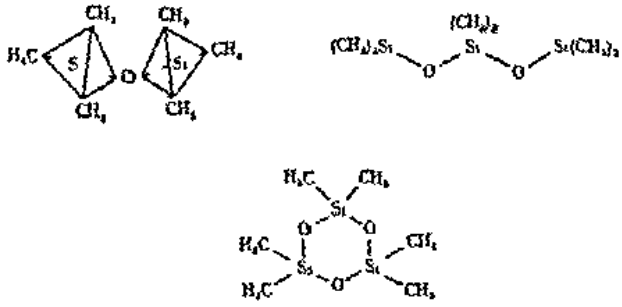
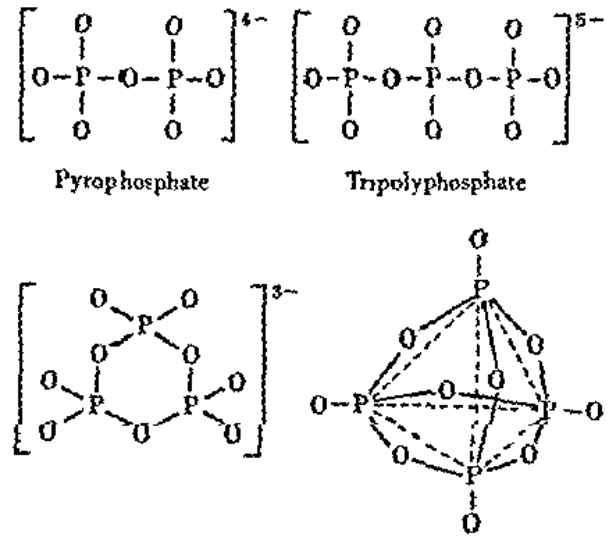


Fig 13 Structures of siloxanes (The Ohio State University)

The polyphosphates also involve the sharing of corners by PO_4 tetrahedrons through oxygen bridges Linear structures cyclic structures and more highly condensed systems are formed (Fig 14) The structure of P_4O_{10}, the anhydride of these acids is included for comparison



Pyrophosphate Tripolyphosphate

Trimetaphosphate Phosphoric anhydride

Fig 14 Structures of polyphosphates and phosphoric anhydride (The Ohio State University)

In addition to the sharing of corners coordination polyhedrons may unite by the sharing of edges or faces Of these edge sharing is the more common (Fig 15)

ELECTRON-DEFICIENT STRUCTURES

The majority of the chemical species which may be classified as molecular or complex ionic involve numbers of electrons which are consistent with the view that at least one pair of electrons is available to join each pair of atoms by covalent bond formation There are important exceptions to this generality Such exceptions are traditionally termed electron-deficient Convenient examples are found among the hydrides of boron The simplest boron hydride, diborane, has the molecular formula B_2H_6 Because this substance is electrically neutral it contains 12 valence electrons, 3 from each boron atom and 1 from each hydrogen atom A total of 14 electrons would be required to form enough covalent bonds to give a structure of the usual type The arrangement of atoms is similar to that of Al_2Cl_6 that is, two edge shared tetrahedrons (Fig 15) According to modern views, a hydrogen

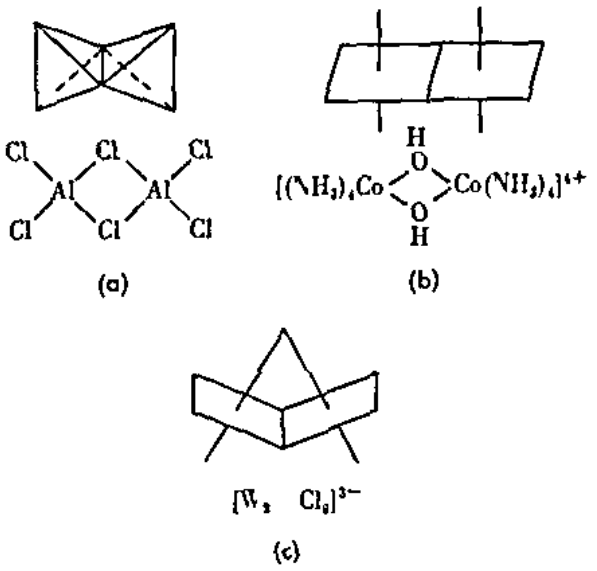


Fig 15 Condensed polyhedrons (a) Edge shared tetrahedron (b) Edge shared octahedron (c) Face shared octahedron (*The Ohio State University*)

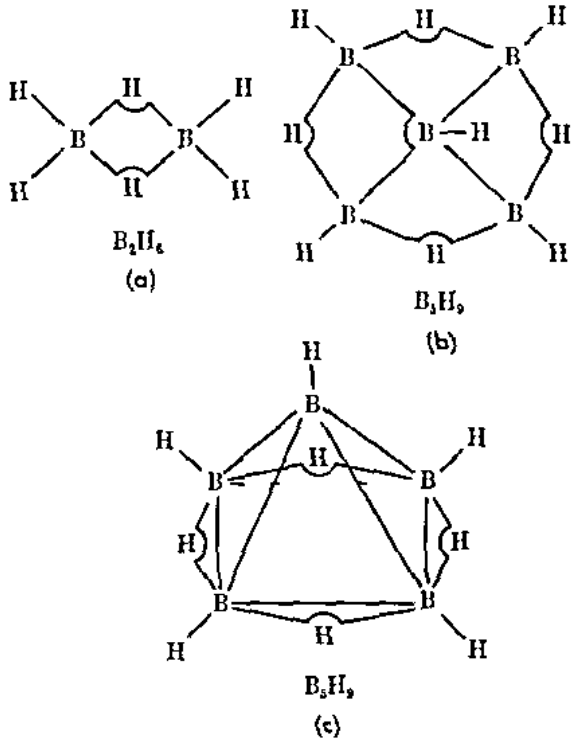


Fig 16 Structures of some boron hydrides (a) Diborane B_2H_6 (b) Planar projection of B_5H_9 (c) Geometric structure of B_5H_9 (*The Ohio State University*)

atom in a bridging position is joined to two boron atoms by a single pair of electrons Because this hypothesis describes the union of three atoms by means of one electron pair the resulting structural unit is called a three-center bond (Fig 16) Three center bonds are also postulated in more complex substances such as B_5H_9 which is also shown in Fig 16 This structure involves 5 normal B—H covalent bonds 2 normal B—B bonds 4 three center B—H—B bonds and 1 three-center B—B—B bond *See* MAGNETOCHEMISTRY, MOLECULAR STRUCTURE AND SPECTRA STEREOCHEMISTRY

[D H B]

Chemical symbols and formulas

A system of symbols and notation for the 102 chemical elements and the combinations of these elements which form numerous chemical compounds This system of symbols devised since about 1800 by chemists consists of letters numerals and marks that are designed to denote the chemical element formula or structure of the molecule or compound These symbols give a concise and instantly recognizable description of the element or compound In many cases through the efforts of international conferences the symbols are recognized throughout the scientific world and they greatly simplify the universal language of chemistry

Elements Each of the 102 presently known chemical elements is given a symbol which usually is derived from the name of the element Several examples of names and symbols are chlorine Cl fluorine F beryllium Be aluminum Al oxygen O and carbon C However symbols for some elements are derived from Latin or other names for the element for example Au gold (from *aurum*) Fe iron (from *ferrum*) Pb lead (from *plumbum*) Na sodium (from *natrium*) and K potassium (from *kalium*) The symbols consist of one or more commonly two letters The first letter is always a capital letter and is followed by a lower case second letter

Inorganic molecules and compounds Simple diatomic molecules of a single element are designated by the symbol for the element with a subscript 2 indicating that it contains 2 atoms Thus the hydrogen molecule is H_2 the nitrogen molecule N_2 and the oxygen molecule O_2 Polyatomic molecules of a single element are designated by the symbol for the element with a numerical subscript corresponding to the number of atoms in the molecule Examples are the phosphorus molecule P_4 the sulfur molecule S_8 and the arsenic molecule As_4

Diatomic covalent molecules containing unlike elements are given a similar designation The formula for hydrogen chloride is HCl for iodine monochloride ICl and for hydrogen iodide HI The more electropositive element is always designated first in the formula

For polyatomic covalent molecules containing unlike elements numerical subscripts are used to designate the number of atoms of each element present in the molecule Examples are phosphorus(III) chloride PCl_3 arsine AsH_3 ammonia NH_3 and water H_2O Again as in diatomic molecules the more electropositive element is placed first in the formula

Ionic inorganic compounds are designated by a similar notation The positive ion is given first in the formula followed by the negative ion subscripts are again used to denote the number of ions

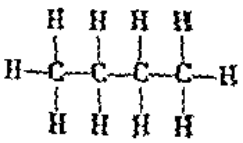
of each element present in the compound The formulas for several common compounds are sodium chloride NaCl ammonium nitrate NH_4NO_3 aluminum sulfate $Al_2(SO_4)_3$ and iron(III) oxide Fe_2O_3

More complex inorganic compounds are designated in a manner similar to that above The positive ion is given first but may contain attached or coordinated groups and this is followed by the negative ion Examples are hexamminecobalt(III) chloride $[Co(NH_3)_6]Cl_3$ dichlorobis(ethylenediamine)chromium(III) nitrate $[Cr(en)_2Cl_2](NO_3)_3$ where en is the abbreviation for ethylenediamine and potassium trioxalatoferrate(III) $K_3[Fe(C_2O_4)_3]$ Hydrates of inorganic compounds such as copper(II) sulfate pentahydrate are designated by the formula of the compound followed by the formula for water the number of water molecules being designated by a numerical prefix Thus the symbol for the above compound is $CuSO_4 \cdot 5H_2O$

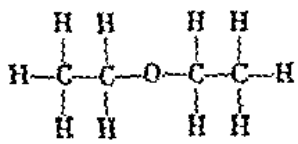
Organic compounds Because there are many more organic than inorganic compounds the designation or notation for the first group becomes exceedingly complex Many different types of organic compounds are known in the case of hydrocarbons there are aromatic and aliphatic saturated and unsaturated cyclic and polycyclic and so on The system of notation used must distinguish between the various hydrocarbons themselves as well as setting this group of compounds apart from others such as alcohols ethers amines esters and phenols

Organic compounds can be designated by several different methods The first is called the empirical formula method Common examples are methane CH_4 ethane C_2H_6 and ethyl alcohol C_2H_6O The disadvantage of this system is that it neither describes the structure of the particular molecule nor distinguishes between isomers

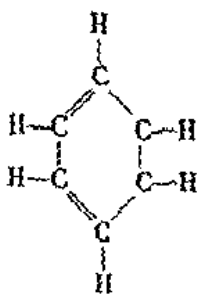
The second method consists of the designation of a compound by its structural formula This method is illustrated by the following examples (I V)



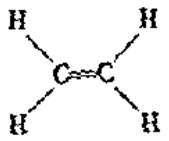
n Butane (I)



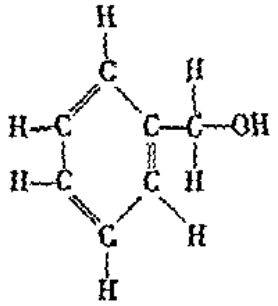
Ethyl ether (II)



Benzene



Ethylene

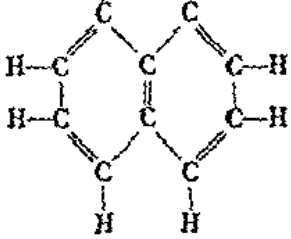


Benzyl alcohol (V)

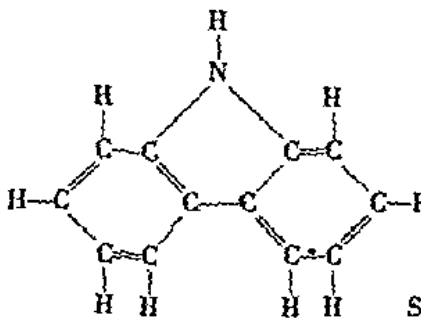
There are many advantages of this method over the first. The exact structure providing it is known is given in a schematic representation This removes any ambiguity concerning isomers or other structural variations

One of the disadvantages of the second method is that in many cases the structures cannot be described on a single line of type Special type is also needed for the various ring systems and other complicating factors To overcome this disadvantage a third method the line-formula designation is used Examples of this method are acetone CH_3COCH_3 3-chloropentane $CH_3CH_2CHClCH_2CH_3$ melamine $NC(NH_2)NC(NH_2)NC(NH_2)$ and malonic acid $HOOCCH_2COOH$ However this method is cumbersome when used with complicated ring systems

To shorten the line-formula method various other line formula methods have been proposed such as those by W J Wiswesser and by G M Dyson In Wiswesser's method symbols are used for the chemical elements involved as well as for function groups and various ring systems Thus 1H is the symbol for methane (1 designates the methyl group CH_3—) 4H is *n* butane (4 designates the butyl group C_4H_9—) 2Q is ethyl alcohol (2 designates the ethyl group C_2H_5— Q is the —OH group) and RH is benzene (R designates the phenyl group C_6H_5—) The advantages of this method are illustrated by (VI) and (VII)



Naphthalene (VI)
Symbol 66



Carbazole (VII)
Symbol b656

The Dyson notation is similar to the Wiswesser method in that the compound can be described on a single line In this method methyl alcohol is C Q *n* propyl alcohol is C_3Q phenol is B6 Q and α naphthol is $B6_2$ Q 3 *See* CHEMISTRY COMPLEX COMPOUNDS INORGANIC CHEMISTRY ORGANIC CHEMISTRY [W W WE]

Chemical warfare

During World War I a toxic chemical was used to produce casualties among the defending forces for the first time in modern warfare There are numerous records of the use in ancient combat of noxious gases *fumes, and smokes such as the combustion* products of sulfur tars and pitch but these attacks were never made on an organized basis with a thorough knowledge of their toxic effects and with munitions designed for their dissemination Although gas warfare was thoroughly exploited during World War I it has not been used in any major conflict since that time

The term chemical warfare although first used to mean the employment of poison gases as antipersonnel agents was later expanded to include flame and incendiary warfare smoke for screening or signaling purposes and eventually biological warfare which encompasses the use of bacteria rickettsia viruses and bacterial toxins for the production of casualties or the destruction of crops *See* INCENDIARY SCREENING SMOKE

The first compounds used in organized warfare were either true gases or vapors of highly volatile liquids and as such were called poison gases This term was soon stretched to cover high boiling liquids and even solids that killed or incapacitated when absorbed through the skin or when inhaled as aerosols or vapors Poison gases may be roughly grouped according to the portal of entry into the body and their gross physiological effects Vesicants or blister gases produce blisters or vesicles on all body surfaces lacrimators or tear gases cause intense eye irritation sternutators or vomiting gases cause nausea and general malaise nerve gases interfere with normal nerve function and lung irritants attack the respiratory tract causing pulmonary edema

Vesicants Vesicants or blister gases attack all body surfaces such as skin mucous membrane and the cornea of the eyes producing at first a reddening or erythema and later blisters or vesicles

Mustard gas was the only vesicant in major use in World War I The first recognized synthesis of this compound bisdichlorodiethyl sulfide $(ClC_2H_4)_2S$ *was accomplished in 1886* by Victor Meyer It has been manufactured in quantity by either the thiodiglycol process

$$(HOC_2H_5)_2S + 2HCl \rightarrow (ClC_2H_4)_2S + 2H_2O$$

or the Levenstein process

$$CH_2{=}CH_2 + S\,Cl_2 \rightarrow (ClC_2H_4)_2S + S$$

Exposure of the skin to either the liquid or its vapor results in erythema or blisters which are slow and painful in healing and may become sources of secondary infection Mustard gas is insidious in its action producing no pain at the time of exposure The damage to the body does not become *apparent until several hours later Inhalation* of air containing 150 mg m^3 for 10 min can cause death Eyes are injured by exposure to air containing 20 mg/m^3 for 10 min Exposure of the skin to air containing 200 mg/m^3 for 10 min will incapacitate Wet or perspiring skin absorbs more mustard than does dry skin Mustard is readily recognized by its garlic or horseradish odor It can be destroyed by chlorination oxidation or slow hydrolysis

In 1918 the United States started large scale production of chlorovinyl dichloroarsine $ClCH{=}CHAsCl_2$ This compound was first synthesized by *W Lee Lewis and named for him lewisite The war* ended before any lewisite reached the European battlefields so it has never been used in combat Lewisite is similar to mustard in that it damages the skin or eye surfaces on exposure to either liquid or vapor in comparable concentrations It is painful on contact and extremely irritating to inhale In low concentrations it has a geraniumlike odor Its rapid rate of hydrolysis coupled with the discovery by R Peters s group of an extremely effective chemotherapeutic compound 2 3 dimercapto 1 propanol commonly termed BAL (British anti Lewisite) make it very doubtful that lewisite will ever again be considered as a war gas

BAL forms a stable and nontoxic compound with arsenic and reacts with almost all organic arsenicals Results are dramatic in the treatment of arsenic poisoning particularly exfoliative dermatitis BAL has also been found extremely effective in the treatment of bichloride of mercury poisoning On the other hand BAL apparently increases the toxicity of lead or cadmium

BAL itself in doses of 5 mg/kg will produce in man symptoms of intoxication which reach their [illegible]

Table 1 Properties of vesicants

Gas	Symbol	M p °C	B p °C	Specific gravity
Mustard gas	H	14	22° 8	1 27
Lewisite	I	−18	190	1 89
Nitrogen mustard	HN1	−34	$8_{3\,10}$	1 09
Nitrogen mustard	HN2	−60	75_{10}	1 15
Nitrogen mustard	HN3	−4	137_{14}	1 24

Table 2 Structures of nitrogen mustards

Agent	Where R in the formula $RN(C_2H_4Cl)_2$ is
HN1	C_2H_5–
HN2	CH_3–
HN3	ClC_2H_4–

Attention was drawn to these compounds about 1935 Although not quite as effective on skin as

mustard gas itself they produce greater eye damage and are comparatively odorless They also have much lower freezing points than does mustard gas The nitrogen mustards are more resistant than mustard gas to destruction by chlorination or hydrolysis On the other hand their low volatilities reduce their effectiveness as vapors

The nitrogen mustards and other amines of similar structure possess the interesting physiological ability to arrest cell mitosis This behavior has led to intensive experimentation with these compounds as possible therapeutic agents in the treatment of neoplasms in particular leukemia

Lacrimators Lacrimators or tear gases cause an intense eye irritation usually resulting in a copious flow of tears The irritation also tends to produce blepherospasm or involuntary inability to open the eyes Although used in World War I these compounds were not effective in producing casualties Recovery in an uncontaminated atmosphere is rapid and complete The gas mask renders these agents harmless Many compounds have lacrimatory action Those shown in Table 3 are the most effective on unmasked personnel

Table 3 Properties of lacrimators

Gas	M p °C	B p °C	Effective concentration mg/m³
α Chloroacetophenone	54	244 (decomposes)	10
α Bromobenzyl cyanide	25	24* (decomposes)	5

Sternutators Sternutators sometimes called sneeze gases or vomiting gases cause physical discomfort such as nausea vomiting respiratory tract irritation and general malaise to such an extent that a casualty results The sternutators rarely cause death Chemically these compounds are organic arsenic derivatives

The symptoms produced by inhalation of these materials are in order irritation of eyes and nose sneezing or coughing headache pain in chest nausea and vomiting There may be a delay of about 1–2 min in the onset of symptoms which can last from ½ to 3 hours after leaving the contaminated atmosphere Their use in World War I was based on the fact that the gas mask originally had no filter The arsenical sternutators disseminated as solid aerosols were not absorbed by the charcoal bed and penetrated the mask canister readily Their use was nullified by a filter in the gas mask

Table 4 Properties of sternutators

Gas	Symbol	Incapacitating concentration for 10 min exposure mg/m³
D phenylchloroarsine	DA	1 2
Diphenylcyanoarsine	DC	1 0
D phenylaminechloroarsine	DM	2 2

Nerve gases The nerve gases or anticholinesterases were developed in Germany during World War II but were never used These compounds destroy or interfere with normal nerve conduction The nerve gases are organic phosphorus derivatives

Table 5 Properties of nerve gases

Gas	Symbol	M p	B p	Lethal concentration, for 10 min exposure mg/m³
Tabun	GA	−50	246	40
Sarin	GB	−56	147	10
Soman	GD	−70	167	10

These compounds are among the most toxic chemicals known to man Except for tabun (GA) which has a fruity odor the nerve gases are odorless As vapors they are extremely effective by inhalation and as liquids they will penetrate the skin without damage or sensation and kill on entering the blood stream They react irreversibly with the enzyme cholinesterase, thus allowing the rapid accumulation of excessive quantities of acetylcholine This results in complete muscular incoordination and finally in death by cessation of respiration Treatment by atropine injection and artificial respiration is recommended In the absence of treatment death may occur within 2–10 min

The nerve gases were discovered as a result of investigations into insecticides Today many modern insecticides having similar chemical structures and physiological actions are available The hazards associated with their use must be recognized

A closely allied compound diisopropylfluorophosphate (DFP) which is not as toxic as the nerve gases has been used in the experimental treatment of glaucoma and myasthenia gravis

Lung irritants Lung irritants attack the respiratory tract in particular the lungs causing pulmonary edema They are disseminated as vapors

Table 6 Properties of lung irritants

Gas	Symbol	B p	Lethal concentration for 10 min exposure mg/m³
Chloropicrin	PS	112	
Phosgene	CG	8	320
Diphosgene	DP	127	320
Chlorine	Cl	−35	600

Chloropicrin (CCl_3NO_2) developed during World War I is also a powerful lacrimator It was not very effective as a war gas since it warned of its presence by its lacrimatory action It has found wide commercial use as an insecticide

Chlorine the first gas used in warfare attacks the upper respiratory system and causes an immediate irritation and choking sensation It was replaced early in World War I by phosgene which is over six times more toxic

Phosgene ($COCl_2$) and diphosgene ($ClCOOCCl_3$) have identical physiological effects [illegible] somewhat irritating when inhaled b[illegible] passes Several hours later the

edema which soon becomes massive and causes death by asphyxiation Their rather low toxicity and the difficulty in handling phosgene due to its low boiling po nt led to its being discarded as a war gas early in the war

All lung irritants are easily protected against by the modern protective mask *See* GAS MASK ORGANOARSENIC COMPOUND ORGANOPHOSPHORUS COMPOUND ORGANOSULFUR COMPOUND [S D S]

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Chemiluminescence

An emission of l ght resulting from a chemical reaction Probably the best known example of chemiluminescence is the faint green glow that accompanies the slow oxidation of white phosphorus in air This phenomenon can be used to generate a cold flame by passing an inert (nonreacting) carrier gas such as carbon dioxide over warmed phosphorus and allowing the stream of gas to emerge into air The chemiluminescence of phosphorus is often called phosphorescence However the latter term is also used in a quite d fferent sense to denote a type of luminescence that is not related to chemiluminescence The term phosphor likewise owes its origin to the above described chemiluminescence of phosphorus but the mechanism of light emission from phosphors is not a chemiluminescence Besides the glow of phosphorus a number of other chemiluminescent reactions are known particularly in the field of organic chemistry Chemiluminescence that occurs in living systems such as the glow of a firefly is called bioluminescence *See* BIOLUMINESCENCE LUMINESCENCE [C C K J H S]

Chemistry

The science of chemistry includes a study of the properties composition and structure of matter the changes in structure and composition which matter undergoes and the accompanying energy changes It grew out of the black magic of the dark ages and the alchemy of the middle ages The exact date of the beginning of chemistry as a science cannot be stated but a date frequently given is the time of the correct interpretation of combustion by the great French scientist A L Lavoisier about 1774

Today the objective of the chemist is to aid in the interpretation of the universe He has made much progress toward meeting this objective because he knows about not only the structure and composition of many of the materials on the earth but also those of the planets the satellites the stars and the materials of interstellar space

Method of science The success of chemistry is largely attributed to the use of the scientific method although not all the discoveries are made by planned research many of them are made by trial and error and l y accident Nevertheless the rigorous procedure of observation classification theorizing and experimentation to test the theory runs throughout this entire science

The huge problem of interpreting the universe is considerably simplified by breaking it down to smaller problems by classifying the great variety of materials in the universe into the two great entities energy and matter Energy can be classified as potential or kinetic energy and can be broken down further into such forms of energy as mechanical electrical radiant and chemical Matter can be classified in a number of different ways One method is in terms of the physical state—solid liquid and gas but probably the most useful method is in terms of composition—elements compounds and mixtures

Chemical elements the periodic table An element is a substance which cannot be broken down to simpler substances by chemical reactions It is also defined as a substance made of one kind of building block only There probably are not more than 90–100 elements that make up the entire universe A careful study of the elements has indicated that they can be classified into families or groups that further simplify the problem of learning about the universe This classification is called the periodic table The elements in each family or group of the periodic table have similar properties *See* ELEMENTS (CHEMICAL) PERIODIC TABLE

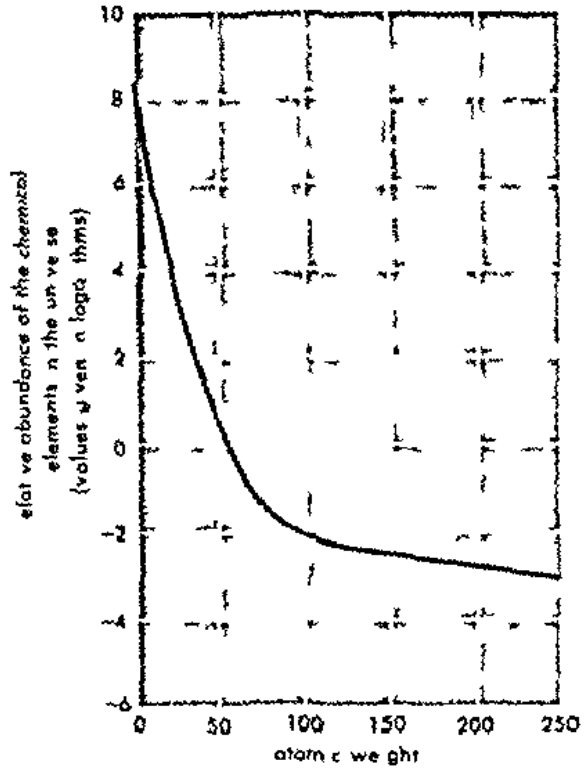
The most abundant element on the earth s surface is oxygen the next being silicon The two most abundant elements in the universe are hydrogen and helium Tables 1 and 2 list the 10 most plentiful elements in the earth s crust and in the human body

Laws of chemical combination The early foundations of chemistry were based on two fundamental laws the law of conservation of matter and

Table 1 Relative abundance of the elements

	Sol d 10 mile crust of earth %	Ocean %	Average %*
Oxygen	46 71	85 79	49 52
S l con	27 69		25 75
Aluminum	8 07		7 51
Iron	5 05		4 70
Calc um	3 65	0 05	3 39
Sod um	2 75	1 14	2 64
Potassium	2 58	0 04	2 40
Magnes um	2 08	0 14	1 94
Titan um	0 62		0 58
Hydrogen	0 14	10 67	0 88
Phosphorus	0 130		0 1"0
Carbon	0 094	0 002	0 087
Chlor ne	0 045	2 07	0 188
Other elements	0 391	0 098	0 295
	100 00	100 00	100 00

* Includ ng crust ocean and atmosphere



Abundances of the elements in the universe Elements of low atomic weight are by far the most abundant

energy and the law of definite composition The establishment of these laws required much careful research on the quantitative relationship of reactants and products in chemical processes and also of the ratio of weights of the elements in compounds The chemical balance became the important instrument in this work After the law of conservation of matter had been established much research was done on the combining weights of elements These data not only led to the law of definite composition (the composition of a pure substance is always perfectly definite) but also to the atomic theory to a system of atomic weights, and to the methods of determining formulas of compounds

Dalton's atomic theory To explain several phenomena including the law of definite composition which resulted from the observation that elements always combine in the same ratio by weight to form a given compound John Dalton proposed *that matter is made of particles called atoms that* reactions must take place between atoms or groups of atoms and that atoms of the same element are all alike but that they differ from atoms of another element These assumptions are the basis of the accepted modern atomic theory They are also most useful in explaining another law of chemical combination called the law of multiple proportions which states that when two or more elements combine in more than one ratio, they do so in the ratio of small whole numbers

Table 2 Average composition of the human body

Element	%	Element	%
Oxygen	65 00	Sodium	0 15
Carbon	18 00	Chlorine	0 15
Hydrogen	10 00	Magnesium	0 05
Nitrogen	3 00	Iron	0 00
Calcium	1 50	Iodine	0 00004
Phosphorus	1 00	Fluorine	Very minute amounts
Potassium	0 35	Silicon and other elements	
Sulfur	0 2		

Atoms molecules and ions *Atoms are made up* of three fundamental particles protons and neutrons at the heart or center of the atom and electrons surrounding the nucleus of protons and neutrons *All the atoms of the same element have the* same atomic number Elements whose atoms have the same number of electrons in the outer shell have similar properties this accounts for the similar properties of the elements in each family of the periodic table The different atoms tend to react with each other by gaining or losing electrons or sharing pairs of electrons If the atoms combine by sharing pairs of electrons molecules are formed If they combine by gaining and losing electrons ions are formed Ions carry positive or negative electrical charges

Structure of atoms The present concept of the *atom is the result of some of the most significant* research in the whole history of chemistry Some high points of these researches follow

1896 *The discovery of radioactivity* by A H Becquerel opened the atomic era and gave the chemist high energy atomic projectiles with which to bombard other elements

1897 The identification of electrons by Thomas Thomson as negative particles of electricity and common to all substances

1911 The discovery by Sir Ernest Rutherford that the atom is a very porous body and that the nucleus is very tiny and is composed of most *of the mass of the atom*

1912 The discovery by H G J Moseley that the positively charged particles are located in the nucleus of the atom

1913 The invention by Niels Bohr of the solar system model of atoms which was successful in explaining the quantum nature of radiation the lines in spectra chemical bonding and periodic properties of elements

1919 The discovery by Sir Ernest Rutherford that *elements could be transmuted by bombard*ment with high energy particles from radium thus changing their atomic numbers

1920 to 1930 The discovery of spinning electrons paired electrons and the distribution of electrical charge over the atom with higher density in *discrete energy levels*

1932 The discovery of the neutron by James Chadwick which identified the third stable particle in the atoms

1934 *The discovery by J F and I C Joliot that* all elements can be made radioactive by bombarding their nuclei with high-energy particles

edema which soon becomes massive and causes death by asphyxiation Their rather low toxicity and the difficulty in handling phosgene due to its low boiling point led to its being discarded as a war gas early in the war

All lung irritants are easily protected against by the modern protective mask *See* GAS MASK ORGANOARSENIC COMPOUND ORGANOPHOSPHORUS COMPOUND ORGANOSULFUR COMPOUND [S D S]

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Chemiluminescence

An emission of light resulting from a chemical reaction Probably the best known example of chemiluminescence is the faint green glow that accompanies the slow oxidation of white phosphorus in air This phenomenon can be used to generate a cold flame by passing an inert (nonreacting) carrier gas such as carbon dioxide over warmed phosphorus and allowing the stream of gas to emerge into air The chemiluminescence of phosphorus is often called phosphorescence However the latter term is also used in a quite different sense to denote a type of luminescence that is not related to chemiluminescence The term phosphor likewise owes its origin to the above described chemiluminescence of phosphorus but the mechanism of light emission from phosphors is not a chemiluminescence Besides the glow of phosphorus a number of other chemiluminescent reactions are known particularly in the field of organic chemistry Chemiluminescence that occurs in living systems such as the glow of a firefly is called bioluminescence *See* BIOLUMINESCENCE LUMINESCENCE [C C K J H S]

Chemistry

The science of chemistry includes a study of the properties composition and structure of matter the changes in structure and composition which matter undergoes and the accompanying energy changes It grew out of the black magic of the dark ages and the alchemy of the middle ages The exact date of the beginning of chemistry as a science cannot be stated but a date frequently given is the time of the correct interpretation of combustion by the great French scientist A L Lavoisier about 1774

Today the objective of the chemist is to aid in the interpretation of the universe He has made much progress toward meeting this objective because he knows about not only the structure and composition of many of the materials on the earth but also those of the planets the satellites the stars and the materials of interstellar space

Method of science The success of chemistry is largely attributed to the use of the scientific method although not all the discoveries are made by planned research many of them are made by trial and error and by accident Nevertheless the rigorous procedure of observation classification theorizing and experimentation to test the theory runs throughout this entire science

The huge problem of interpreting the universe is considerably simplified by breaking it down to smaller problems by classifying the great variety of materials in the universe into the two great entities energy and matter Energy can be classified as potential or kinetic energy and can be broken down further into such forms of energy as mechanical electrical radiant and chemical Matter can be classified in a number of different ways One method is in terms of the physical state—solid liquid and gas but probably the most useful method is in terms of composition—elements compounds and mixtures

Chemical elements, the periodic table An element is a substance which cannot be broken down to simpler substances by chemical reactions It is also defined as a substance made of one kind of building block only There probably are not more than 90–100 elements that make up the entire universe A careful study of the elements has indicated that they can be classified into families or groups that further simplify the problem of learning about the universe This classification is called the periodic table The elements in each family or group of the periodic table have similar properties *See* ELEMENTS (CHEMICAL) PERIODIC TABLE

The most abundant element on the earth s surface is oxygen the next being silicon The two most abundant elements in the universe are hydrogen and helium Tables 1 and 2 list the 10 most plentiful elements in the earth s crust and in the human body

Laws of chemical combination The early foundations of chemistry were based on two fundamental laws the law of conservation of matter and

Table 1 Relative abundance of the elements

	Solid 10 mile crust of earth %	Ocean %	Average % *
Oxygen	46 71	85 79	49 52
Silicon	27 69		25 75
Aluminum	8 07		7 51
Iron	5 05		4 70
Calcium	3 65	0 05	3 39
Sodium	2 75	1 14	2 64
Potassium	2 58	0 04	2 40
Magnesium	2 08	0 14	1 94
Titanium	0 62		0 58
Hydrogen	0 14	10 67	0 88
Phosphorus	0 130		0 1?0
Carbon	0 094	0 002	0 087
Chlorine	0 045	2 07	0 188
Other elements	0 391	0 098	0 ?95
	100 00	100 00	100 00

* Including crust ocean and atmosphere

Fields of chemistry The field of chemistry is now a very large one There are 31 different branches of chemistry recognized by the chemical publication journal called *Chemical Abstracts* Some of the better known fields are inorganic chemistry organic chemistry physical chemistry analytical chemistry, biological chemistry pharmaceutical chemistry, nuclear chemistry industrial chemistry colloidal chemistry and electrochemistry

Chemical literature There are many articles published on chemical topics each year in a great variety of journals all over the world Probably the most important scientific journal is *Chemical Abstracts*, which publishes the abstracts of all the chemistry articles published by any of the journals in the world This means abstracting articles from some 6000 or 7000 scientific journals and publishing about 100 000 abstracts per year

Chemical industry The chemical manufacturing industry is now the major industry in the United States in terms of value of production It shows promise of expanding very rapidly in the future From 1939 to 1954 the chemical industry increased fivefold and another fivefold increase is predicted by 1975

Employment for chemists. Chemists perform a number of different and important jobs In the research laboratory the chemists work on fundamental research such as synthesizing new compounds and studying the properties of others The importance of fundamental research is recognized when it is realized that half of the jobs of the nation can be traced to the research laboratory In the analytical laboratory chemists develop methods of analysis of elements and of compounds In industrial chemistry, one of the important jobs is the synthesis or purification of chemicals on a large scale for production purposes. *See* CHEMICAL ENGINEERING

There are many other jobs for chemists in industry such as writing literature abstracting promotion of product and patents There is also the very important field of teaching in high schools colleges and universities

Chemists work in many different types of laboratories Many industries such as oil plastics fabrics rubber drugs, and iron and steel have research laboratories and analytical and testing laboratories There are the government laboratories such as the Atomic Energy centers the Regional Agricultural Research Laboratories, and the National Bureau of Standards Also there are the independent research foundations such as Mellon Institute Rockefeller Foundation and Battelle Memorial Institute The universities have research laboratories in which are trained the graduate students who are to become the research chemists for these many other laboratories as well as the teachers for colleges and universities *See* ANALYTICAL CHEMISTRY BIOCHEMISTRY INORGANIC CHEMISTRY ORGANIC CHEMISTRY PHYSICAL CHEMISTRY

[A B C]

Chemoreception

The response of most organisms to a change in their chemical environment Lower forms such as protozoans react to chemical stimuli as a consequence of a general property of irritability inherent in all living matter A similar response to certain obnoxious chemicals is initiated by the small fine nerve endings commonly found in the cornea and mucous membranes of mammals Such responses are associated with a common chemical sense

The chemical senses play an important role in the nutrition of all forms of animals This importance is emphasized by the fact that specialized chemical sense organs evolved much earlier than the receptors of the other major senses Specialized taste receptors are responsive to water soluble chemicals and are important in the monitoring of all food entering the oral cavity of many animals The acceptance or rejection of the food depends upon its taste which is usually related to its nutritive or harmful qualities Olfactory receptors respond to minute concentrations of odors Such receptors may play a large role in the male to female attraction among insects and many vertebrates and are important in the initiation of reproductive behavior The olfactory receptors and trigeminal nerve endings monitor inspired air An animal may be sufficiently alerted if a strange odor is present in the inspired air so that rejection may occur if the substance is highly toxic

Specialized chemoreceptors are found within many mammals and help maintain the internal environment of the organism The respiratory center of the medulla responds to carbon dioxide of the blood and controls respiration and the oxygen content of the blood Changes in the bodily constituents of an animal due to a disease may change the taste sensitivity An animal may tend to compensate for its deficiency to a particular chemical by better detection and greater intake Thus chemoreception plays an important role in all organisms particularly in those functions involved with survival and reproduction *See* SENSE ORGAN

Gustation The sensation of taste may be described in two common groups of animals—vertebrates and insects

Vertebrates Taste buds the organs of taste in vertebrates were first discovered around the oral cavity and along the sides of teleosts (bony fishes) In mammals they are largely located on the tongue, although taste buds do exist elsewhere in the oral cavity They are associated with the fungiform papillae on the anterior two-thirds of the tongue and with the circumvallate and foliate papillae on the posterior third The chorda tympani nerve innervates the anterior taste buds and the glossopharyngeal the posterior Each taste bud has a diameter of about 70 μ and consists of 5–7 sensory cells surrounded by a slightly larger number of supporting cells It is located near the tongue

surface and each taste cell communicates with the aqueous medium above with small villilike structures called taste hairs which project through the taste pore Salty sour bitter and sweet are the basic taste qualities sensed by man they may be elicited by salts acids alkaloids, and sugars respectively Sweet tastes may be completely inhibited by gymnemic acid without appreciably affecting the salty or sour tastes Thus granulated sugar tastes like sand

Most flavors are a blend of the four basic taste qualities plus various olfactory components Other receptors of the oral cavity such as tactile temperature and pain may contribute to the over all quality of a sapid substance placed into the mouth The reception of a sweet sensation is greatest from the tip of the tongue whereas bitter sensation is greatest from the base

Taste sensitivity varies from one person to another The ability to perceive the bitter taste of phenylthiourea is genetically determined About 70% of the population are tasters and 30% non tasters (*see* TASTE) Individual differences are also found in the number and distribution of taste buds on the tongue The number of sweet receptors at the tip of the tongue diminishes with age but no large decrease occurs in the bitter receptors at the base

Table 1 Human taste thresholds

Stimulus	Threshold moles/liter
Sucrose	2×10^{-2}
Sodium chloride	3.5×10^{-2}
Hydrochloric acid	2×10^{-2}
Quinine sulfate	4×10^{-7}

A single nerve fiber may innervate several taste cells each of which may have different sensitivity to one or more chemicals corresponding to the four taste qualities The stimulation of a taste cell by a chemical results in an electrical depolarization of its surface This initiates nerve impulses in the taste nerve which are transmitted to the central nervous system Since a single nerve fiber innervates more than one taste cell each fiber may respond to the stimuli of one or more taste qualities Threshold varies considerably with the nature of stimulus as shown in Table 1 and also with the species

Responses may be measured by recording the electrical activity from a taste nerve in response to chemical stimulation of the taste buds The magnitude of this electrical response may be determined at different concentrations of stimuli as shown in Fig 1 Much taste data may be quantitatively described by assuming that the sapid substance adsorbed to the surface of the taste receptor initiates the electrical depolarization of the taste cell The basic taste equation is

$$\frac{C}{R} = \frac{C}{R_s} + \frac{1}{KR_s}$$

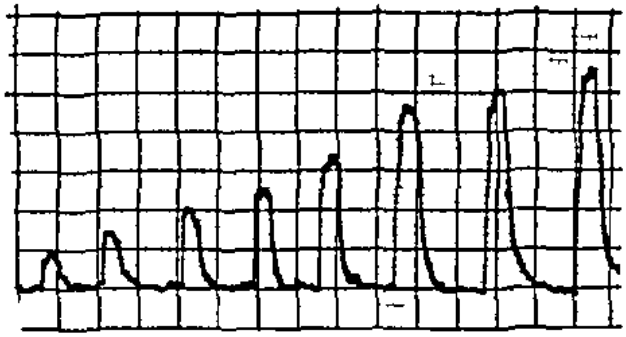


Fig 1 Summated electrical response of a population of taste receptors of rat to sodium chloride of concentration 0 005 M 0 01 M 0 025 M 0 05 M 0 10 M 0 25 M 0 50 M 1 0 M Test solutions were applied 7–10 sec and were alternated with water rinses One large division equals 20 sec

where C is the concentration of the chemical stimulus R is the magnitude of the response to the stimulus R_s is the maximum response obtainable at very high concentrations and K is the equilibrium constant of the adsorption reaction

Insects Insects detect chemical substances in their environment by means of chemoreceptors located in the mouth parts distal segments of the legs antennae and ovipositor Insect chemoreception may be studied by observing the behavioral response to chemical stimuli Many insects extend the proboscis when their tarsi are stimulated by acceptable substances such as sugars and withdraw it if salts, acids or bitter substances are added to the sugar This response may be initiated by the stimulation of a single receptor of the blowfly Like man insects can differentiate four taste qualities

The receptor organ is a hairlike structure containing three bipolar neurons two of which send distal processes to the tip of the end organ where they are sensitive to chemical stimulation Stimulation with sugars excites one nerve and causes proboscis extension whereas nonsugars cause proboscis withdrawal or extension inhibition by exciting the other nerve process

Insect taste receptors also respond to glycols, ketones aldehydes alcohols and organic salts Sensitivity increases with chain length

Olfaction The sense of smell is discussed in relation to vertebrates and insects

Vertebrates The olfactory receptors of mammals are located in a small area (about 1 sq in) of epithelium covering the medial wall of the superior concha and the lateral wall of the nasal septum Each olfactory receptor is a bipolar neuron with its distal end terminating in a number of very small villilike structures called olfactory hairs that extend upward into the layers of mucus that continually flows over the olfactory epithelium The proximal end of each cell is a fine nerve fiber that extends to the olfactory bulb In the rabbit there are approximately 100 000 000 olfactory receptors



Fig 2 Electrical activity of rabbit olfactory nerve in response to amyl acetate odor stimulation Greatest activity occurs during inspiration

each of which sends its own nerve fiber to the olfactory bulb of the brain Approximately 26 000 receptors synapse with each glomerulus in the olfactory bulb and each of these in turn synapses with other cells whose nerve fibers project into the secondary olfactory centers of the brain

The olfactory nerves are 0 2 μ in diameter and conduct nerve impulses at a speed of 0 4 m/sec They respond to odor stimulation by an increase in frequency of neural discharge up to 10 per sec (Fig 2) Receptor adaptation occurs only with very high concentrations of odor stimuli However the cells of the olfactory bulb may adapt to much lower odor concentration When an odor is inhaled the intensity of sensation that is produced rapidly declines When this occurs the initial sensitivity to another odor of a different quality may remain unchanged

The olfactory epithelium does not lie in the direct stream of air flow between the nares and the trachea Sniffing enhances odor detection by increasing odor flow to the olfactory area Odor can be detected only during breathing Congestion of the mucous membrane due to a common cold or to vascular changes during emotional stress may interfere with olfactory function

Although direct evidence is lacking, it is usually thought that olfactory receptor stimulation is a result of adsorption of the odor on the olfactory receptor hairs The odorous material must have a sufficient vapor pressure so that a detectable number of odorous molecules is mixed with the air stream that enters the nasal area and passes over the olfactory epithelium The olfactory receptors are considered to be much more sensitive to chemical stimulation than the taste receptors, as shown in Table 2 Man for example can detect 1 molecule of mercaptan in 5×10^{10} molecules of air

Table 2 Human thresholds to odor ratio of stimulus to air

Stimulus 1 molecule	Air molecules
Chloroform	$2\,8 \times 10^{-8}$
Amyl alcohol	$2\,6 \times 10^{-9}$
Pyridine	$4\,0 \times 10^{-7}$
Amyl acetate	$3\,0 \times 10^{-7}$
Butyric acid	$1\,0 \times 10^{-7}$
Propyl mercaptan	$7\,9 \times 10^{-9}$
Amyl thioether	$5\,8 \times 10^{-9}$

Dogs can track humans by detecting the fatty acids deposited by the foot on the trail Trained humans may detect and differentiate up to 5000 different odors.

According to one classification there are four odor qualities (1) fragrant or sweet (2) acid or sour (3) burnt and (4) caprylic or goaty Whether separate receptors exist for each of these different odor qualities is not known although certain areas of the olfactory bulb are more highly stimulated by some odors than by others It is quite probable that different odors set up different temporal and spatial neural patterns which are then transmitted to the olfactory bulb The sense of smell is sufficiently analytic to permit identification of a single odor in a mixture of many

Some odors may be detected at a lower concentration by the trigeminal nerve fibers whose bare nerve endings terminate throughout the nasal area than the olfactory receptors although the opposite is the usual case The role of the trigeminal nerves in odor detection is not completely known

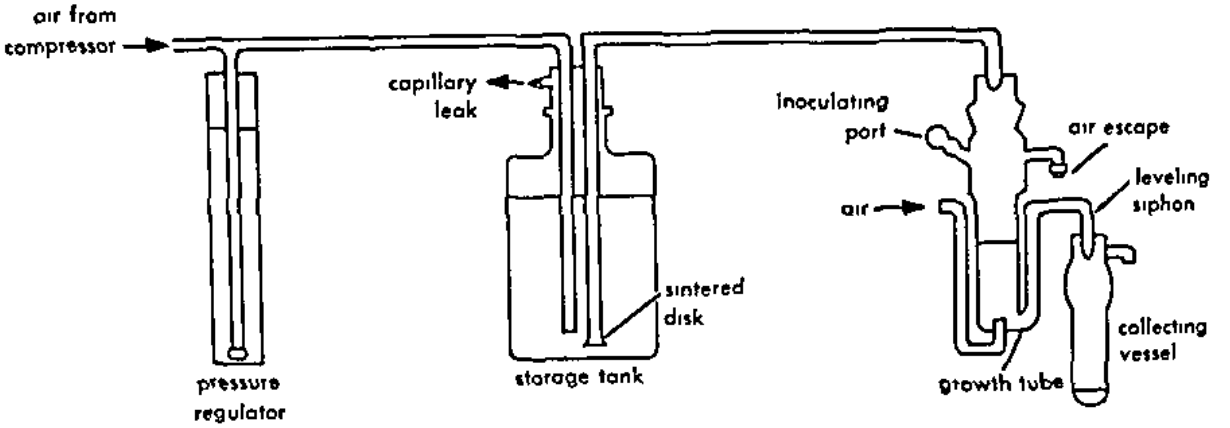
Insects Olfactory end organs in the antennae of insects respond to a wide variety of odors Some insects are highly sensitive to particular odors For example the male gypsy moth may detect the presence of the female moth several miles distant The olfactory receptors of insects are bipolar sense cells found in pore plates in thin wall pegs or cones or in thin wall pegs or cones sunken in pits The sense cell is covered by a very thin cuticle The response to a homologous series of alcohols shows an increased sensitivity with chain length up to four carbons and then a decrease up to the eighth carbon Olfactory stimulation depends upon the shape of the odorous molecules and the oil water partition coefficient *See* SMELL [L.M.BE.]

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Chemostat

An apparatus for the continuous culture of a bacterial population in a steady state achieved by restricting the concentration of a nutrilite in the medium It is also known as a bactogen

The apparatus (see illustration) consists of a pressure regulator a storage tank and a growth tube The pressure regulator regulates air pressure by changing the water level in the open glass cylinder The height of the water column ensures that the pressure at the bottom of the storage tank will always be greater than that of the outside air The nutrient solution is forced through the sintered glass filter into the growth tube The capillary leak reduces the pressure in case of a sudden lowering of barometric pressure The air inlet in the growth tube keeps the contents in a continuous state of agitation The siphon sets the level of the and allows the bacteria suspended in th solution to leave at the same rate at



Chemostat (A Novick and L Szilard, Description of the chemostat, Science, 112 715–716, 1950)

nutrient enters The air escape ensures that the pressure forcing liquid through the sintered disk in the storage tank is always equal to the height of the water column in the pressure regulator

The entering nutrient contains an excess of all the factors needed for the growth of the bacteria except one the controlling growth factor which is present at a selected concentration Initially rate of growth of the bacteria exceeds rate of removal The resulting rise in bacterial density (number of organisms per ml) causes a fall in the concentration of the controlling growth factor in the growth tube Eventually the concentration falls so low as to cause a reduction in the specific bacterial growth rate When the specific growth rate falls to the level of the dilution rate, a steady state is achieved in which the bacterial density remains constant and the concentration of the controlling growth factor in the growth tube has become independent of its concentration in the incoming nutrient Because the concentration of all chemical substances in the growth tube remains constant, the bacterial population will grow for long periods of time in a constant physiological state

The chemostat offers some unique advantages in microbiological experimentation The constancy of the population size and of the concentrations of chemical substances in the growth tube permits high precision in experimentation Moreover the bacterial growth rate may be varied, within limits by varying the dilution rate The population size can be selected by choosing the appropriate concentration of the controlling growth factor in the incoming nutrient Selection of the substance used as the controlling growth factor provides another experimental variable

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microbiology, physiology, genetics, and biochemistry *See* BACTERIAL GENETICS, BACTERIAL GROWTH, BACTERIAL METABOLISM, BIOCHEMISTRY, ENZYME, GENETICS, MICROBIOLOGY, MUTATION; PHYSIOLOGY, GENERAL [A N]

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Chemotherapy

The term chemotherapy implies the treatment of the sick with chemical substances It is used today, however, in a more restricted sense, namely, the treatment with chemical agents of diseases caused by parasitic organisms and by cancer cells Except for the treatment of cancer, this is in essence the use of the term intended by the father of chemotherapy, the German bacteriologist, Paul Ehrlich Remarkable advances have been made in all branches of medicine during the last few decades, none, however, so rapid and far reaching in importance as those in chemotherapy

The substances used in chemotherapy include those synthesized by chemists, such as sulfadiazine and chloroguanide, and those which occur naturally, such as emetine and penicillin (see PENICILLIN, SULFA DRUGS) All of these substances are called chemotherapeutic drugs, distinguishing them from substances such as antibodies which are produced by the host as its defense against the invading parasite

Basic principles of chemotherapy. While the concept of chemotherapy had a vague form in the minds of some men since Paracelsus in the sixteenth century, it was not crystallized until the brilliant and imaginative work and writings of Paul Ehrlich in the mid nineteenth century The essence of Ehrlich's concept of chemotherapy is specificity of action which he clearly defined in 1907 when he wrote of a *"chemotherapia specifica"* He considered such a compound as a chemical agent taken up by parasites in quantities sufficient for lethal action while being tolerated by the organism harboring the parasite

This is the origin of the term specifics, which is sometimes applied to this group of drugs Ehrlich never realized the fulfillment of his dream of a

magic bullet with such specificity even in his most practical achievement the arsenical drug salvarsan which had been used in the treatment of syphilis The closest to Ehrlich s ideal came approximately 40 years later in the remarkable antibiotic penicillin This drug has a very low inherent toxicity for mammals except in the sensitized individual in whom it may produce a wide range of allergic manifestations (*see* HYPERSENSITIVITY) Penicillin has the amazing property of preventing the synthesis of the outer wall of certain bacterial cells without influencing the development of mammalian cells Such a specificity implies that the drug can distinguish subtly between the biochemistry of parasitic and host cells This ability is decreased in virus infections and in cancer in which the metabolism of the parasite or neoplasm is intimately associated with that of the host

Most of the clinically useful chemotherapeutic agents are not so highly specific that their effects apply only to pathogenic organisms or even to a single kind of microorganism Thus these drugs display spectra of activities from the relatively narrow spectrum of penicillin (most specific) to the so called broad spectrum antibiotics such as tetracycline oxytetracycline and chlortetracycline (*see* ANTIBIOTIC) Broad spectrum antibiotics inhibit the growth of Rickettsiae and large viruses as well as numerous types of bacteria

The second great principle of chemotherapy was laid down when Ehrlich concluded early in his studies on the destruction of trypanosomes that a compound will not act unless it is first fixed to the cell on which it is expected to act (*see* PARASITOLOGY MEDICAL) It was the development of this idea of fixation that led to the formulation of Ehrlich s chemoreceptor or side chain theory This theory puts forward the concept that the parasitic cell possesses chemical groupings or side-chains on its surface for which the chemotherapeutic drug has an affinity Once the drug fixes itself to these side chains the specific lethal action on the parasite is initiated Such a concept is used today and except for the fact that Ehrlich s side chains are now called receptors little basic information has been added since Ehrlich s time Nevertheless it has been a useful working hypothesis which with a certain extension into the area known as competitive inhibition or metabolite antagonism has led to the development of a number of drugs useful in malaria leukemia and various lymphomata (*see* ENZYME INHIBITION) In addition these concepts have served admirably in explaining at least in part the chemical mechanism of action of such chemotherapeutic agents as the sulfonamides

The third basic principle proposed by Ehrlich is that a chemotherapeutic drug when injected into an infected host must be distributed in effective concentration to the site of the infection This criterion must be met before fixation to the parasite and the killing action can take place Early attempts at treating infection were almost invariably directed to the affected part if it happened to be available to treatment Herein lies one of the great advantages of the modern chemotherapeutic approach it is possible to attack an occult (hidden) infection by simply introducing the chemotherapeutic agent either directly into the blood stream or indirectly via the oral route However problems emerge of accessibility of the drugs to the site of infection Some areas like the brain have natural barriers to drugs entering from the blood some areas have a poor blood supply for example certain parts of bones some infectious agents through the host s response to their presence are hidden away from blood borne drugs in calcified tubercles or in fibrinous vegetations (subacute bacterial endocarditis) (*see* ENDOCARDITIS TUBERCULOSIS) The most marked activity of an effective chemotherapeutic agent occurs when the infection is in the bloodstream (a bacteremia) In this instance the drug would have its most intimate and unhindered contact with the parasite

Host parasite drug relationship When a chemotherapeutic agent is administered to an infected host a system of interrelationships is established involving three components the human host the infecting parasite and the chemotherapeutic drug Each of these may act upon and react to the other two The drug itself exerts its lethal action on the parasite but at the same time produces certain toxic effects upon the infected host Each of these organisms reacts to the drug in characteristic fashion The parasite often possesses enzymes which can destroy the drug (such as penicillinase which destroys penicillin) and in addition a small proportion of the population of parasites may have other mechanisms for resisting the action of the drug It is these drug resistant organisms which may upon continued use of a drug grow into a drug resistant population when all susceptible members of the original population have been destroyed by the drug The host disposes of the drug usually by first metabolically altering it and then excreting it chiefly via the kidneys Finally the host reacts to the presence of the parasite independently of the presence of the drug by marshaling its cellular and immunochemical defense forces to rid itself of the parasite It is probably the combined action of these forces and the drug which ultimately eradicates the infection One of the great obstacles in the path of effective cancer chemotherapy may be related to the poorly developed host defense mechanisms against invasion by the malignancy *See* PARA AMINOSALICYLIC ACID ANTIMICROBIAL AGENTS ISONICOTINIC ACID HYDRAZIDE NITROFURAN SULFONE (ANTIMICROBIAL USE) THIOSEMICARBAZONE [N J C]

Chemurgy

The application of science to extend the profitable utilization of agricultural products particularly for nonfood purposes Recognizing that modern farm

technology causes chronic oversupplies of food materials chemurgy emphasizes use of the starch sugar proteins oils fats and cellulose from the crop output as industrial raw materials Chemurgy is concerned also with establishment of crops new to agriculture and with development of profitable uses for agricultural residues Chemistry genetics bacteriology physics engineering and other sciences are involved The term chemurgy describes a concept rather than a particular phase of exact science

Industrial raw materials Starch illustrates the industrial use phase of chemurgy As a major component in the cereal grains and in potatoes starch is abundant It has long been used as a sizing coating and adhesive for paper products Textile sizing and laundry use consume large amounts and it enters into scores of products as diverse as chewing gum and oil well drilling mud Chemists believe however that the industrial utilization of starch can be greatly expanded They suggest that it may be adapted as a soil stabilizer in highway construction for greater use in oil well drilling muds as a major ingredient in construction materials as well as in plastics and plasticizers surfactants detergents emulsifiers and antioxidants These purposes envision consumption of starches in amounts large enough to diminish perceptibly the oversupplies of grains

Soaps formerly consumed 80% of the supply of inedible animal fats which amounts to 3 000 000 000 lb annually The rise of synthetic detergents reduced the 80% to 30% Chemurgic research in turn produced millions of pounds of vinyl stearate from animal fats for use in plastics

Some of the well known products of chemurgic research are casein and lactose from milk dextrin and zein from corn monosodium glutamate from wheat industrial alcohol from grains lecithin and other items from soybeans pectin from cannery waste furfural from oathulls and corncobs paint from flaxseeds and other oilseeds Because relatively little research has been devoted to crop materials compared to what has been done for petroleum and other minerals the advocates of chemurgy are confident that the utilization of farm products can be increased many times

New crops The world's agriculture is based largely upon cultivation of about 150 species of plants Only about 90 species contribute annually more than $1 000 000 each to United States farm income Nearly all present crop species were first cultivated by prehistoric man who necessarily chose plants which with his hands or primitive tools he could utilize as food or fiber Botanists have identified and classified at least 250 000 species of the higher plants and with modern laboratory instruments plants can be analyzed and searched for constituents of value to man which escaped the notice of the original farmers Comprehensive laboratory examination of the earth's entire flora wild and tame continues to be one of chemurgy's objectives Two urgent reasons are advanced (1) that new commodities are likely to be disclosed, (2) that profitable new crops are urgently needed to occupy acres which now produce the old crops such as wheat and cotton in excess of current needs

The discoveries of reserpine from an Indian variety of snakeroot and of cortisone sources from a Mexican yam are cited as examples of human needs recently met by examination of plants hitherto ignored Outstanding among crops comparatively new in the United States is the soybean introduced from the Orient which began to achieve commercial importance just before 1930 More than 500 end uses for the soybean's oil and protein content have been listed Although soybean output has exceeded 500 000 000 bushels it has at no time been a surplus crop The more than 20 000 000 acres planted to soybeans would had the crop not become established have been piling up added surpluses of corn and oats

Korean lespedeza and Sudan grass are other new crops which have occupied considerable acreages Safflower unknown a few years ago to American agriculture although ancient abroad has spread to 100 000 acres in California and other western states The castor bean whose unique oil fills many industrial needs has been established in the Southwest markets for castor beans from a million acres are foreseen

Early studies of bamboo indicate that it may eventually be cultivated over wide southern areas as a source of cellulose for paper products Jojoba and candelilla for waxes guar for gums canaigre for tanning materials kenaf for fiber and sesame for food uses are species which may have agricultural futures

The U S Department of Agriculture has conducted plant exploration work abroad for more than half a century However more than 90% of the introductions have been strains of wheat potatoes and other established crops designed to provide genetic material for the increase of yields or resistance to diseases Aside from this the most active searches for new plant species have been conducted by pharmaceutical companies seeking precursor sources for cortisone reserpine and other drugs

Use of agricultural residues The total tonnage of residues exceeds the marketable portion of farm output It includes stalks straw hulls rinds pomace pits seeds cobs and other vegetable substances as well as feathers and inedible portions of poultry and animals In general it may be said that the degree of their utilization depends upon the cost of collection and transportation Bagasse the fibrous by product of sugar extraction is used extensively in manufacture of wallboards Oathulls are converted into furfural So are corncobs used also in increasing quantities for soft abrasives Bagasse oathulls and corncobs have in common the fact that they are assembled in large quantities incident to processing more valuable ingredients of the plants Straw is gathered to a limited extent for making boxboard While cornstalks afford an abundant source of cellulose and processes for their uti

lization in building materials have been worked out the cost of assembling industrial quantities remains high

Research on chemurgic problems is conducted by the U S Department of Agriculture in laboratories located at Wyndmoor Pennsylvania Peoria Illinois New Orleans Louisiana and Albany California Several state agricultural experiment stations also have projects

The Chemurgic Council of New York N Y was founded in 1935 It acts as a clearing house for chemurgic information and promotes interest in farm product research *See* AGRICULTURAL CHEMISTRY AGRICULTURAL SCIENCE (ANIMAL) AGRICULTURAL SCIENCE (PLANT) [W M]

Bibliography Senate Document No 45 Eighty fifth Congress

Cherry

The two principal cherries of commerce are the sweet cherry *Prunus avium* and the sour cherry *Prunus cerasus* Others of minor importance are the dwarf or sand cherries *Prunus besseyi* of the Plains region of North America the Duke cherries which are supposedly natural hybrids between the sweet and the sour cherry and the Padus cherries which bear their small fruits in long clusters or racemes rather than in short clustered fascicles *See* FRUIT (BOTANY)

The cherry is of ancient origin and was mentioned in 300 B C by the Greek botanist Theophrastus It was brought to America from Europe

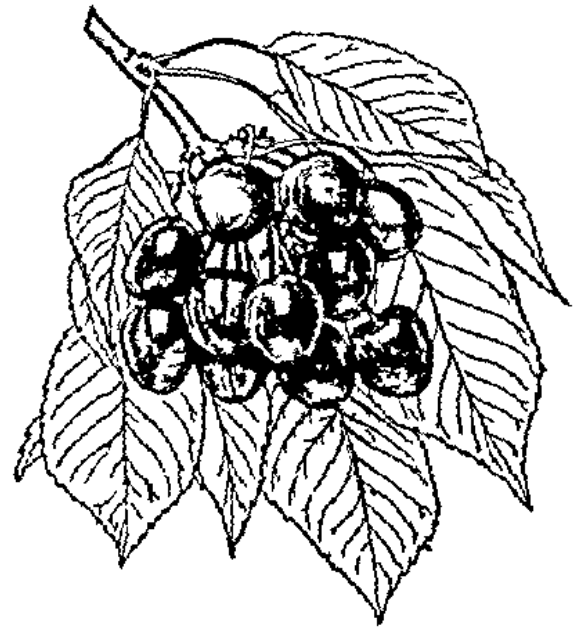
Propagation and types Trees are propagated by budding onto seedlings of the wild sweet cherry or of *Prunus mahaleb* commonly called the perfumed cherry of southern Europe The former is best suited to the sweet cherry and the latter to the sour cherry *See* BUDDING REPRODUCTION PLANT

The sweet cherry is somewhat hardier than the peach and the sour cherry is hardier than the sweet Wild sweet cherry trees called mazzard may grow 100 ft high and reach an age of 200 yrs. Cultivated varieties grow 30–40 ft high and should be planted 30–35 ft apart Sour cherry trees reach a height of 20–25 ft and should be planted 18–22 ft apart Cherry trees will not tolerate wet soil Sweet varieties require cross pollination common sour varieties are self fruitful (self pollinated)

Sweet cherries may be divided into two groups firm fleshed types known as Bigarreaus represented by Napoleon and soft fleshed types known as Hearts Guignes or Jeans represented by Black Tartarian Sour cherries may also be divided into two groups clear juice or Amarelle types represented by Montmorency and colored juice or Morello types represented by English Morello

In North America the principal sweet commercial varieties are Napoleon (white) and Schmidt and Windsor (dark) Royal Anne is a synonym for Napoleon The principal commercial variety of sour cherry is Montmorency

Production and economic importance Commercial production of sweet cherries in the United States in 1957 was 89 000 tons of which California produced one third Commercial production of sour cherries in 1957 was 149 520 tons of which Michigan produced 71 000 tons Returns to growers were $303 a ton for sweet cherries and $143 for sour cherries *See* FRUIT (TREE) [H B T]



The Napoleon Royal Anne or white sweet cherry (*From L H Bailey The Standard Cyclopedia of Horticulture vol 1 Macmillan 1937*)

Cherry diseases Leaf spot a serious fungus disease caused by *Coccomyces hiemalis* affects sweet and sour cherries Diseased leaves drop prematurely tree growth is retarded and the cherries are reduced in size and number This disease may be controlled by spraying trees with lime sulfur solution copper compounds or ferbam an organic fungicide *See* FUNGISTAT AND FUNGICIDE Black knot a fungus disease characterized by the development of rough black swellings on the branches is prevalent on neglected trees It may be controlled by removing diseased branches and spraying the tree with a copper compound to prevent further infections by spores of the causal agent *Dibotryon morbosum*

Other fungus diseases are mildew which covers the leaves with a weblike mass of fungus filaments and bitter rot and brown rot which destroy the fruit Brown rot is particularly destructive to sweet cherries growing under humid conditions *See* FUNGI

Sour cherry yellows ring spot and little cherry are virus diseases that reduce fruit size and ultimately make the trees unfruitful Control of these diseases is achieved by propagation of virus free nursery stock or in the case of little cherry by removal of all diseased trees to prevent further spread of the virus Many cherry trees die from too low temperatures or excessive soil moisture *See* FRUIT (TREE) FRUIT (TREE) DISEASES PLANT DISEASE CONTROL PLANT VIRUS [J C DU-

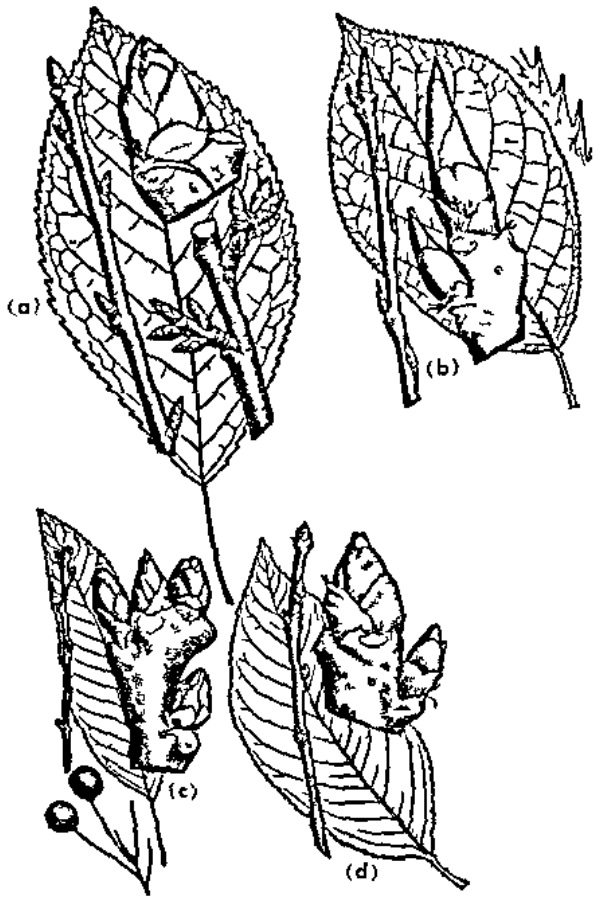
Cherry, wild black

Prunus serotina, also called wild black cherry The tree grows to a height of 90 ft It belongs to the [illegible] of

[illegible] ive

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cent Canada it reaches its largest size in the southern Appalachian Mountains The deciduous leaves



(a) Sweet cherry or mazzard Prunus avium (b) Choke cherry P virginiana (c) Pin or fire cherry, P pensylvanica (d) Black cherry P serotina (From A H Graves Illustrated Guide to Trees and Shrubs Harper 1956)

are long pointed thickish and shining above The edible fruit is a shiny black drupe found in long clusters The hard strong wood is a red brown and is used for furniture, often as an imitation mahogany A few years ago it was estimated that the supply of merchantable black cherry timber was about 250 000 000 board ft

The sweet cherry or mazzard, *P avium*, which grows to 70 ft, is naturalized over a large part of the United States This is the cherry of the horticultural gardens and has fruits borne in umbel like clusters It also differs from the wild black cherry in having more ovate leaves with rounded teeth

The Japanese flowering cherries are varieties of *P serrulata* which attract much attention at blossoming time in early May *See* CHERRY, FOREST AND FORESTRY, TREE [A H G]

Chert

A dense, micro or cryptocrystalline rock composed of chalcedony and microcrystalline quartz. Chalcedony is a microcrystalline, fibrous form of silica that is now thought to consist mainly of quartz with only small amounts, if any, of amorphous silica or opal between the fibers It may be almost any color, depending on impurities, but most cherts are light colored It breaks with conchoidal to splintery fracture Flint is synonymous with chert The latter term is preferred for the rock although the former is still used for artifacts such as arrowheads Other names that have been used for chert are silexite, hornstone, and phthanite Porcellanite is a dense, hard siliceous rock with the texture and fracture of unglazed porcelain It usually is a chert with much included material mainly argillaceous or calcareous material Novaculite is a bedded chert that consists dominantly of microcrystalline quartz, the term has been used chiefly in Arkansas and Oklahoma to describe some of the cherts of the Ouachita Mountains

Composition The composition of cherts varies with age Opal a hydrated form of amorphous silica occurs only in Tertiary cherts, not in older beds The older cherts consist of microcrystalline quartz and chalcedony Common nonsilica components of cherts are calcite and dolomite detrital quartz and clay minerals

Occurrence. Chert is found in two forms as *nodules in limestones and dolomites, and as* bedded formations The nodules are flattened parallel to the bedding and vary in size from a few inches to several feet in diameter (Fig 1) Some nodules show traces of bedding that is continuous with the enclosing rock Fossils are common in the nodules The bedded cherts are tens of feet thick and areally extensive for hundreds of square miles Typically they are layered, the layers are a few inches thick and may be separated by thin beds of shale, siderite *or hematite (Fig 2) Some cherts are* oolitic and clearly show evidence of having formed by the replacement of original calcareous oolites Carbonate inclusions in the chert are common and



Fig 1 Chert nodules in Hardy Creek limestone of southwest Virginia *(Photograph by L D Harris USGS)*

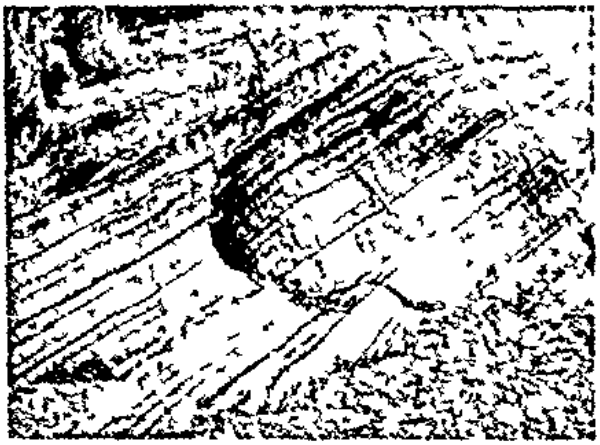


Fig 2 Bedded chert Monterey formation (Miocene) California (Photograph by M N Bramlette USGS)

many of the original concentric rings of the oolites have been obliterated See OOLITE AND OOLITIC

Origin Two theories have been suggested for the origin of chert One is that of replacement origin of originally calcareous materials The other calls for primary precipitation of silica from the water of the depositional environment

Replacement origin In the case of the nodular cherts the evidence is good for replacement origin The evidence includes the presence of silicified fossils, the irregular shape of the nodules the inclusion of patches of limestone within the nodule the preservation of original bedding and other textures in the nodules and the undoubted replacement origin of the silicified oolites The most likely sources of the silica are the siliceous skeletal materials of sponges diatoms and radiolaria which are originally present and disseminated throughout the sediment Early diagenetic processes lead to solution of the amorphous silica that composes all of the shells and spicules and reprecipitation in segregations

The process of solution and reprecipitation may be linked to decay of organic matter and its effect on the pH (alkalinity acidity) of the interstitial waters which affects the solubility of silica Evidence for this process in some limestones is the presence of abundant spicules and siliceous tests in nodules and complete lack of silica in the surrounding limestone It is doubtful however whether this explanation will hold for Precambrian cherts for silica secreting species apparently did not evolve until the Cambrian See DIAGENESIS

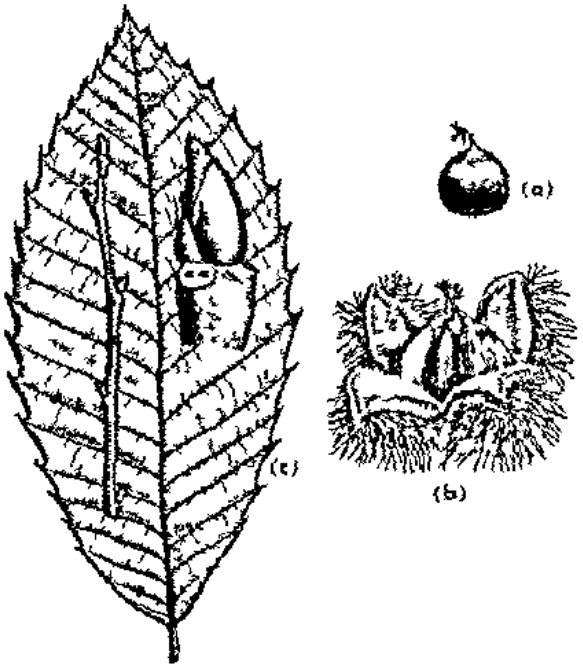
Primary precipitation The origin of the bedded cherts is much more in doubt than that of the nodules The leading theory for bedded chert formation involves the inorganic precipitation of silica from sea water However some authorities believe that bedded cherts are altered equivalents of widespread biogenic silica deposits such as diatomaceous oozes found on the present day sea floor Two arguments against the latter theory are the absence of any preserved remains of spicules or shells of silica secreting organisms and the occurrence of bedded cherts of ages older than the evolution of the diatoms and radiolaria There is no doubt that some Tertiary bedded cherts are the result of lithification and recrystallization of diatomaceous deposits The inorganic precipitation of silica to make bedded cherts implies waters that were at least locally supersaturated with silica and a sedimentary basin of deposition that was starved that is had little or no supply of clastic material Supersaturation may have been achieved in the Precambrian in the absence of silica secreting organisms and in later periods by volcanic activity that increased silica concentrations See CHALCEDONY DIATOMACEOUS EARTH SEDIMENTARY ROCKS [R S]

Bibliography W A Tarr The origin of chert and flint *Univ Missouri Studies*, vol 1 no 2 1926

Chestnut

A large forest tree *Castanea dentata* which grows to a height of 90 ft and has simple deciduous coarsely toothed leaves It is native to the Appalachian Mountain and Ohio Valley regions Formerly one of the most valuable timber trees of the eastern United States it is now practically extinct as a result of the attacks of a fungus parasite *Endothia parasitica* which was accidentally imported from the Orient Because the roots resist the attacks of the fungus buds at the base of a dying tree can develop new shoots unfortunately the new shoots become blighted in a few years and die

The wood was used for construction timbers furniture paneling caskets and boxes and crates and the tall straight trunks were used for utility poles The nuts from three to five in a spiny bur are greatly relished by wild animals The Chinese and



American chestnut *Castanea dentata* (a) Bur (c) leaf twig and bud (From A H ... trated Guide to Trees and Shrubs Har...

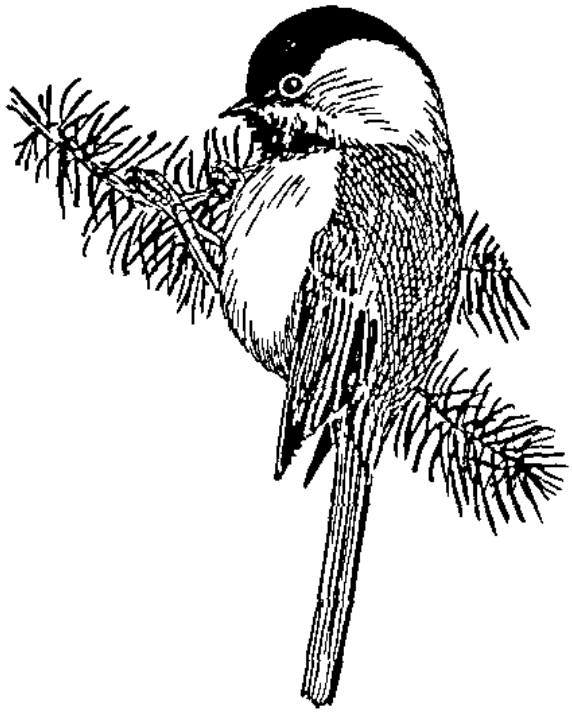
Japanese chestnuts, *Castanea mollissima* and *C crenata* are resistant to the attack of the parasite, but they are comparatively small trees Successful crosses of these Oriental varieties with the American chestnut have recently been made and are resulting in new races of blight resistant chestnut of a tall timber type resembling the American species

Chinquapins several species of which grow in the southeastern United States and in eastern Asia belong to the genus *Castanea*, but they are smaller trees, often merely bushes They bear only one nut in a bur *See* FOREST AND FORESTRY, TREE

[A H G]

Chickadee

Any of 22 species of the genus *Parus* a Holarctic and African group of the family Sittidae 6 of which are resident in the United States Chickadees are usually gray, smaller than a sparrow, slender, and have relatively long tails The call note of the black capped chickadee, *P atricapillus*, provides

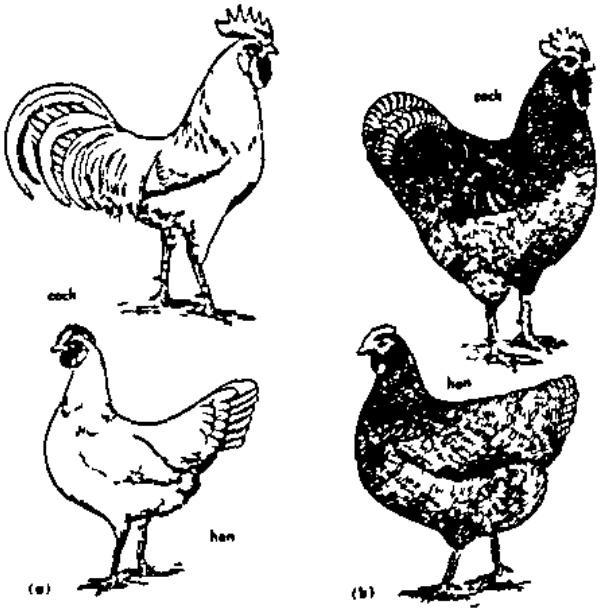


The black-capped chickadee, *Parus atricapillus*, length 5¾ in (*From E L Palmer, Fieldbook of Natural History, McGraw Hill, 1949*)

this group with its common name The chickadees like the related titmice scan the leaves and twigs of trees for insect food, they are famed for their acrobatic habits their friendly manner, and cheery call *See* PASSERIFORMES, TITMOUSE [J D B]

Chicken

A fowl, *Gallus gallus* (*domesticus*), of the family Phasianidae The chicken is unquestionably the most valuable of all domesticated birds Over many centuries the chicken has been developed into numerous strains The Mediterranean breeds exemplified by the Leghorns, are lightweight birds specially developed for egg production The American breeds of which the Plymouth Rock is typical, are heavier bodied and have been developed for meat alone or for both meat and egg production English breeds, such as the Orphingtons and Cornish, have limited popularity The Asiatic breeds are developed either for meat, as the Cochin, or as ornamental birds such as the Silkies and Sultans In the past few years American poultrymen have produced hybrids with excellent egg production and good meat qualities *See* ECC (FOWL); POULTRY PRODUCTION [J D B]



Chickens (a) Leghorn (b) Barred Plymouth Rock (*From E L Palmer, Fieldbook of Natural History, McGraw Hill, 1949*)

Chickenpox and shingles

Chickenpox is a mild, highly infectious viral disease characterized by vesicular rash, which occurs chiefly in epidemics among children. It is also known as varicella Shingles (zoster), a sporadic, severe disease of adults, is characterized by inflammation of certain posterior nerve roots and ganglia, and is accompanied by skin vesicles limited to areas associated with the affected nerves *See* ANIMAL VIRUS

The viruses of chickenpox and shingles are so similar morphologically and antigenically that many consider them identical They induce no disease in laboratory animals, but produce intranuclear inclusions in cultures of human embryonic tissue

In chickenpox, malaise and fever precede the rash, which erupts in successive crops; fever continues after eruption In shingles, malaise and fever are followed by severe pain, and eruption of vesicles in skin areas supplied by sensory nerves associated with the particular dorsal nerve roots and ganglia affected

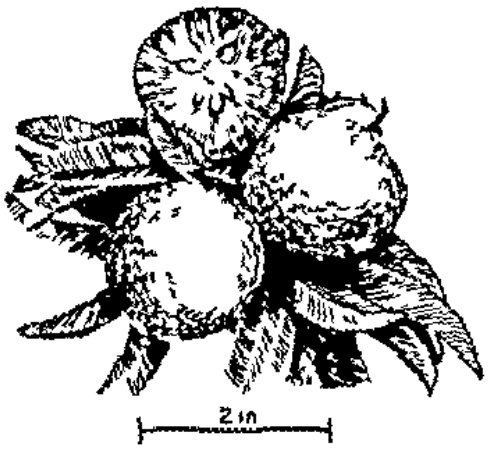
Shingles can be the source of epidemics of chickenpox in children; and adults exposed to chickenpox may develop shingles Infections confer

enduring immunity but shingles may occur in persons who have had chickenpox in the past This phenomenon may represent latent persistence of virus after chickenpox infection until trauma precipitates development of shingles or massive exposure may overwhelm the individual s immunity *See* IMMUNITY

Treatment is symptomatic The use of ultraviolet light in schools is said to reduce the explosiveness of chickenpox epidemics, but it does not completely prevent them [J L M]

Chicle

A gummy exudate used in the manufacture of chewing gum It is contained in the bark of a tall evergreen tree *Achras zapota* belonging to the sapodilla family (Sapotaceae) The species is a native of Mexico and Central America The latex (secretion) is collected and carefully boiled to remove excess moisture When the water content is reduced to 33% the chicle is poured off and molded into



Sapodilla the fruit of Achras zapota (L H Bailey The Standard Cyclopedia of Horticulture vol 3 Macmillan 1937)

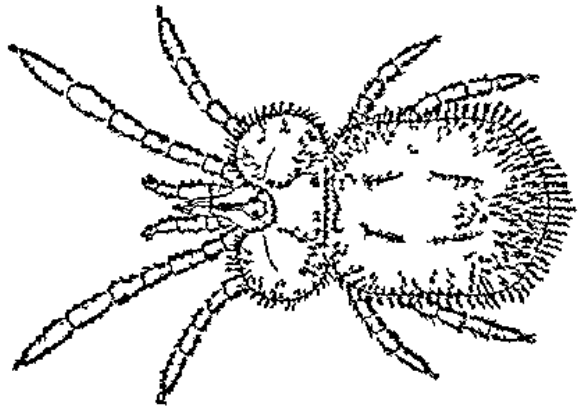
blocks Crude chicle contains resin arabin gutta sugar calcium and different soluble salts For refining it is broken up washed in strong alkali neutralized with sodium acid phosphate rewashed dried and powdered The resulting product is an amorphous pale pink powder insoluble in water and forming a sticky paste when heated In the manufacture of chewing gum the chicle is cleaned filtered sterilized and various flavoring materials and sugar are added *See* EBENALES RUBBER [P D S]

Chicory

The plant *Cichorium intybus* is a perennial herb with a long taproot a coarse branching stem and a basal rosette of numerous leaves Although the plant is a native of Europe it has become a common weed in the United States It is used as a salad plant or for greens The roasted root is also used as an adulterant of coffee *See* CAMPANULALES SPICE AND FLAVORING

Chigger

A species of mite *Eutrombicula alfreddugesi* sometimes called red bug which is one of the most widespread and irritating external parasites of man A few less common related species are also usually included in the common name chigger



The chigger Trombicula irritans length 1 mm (from E L Palmer Fieldbook of Natural History McGraw Hill 1949)

Chiggers sometimes occur in weeds and grass in great numbers and are brushed off plants onto clothing Only the six legged larval stage attacks animals Their bites result in a characteristic red spot that itches intensely After feeding the larva drops to the ground molts into the nymphal stage and then soon after molts again into the adult form Nymphs and adults live in the soil and feed upon organic matter

In addition to man chiggers feed upon many other animals including most other mammals chickens snakes and turtles

Chiggers are among the smallest of mites being about 1/150 in in diameter barely visible to the naked eye *See* ACARINA [J D B]

Chilopoda

An order of the group Myriapoda commonly known as the centipedes Like all myriapods centipedes are ground dwellers whose spatial movements are restricted largely by a dependence upon high environmental moisture Unlike the others centipedes are evidently exclusively carnivorous and predatory a way of life reflected in their great agility or fleetness and especially in the extraordinary modification of the first trunk appendages into a pair of usually massive raptorial pincers the prehensors (Fig 1) Each prehensor contains a poison gland from which venom is conducted through a terminal claw into the victim s body The poison immobilizes or kills arthropods and even some small vertebrates but so far as is known it seems only harmlessly painful to human beings

Excluding the last two or three trunk each segment bears a single pair of fu
The genital ducts open at the post

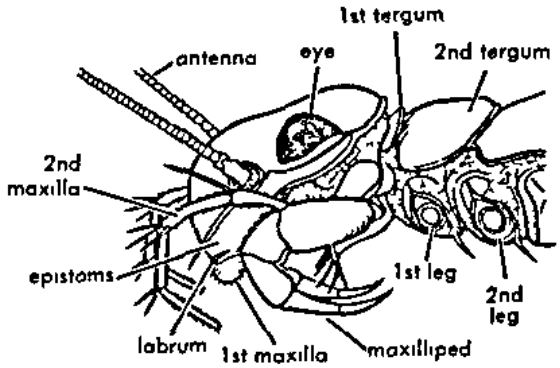


Fig 1 Chilopoda (Scutigeromorpha), *Scutigera coleoptrata* (L) (*From R E Snodgrass, A Textbook of Arthropod Anatomy, Cornell University Press, 1952*)

and circulatory systems are present and often elaborate The antennae are unbranched, the eyes when present are either of the compound type or appear as simple ocelli The mandibles have a partially free and movable gnathal portion There are two pairs of maxillae, as in symphylans and insects Some centipedes are anamorphic, some are epimorphic

Distribution In terms of families, genera, and individuals, the Diplopoda or millipedes are most abundant in the tropics but this is not true of centipedes as a group for whereas certain orders are basically tropical (Scutigeromorpha Scolopendromorpha) one order, the Lithobiomorpha is essentially temperate and the Geophilomorpha is abundant in both zones Indeed there are some Lithobiomorpha and Geophilomorpha that occur as far north as the Arctic Circle In general centipedes seem less affected by temperature and more sensitive to environmental moisture than are millipedes

Taxonomy. The class is divisible into two subclasses the Notostigmophora and the Pleurostigmophora The notostigmophorous centipedes comprise a single order Scutigeromorpha Its members which are peculiar in embodying primitive as well as highly advanced characters, are signalized by possession of dorsal respiratory openings (stomata) of compound type eyes, of long flagellate, multisegmental antennae and of long thin legs with multisegmental tarsi The trunk has 15 leg bearing segments but only seven terga All are anamorphic The order is probably known to most persons through acquaintance with the common house centipedes *Scutigera coleoptrata* (L), which is shown in Fig 2

Pleurostigmophora The Pleurostigmophora, in contrast, have lateral respiratory openings, spiracles They are reducible into five orders Of these, the Lithobiomorpha however, when eyes are present they are ocellar The majority of these centipedes are rather small in size, few exceeding 1½ inches in length Like the scutigeromorphs, they are rapid runners Although the order is typically temperate in distribution, there are a few mainly tropical or subtropical groups, but apparently few species are exclusively tropical The order Craterostigmomorpha, represented by a single known species inhabiting Tasmania and New Zealand, resembles the Lithobiomorpha in having 15 leg bearing segments with associated sternites, they differ notably in possessing 21 tergites and large, peculiar prehensors In fact many of their characteristics seem annectant, linking them both with the Lithobiomorpha and the Scolopendromorpha

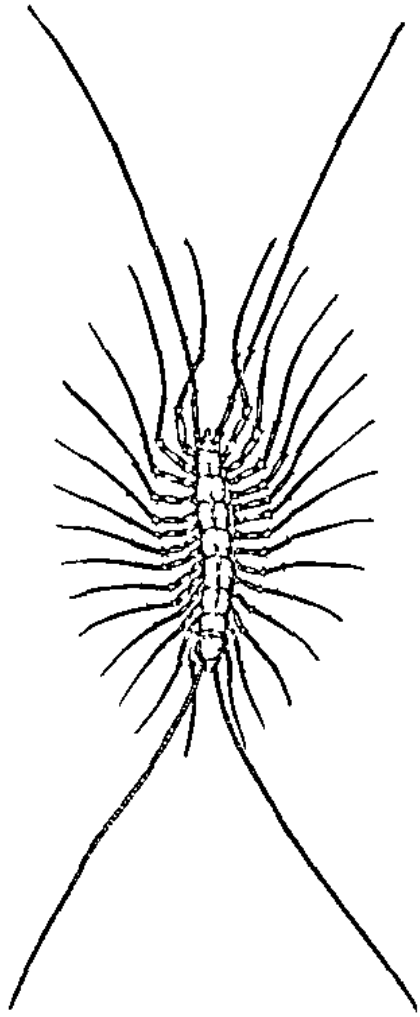


Fig 2 Chilopoda, *Scutigera coleoptrata* (L), the house centipede, body length about 25 mm (*From R E Snodgrass, A Textbook of Arthropod Anatomy, Cornell University Press, 1952*)

Scolopendromorpha The Scolopendromorpha (Fig 3*a*) are the dominant tropical chilopods being the most abundant centipedes in the tropics where the order exhibits its greatest elaboration into species and genera They include also the largest of centipedes some achieving lengths of nearly 1 foot The order in addition includes a sizable temperate zone representation whose members can be quite small The order is divisible into two families, the Scolopendridae, possessing eyes, and the Cryptopidae, which are blind Depending upon the

group there are either 21 or 23 pairs of legs All are epimorphic.

Geophilomorpha The Geophilomorpha (Fig 3b) represent the most specialized of all centipedes Unlike most other chilopods, which are voracious hunters emerging at night to seek their prey in the open the geophilomorphs are adapted to the special requirements of life in the soil in the close confines of leaf litter in general in the crevice crannj type of habitat All are dorsoventrally flattened and their bodies are long and pliable permitting them to squeeze through tight openings All are blind and epimorphic In all species the spiracles occur as an unbroken series from the second through the last or next to-last leg bearing segment Depending upon the family genus or even the species the mouthparts display a very wide range of variations this is in contrast to the uniformity encountered in most other centipedes Unique to them is the intraspecific variability in number of trunk segments For the whole order the number of trunk segments bearing legs ranges approximately from 33 to more than 183

As has been mentioned already the Scutigeromorpha Lithobiomorpha and Craterostigmomorpha are anamorphic the young hatching with 7 pairs of legs thereafter undergoing molts until the adult complement is achieved The Scolopendromorpha and Geophilomorpha are epimorphic that is upon hatching the young already possess the adult complement of leg bearing segments and successive molts merely permit an increase in size There is evidence to suggest that all centipedes continue to molt even after reproductive capacity is gained and perhaps throughout life in some species this may entail many years Finally it is interesting to note that in the epimorphic orders the female broods her eggs and after they have hatched even guards the young for a time Theoretically the young Epimorpha emerge from the egg in a semiembryonic condition so that without the attention of the female they would succumb to the fungi and bacteria of the forest floor None of the anamorphic Chilopoda is known to practice brooding *See* Myriapoda [R E C]

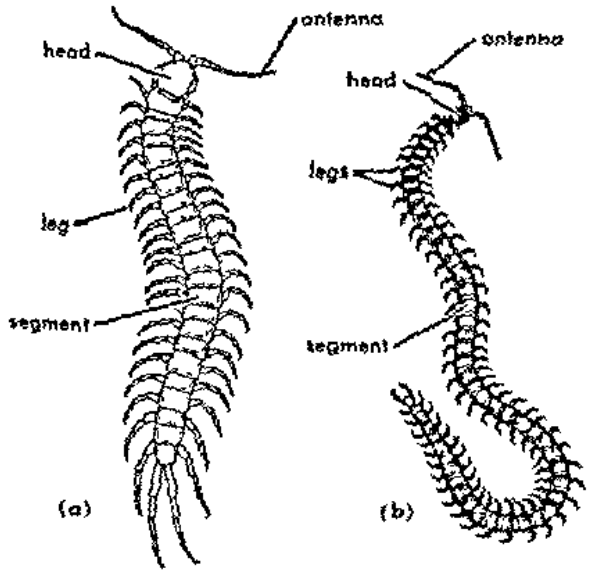
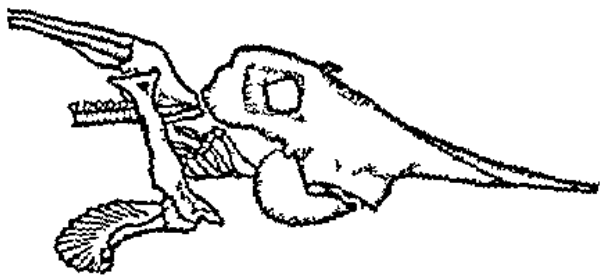


Fig 3 (a) Scolopendromorpha *Otocryptops sexspinosa* (Say) body length about 65 mm (b) Geophilomorpha a geophilid unidentified species 40 mm long (*From* R E Snodgrass A Textbook of Arthropod Anatomy Cornell University Press 1952)

Chimaerae

A relatively rare group of cartilaginous fishes (Chondrichthyes) distantly related to the sharks but aberrant in the development of their jaw apparatus and crushing tooth plates The chimaerae



Skull and shoulder region of a Jurassic chimaera Acanthorhina about natural size (After Fraas)

or rat fishes first appeared in the Jurassic flourished moderately during that period and in the Cretaceous but diminished in importance during the Tertiary They are probably derived from the cochliodonts a family of Paleozoic sharklike forms of the order Bradyodonti with similar tooth plates the still more ancient ptyctodonts of the Devonian have also been suggested as ancestors *See* Bradyodonti Chondrichthyes [A S R]

Chimney

A vertical hollow structure of masonry steel or concrete built to convey gaseous products of combustion from a building A chimney should be high enough to furnish adequate draft and also to discharge the products of combustion without causing excessive local air pollution For adequate draft small industrial boilers and home heating systems depend entirely upon the enclosed column of hot gas A draft is produced because the density of the hot gas inside is less than that of the air outside The diameter as well as the height of a chimney determines the draft Also for adequate draft a chimney in a building should extend at least 3 ft above the point where it passes through the roof and at least 2 ft higher than any ridge within 10 ft of it

Large power plants depend almost entirely upon forced-draft fans and induced draft fans to produce the draft necessary for operation and the chimney is used only for removal of the flue gas It is seldom economical to build chimneys to a height of more than 200 ft

A chimney is designed to withstand the due to wind pressure and to its own

pressure on a cylindrical surface is about two thirds that on a plane surface Thus with a wind pressure of 30 lb/ft² the pressure per foot of height of chimney is 20 times the diameter in feet of the chimney

Short self supporting steel chimneys are called stacks Tall steel chimneys of small diameter can not economically be made self supporting and must be guyed Steel chimneys are usually shop welded into sections which are assembled in the field by riveting or welding

Concrete chimneys may be plain or reinforced If the moment due to wind on short stacks and the upper part of tall chimneys is not large enough to cause tension on the leeward side reinforcing is unnecessary To prevent temperature cracking some plain concrete stacks have a fire clay lining with an air space between the lining and the outer shell

Masonry chimneys are usually constructed of perforated radial brick molded to suit the diameter of the chimney Because the compressive strength of the brick is much greater than that of the mortar the design strength is determined by the strength of the mortar Unlike its steel or reinforced counterpart a brick chimney cannot resist tensile stresses

Chimney foundations are usually square circular or octagonal in form Octagonal shapes are generally used for circular chimneys The design of the foundation is controlled almost entirely by the overturning moment due to wind [CNC]

Chimpanzee

The chimpanzee *Pan troglodytes* is a member of the ape family Pongidae and is native to the forests of western and central Africa It is black stands about 5 ft tall weighs up to 175 lb when mature and is equally at home on the ground or in trees The chimpanzee has well developed legs Its arms are somewhat shorter than those of other apes a reflection of its more terrestrial habits



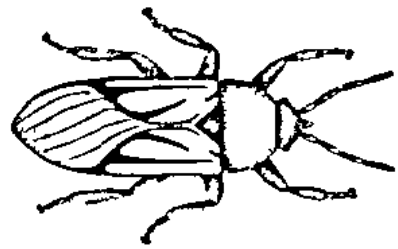
The chimpanzee *Pan troglodytes* height to 5 ft (*From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd London*)

Chimpanzees spend most of their time on the ground in underbrush in search of various foods they show some preference for bananas and other fruits They are gregarious intelligent friendly animals easily tamed with kind treatment and are of great value in medical and psychological research because of their close relationship to man *See* PRIMATES [JDB]

Chinch bug

A well known insect pest *Blissus leucopterus* of the family Lygaeidae order Hemiptera

The chinch bug is one of the most destructive of field crop pests and causes great damage to corn wheat oats barley and other members of the grass family Chinch bugs suck the juices from these plants and although they are small in size (about ⅙ in) may seriously damage crops by their great numbers



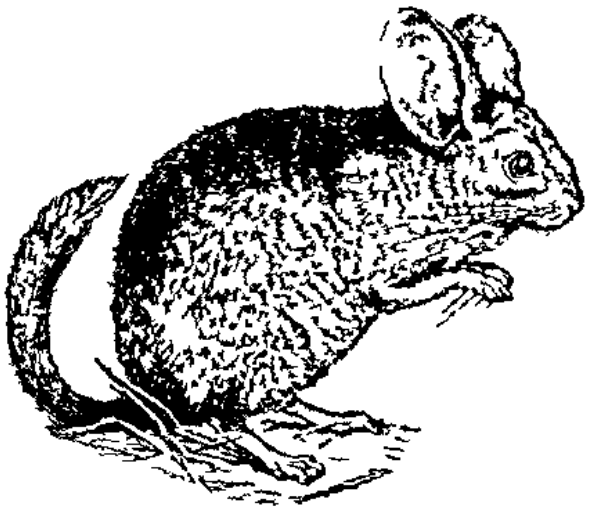
The chinch bug *Blissus leucopterus* length under ¼ in (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

Adult chinch bugs are black and have white outer wings with a black spot on the outer margin of each wing They usually produce two generations a year but may have three in the southwestern United States

In the midwestern part of the United States oats and wheat are usually harvested before the first generation of chinch bugs is complete and therefore the nymphs migrate in vast numbers to later maturing corn *See* HEMIPTERA INSECTA [JDB]

Chinchilla

Any of several South American rodents comprising the genus *Chinchilla* and characterized by a coat of luxurious soft silky blue gray fur The chinchillas are native to the higher Andes but have been so extensively hunted that wild ones are now quite rare One type known as the royal chinchilla has a fluffy squirrel like tail It and another short tailed type are raised in captivity and formerly commanded extremely high prices as fur animals Each



The chinchilla *Chinchilla lanigera* length to 9 in (From P Martin Duncan ed *Cassell's Natural History* Cassell & Company Ltd London)

Chinchillas are nocturnal terrestrial animals about 9 in long exclusive of the tail which on the royal chinchilla is about 5 in long *See* RODENTIA [J D B]

Chinook

A mild dry extremely turbulent westerly wind on the eastern slopes of the Rocky Mountains and closely adjoining plains The term is an Indian word which means snow eater appropriately applied because of the great effectiveness with which this wind reduces a snow cover by melting or by sublimation The chinook is a particular instance of a type of wind known as a foehn wind Foehn winds initially studied in the Alps refer to relatively warm rather dry currents descending the lee slope of any substantial mountain barrier The dryness is produced by the condensation and precipitation of water from the air during its previous ascent of the windward slope of the mountain range The warmth is attributable to the previous release of latent heat of condensation in the air mass and to the turbulent mixing of the surface air with the air of greater heat content aloft

In winter the chinook wind sometimes impinges upon much colder stagnant polar air along a sharp front located in the foothills of the rockies or on the adjacent plain Small horizontal oscillations of this front have been known to produce several abrupt temperature rises and falls of as much as 50°F at a given location over a period of a few hours

In the Alpine regions adverse psychological and physiological effects have been noted in humans during prolonged periods of foehn wind These phenomena have been referred to as foehn sickness *See* FRONT ISENTROPIC SURFACES PRECIPITATION (METEOROLOGY) WIND WIND STRESS [F S]

Chipmunk

Any of several small squirrel like terrestrial rodents in the genera *Tamias* and *Eutamias* family Sciuridae *Tamias* contains only one species *T striatus* the eastern chipmunk which is represented by several distinct subspecies throughout



The eastern chipmunk *Tamias striatus* length to 9½ in (From P Martin Duncan ed *Cassell's Natural History* Cassell & Company Ltd London)

most of the United States east of the Great Plains The western chipmunks comprising about 15 species in the United States are found in western North America and Asia They are brightly colored and marked with contrasting stripes of black gray and usually rich shades of brown They are active inquisitive little animals and are easily tamed They store quantities of plant foods in the fall and hibernate during part of the winter Their summer diet is rather diverse and includes plant foods insects and other small animals *See* RODENTIA [J D B]

Chiroptera

One of the largest orders of mammals The bats of which more than 150 genera are known are included in Chiroptera These are the only mammals capable of true flight and the specializations for flying make this one of the most sharply characterized of all mammalian orders The bats must have evolved rapidly for in the Eocene there were bats as highly developed as the modern forms The order divides easily into two suborders the Megachiroptera or fruit eating bats found only in the Old World and the Microchiroptera or predominantly insect eating bats which are world wide in their distribution There are numerous remarkable specializations in food habits including fruit eating nectar feeding pollen eating fish eating and even blood eating in the vampire bats of the American tropics *See* EUTHERIA MAMMALIA [D D D]

Chiroptera fossils

Bats are poorly represented in the fossil record although some remarkably preserved skeletons have been found in Eocene deposits in Germany and in Wyoming Bones of flying animals are seldom preserved in sediments other than pond water deposits or fissure fills

The suborder Megachiroptera larger fruit eating bats with relatively smooth-crowned molars bearing a longitudinal furrow is recognizable back into Oligocene time The suborder Microchiroptera

includes animals with many adaptations in eating habits carnivores blood suckers insectivores fruit eaters and others As would be expected many different dental specializations are seen in both fossil and living representatives Early forms and primitive forms seem to have insectivorous carnivorous habits and their teeth are tubercular and have transverse furrows In these characters their teeth conform to other primitive generalized mammalian dentitions Early microchiropterans are ancestral to Megachiroptera but the exact lineages are uncertain

Middle Eocene representatives such as *Archaeonycteris* and *Palaeochiropteryx* from Europe demonstrate a completed structural modification necessary for flying

A search must be made for fossil evidence of the great transition from a probable tree climbing ancestor to the flying form in early Cenozoic or late Mesozoic rocks Scattered middle and later Cenozoic fossils are referable to living families

[DES]

Chitin

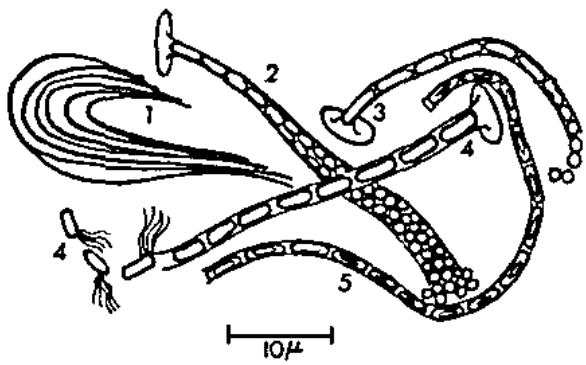
A polysaccharide found abundantly in nature Chitin is not known to be used by animals as a food Some authorities have reported that the snail *Helix* is apparently capable of digesting chitin Chitin is synthesized by some plants and animals and forms the basis of the hard shells of crustaceans such as the crab lobster and shrimp The exoskeleton of insects is also chitinous and the cell walls of certain fungi contain this substance Chitin may powder after dissolution of the calcium carbonate with mineral acids and removal of the proteins It is insoluble in water dilute mineral acids and alkalies and in these respects resembles cellulose it is however insoluble in Schweizer s reagent Dissolution takes place in concentrated mineral acids and chitin apparently unchanged is precipitated on dilution Hydrolysis however takes

cule consisting entirely of *N* acetyl D glucosamine units linked by β 1 4 bonds It may be contemplated as cellulose in which the hydroxyl groups on the second carbon are replaced with $NHCOCH_3$ groups *See* OPTICAL ACTIVITY POLYSACCHARIDE

[WZH]

Chlamydobacteriales

An order of bacteria of the class Schizomycetes characterized by the filamentous arrangement of their gram negative cells within a delicate sheath of organic material The sheath is often impregnated or encrusted with iron and manganese oxides Members of this group have been referred to as the iron bacteria Some members of the order like *Sphaerotilus* become a problem in sewage plants and paper mills Reproductive units may be nonmotile or swarming with the help of subpolar flagella These swarmers closely resemble cells of *Pseudomonas* a genus from which the Chlamydobacteriales may have been derived in the course of evolution (see illustration)

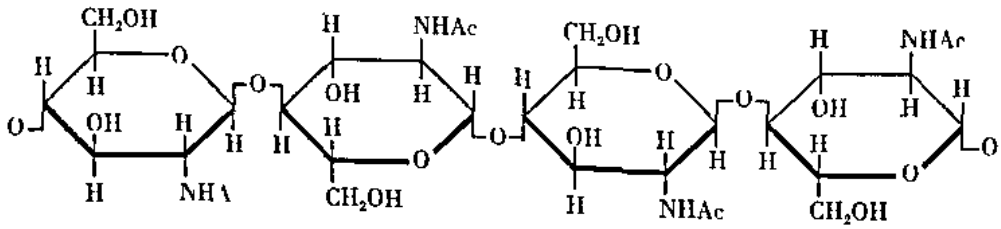


1 *Toxothrix* (Chamydobacteraceae)
2 *Crenothrix* (Crenotrichaceae)
3 *Clonothrix* (Crenotrichaceae)
4 *Sphaerotilus* (Chamydobacteraceae)
5 *Pelonema* (Pelopocaceae)

Representative genera of the Chlamydobacteriales (*V B D Skerman*)

Although Bergey s *Manual of Determinative Bacteriology* (1957) includes the following three families in the Chlamydobacteriales Chlamydobacteriaceae Crenotrichaceae and Peloplocaceae there is some doubt as to the desirability of including the last family There is also a difference of opinion on *Crenothrix* a genus now included in Chlamydobacteriales Some authorities claim that the genus should be in the Beggiatoales

Chlamydobacteriaceae The relationship between *Sphaerotilus Leptothrix* and *Toxothrix* as represented in Bergey s Manual is also not generally accepted *Sphaerotilus natans* and *Sphaerotilus dichotomus* are merely modifications of a species



Chain of β N acetyl D glucosamine units of chitin

which is also found in a *Leptothrix* form reported by E G Pringsheim in 1949 The difference between the *Leptothrix* form and the true *Leptothrix* is by no means clear as indicated by P Prave in 1957 *Toxothrix* is different from *Sphaerotilus* only in that its sheaths split longitudinally into fine shreads This affects the appearance of the growths but does not appear sufficient for generic differentiation

The taxonomy of the Chlamydobacteriaceae in spite of their economic importance is still in an unsatisfactory state owing to the great dependence of their appearance on surrounding conditions and also to the lack of well planned culture experiments The taxonomic nature of such changeable organisms cannot be established by mere inspection

The most important species the very common *Sph natans* appears in waste waters rich in organic matter It is seen as soft, slimy tassels composed of chains of rod shaped cells held together by a tough but pliable tube of organic nature In water containing decaying plant material it has the appearance of branched rigid structures with a firm sheath Previously this organism has been identified as *Cladothrix dichotoma* but it is only one of the modifications of *Sph natans* It may also be encrusted with iron hydroxide in which case it is rigid and very similar to *Leptothrix ochracea*

Sphaerotilus reproduces by motile swarmers or by the detachment of nonmotile cells from the filamentous chains After settling on solid bodies in the water these cells grow out again into long chains The swarmers swim with the help of flagella inserted near their ends they are gram negative resembling in these respects the members of the bacterial genus *Pseudomonas*

Sph discophorus formerly *Leptothrix discophora* is very similar to *Sph natans* except for the much thicker layer of iron compounds deposited on the sheath which is colored golden brown by its content of manganese dioxide There may be more species not yet satisfactorily defined by observation under controlled conditions

The species of *Sphaerotilus* can be grown on agar plates with a low content of organic nutrients for example meat extract This provides a means of separating them from other bacteria The growth on the agar surface is characteristically composed of filaments which form curly wavy or spirally structured colonies They might be confused with those of *Bacillus mycoides* or with those of Vitreoscillaceae which sometimes occur in the same habitat

The ramification of the *Cladothrix* form is caused by cells growing out into side-branches which have broken out of the chain owing to the pressure set up in elongating filaments as the result of their increase in mass during growth In the true *Sphaerotilus* form the sheath is too soft in the *Leptothrix* form it is too firm to allow for this phenomenon

In heavily polluted waste waters of sugar and cellulose factories paper mills and the like *Sphaerotilus* may develop in such enormous quantities as to cause serious problems When the masses of *Sphaerotilus* begin to rot and cause bad odors the high concentration of putrescible organic material must be oxidized in special processing plants Killing the organisms by disinfection would only delay decomposition

In nature the species of *Sphaerotilus* occur as inconspicuous floccules between plant residues The *Cladothrix* form is restricted to quiet waters not containing much dissolved organic matter and usually has been recorded from material standing in the laboratory Since its iron deposits and also those of the *Leptothrix* form of *Sph natans* are only faintly yellowish they had not been recognized as such until the Prussian blue reaction with potassium ferrocyanide and hydrochloric acid revealed their true nature The brown color of deposits believed to be characteristic of rustlike compounds is due to the admixture of manganese

The deposits result from the oxidation of ferrous to ferric compounds causing a precipitation of $Fe(OH)_3$ (ferric hydroxide) on the sheaths of *Sphaerotilus* S Winogradsky suggested that the organisms might use the energy released in this oxidation just as the nitrifying bacteria use energy obtained from the oxidation of ammonia and nitrite But this has not yet been shown with cultures of *Sphaerotilus* which in contrast to the nitrifying bacteria satisfies its energy requirements by oxidizing organic substances A special dissimilation metabolism in addition to the oxidation of ferrous to ferric compounds furnishes energy for the physiological processes existing in the iron bacteria as in other living organisms

Moreover the energy output of the oxidation of ferrous compounds is low so that a large quantity of ferrous compounds must be assumed to be available in order to maintain an adequate energy level This unavoidable consequence is however not inconsistent with Winogradsky s theory since the amount of iron deposits compared with organic matter produced may be very high

Considerable quantities of iron oxides conspicuous by their orange hue are often seen in nature for instance where water rich in humic acid from peaty swamps flows over mineral layers containing iron compounds Such accumulations of ocher seem to have been one of the earliest sources of ore used for making iron by primitive man apart from being employed as pigments

Crenotrichaceae and Peloplocaceae The Crenotrichaceae have trichomes differentiated into base and tip The base is attached to a firm substrate The Peloplocaceae have cells containing false vacuoles in trichomes which are enclosed in a thin sheath *See* BACTERIA TAXONOMY OF SCHIZOMYCETES SOIL MICROBIOLOGY *see also* PSEUDOMONADACEAE. [G P]

Bibliography E G Pringsheim ... lation ... ship between bacteria and M, ... *terio* ... *Rev* 13 47 98 1949

Chloramine T

A derivative of *p* toluenesulfonamide prepared by treating the latter with sodium hypochlorite

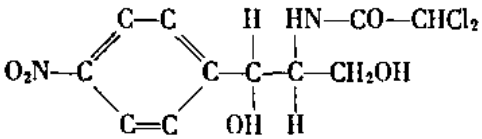
$$p\ CH_3C_6H_4SO_2NH_2 + NaOCl \rightarrow p\ CH_3C_6H_9SO_2NClNa$$

Dilute solutions have antiseptic values in dressing and irrigating wounds *See* ANTIBACTERIAL AGENTS ORGANOSULFUR COMPOUND SULFONAMIDE [N K]

Chloramphenicol

A broad spectrum antibiotic also known as Chloromycetin used to treat serious infectious diseases caused by bacteria rickettsiae and certain large viruses (*see* BACTERIA RICKETTSIOSES VIRUS)

Crystalline chloramphenicol has an empirical formula of $C_{11}H_{12}Cl_2N_2O_5$ a molecular weight of 323 and a melting point of 150 5 151 5°C It is moderately soluble in water (2 5 milligrams/milliliter at 25°C) neutral (nonionic but pH 5 5 in water) absorptive of ultraviolet in water solution (peak a = 29 8 at 278 mμ) and optically active ($[\alpha]_D^{25} = +19°$ 5% solution in absolute alcohol) The chemical structure is known as D (−) *threo* 2 dichloroacetamido 1 *p* nitrophenyl 1 3 propanediol and the substance can be manufactured by strictly chemical methods as well as by the biochemical method



Chloramphenicol

The biochemical method of manufacture involves aseptic aerobic fermentation of a nutrient broth culture medium seeded with *Streptomyces venezuelae* a species of the Streptomycetaceae (*see* STREPTOMYCETACEAE) The fermenting broth is aerated and agitated by bubbling filtered compressed air and mechanical stirring After fermentation at 27 8°C for approximately 3 days the broth is filtered and the active material extracted from the filtrate with amyl acetate The extract is concentrated washed with dilute sulfuric acid sodium bicarbonate and deionized water It is concentrated further and cooled to 8°C whereupon crystallization occurs The crude crystals are filtered out vacuum dried and dissolved in hot water the solution is decolorized with carbon filtered and cooled to provide a recrystallized product The purified crystals are filtered washed dried pulverized and sieved

Chloramphenicol inhibits species of gram positive bacteria such as *Diplococcus Staphylococcus Streptococcus* gram negative bacteria such as *Brucella Hemophilus Neisseria Pasteurella Proteus Salmonella Shigella* spirochetes such as *Borrelia Leptospira Treponema* actinomycetes, rickettsiae and large viruses It does not significantly inhibit protozoa fungi or small viruses (*see* BRUCELLACEAE ENTEROBACTERIACEAE NEISSERIACEAE PNEUMOCOCCUS SPIROCHAETALES STAPHYLOCOCCUS STREPTOCOCCUS)

Chloramphenicol is used to treat many infectious diseases notably typhoid fever and *H influenzae* meningitis It is widely used in systemic infections including resistant staphylococcal infections meningitis septicemia osteomyelitis typhus and other rickettsial fevers brucellosis tularemia relapsing fever plague pneumonia whooping cough psittacosis endocarditis peritonitis and gastrointestinal genitourinary eye ear nose throat and skin infections (see articles on individual diseases)

Humans absorb oral doses of chloramphenicol efficiently attain bacteriostatic body fluid and tissue levels rapidly and excrete most of the drug in the urine as a conjugate with glucuronic acid

The United States output of chloramphenicol has been estimated to be approximately 85 000 lb/year *See* INDUSTRIAL MICROBIOLOGY [J E]

Chlorate

A negative ion having the formula ClO_3 and derived from chloric acid $HClO_3$

Chloric acid exists only in solution The chlorates are more stable than hypochlorites and chlorites but less stable and thus better oxidizing agents than bromates iodates and perchlorates Chlorates are decomposed on heating to liberate oxygen

$$2KClO \rightarrow 2KCl + 3O_2$$

Both potassium and sodium chlorates are prepared by electrolysis of a hot chloride solution Chlorine liberated at the anode is allowed to react with OH as in the equation

$$3Cl_2 + 6OH \rightarrow ClO_3 + 5Cl + 3H_2O$$

Hydrogen is liberated at the cathode and the overall reaction is

$$NaCl + 3H_2O \rightarrow NaClO_3 + 3H_2$$

Sodium chlorate is used mainly in the production of perchlorates but also as a weed killer potassium chlorate is used in the manufacture of matches *See* BROMATE CHLORINE HERBICIDE, IODATE MATCH OXIDIZING AGENT PERCHLORATE [E E WR]

Chloride

A compound which is derived from hydrochloric acid HCl and which contains the chlorine atom in the 1− oxidation state Compounds containing this group may be organic or inorganic The inorganic chlorides can be divided into three classes covalent chlorides ionic chlorides and complexes The covalent chlorides are recognizable because of their low boiling and melting points Examples are the nonmetallic chlorides such as boron trichloride BCl_3 carbon tetrachloride CCl_4 and phosphorus pentachloride PCl_5 and metallic chlorides such as aluminum chloride Al_2Cl_6 stannic chloride $SnCl_4$ and antimony pentachloride $SbCl_5$

The ionic chlorides have high melting and boiling temperatures good electrical conduction in the

molten state, and are the most numerous They are illustrated by sodium chloride, NaCl, calcium chloride $CaCl_2$ and magnesium chloride, $MgCl_2$ The dividing line is not clear cut between these two groups, and beryllium chloride, $BeCl_2$, zinc chloride, $ZnCl_2$, and mercuric chloride, $HgCl_2$ fall in this borderline region Since formation of a covalent bond is enhanced by a large anion iodides have the greatest tendency to be covalent followed by bromides, chlorides, and fluorides in that order

Most metallic chlorides are water soluble Some of the insoluble or slightly soluble salts include lead chloride, $PbCl_2$, copper(I) chloride CuCl, silver chloride AgCl mercurous chloride Hg_2Cl_2, thallous chloride, TlCl, and gold(I) chloride AuCl

Evidence for the formation of coordination complexes is observed when an insoluble chloride such as silver chloride dissolves in the presence of excess chloride ion to give the silver chloride complex ion $AgCl_3^{2}$

Other common chloro complexes are those of copper, cobalt, tin, and platinum, $CuCl_2$, $CoCl_4^{2}$, $SnCl_6^{2}$, and $PtCl_6^{2-}$, respectively

Complex formation is a general property of all the halide ions, and complexes are observed with all metal ions, except those of the alkali and alkaline-earth metals Of the halide complexes the most stable are the chloro complexes, followed by bromo and iodo complexes Fluoro complexes are sometimes more stable and at other times less stable than chloro complexes

Of the chlorides, sodium chloride is most important commercially Sodium chloride occurs widely in nature and is the starting point for all sodium, chlorine, and compounds containing these two elements Calcium chloride is obtained as a by product in the Solvay soda ash process

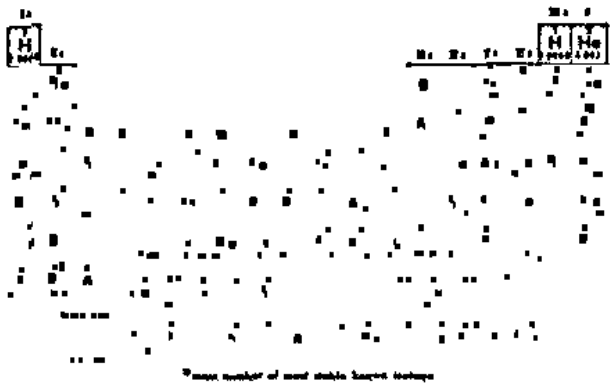
The insoluble silver chloride is used to identify the chloride ion in the absence of bromide ion Br and iodide ion I *See* CHEMICAL BINDING, CHLORINE, COMPLEX COMPOUNDS HALIDE, HALOGENATED HYDROCARBON [E E WR]

Chlorine

Element number 17, chlorine, Cl, is a greenish yellow gas at ordinary temperatures and pressures It is second in reactivity only to fluorine among the halogen elements, and hence is never found free in nature except at the elevated temperatures of volcanic gases *See* HALOGEN ELEMENTS It is estimated that 0 045% of the earth's crust is chlorine It combines with metals, nonmetals and organic materials to form many hundreds of chlorine compounds Only the most important compounds are discussed here

Both chlorine and its common acid derivative hydrochloric (or muriatic) acid were probably noted by experimental investigators starting in the thirteenth century C W Scheele identified chlorine as "dephlogisticated muriatic acid" in 1774 and H Davy proved that a new element had been found in 1810 Extensive production started 100 years later During the twentieth century, the amount of chlorine used has been considered a measure of industrial growth

The importance of chlorine has changed, as new derivatives have been added Whereas in 1925 paper and pulp used over one half the chlorine made and chemical products only 10%, the additional new chemicals manufactured later raised chemical use to 80% in 1955 Sanitation uses contributed to the growth of large cities, and new textiles, plastics paints and miscellaneous uses have raised man's standard of living Many large chemical companies are based primarily on the manufacture of chlorine and its compounds



The logarithmic chart in Fig 1 shows chlorine production increases in the United States It indicates a yearly increase of 15%

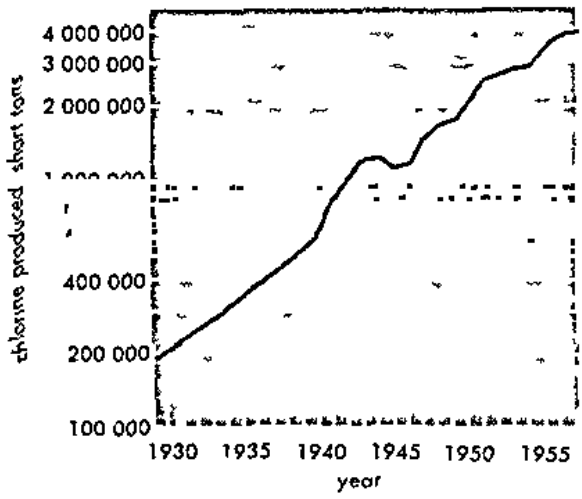


Fig 1 Chlorine produced in the United States (*Dow Chemical Co*)

Uses Chlorine is an excellent oxidizing agent Historically, the use of chlorine as a bleaching agent in the paper, pulp and textile industries and as a germicide for drinking water preparation swimming pool purification, and hospital sanitation has made community living possible

Chlorine is used to produce bromine from bromides in brines and sea water Bromine is particularly important for the production of ethylene dibromide for use in gasoline Of the bromine produced 95% is so used and 5% goes to the

Table 1 Major chlorine-consuming industries, 1956

Industry	Chlorine requirements, tons
Chemicals	3 020 000
Ethylene glycol	492 000
Carbon tetrachloride	347 000
Tetrachloroethane[a]	310 000
Chlorobenzene	198 000
Ethylene dichloride	186 000
Hydrogen chloride[b]	176 000
Glycerin-epichlorohydrin	117 000
Bromine (iodine)	83 000
Methylene chloride	76 000
Chloroform	42 000
Benzene hexachloride	63 000
Propylene glycol	60 000
Sodium hypochlorite	60 000
Chloral	60 000
Calcium hypochlorite	54 000
Perchloroethylene	39 000
Dichlorobenzenes	37 000
Aluminum chloride	30 000
Methyl chloride	26 000
Titanium tetrachloride	24 000
Phosgene[d]	2 000
Pentachlorophenol	21 000
Chloroacetic acid	17 000
Dichlorophenol	16 000
Phosphorus trichloride	13 000
Others	471 000
Sewage and sanitation	150 000
Pulp and paper textiles	615 000
Total	3 785 000

SOURCE Dow Chemical Company
[a] For trichloroethylene and perchloroethylene production [b] From chlorine burning From tetrachloroethane [d] For toluene diisocyanate production

duction of other bromides From sea water the main reaction is

$$2NaBr + Cl_2 \rightarrow 2NaCl + Br_2$$

From brine the reaction is

$$CaBr_2 + Cl_2 \rightarrow Br_2 + CaCl_2$$

Both processes are followed by concentration and purification steps using iron and sulfur dioxide *See* BROMINE

Compounds of chlorine are used as bleaching agents oxidizing agents solvents and intermediates in the manufacture of other substances *See* ANTIMICROBIAL AGENTS BLEACHING

Natural occurrence Because many inorganic chlorides are quite soluble in water they are leached out of land areas by rain and ground water to accumulate in the sea or in lakes that have no outlets Sea water contains 18 97 g of chloride ion per kilogram (3% sodium chloride) Solar evaporation produces large deposits of salts in land locked areas Similar evaporation in the past is responsible for vast underground deposits of rock salt and brines which may be found in Michigan central New York, the Gulf Coast of Texas Stassfurt in Germany, and other places These deposits are mainly of sodium chloride the supply of which is unlimited for practical purposes Other rocks and minerals in the earth's surface average slightly over 0 03% chloride *See* HALOGEN MINERALS

Physical properties. The atomic weight of naturally occurring chlorine is 35 457 It is formed of stable isotopes of mass 35 and 37 Radioactive isotopes have been made artificially, also The diatomic gas has a molecular weight of 70 914 The boiling point of liquid chlorine (golden yellow in color) is −34 15°C at 760 mm and the melting point of solid chlorine (tetragonal crystals) is −100 98°C *The critical temperature is* 144°C, *the critical pressure* is 76 atm critical volume is 1 763 ml/g, and density at the critical point is 0 5672 g/ml Thermodynamic properties include heat of sublimation at 7370 ± 10 cal/mole at 0°K heat of evaporation at 4878 ± 4 cal/mole at −34 05°C heat of fusion at 1531 cal/mole heat capacity at 7 99 cal/mole at 1 atm and 0°C, and 8 2 at 100°C Other properties are shown in Figs 2 7 Chlorine forms solid hydrates $Cl_2\ 6H_2O$ (pale green crystals) and $Cl_2\ 8H_2O$ It hydrolyzes in water

$$Cl_2 + H_2O \rightarrow HClO + HCl$$

Chemical properties Chlorine is one of four closely related chemical elements which have been called the halogen elements Fluorine is more ac

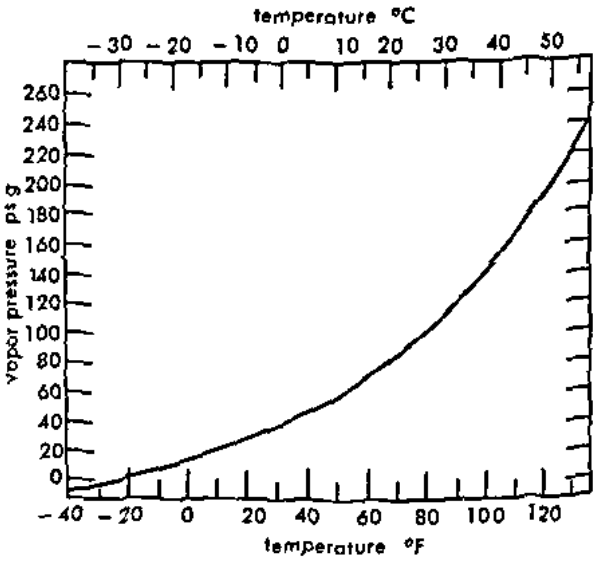


Fig 2 Vapor pressure of liquid chlorine (*Hooker Chemical Corp*)

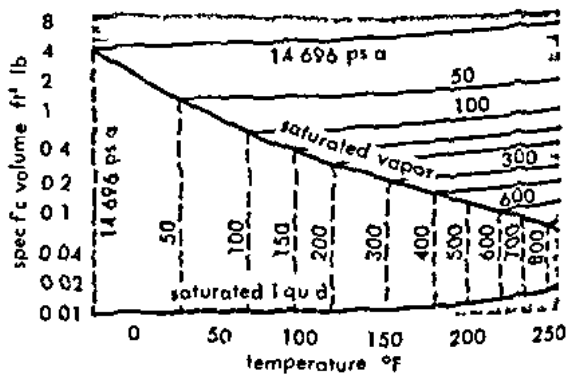


Fig 3 Specific volume of chlorine at various temperatures and pressures (*Diamond Alkali Co*)

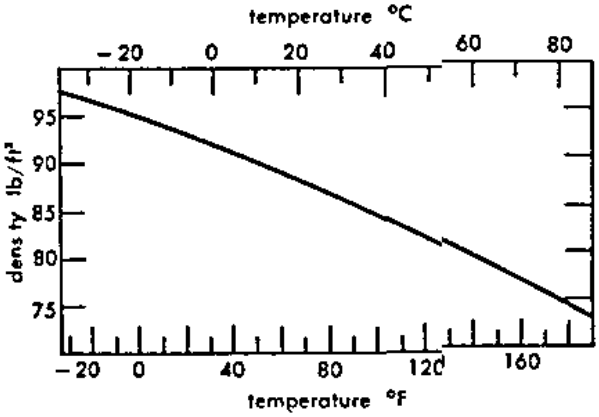


Fig 4 Density of liquid chlorine (*Hooker Chemical Corp*)

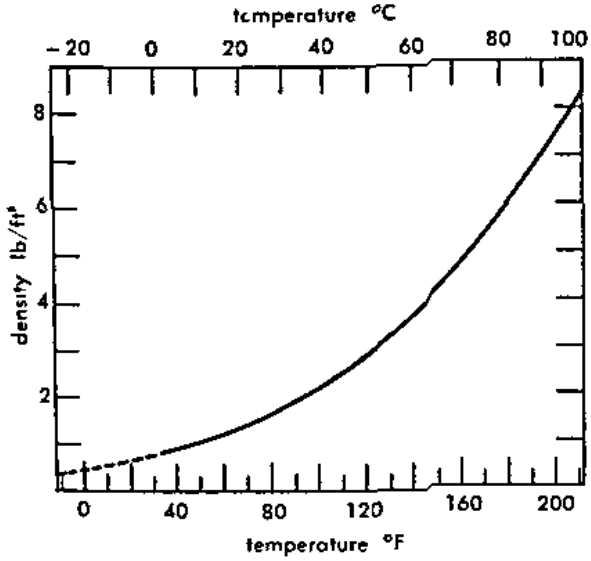


Fig 5 Density of saturated chlorine gas (*Hooker Chemical Corp*)

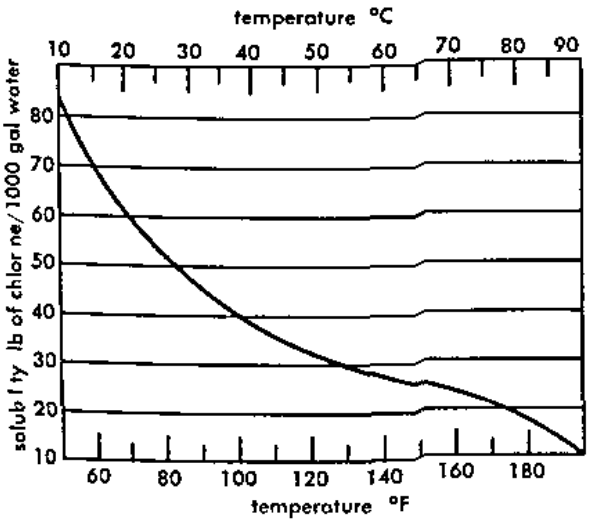


Fig 6 Solubility of chlorine in water (*Hooker Chemical Corp*)

tive chemically, and bromine and iodine are less active Chlorine replaces iodine and bromine from their salts It enters into substitution and addition reactions with both organic and inorganic materials Dry chlorine is somewhat inert, but moist chlorine unites directly with most of the elements

Safety precautions Chlorine attacks the tissues of nose throat and lungs Its pungent odor allows easy detection which should not be ignored because 30 parts per million (ppm) in air cause coughing and higher concentrations are quite dangerous Chlorine reacts violently with many materials Explosive mixtures are formed with hydrogen, and metals such as iron will begin to burn in it with only a slight amount of heating Many organic reactions with chlorine are highly exothermic Entire industries based on chlorine reactions have excellent safety records but each use must be carefully considered and each operation checked for safety hazards All persons working with chlorine should be familiar with the use of gas masks

Manufacture The first electrolytic process was patented in 1851 by Charles Watt in Great Britain Henry Deacon produced chlorine from hydrochloric acid and oxygen at 400°C with copper chloride absorbed in pumice stone as a catalyst (1868)

$$4HCl + O \rightarrow 2Cl_2 + 2H_2O$$

The electrolytic cells used may be classified into diaphragm and mercury types and both make caustic (NaOH or KOH) and chlorine so that the economics of this industry involves the marketing or internal use of two materials in the same proportions as obtained from the process

Diaphragm cells The Hooker diaphragm cell illustrates the principles of operation with porous asbestos pulp diaphragms Diaphragms separate the anode compartment containing the brine feed to the cell and chlorine produced from the cathode compartment The cathode compartment contains the sodium hydroxide (caustic) produced as a solution in undecomposed brine (which has percolated through the diaphragm) and hydrogen gas

To minimize back diffusion and migration of caustic the flow rate of brine through the dia

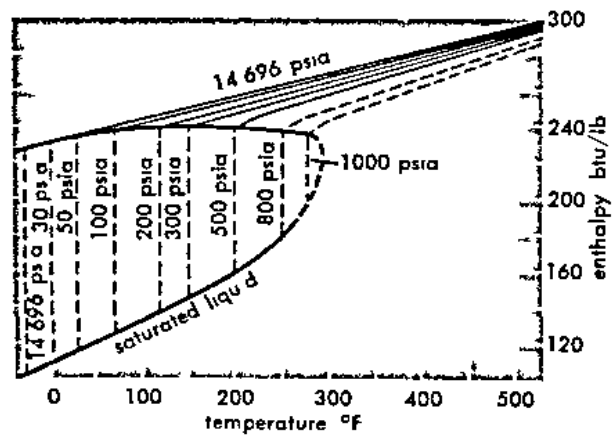


Fig 7 The enthalpy temperature relations of chlorine (*Diamond Alkali Co*)

phragm is faster than salt can be electrolyzed so that only part of the salt is converted Diaphragms must be renewed if brine is not sufficiently purified or if oils from graphite and calcium or iron from cell bodies cut down the flow rate These impurities are all collected by the diaphragms Diaphragm cells produce solutions containing about 10% sodium hydroxide and 15% sodium chloride This is used directly in some chemical processes Usually commercial caustic is evaporated to 50% or 73% solutions or to dry sodium hydroxide NaOH Most of the salt then crystallizes out and is returned to the process

In general very little unused chlorine capacity exists in the industry The installed capacity of Hooker cells and the Columbia Southern variation of them is approximately 5000 short tons of chlorine per day Dow diaphragm cells have a similar installed capacity and Diamond Alkali cells rank third (1958) Dow diaphragm cells are erected in blocks of about 50 cells and each block operates as one unit in contrast to single cell units in all other diaphragm installations In Dow cells electricity passes through a multiple unit series without electrical cables or bus bars between cells Abutting frames are pressed together to form a tight block with each unit connected electrically to the next cell within the frames of the series Chlorine and hydrogen gases are each collected in inverted trough concrete headers on top of the cells and caustic is collected at the side through a trap

Diaphragm cells usually operate at currents of up to 30 000 amp and at less than 4 volts per cell The voltage is determined by the sum of anode and cathode potentials (dependent on surface characteristics of each electrode temperature and current density which affect the chlorine and hydrogen overvoltages) the resistance through the electrolyte the resistance through the diaphragm the resistance through anode and cathode leads and across contacts and the diffusion potential

Anodes are made of graphite They must be replaced periodically and are therefore an additional item of expense in all cell operation Graphite is oxidized to carbon dioxide gas which leaves the cell with the chlorine gas Iron screen cathodes and concrete cell bodies are smaller items of expense since they need not be replaced so often Cylindrical cells usually have less concrete since the vessels are made of iron and need not be replaced often Vorce Wheeler and Gibbs cells are cylindrical whereas Nelson and Allen Moore cells are rectangular

Figure 8 shows a Hooker cell in which chlorine gas is produced on the graphite anodes It then rises through a reservoir of incoming brine and is collected in pipelines connected to each cell The chlorine contains water vapor which makes it a

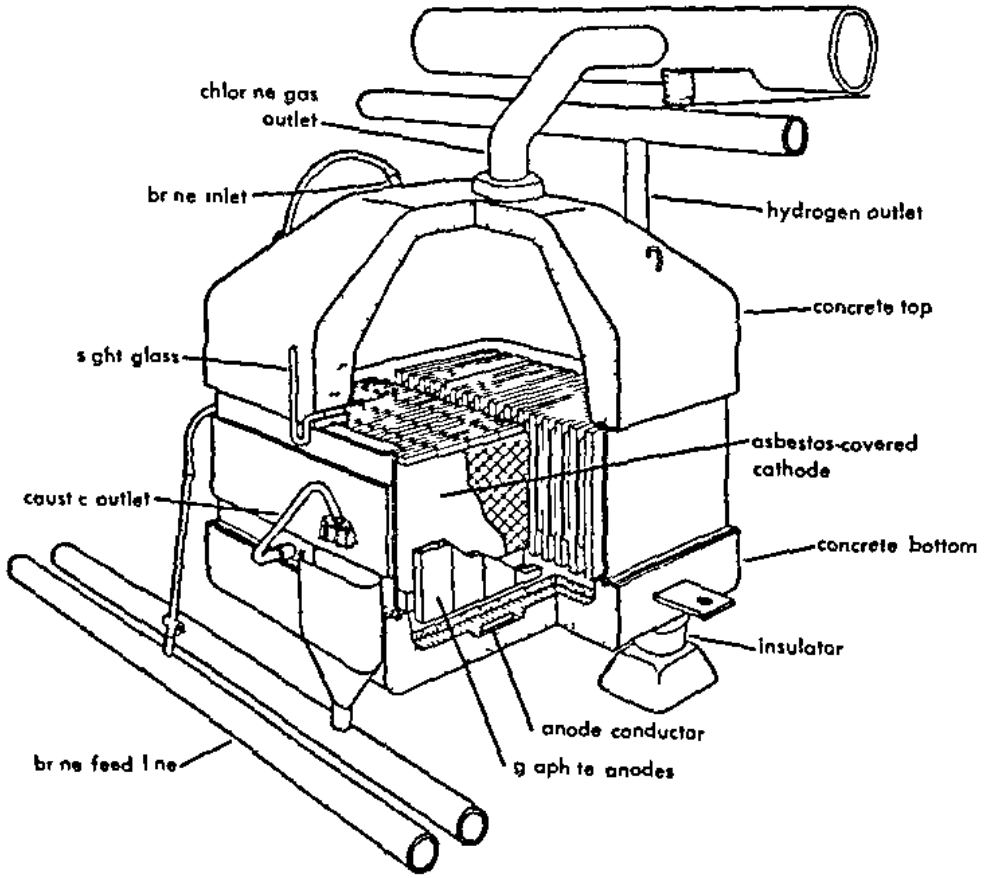


Fig 8 Hooker type S-3B chlorine cell (Hooker Chemical Corp)

very corrosive material It must be handled in rubber lined steel glass Haveg or similar corrosion resistant materials However when cool and dry, chlorine may be handled in equipment made of black iron steel copper, nickel or lead Processing consists of cooling drying (with sulfuric acid) pumping and perhaps liquefying for storage or shipment Liquefaction occurs at increased pressure (usually 100 psi) perhaps with some cooling (or by decreasing temperature to −40°C at low pressure) Shipments are common in 100 lb 150-lb and 1 ton cylinders, in 16- 30- and 55 ton railroad tank cars and in tank barges of 380 and 600 tons capacity

Hydrogen gas and caustic are produced inside the asbestos covered iron screen cathode pockets shown in Fig 8 The caustic solution drops from the outlet into a funnel (to break the electric current path) and is then collected and pumped to the evaporators Hydrogen is collected as shown behind the cell scrubbed with caustic to remove chlorine and often converted into ammonia hydrochloric acid or used for hydrogenation of oils

Mercury cells This type of cell has been operated during the entire period of commercial production of chlorine starting with the Castner cell and continuing in the United States with the Mathieson cell They achieved increased importance in Germany during World War II and other countries have now renewed their interest New mercury cell plants are now being erected by many companies in the United States

In the mercury cell the cathode is metallic mercury to which current is led by the steel body of the cell or other metallic contacts Sodium amalgam is produced in the cell It is led away from the cell to a decomposer also containing graphite which in this case serves as a cathode The amalgam serves as an anode in a short circuited cell

Pure water is added in the decomposer to produce concentrated sodium hydroxide solutions and hydrogen Such caustic is very pure and may be sold without further treatment This constitutes the main economy of a mercury cell installation compared with a diaphragm cell–caustic evaporator installation However mercury cells operate at higher voltage than diaphragm cells (approximately 5 volts compared with less than 4 volts) and the cost of mercury (of which there are losses in operation) is considerable

Mercury cells overflow some brine continuously to maintain salt concentration in the electrolyzer This brine is usually resaturated purified and recycled Sodium amalgam forms in the electrolyzer rather than caustic and hydrogen This occurs because the discharge potential of hydrogen is higher than that of sodium because of the high overvoltage of hydrogen on mercury Cells are usually constructed of steel and are rubber lined when necessary for protection against wet chlorine DeNora cells however employ chemically resistant stone instead of rubber lining Graphite anodes are parallel to the mercury surface as shown in Fig 9

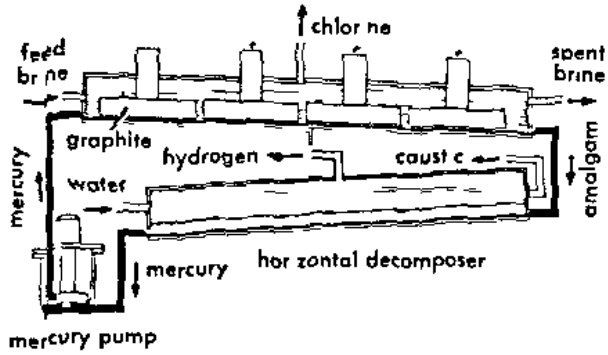


Fig 9 A mercury cell for producing chlorine

and are suspended from the cover by means of graphite pins Whereas the decomposition voltage in diaphragm cells is about 2 3 volts in mercury cells it is about 3 1 volts

The tremendous interest in mercury cells arises from the large units which have been developed In Europe mercury cells previously were operated at currents of up to 40 000 amp but since 1950 new designs by all manufacturers of cells have increased the operating range to 100 000–180 000 amp Besides the higher amperage multilevel layouts and extremely close spacing of cells have cut down floor space requirements tremendously Other new innovations include improvements in cell cover sealing arrangements automatic anode adjustments decomposer arrangements and cleaning devices

Other methods Chlorine can also be produced in other ways than by the electrolysis of sodium chloride brine Table 2 shows how chlorine production was distributed in 1957

Chlorine production by brine electrolysis was divided at 15 4% made in mercury cells and 84 6% in diaphragm cells Electrolysis of potassium chloride brine in either diaphragm or mercury cells produces potassium hydroxide KOH as the second product Molten sodium chloride is electrolyzed in cells such as the Downs cell operating at 600°C to produce sodium metal as the second product Caustic cell liquor can be converted to the carbonates as second products instead of being left as hydroxides to produce soda ash Na_2CO_3 and potassium carbonate K_2CO_3

Hydrochloric acid is often in oversupply because of its production as a by product of organic syn

Table 2 Chlorine produced by different processes

Process	Tonnage produced	Portion of total %
Cl_2 equivalent of NaOH	3 523 384	90 0
Cl_2 equiv of KOH	47 714	1 2
Cl_2 equiv of Na	204 958	5 2
Cl_2 equiv of electrolytic soda ash	141 363	3 6
Cl_2 equiv of K_2CO_3		
Cl_2 equiv of nitrosyl process		
Cl_2 equiv of HCl oxidation		
Total Cl_2 gas produced	3 917 419	100 0

SOURCE The Electrochemical Society Inc Chlor Alkali Committee Report

theses It can be converted to chlorine chemically by reaction with nitric acid in the nitrosyl chloride process

$$3HCl + HNO_3 \rightarrow Cl_2 + NOCl + 2H_2$$

Hydrochloric acid can also be oxidized by oxygen directly in the obsolete Deacon process Small amounts of chlorine are made as by products of the electrolysis of fused magnesium chloride $MgCl_2$ in the production of magnesium metal and of the electrolysis of fused lithium chloride in lithium metal production In 1958 chlorine was made in 75 installations by 42 different companies in the United States Canada had 12 plants and West Germany Great Britain France and Italy were the most important European producers Total European production is equal to about two thirds of production in the United States Latin America Japan India and other countries are developing chlorine production as their standard of living is improved for large masses of people

Natural compounds Sodium chloride NaCl is used directly as mined (rock salt) or as found on the surface or as brine It may also be dissolved purified and reprecipitated for use in foods or when chemical purity is required Its main uses are in the production of soda ash and chlorine products Farm use refrigeration dust and ice control water treatment food processing and food preservation are other uses

Calcium chloride CaCl is usually obtained from brines or as a by product of chemical processing Its main uses are in road treatment coal treatment concrete conditioning and refrigeration

Inorganic compounds Wet chlorine reacts with metals to form chlorides most of which are soluble in water It also reacts with sulfur and phosphorus and with other halogens as shown in the following reactions

$$H_2 + Cl_2 \rightarrow 2HCl$$
$$2Fe + 3Cl_2 \rightarrow 2FeCl_3$$
$$2S + Cl_2 \rightarrow S_2Cl_2$$
$$S + Cl_2 \rightarrow SCl_2$$
$$S + 2Cl_2 \rightarrow SCl_4$$
$$P_4 + 6Cl_2 \rightarrow 4PCl_3$$
$$P_4 + 10Cl_2 \rightarrow 4PCl_5$$
$$Br_2 + Cl_2 \rightarrow 2BrCl$$
$$2F_2 + Cl_2 \rightarrow ClF + ClF_3$$

Oxygen containing compounds The oxides of chlorine dichlorine monoxide Cl_2O chlorine monoxide ClO chlorine dioxide ClO_2 chlorine hexoxide Cl_2O_6 and chlorine heptoxide Cl_2O_7 are all made indirectly Cl_2O is commonly called chlorine monoxide also Chlorine dioxide *a green gas* is becoming increasingly important in commercial bleaching of cellulose water treatment and waste treatment It is usually liberated at the plant site by the action of a reducing agent on a chlorate

$$2NaClO_3 + H_2SO_4 + SO_2 \rightarrow 2ClO_2 + 2NaHSO_4$$

Sodium and calcium hypochlorite solutions made by passing chlorine gas into alkaline solutions are in general use for their oxidizing power or bleaching power Various solid hydrates and basic compounds may be prepared and sold but the most common called bleaching powder has been assigned various formulas The stability of these compounds varies with the water and metallic impurity present One formula

$$Ca(OCl)_2\,CaCl_2\,Ca(OH)_2\,2H_2O$$

would correspond to 35% bleach $CaOCl_2$ is the simplest formula to use Hypochlorite production began in earnest in 1823

Many special processes are used and mixtures are prepared to stabilize high available chlorine for bleaching purposes without obtaining detrimental insoluble materials High test hypochlorite (H T H) is calcium hypochlorite $Ca(OCl)_2$ containing 70% available chlorine Production started in 1923 and is increasing rapidly going from 10 000 short tons in 1955 to 12 800 in 1956

The corresponding acid for hypochlorites is hypochlorous acid HClO which may be prepared by action of carbonic acid on a hypochlorite

$$NaClO + H_2CO_3 \rightarrow NaHCO_3 + HClO$$

See Hypochlorite

Chlorites such as $NaClO_2$ are produced by reduction of calcium chlorate by hydrochloric acid to chlorine dioxide followed by absorption and reduction with caustic and peroxide

$$Ca(ClO_3)_2 + 4HCl \rightarrow 2ClO_2 + Cl_2 + CaCl_2 + 2H_2O$$
$$2ClO_2 + 2NaOH + H_2O_2 \rightarrow 2NaClO_2 + O_2 + H_2O$$

The use of sodium chlorite permits controlled bleaching and it is stable unless heated With organic matter present explosions can result however The corresponding acid for chlorites is chlorous acid $HClO_2$

Acidified sodium chlorite bleaches are very popular for cellulose and textile processing

Chlorates may be prepared by direct electrolysis of a chloride in cells in which the products of electrolysis are allowed to mix

$$NaCl + 3H_2O \rightarrow NaClO_3 + 3H_2$$

Graphite anodes are used and cooling coils or jackets are provided to remove heat The effluent may be cooled to crystallize out sodium chlorate Calcium chlorate may be prepared by chlorination of lime with heating of the acidified solution to 50–70°C followed by filtration and removal of insolubles Sodium chlorate is used as an intermediate in perchlorate production It is a weed killer and is also used in dye preparation textile and fur processing and metallurgical operations Potassium chlorate $KClO_3$ is a white powder or transparent colorless monoclinic crystals It is poisonous and may explode on contact with combustible substances

Sodium chlorate, $NaClO_3$, is a colorless, odorless, cubic, or trigonal, crystal material *See* CHLORATE

Perchlorates may be produced by electrolysis of sodium chlorate, using platinum anodes, followed by conversion to any desired salt

$$4NaClO_3 \rightarrow 3NaClO_4 + NaCl$$
$$NaClO_4 + KCl \rightarrow KClO_4 + NaCl$$

The corresponding acid is perchloric acid, $HClO_4$, a colorless, fuming liquid that can be used as an oxidizing agent

Potassium perchlorate, $KClO_4$ and ammonium perchlorate, NH_4ClO_4, are becoming important as fuels for rockets and jet propulsion and as explosives *See* PERCHLORATE

Chlorides Hydrogen chloride, HCl, is a colorless, pungent, poisonous gas which liquefies at 82 atm at 51°C It boils at −85°C at 1 atm This acid is produced by the LeBlanc process

$$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$$
$$NaHSO_4 + NaCl \rightarrow Na_2SO_4 + HCl$$

It is also a by product of many organic chlorinations It can be made by direct reaction of chlorine and hydrogen in an open combustion chamber submerged in cooled, aqueous hydrochloric acid solution Constant boiling solutions at 760 mm pressure contain 20 24% HCl, but a saturated solution at 15°C contains 43 4% HCl and has a specific gravity of 1 231 It is used as a strong acid and as a reducing agent.

Aluminum chloride, $AlCl_3$, is an anhydrous white, deliquescent, hexagonal crystalline substance Either scrap aluminum or the oxide (bauxite) may be chlorinated Scrap or pig aluminum is melted at 660°C chlorinated, and aluminum chloride vapor is condensed Bauxite is calcined at 980°C, mixed with coal or coke, pulverized briqueted with asphalt, recalcined to 18% carbon, heated to 870°C in a bauxite lined vertical kiln, and chlorinated Aluminum chloride is a catalyst for production of cumene, styrene, and isomerized butane

$$Al_2O_3 + 3C + 3Cl_2 \rightarrow 2AlCl_3 + 3CO$$

Of the aluminum chloride 70% is used in refining and catalysis in the petroleum industry, 20% for manufacture of dyes and 10% for other purposes

Titanium tetrachloride $TiCl_4$ is a clear, colorless liquid Production of titanium metal became of considerable interest in the 1950s for military uses This required production of titanium tetrachloride from chlorination of rutile (TiO_2) or ilmenite ($FeO\ TiO_2$)

$$TiO_2 + 2Cl_2 \rightarrow TiCl_4 + O_2$$

Usually mixtures of carbon and rutile are chlorinated Titanium tetrachloride is also used as a polymerization catalyst, and as a smoke screen agent, or for sky writing

Zirconium tetrachloride, $ZrCl_4$, is a colorless solid Titanium technology is applicable to other metals, among which zirconium became of interest in the late 1950s Zirconium tetrachloride is manufactured by chlorination of zirconium carbide or zirconium cyanonitride It is also made by action of chlorine and carbon on the ores, zircon ($ZrSiO_4$) or zirconia (ZrO_2), or by treating ores with carbon tetrachloride or phosgene

Phosphorus trichloride, PCl_3, and phosphorus oxychloride, $POCl_3$, are important reagents in organic chemical synthesis The oxychloride is a clear, colorless, fuming liquid Chlorine is bubbled through phosphorus pentoxide in phosphorus trichloride, and the oxychloride is removed by distillation

$$P_2O_5 + 3PCl_3 + 3Cl_2 \rightarrow 5POCl_3$$

Ferric chloride, $FeCl_3$, is a solid composed of dark, hexagonal crystals Much weak chlorine from chemical processes is converted to ferric chloride, which is then used for the manufacture of salts, pigments, pharmaceuticals, dyes, and for photoengraving, preparation of catalysts and for waste and sewage treatment *See* CHLORIDE

Organic compounds. Methane may be chlorinated to a variable extent

$$CH_4 \xrightarrow{Cl_2} CH_3Cl \xrightarrow{Cl_2} CH_2Cl_2 \xrightarrow{Cl_2} CHCl_3 \xrightarrow{Cl_2} CCl_4$$

The reaction may be carried out by light activation or through use of catalysts It may be controlled to produce methyl chloride mainly, with only slight amounts of the other products Recycling then produces the other chloromethanes If all products are produced in one reaction, they may be separated by distillation

Saturated aliphatic compounds Methyl chloride, CH_3Cl, is a colorless noncorrosive, liquefiable gas which condenses to a colorless liquid About 45% of the total produced is made by direct chlorination of methane and a 90% yield can be obtained It may also be made from methyl alcohol with 90% yield

$$CH_3OH + HCl \rightarrow CH_3Cl + H_2O$$

In 1954 butyl rubber catalyst solution used 45% of all CH_3Cl made, silicone production 35%, refrigeration 8%, manufacture of methyl cellulose, 7%, and miscellaneous uses 5%

Methylene chloride, CH_2Cl_2, is a clear, colorless, volatile liquid Direct chlorination of methane is the predominant process (10% is produced by further chlorination of methyl chloride) In 1954, paint remover used 70% and photographic film production 18%, leaving 12% for other uses

Chloroform, $CHCl_3$ is a colorless, nonflammable volatile liquid Direct chlorination of methane is the predominant process although 88% yield may be obtained from the reaction

$$2CH_3COCH_3 + 6CaOCl_2\ H_2O \rightarrow$$
$$2CHCl_3 + Ca(OAc)_2 + 2Ca(OH)_2 + 3CaCl_2 + 6H_2O$$

and 80% yield may be obtained by

$$CCl_4 + 2[H] \xrightarrow{(Fe\ HCl)} CHCl_3 + HCl$$

Penicillin production requires 42% of the chloroform made and another 42% is used in the preparation of chlorofluorohydrocarbons 8% goes into dyes and drugs and 8% is used as an anesthetic

Carbon tetrachloride CCl_4 is a colorless nonflammable liquid Various processes involving chlorination of methane natural gas or aliphatic hydrocarbons in general yield carbon tetrachloride but considerable amounts are still produced (1958) by the carbon disulfide method which proceeds with 90% yield

$$CS_2 + 3Cl_2 \xrightarrow{Fe} S_2Cl_2 + CCl_4$$
$$CS_2 + 2S_2Cl_2 \rightarrow 6S + CCl_4$$
$$6S + 3C \rightarrow 3CS_2$$

In 1956 chlorofluorohydrocarbons took 70% of production grain fumigating 13% other chemical and miscellaneous uses 12% fire extinguishing 4% and industrial cleaning 1%

The most important product made using chlorine ethylene glycol does not contain chlorine itself but has often been made from the chlorine compound ethylene chlorohydrin

Ethylene glycol $HOCH_2CH_2OH$ is a colorless sirupy sweet tasting hygroscopic liquid The chlorohydrin process has been preferred and still accounts for about 46% of the production The chlorohydrin production reactions (70% yield) are

$$CH_2{=}CH_2 + HOCl \rightarrow CH_2ClCH_2OH$$
$$CH_2ClCH_2OH + \tfrac{1}{2}Ca(OH)_2 \rightarrow \underbrace{CH_2{-}CH_2}_{O} + \tfrac{1}{2}CaCl_2 + H_2O$$
$$\underbrace{CH_2{-}CH_2}_{O} + H_2O \rightarrow HOCH_2CH_2OH$$

There is an alternate reaction with 65% yield

$$CH_2ClCH_2OH + NaHCO_3 + H_2O \rightarrow HOCH_2CH_2OH + CO_2 + H_2O + NaCl$$

[illegible]

oxidation of ethylene or by starting with formaldehyde and carbon monoxide to form an ester of [illegible]

[illegible]

distillation [illegible]

$$C_2H_2 + 2Cl_2 \xrightarrow{SbCl_5} \begin{matrix} CHCl_2 \\ | \\ CHCl_2 \end{matrix}$$

The principal use of the compound is in the manufacture of the solvents perchloroethylene and trichloroethylene Another process used involves the chlorination of propane

$$C_3H_8 + xCl_2 \xrightarrow{\Delta} Cl_2CHCHCl_2 + xHCl$$

Ethylene dichloride $ClCH_2CH_2Cl$, is a colorless oily sweet tasting liquid with a chloroformlike odor

$$CH_2{=}CH_2 + Cl_2 \rightarrow ClCH_2CH_2Cl$$

Ethylene dichloride is also produced in the chlorohydrin process for making ethylene glycol, by direct chlorination of ethane as a by product of ethyl chloride manufacture and by treatment with hydrochloric acid and oxygen

$$C_2H_6 + 2HCl + O_2 \rightarrow ClCH_2CH_2Cl + 2H_2O$$

In 1953 vinyl chloride used 60% of the ethylene dichloride produced antiknock liquids 36%, and miscellaneous uses 4%

Ethyl chloride C_2H_5Cl is a colorless gas that is easily compressed to a colorless flammable liquid Ethylene may be treated with hydrochloric acid using aluminum chloride catalyst, to give a 90% yield

$$C_2H_4 + HCl \xrightarrow{AlCl_3} C_2H_5Cl$$

This is the predominant method of production but ethyl alcohol may also be used as raw material with 95 98% yield

$$CH_3CH_2OH + HCl \rightarrow C_2H_5Cl + H_2O$$

About 90% of the ethyl chloride produced is used in the manufacture of tetraethyllead and 10% in the production of ethyl cellulose as a refrigerant or anesthetic and other miscellaneous uses

Chloral CCl_3CHO is a colorless oily liquid which became important after World War II with the introduction of newer insecticides About 50% of chloral production starts with chlorination of ethyl alcohol

$$C_2H_5OH + Cl_2 \rightarrow C_2H_5OCl + HCl$$
$$C_2H_5OCl + C_2H_5OH \rightarrow CH_3CH(OH)OC_2H_5 + HCl$$
$$CH_3CH(OH)OC_2H_5 + 3Cl_2 \rightarrow CCl_3CH(OH)OC_2H_5 + 3HCl$$
$$CCl_3CH(OH)OC_2H_5 \xrightarrow{H_2SO_4} CCl_3CHO + C_2H_5OH$$

The yield is 83% Chlorination of acetaldehyde is the other method of chloral manufacture

$$2CH_3CHO + 3Cl_2 \rightarrow (CH_2ClCHO \overset{\text{mixture}}{+} Cl_2CHCHO) + 3HCl$$

The [illegible]

[illegible]

yield

$$CH_2ClCHO + Cl_2CHCHO + 3Cl_2 \xrightarrow{SbCl_3} 2Cl_3CCHO + 3HCl$$

Various mechanisms have been proposed for the reaction one of them involving the formation of ethyl hypochlorite, decomposition to acetaldehyde and polymerization to paraldehyde and chlorination DDT manufacture consumes 99% of the chloral made

Other saturated chlorine compounds of interest are ethylidene chloride, a colorless liquid, $C_2H_4Cl_2$ (an isomer of ethylene dichloride), pentachloroethane C_2HCl_5 a colorless liquid chemical intermediate, hexachloroethane, C_2Cl_6, a white rhombic, solid chemical intermediate and insecticide, propylene chloride, $C_3H_6Cl_2$, a colorless liquid chemical intermediate, fumigant, insecticide, and solvent; 1,2,3 trichloropropane, $C_3H_5Cl_3$, a colorless liquid solvent and chemical intermediate, *n* butyl chloride, C_4H_9Cl, a colorless liquid solvent and alkylating agent, 1,4-dichlorobutane, $C_4H_8Cl_2$, a colorless liquid used in the manufacture of nylon, amylchlorides, $C_5H_{11}Cl$, chemical intermediates, *dichloropentanes*, $C_5H_{10}Cl_2$, *colorless liquids* when pure, used as solvents in the rubber, resin, and paint industries; chlorinated paraffins liquids or solids, used as plasticizers, lubricant additives, and weather and flame proofing agents

Unsaturated aliphatic compounds Perchloroethylene, $Cl_2C{=}CCl_2$, is a colorless nonflammable stable, heavy, toxic liquid It may be made from tetrachloroethane by chlorination to pentachloroethane However, trichloroethylene may be made first by lime treatment

$$2CHCl_2CHCl_2 + Ca(OH)_2 \rightarrow 2ClHC{=}CCl_2 + CaCl_2 + 2H_2O$$

Trichloroethylene is also a colorless, nonflammable, stable heavy, toxic liquid which has other end uses besides perchloroethylene manufacture In 1955, these other uses were for metal degreasing (92%) and as an extraction solvent

Trichloroethylene may then be chlorinated to pentachloroethane

$$ClHC{=}CCl_2 + Cl_2 \rightarrow Cl_3CCHCl_2$$

which produces perchloroethylene on treatment with lime or heat

$$2Cl_3CCHCl_2 + Ca(OH)_2 \rightarrow Cl_2C{=}CCl_2 + CaCl_2 + 2H_2O$$

Perchloroethylene may also be made by pyrolysis of carbon tetrachloride, or by direct chlorination of ethane

$$C_2H_6 + 5Cl_2 \xrightarrow{\Delta} Cl_2C{=}CCl_2 + 6HCl$$

[illegible]

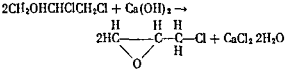
manufacture of the important compound glycerol Allyl chloride, $CH_2{=}CHCH_2Cl$, is made by high temperature chlorination of propylene from petroleum cracking

$$CH_2{=}CHCH_3 + Cl_2 \rightarrow CH_2{=}CHCH_2Cl + HCl$$

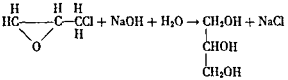
This will react with hypochlorous acid to make dichlorohydrins

$$CH_2{=}CHCH_2Cl + HOCl \rightarrow CH_2OHCHClCH_2Cl$$

which may in turn be reacted with lime to produce epichlorohydrin



This finally may be hydrolyzed to glycerol with sodium hydroxide in 75–80% yield



[illegible]

[illegible] *droxide to make CH_2CHCH_2OH and glycerol, ac*counts for all manufacture of glycerol except that resulting from saponification of fats and oils In another process, propylene is oxidized with oxygen instead of chlorine, to make acetone as a by product, but 78% of the capacity remains in the chlorine process

Vinylidene chloride, $C_2H_2Cl_2$ is a low boiling liquid made by the reaction of acetylene with chlorine in the presence of tetrachloroethane and ferric chloride at 135°C, or by treating 1,1,2 tri*chloroethane with alkali It polymerizes easily and* hence is used to make copolymers, such as Saran Geon and Velon

Vinyl chloride, C_2H_3Cl is a colorless gas made by the reaction of acetylene and hydrochloric acid using catalysts such as mercury salts, or by treating ethylene chloride with alkali It also polymerizes to make polymers such as Koroseal Vinylite, Geon, Tygon, Velon, and Saran

Most propylene glycol production involves reaction of propylene and hypochlorous acid

$$CH_2{=}CHCH_3 + HOCl \rightarrow HOCH_2CHClCH_3$$

Lime and water treatments then produce the oxide *and glycol*

Other unsaturated compounds of interest are chloroacetylene, C_2HCl, an unstable gas, dichloroacetylene, C_2Cl_2, a colorless gas which is quite explosive, methallyl chloride, C_4H_7Cl, a colorless liquid which has been used as a fumigant, and chloroprene C_4H_5Cl, a colorless liquid used to make synthetic rubbers and plastics

Alicyclic compounds Benzene hexachloride, $C_6H_6Cl_6$ forms colorless to yellow crystals or flakes Direct chlorination of benzene, using the light from a mercury vapor lamp to activate the reaction, produces a 95% yield of a mixture of geometric isomers

$$C_6H_6 + 3Cl_2 \xrightarrow{Light} C_6H_6Cl_6$$

The γ isomer is toxic to insects and is concentrated by crystallization steam distillation and further fractional crystallization It is used as an insecticide

Chlordan $C_{10}H_6Cl_8$ is a viscous colorless odorless liquid used as an insecticide

Aromatic compounds Chlorobenzene C_6H_5Cl is a colorless mobile volatile liquid with an almond like odor Chlorination of dry benzene at 40°C using ferric chloride or other catalysts in iron tanks produces monochlorobenzene at 70–75% yield In 1955 60% was used for phenol production 25% for DDT and 15% for aniline and miscellaneous uses

$$C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$$

Dichlorobenzene $C_6H_4Cl_2$ exists in two isomeric forms The ortho form is a colorless volatile liquid whereas the para isomer consists of white volatile crystals It is obtained by chlorination of monochlorobenzene

$$C_6H_5Cl + Cl_2 \rightarrow C_6H_4Cl_2 + HCl$$

Mixtures of mono and dichlorobenzene may be made slightly alkaline allowed to settle and then separated by fractional crystallization The para form usually is present in three times the amount of the ortho isomer Small amounts of polychlorobenzenes are simultaneously produced In 1955 moth repellants and deodorants took 65% of the *p* dichlorobenzene made

Other aromatic chlorine compounds of interest are benzyl chloride $C_6H_5CH_2Cl$ benzal chloride $C_6H_5CHCl_2$ and benzotrichloride $C_6H_5CCl_3$ These three colorless liquids are starting materials for the synthesis of pharmaceuticals (Benzedrine Demerol) and are used as constituents of perfumes and as starting materials for the preparation of insecticides and insect repellants They are also used as lubricants and as intermediates in dye manufacture

The chlorinated biphenyls find use in electrical insulation hydraulic mediums lubricants and as constituents of paints varnishes and plastics They are chemically inert Chlorinated naphthalenes are used in chemical lubricant and electrical insulation applications

Phenol C_6H_5OH may be made by alkaline hy

servative

$$C_6H_5OH + 5Cl_2 \rightarrow C_6Cl_5OH + 5HCl$$

Dichlorophenol $Cl_2C_6H_3OH$ is important in the production of another chlorine compound 2 4-dichlorophenoxyacetic acid (2 4-D) 2 4-D is produced by reaction of the sodium salt of dichlorophenol with the sodium salt of chloroacetic acid The compound 2 4-D is widely used as a weed killer (*see* Herbicide)

Miscellaneous compounds Phosgene $COCl_2$ is a very poisonous gas The pure product is a colorless liquid that boils at 7 48°C It is produced by the reaction of dry carbon monoxide and chlorine gases conducted over activated charcoal

$$CO + Cl_2 \rightarrow COCl_2$$

Phosgene is used primarily in the manufacture of toluene diisocyanate which is becoming important in making foams and special rubbers Other isocyanates are being used in making adhesives

Monochloracetic acid $CH_2ClCOOH$, white deliquescent crystals is made by chlorination of acetic acid with a catalyst in acid resistant equipment It is used as a chemical intermediate for making dyes coumarin pharmaceuticals, cosmetics weed killers and insecticides Dichloroacetic acid $CHCl_2COOH$ results from further chlorination of acetic acid Trichloroacetic acid CCl_3COOH is a white crystalline material which results from still further chlorination of acetic acid It is used medicinally and the sodium salt is used as a weed killer

Other compounds such as chloramines have been promoted as bactericides germicides and surgical antiseptics *See* Halogenated hydrocarbon, *see also* Electrochemical process, Insecticide

[F W K]

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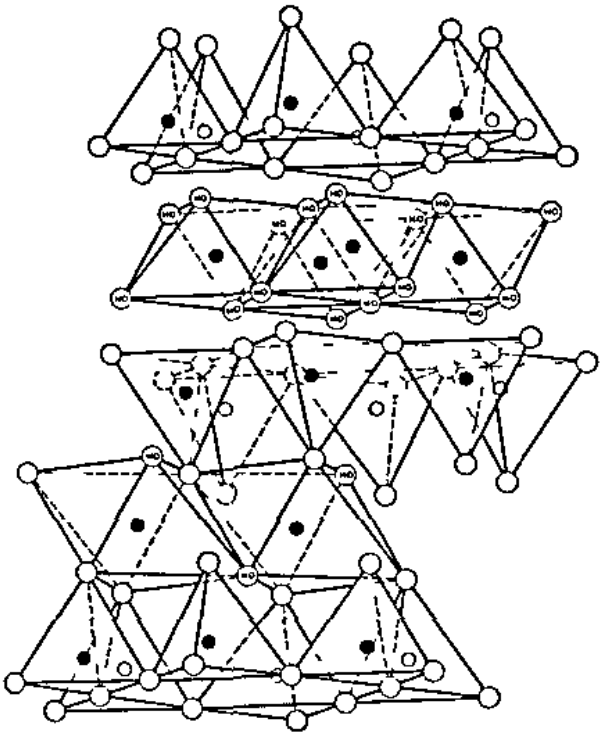
Chlorite

The chlorites are a group of hydrous silicates which are closely related to the micas They are normally green in color and contain appreciable amounts of ferrous iron *See* Clay minerals Mica

Structurally the chlorites are regular interstratifications of single biotite mica layers and brucite layers (see figure) The micalike layers are trioctahedral and are unbalanced by substitution of aluminum for silicon The brucitelike layer has the general composition $(Mg\ Al)_6(OH)_{12}$ and balances the charge deficiency of the mica layer The chlorite unit cell is composed of two brucitelike and two micalike layers

Various members of the chlorite group differ from each other in the kind and amount of structural substitutions They also exhibit polymorphic forms and show different stacking arrangements of the chlorite layers

Chlorites can form from magnesium rich minerals such as hornblende and biotite by hydrothermal or weathering processes Poorly crystalline varieties of chlorite are frequent components of Recent marine sediments and soils The mineral forms readily in the marine environment from degraded micas



Diagrammatic sketch of the structure of chlorite (From R E Grim, Clay Mineralogy, McGraw-Hill, 1953)

montmorillonite, and possibly kaolinite by a process involving taking up magnesium from sea water Chlorites somewhat better crystallized, are also frequent clay mineral constituents of ancient sediments *See* AUTHIGENIC MINERALS, DIAGENESIS

[F M W , R E GR]

Chloritoid

A member of the brittle mica (clintonite) group, which are hydrous aluminum silicates resembling both micas and chlorites Although they also possess a perfect basal cleavage, cleavage flakes of the clintonites are distinctly more brittle than those of the micas The composition is [Fe(II) Mg] [Al Fe(III)] $(Si,Al)O_5(OH)_2$ The variety ottrelite also contains manganese Margarite prehnite, and stilpnomelane are other members of the group Chloritoid has both monoclinic and triclinic modifications which may occur together It forms rosettes, foliated aggregates, and plates, the last with pseudohexagonal, or rhombic, outlines The color is gray to green, and crystals are weakly pleochroic Face-locl zoning (hour glass structure) is distinctive The hardness is 6 5, specific gravity 3 5 Inclusions of quartz and magnetite are common

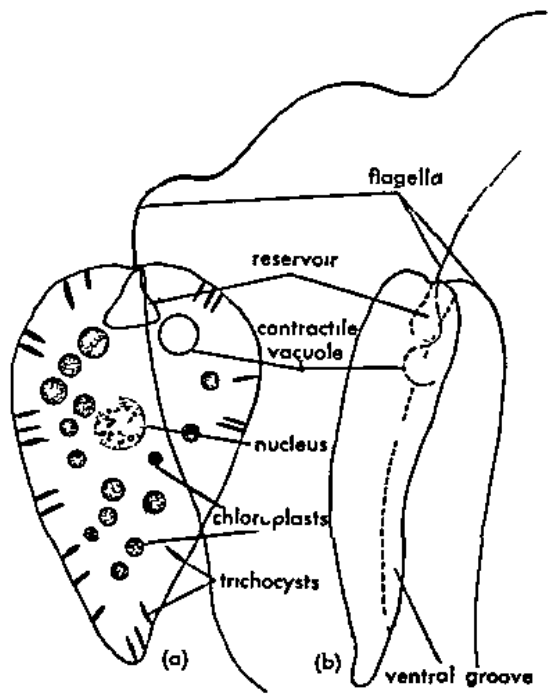
Chloritoid is principally a metamorphic mineral in schists phyllites and quartzites, and is associated with quartz muscovite and chlorite Chloritoid rocks result from the low to medium grade metamorphism of pelitic sediments rich in aluminum and iron but relatively low in potassium, calcium, and magnesium Chloritoid also forms in some quartz ankerite veins It alters to pennine *See* MICA, SILICATE MINERALS [E W H]

Chloroform

A colorless, sweet smelling, nonflammable liquid CH_3Cl_3, with specific gravity, 1 489, boiling point, 61 2°C, refractive index, 1 4422 It is also called trichloromethane and is manufactured by the chlorination of ethyl alcohol or acetone in alkaline solution (usually $CaOCl_2$), or by the reduction of carbon tetrachloride It is insoluble in water but soluble in organic solvents In the presence of ultraviolet light chloroform tends to react with oxygen of the air to produce poisonous phosgene Therefore, commercial chloroform contains about 2% ethanol to act as an inhibitor It is a powerful anesthetic, but prolonged use causes metabolic disturbances and damage to the heart, liver, and kidney, so that it commonly has been replaced by less toxic anesthetics It is widely used as an extractant and solvent, a chemical intermediate in the production of dyes and drugs, and as an antispasmodic and sedative (particularly in cough medicines) *See* HALOGENATED HYDROCARBON [E H H]

Chloromonadida

An order of the class Phytomastigophorea also known as the Chloromonadina These poorly known flagellates are grass green or colorless, somewhat flattened and have two equal flagella one anterior, the other trailing All known genera are free-swimming although *Reckertia* and *Thaumatomastix* form pseudopodia They vary in size from 30–100 μ Chromatophores are small disks, stigmas are lacking and fat is the storage product Trichocysts are found in three genera The nucleus is large, with nucleoli and chromosomes visible during interphase One or two anterior vacuoles are



Gonyostomum semen (a) Dorsal view (b) Side view

present and a reservoir seems to be present in *Trentonia* and *Gonyostomum* (see illustration) Life cycles are unknown but longitudinal division occurs Blooms are unknown, but *Gonyostomum* and *Vacuolaria* occur commonly in acid bog waters, *Reckertia* has been found in marine waters, and *Trentonia* in Warm Mineral Springs, Florida, an anaerobic highly saline habitat The taxonomic position of the class is poorly defined *See* PHYTOMASTIGOPHOREA [J B L]

Chlorophyll

The generic name for the green pigments which are the photoreceptors of light energy in photosynthesis These pigments belong to the family of organic compounds the tetrapyrroles which include the open chain bile pigments and the large-ring compounds The large ring compounds are comprised of porphyrins dihydro and tetrahydroporphyrins, as well as their derivatives chelated with metals such as iron or magnesium

Occurrence. Five closely related chlorophylls designated *a* through *e* occur in higher plants and algae Vascular green plants contain chlorophylls *a* and *b* in the ratio of about 3 1 Other chlorophylls when present are in small or trace amounts Trace amounts of biochemical precursors of chlorophyll for example protochlorophyll and Mg protoporphyrin are found under certain conditions In certain algae open chain metal free tetrapyrrole pigments called phycobilins are found attached to proteins (*see* ALGAE) From certain photosynthetic bacteria two greenish pigments bacteriochlorophyll and bacterioviridin have been isolated from different species (*see* BACTERIA)

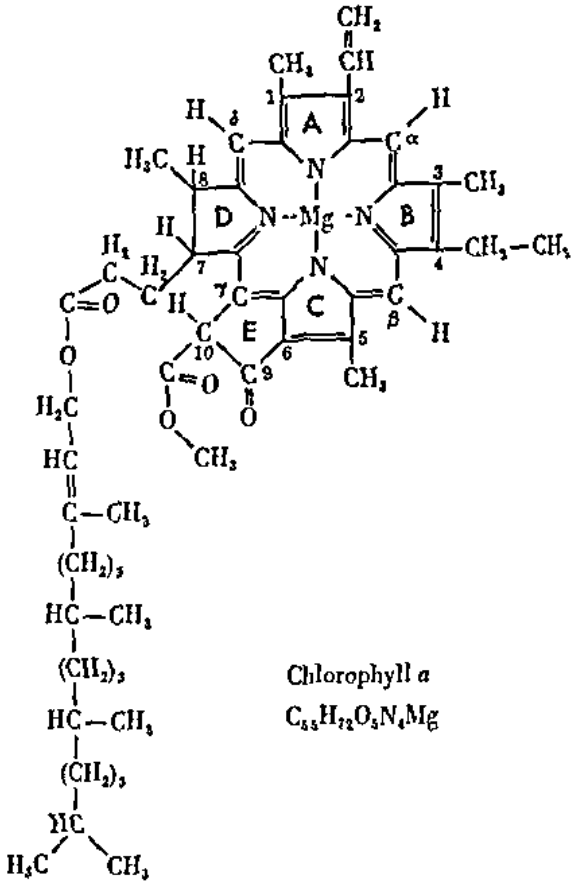
The chlorophylls including the above compounds are contained in lipoprotein bodies the plastids In green plants, chlorophylls *a* and *b* constitute 15–20% of the dry weight of these bodies known as chloroplasts The chloroplasts are made up of finely lamellated membranes 30–50 A thick on which the chlorophylls are thought to be arranged in close packed array Similar lamellated structures have been found in the photosynthetic bacteria *See* CELL PLASTIDS, PHOTOSYNTHESIS

Function. Chlorophyll *a* is the functional photoacceptor in the photosynthesis of plants, and is also the major pigment in the plastids Chlorophyll

the plant phylum there may be one or several accessory pigments that cooperate, these include

hundred chlorophyll *a* molecules (photosynthetic unit) to a site or energy sink where it is converted to chemical energy

Chemistry. The structure of chlorophyll *a* and related compounds is shown by the following formula To get the structure of the following compounds, substitute in the chlorophyll *a* the atoms or groups in the positions noted



Chlorophyll *a*

$C_{55}H_{72}O_5N_4Mg$

Chlorophyll *b* in position 3, substitute —CHO for —CH_3

Bacteriochlorophyll in positions 3 and 4, add H atoms, in position 2 substitute —CO CH_3 for —CH=CH_2

Bacterioviridin in position 2, substitute —CO CH_3 for —CH=CH_2 (formula in doubt)

Pheophytin remove Mg and add two H atoms on two of the N atoms

Pheophorbid remove Mg and phytol

Protochlorophyll in positions 7 and 8, remove H

The characteristic features of chlorophyll *a* are that it is a magnesium chelate of a dihydroporphyrin with a cyclopentanone ring E, and is esterified with phytol Chlorophyll *a* consists of four 5 membered rings (A–D) which form part of the large macro ring Rings A–C are pyrrolic nuclei, whereas ring D is a dihydropyrrolic nucleus containing two extra hydrogen atoms Tracer studies indicate, however, that hydrogen atoms in rings D or E of chlorophyll *a* are not involved in the chemical reactions of photosynthesis On the outside of each of the 4 small rings are two side chains numbered 1–8 These consist of 4 methyl groups, one ethyl, and one vinyl, at position 7 is a propionic acid group esterified with the C_{20} alcohol phytol,

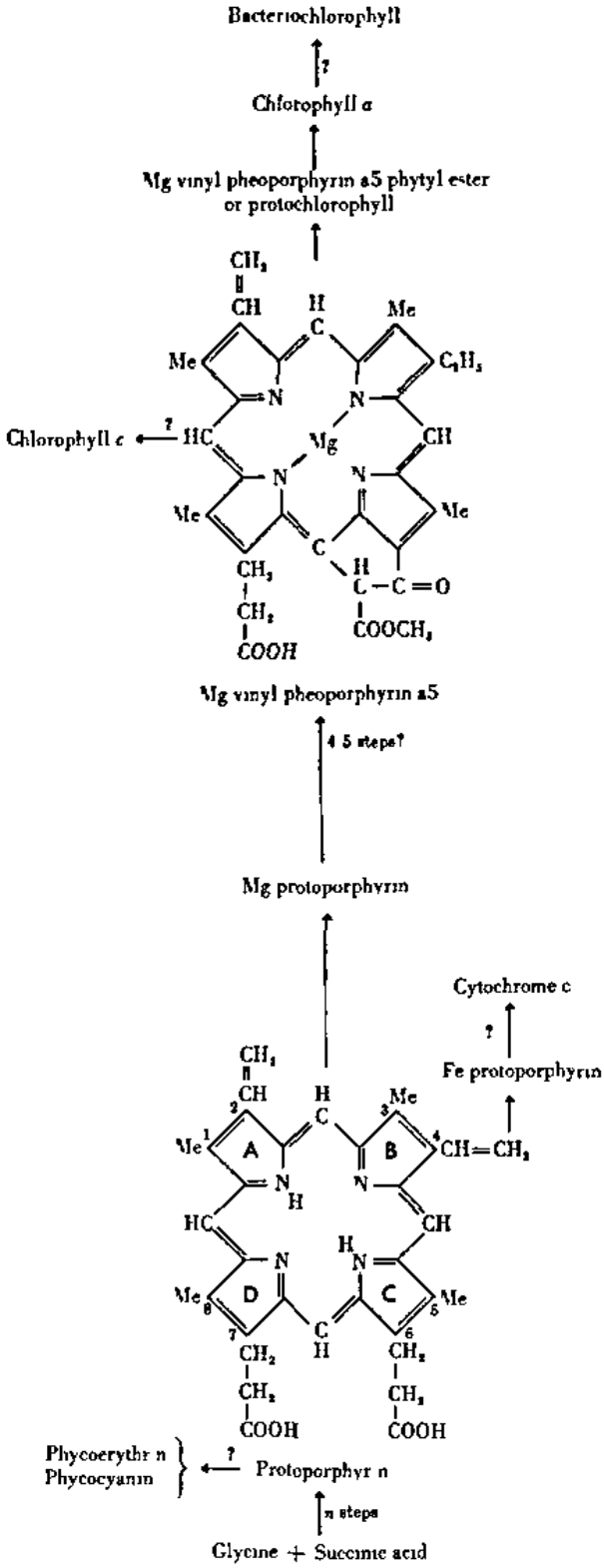
and the 6 position is an oxidized propionic acid group esterified with methanol which forms the cyclopentanone ring E This ring contains the carbonyl oxygen at position 9 and the enolizable hydrogen atom at 10 The small rings are linked together through methine bridges ($\diagdown\!\!\diagup C{-}H$) α through δ to form the large inner 16 membered ring of carbon and nitrogen atoms attached to each other through alternating single and double bonds

The parent compound porphyrin or porphin, consists of four pyrrole nuclei and is red as in protoporphyrin When a dihydropyrrole replaces one pyrrolic nucleus the resulting compound is a dihydroporphyrin or chlorin and is green as in chlorophyll When two dihydropyrroles replace two pyrrolic nuclei as in bacteriochlorophyll the main absorption is in the far red

Biosynthesis The two major pigments of protoplasm, the green chlorophyll and the red heme are both synthesized along the same biosynthetic pathway to protoporphyrin as shown by tracer and enzyme studies (*see* HEMOGLOBIN) Starting from the small building blocks, glycine and succinic acid, they are converted in a series of enzymic steps, identical in plants and animals, to protoporphyrin Here the pathway branches to form (1) a series of porphyrins chelated with iron as heme and related cytochrome pigments and (2) a series of porphyrins chelated with magnesium which are precursors of chlorophyll

The evidence for the steps in the conversion of protoporphyrin to chlorophyll is based mainly on isolation of pigments from *Chlorella* mutants First magnesium is inserted to form Mg protoporphyrin, a compound found in one mutant From another mutant Mg vinyl pheoporphyrin a5 has been isolated To get to this stage requires several enzymic steps which include the reduction of the vinyl group at the 4 position the oxidation of the propionic acid group at the 6 position its esterification with methanol and its cyclization to form the cyclopentanone ring E Protochlorophyllide is then formed by esterification with phytol of the propionic acid group at the 7 position Protochlorophyll has been found in dark grown barley leaves and other plants in minute amounts The conversion to chlorophyll requires a reduction that is addition of two hydrogen atoms to the 7 and 8 positions of ring D In a few plants such as *Chlorella*, this reduction can occur enzymically so that chlorophyll is formed in the dark However in most plants light is required for the last step Among additional factors required for chlorophyll formation are Fe Mg and O_2 In the young cells of higher plants the immature chloroplasts form internal fine lipoprotein lamellae concomitant with chlorophyll synthesis suggesting that chlorophyll may reside on these lamellae

The possible relations of phycobilin pigments chlorophyll *c*, and bacteriochlorophyll to the biosynthetic pathway of chlorophyll *a* are shown in the formula The synthesis to protoporphyrin is identical in plants and animal cells



Biosynthesis of chlorophyll

Bulk isolation Isolation of chlorophylls *a* and *b* consists in extracting leaves such as nettles or spinach which have little chlorophyllase, with 80% acetone containing some Na_2CO_3 (to neutralize plant acids) Petroleum ether is added the ace

tone washed out with water then with methanol to remove carotenols Finally the petroleum ether is washed free of acetone and methanol with water, which causes the chlorophyll to precipitate It is filtered onto a layer of talc and the talc is washed with petroleum ether to remove carotenes The chlorophyll is then extracted with ether The ether is dried with anhydrous Na_2SO_4 and chlorophyll is precipitated with petroleum ether Separation of the chlorophylls dissolved in a small volume of pyridine and diluted with petroleum ether is achieved by chromatography on powdered sucrose columns (*see* CHROMATOGRAPHY) The column is developed with 0 5% isopropanol in pentane Crystalline chlorophyll *a* is obtained by addition of water to an ether solution of chlorophyll which is slowly evaporated in vacuo

Separation of plant pigments. Identification by paper chromatography is readily achieved The method of E F Lind H C Lane and L S Gleason (1953) is given as example The pigments in *skellysolve B* (a petroleum ether fraction) are placed on Whatman #1 paper (prewashed in this *solvent and dried in air*) Then after drying the spots are developed with this solvent air dried and further developed with a *solution of* 1% *pro* panol in this solvent For development *in a second*

reversed phase column and paper chromatography method of H H Strain the liquid liquid counter

to chlorin e and rhodin g and their separation by extraction from ether with increasing *concentra* tions of HCl

Determination of chlorophyll concentrations. Assuming that no pheophytins are present chlorophylls $a + b$ can be estimated by O Warburg's method of extraction of leaves with methanol and the determination of the optical density D in a cell of 1 cm light path at 578 mμ

$$\frac{D_{678\ m\mu}}{78} = \text{mg chlorophylls } a + b/\text{ml}$$

For an ether solution J H C *Smith and A* Benitez give the equation

$$\frac{D_{600\ m\mu}}{9\,95} = \text{mg chlorophylls } a + b/\text{ml}$$

The method of G Mackinney gives the concentrations *of both chlorophyll* $a + b$ in 80% acetone by solving the following simultaneous equations,

$$D_{663\ m\mu} = 82\,04\,C_a + 9\,27\,C_b$$
$$D_{645\ m\mu} = 16\,75\,C_a + 45\,6\,C_b$$

where C_a and C_b are the concentrations in milligrams per milliliter of chlorophylls *a* and *b*, respectively

[S CR]

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Chlorophyta

Green algae a phylum of the plant subkingdom Thallophyta comprising about 5800 known species Botanists generally regard Chlorophyta as extremely important from the evolutionary standpoint, since it is thought that higher groups of green plants such as mosses, ferns, seed plants, and others evolved ultimately from Chlorophyta (probably those of the filamentous types) The plants owe their grass green color to chlorophyll to carotene (a yellowish orange pigment), and to xanthophyll (a yellow pigment) These pigments are chemically identical with the leaf pigments of higher plants and they occur in the same proportions in green algae as they do in higher green plants

Morphology. Chlorophyta are relatively simple in body structure, with little differentiation of their cells, they have no strengthening or conducting tissues (xylem and phloem) There are five principal body types of Chlorophyta (Fig 1)·

1 Microscopic, nonmotile, 1 celled plants such as *Chlorella*, which occur commonly in water (especially fresh water) and *Protococcus*, seen commonly as a greenish growth on shaded tree bark, soil bricks and stones, and erroneously termed moss

2 Motile colonies, such as *Volvox* In *Volvox* the plant body is a hollow sphere of hundreds or thousands of loosely organized cells with protoplasmic appendages (cilia) the rhythmic movements of which cause the colonies to move in water

3 Tubular plants lacking crosswalls, in which the body consists of a much elongated thread often branched and filled with living protoplasm, as in *Vaucheria*

4 Filamentous or threadlike plants such as *Spirogyra*, in which the body consists of a series of cells arranged end to end commonly with the basal cell or cells forming a holdfast which anchors the filament to submerged rocks or twigs In most species of this type the filaments are unbranched but in some the bod

leaf, usually two cells thick and often a foot or more long and bearing a well developed holdfast as in *Ulva*, or sea lettuce a common marine green alga

Distribution. Green algae principally inhabit fresh water and shaded, moist surfaces of soil tree bark *and* stones Some aquatic species float upon or swim in water, others grow attached by their hold

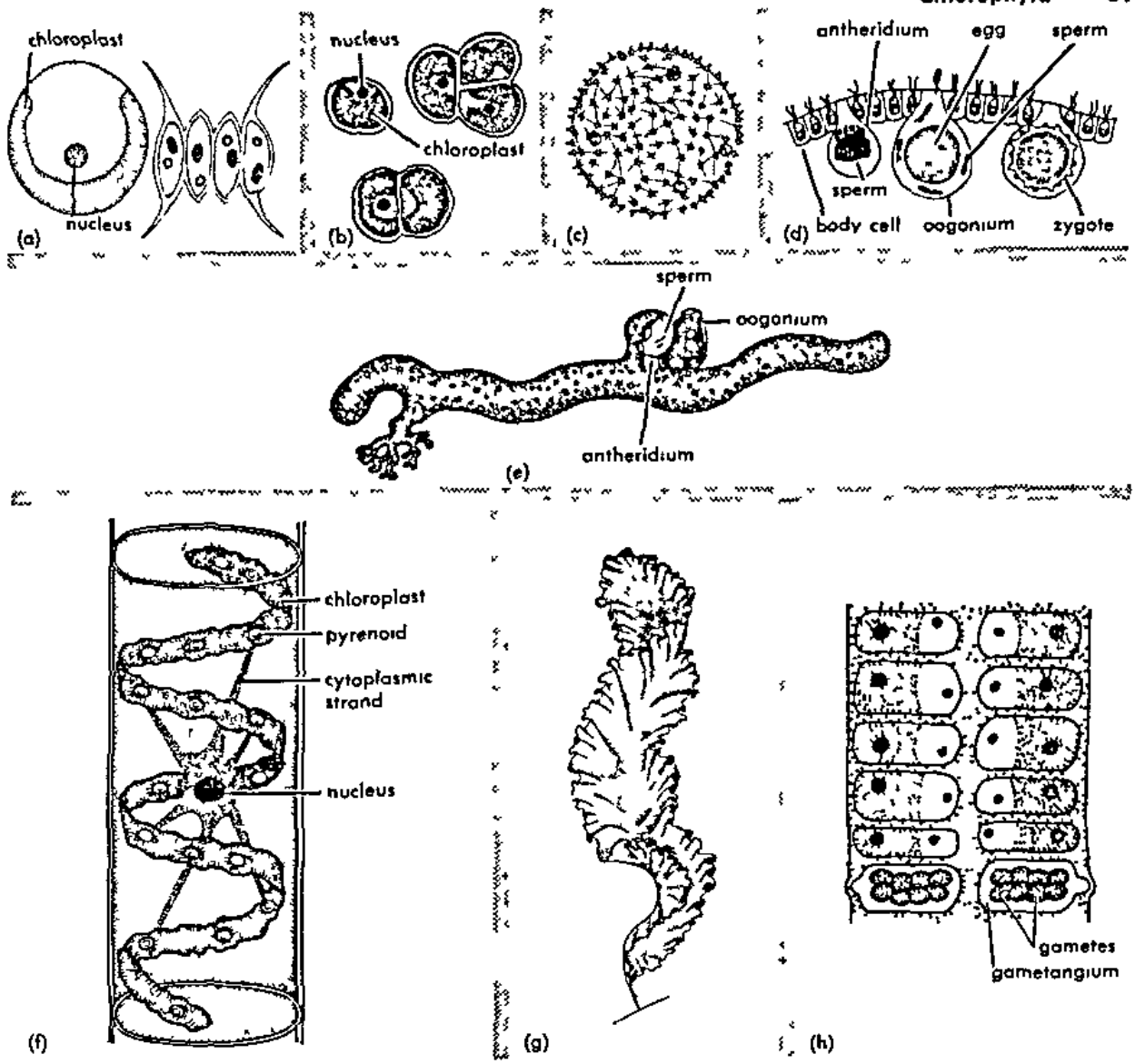


Fig 1 Principal body types of Chlorophyta (a) *Chlorella*, with cup shaped chloroplast and central nucleus (b) *Protococcus* (c) *Volvox*, a colony made up of numerous cells arranged to form a hollow sphere Large, dark objects are new daughter colonies (d) Portion of a section through the colony of *Volvox* In addition to the body cells which form the outer layer of the sphere, there are shown an antheridium with numerous biflagellate sperm cells an oogonium with an unfertilized egg and an oogonium with a thick walled zygote (e) *Vaucheria*, tubular body or coenocyte bearing an antheridium and an adjacent oogonium (f) *Spirogyra*, single cell with spiral chloroplast bearing numerous circular pyrenoids central nucleus, and cytoplasmic strands extending from the nucleus to the pyrenoids (g) *Ulva*, or sea lettuce, thallus (h) *Ulva*, a section of thallus showing two cell layers Each vegetative cell has one nucleus and a single chloroplast Two lower cells are gametangia with gametes (*H J Fuller and O Tippo, College Botany, rev ed , Holt, 1954*)

fasts to submerged stones and twigs or to the surfaces of fish and other water animals They often grow in such quantities that they give ponds, lakes, puddles, horse troughs streams, and swimming pools a bright green or yellowish green color Some species impart unpleasant tastes and fishy odors to water, creating continuing pollution problems for sanitary engineers in charge of open water reservoirs and water supply systems A minority of species inhabits the salt water of the world's seas and oceans Some grow attached to the hair and hides of water animals, a few live within the body cavities of tiny, translucent hydras (members of the jellyfish animal phylum), giving them a pale green color Because they are green, photosynthetic plants, Chlorophyta flourish only where they have access to light, most species do best in light of moderate intensity, but some grow well in full sunlight

Reproduction. Reproductive methods of green algae are extremely varied and frequently complex Reproduction may be either asexual, in which no

sexual process is involved or sexual in which specialized sex cells (gametes) are formed and fuse in pairs to give rise to offspring

Asexual reproduction may occur either by spores or by cell division Spores are 1 celled structures formed directly by certain body cells In some species a body cell produces only one spore in others it may produce several A few species form immobile spores In most species however the spores are swimming bodies (zoospores) equipped with cilia that propel them through water When a zoospore sprouts it grows directly into a new plant In cell division a 1 celled alga such as *Protococcus* divides forming two new 1 celled algae which sometimes cohere forming irregular colonies of variable size

Sexual reproduction may occur by isogamy conjugation or heterogamy Isogamy (Fig 2) is illustrated by *Ulothrix* in which gametes alike in size and structure are first liberated into the water from parent plants and then fuse in pairs forming zygotes When this zygote sprouts it forms 4 zoospores The zoospores and gametes are virtually identical in structure except that the gametes are smaller than the zoospores and bear only two cilia whereas the larger zoospores have 4 cilia *Ulothrix* is often cited as an example to support the hunger theory of sex According to the hunger theory the gametes are too small and lack sufficient stored food to enable them to grow individually into new plants by fusing in pairs they get sufficient food reserves to enable the fused cell to grow into a new individual or into zoospores

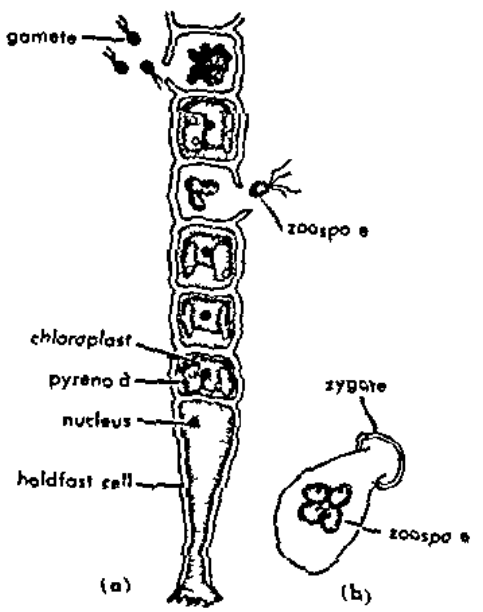


Fig 2 *Ulothrix* (a) Multicellular filament with basal holdfast cell vegetative cells each with a single chloroplast and nucleus zoosporangium with 4 to 32 zoospores and gametangium with numerous small gametes (b) Zygote which has produced 4 zoospores (*H J Fuller* and *O Tippo College Botany rev ed Holt 1954*)

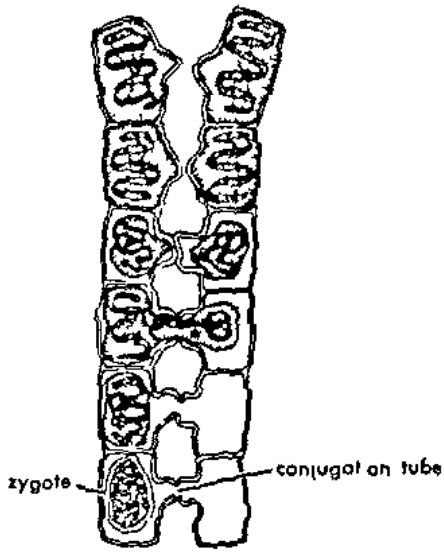
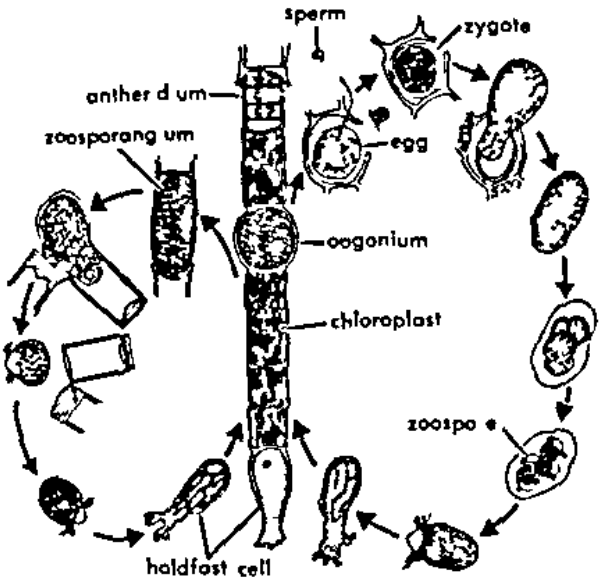


Fig 3 *Spirogyra* Stages in conjugation Beginning at the top protuberances are shown which later fuse to form a conjugation tube The contents of one cell move across the tube to another cell where fertilization occurs producing a zygote (*H J Fuller* and *O Tippo College Botany rev ed Holt 1954*)

Conjugation (Fig 3) exemplified by *Spirogyra* is basically a kind of isogamy however the like gametes formed in the parent plant or plants are not liberated into the water before fusing Instead conjugation tubes are formed connecting cells of the same filament or adjacent filaments The entire protoplast of one cell moves through the connecting tube and fuses with the protoplast of the other (receiving) cell forming a zygote which subsequently germinates to form a new *Spirogyra* plant

In heterogamy the two gametes differ in size and structure the smaller or male sex cell is called the sperm the larger or female sex cell is called the egg In *Oedogonium* which illustrates heterogamy (Fig 4) certain cells of a filament develop into sperm forming antheridia each producing usually two sperms that are liberated into the water other cells become oogonia or female sex organs each producing one egg An oogonium develops a tiny pore through which a swimming sperm enters then fuses with the egg in a process termed fertilization The fertilized egg or zygote subsequently germinates to form 4 zoospores In some *Oedogonium* species antheridia and oogonia develop on the same filament in others antheridia and oogonia are borne on separate male and female filaments a condition known as heterothallism

In a few green algae a reproductive cycle called alternation of generations occurs For example in *Ulva* an asexual plant reproduces by zoospores that grow into sexual plants some of which form sperms while others produce eggs Fertilization of an egg by a sperm occurs in sea water and the zygote then grows into the asexual plant which again reproduces by zoospores The asexual plant or sporophyte generation and the sexual plant or gameto-



Fg 4 Oedogon um L fe cycle In d agrammat c form c rcle to left represents asexual cycle and c rcle to r ght dep cts sexual phase (*H J Fuller and O T ppo College Botany rev ed Holt 1954*)

phyte generation are identical in structure differ ing only in their method of reproduction Although alternation of generations occurs rarely among algae it is common in higher groups of plants

Economic importance Green algae are impor tant to life in many ways Along with other groups of algae they constitute the ultimate sources of food for all aquatic animals Aquatic algae by liberating oxygen into water as a result of their photosynthesis provide oxygen for other aquatic life This aeration of water also helps purify it by promoting the growth and activities of bacteria which decompose dung dead bodies and plant residues A few species of oceanic green algae secrete calcium carbonate (limestone) thus help ing to form coral reefs Some species particularly *Ulva Spirogyra* and *Oedogonium* are used as sources of human food especially in the Orient *See* ALGAE [H J F]

Bibliography See THALLOPHYTA

Chloroplatinate

One of a group of compounds containing the an ion $PtCl_6$ which is derived from chloroplatinic acid This acid is produced when platinum is dis solved in aqua regia Of the many salts known the ammonium and potassium chloroplatinates are the most useful because of their low solub lity The formation of a precipitate is used as a qualita tive test for the ammonium and potassium ions *See* AQUA REGIA PLATINUM [E E WR]

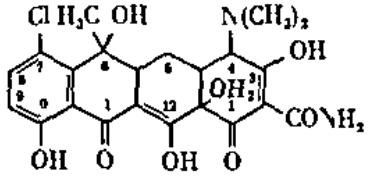
Chlortetracycline

A broad spectrum antibiotic discovered by B M Duggar and coworkers and introduced by Lederle Laborator es in 1948 It was the first of the tetra cycline antibiotics and is effective against a wide variety of infections *See* ANTIBIOTIC TETRA CYCLINE

This crystalline yellow compound (trademark Aureomycin) is produced by the soil microorgan ism *Streptomyces aureofaciens* (*see* ACTINOMY CETALES) The original culture has been mutated in order to obtain a strain which produces satis factory yields of chlortetracycline for commercial production (*see* MUTATION) After several trans fers in increasingly larger fermenters the culture is finally grown for several days in 20 000-gal tanks A wide variety of media may be used but among the mo t satisfactory are those which con tain corn steep liquor carbohydrate and calcium carbonate The fermentation is carried out under sterile conditions in closed vats with aeration and agitation Yields have been reported at several milligrams per milliliter

A number of different processes may be used to isolate the antibiotic from the fermentation liq uors Generally the first step involves the separa tion of the insoluble calcium salt of the antibiotic along with the mycelium from the liquid Chlor tetracycline is then extracted from this filter cake and after a number of extractions and precipita tions the pure antibiotic is obtained Chlortetra cycline is an amphoteric substance which is most commonly used as the hydrochloride salt In some formulations the insoluble calcium salt is used The empirical formula for chlortetracycline is $C_{22}H_{23}O_8N_2Cl$ The chemical structure is desig nated as 7 chloro-4-dimethylamino 1 4 4a 5 5a 6 11 12a octahydro 3 6 10 12 12a penta hydroxy 6 methyl 1 11 dioxo 2 naphthacenecarboxamide

Chlortetracycline content is determined by ei ther microbiological or physicochemical methods *Staphylococcus aureus* is a commonly used assay organism for turbidimetric or agar diffusion pro-



Chlortetracycline

cedures A concentration of as little as 0 1 μg/ml of this drug can inhibit microorganisms In the dry state it is stable indefinitely but in aqueous solu tion decomposition takes place

The antib otic is used orally parenterally and topically It is rapidly absorbed from the intestinal tract and is distributed into all body tissues The average daily oral dosage is 12 5 20 mg/kg of body weight At therapeutic levels this drug shows no effect on renal or liver function or on blood chem istry Occasionally reported side reactions include nausea vomiting or loose stools glossitis stoma titis and dermatitis

This drug is widely used in both human and vet erinary medicine for infections caused by sensitive

organisms It is indicated for infections caused by the following gram positive and gram negative bacteria spirochetes rickettsia viruses of the lymphogranuloma psittacosis group protozoa ac tinomyces and nocardia This antibiotic is not used in systemic proteus or pseudomonas infections tuberc losis or fungal infections *See* BACTERIA MYCOLOGY MEDICAL PARASITOLOGY MEDICAL RICKETTSIOSES VIRUS

Chlortetracycline is widely used as a feed sup plement and as a food preservative It promotes growth of poultry hogs and calves when used in their rations At very low concentrations it in creases the shelf life of perishable foods such as meats Commercially it has been used for the preservation of poultry and fish *See* FOOD ENGI NEERING [N BO]

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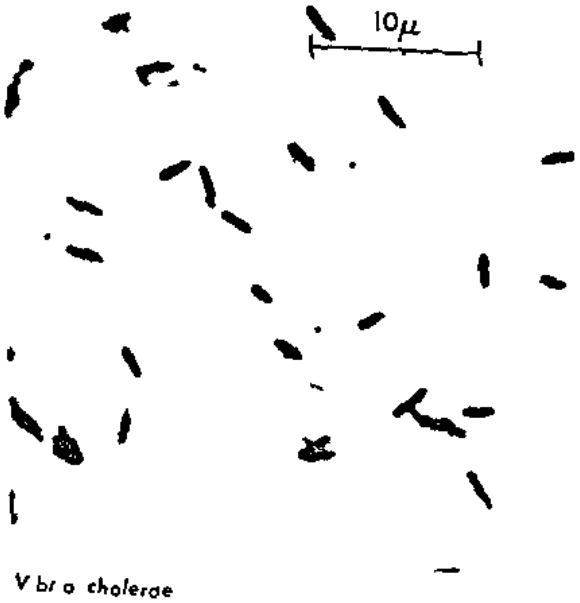
Choke (filter)

An inductor used in a low pass filter in which the useful output is a direct current as in the filter of a power rectifier At usual power frequencies a fil

ment is an inductance) some economy is sometimes afforded by *designing the choke* so that its induc tance is allowed to reduce due to *saturation* at high currents Such a choke is called a *swinging* choke *See* POWER SUPPLY ELECTRONIC [W R L]

Cholera vibrio

A gram negative slightly curved rod shaped *bacte* rium 1 5–3 0 × 0 4–0 6 μ in size which is cultivable *on ordinary* bacteriological media It is the spe cific agent that causes Asiatic cholera an acute diarrheal disease with a case fatality rate of 50–60% which may be reduced to 20% by treatment with intravenous saline Cholera vibrio is character ized immunologically by the specificity of its heat stable somatic O antigen (O subgroup I) and oc curs in three strains or serotypes Inaba Ogawa, and Hikojima It typically ferments sucrose and mannose but not arabinose (Heiberg type I) and is separable from the culturally and immunologi cally identical El Tor and Celebes vibrios by the failure of its peptone water cultures to lyse sheep or goat erythrocytes (Greig test) It produces a mucinase and an endotoxin which increase the permeability of the bowel It is closely related to the nonpathogenic paracholera vibrios and to cer tain water vibrios and more distantly to *Vibrio metschnikovi* which is pathogenic for birds es pecially pigeons and *Vibrio foetus* of swine The endemic foci of infection are confined to Southea t Asia particularly the Ganges delta and Burma *See* ANTIGEN EPIDEMIOLOGY, TOXIN BACTERIAL [W BL]

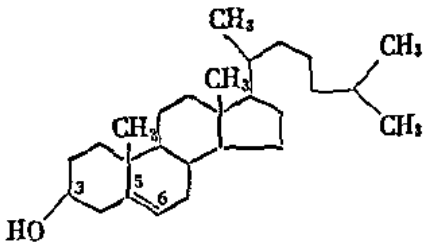


Vibrio cholerae

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Cholesterol

The most common of the zoosterols or animal ster ols The name which means bile solid alcohol is derived from the fact that this substance was first isolated from human gallstones which contain cholesterol as the chief component It is a white crystalline solid insoluble in water and soluble in a number of organic solvents including ether chloro form and acetone The structural formula is



The hydroxyl group at carbon atom 3 is in the β configuration and a position of unsaturation

by a variety
ably occur

Experiments with animals have indicated that the rate of formation of cholesterol is in inverse proportion to the amount of choles terol in the diet Not all but many of the steps are known in the process by which cholesterol is formed in the cell The basic source of carbon for the choles terol molecule is the 2 carbon compound acetic acid As the result of radioisotope studies the se quence in biosynthesis has been proposed as

Acetate (acetic acid) → mevalonic acid → squalene → cholesterol

When acetic acid containing radioactive carbon is

administered to an animal cholesterol containing radioactive carbon is formed Of the 27 carbon atoms of cholesterol 15 are derived from the methyl carbon and the remaining 12 from the carboxyl carbon of acetic acid Acetic acid bound to coen zyme A a substance which contains the vitamin pantothenic acid is formed from the digestion and metabolism of carbohydrate fat and protein Therefore all three major classes of foodstuffs serve as sources of carbon for cholesterol formation (*see* COENZYME) A key intermediate derived from three units of acetyl coenzyme A is mevalonic acid which contains six carbon atoms Six of these molecules condense in a series of steps to form the 30-carbon compound squalene with the loss of one carbon atom from each mevalonic acid Squalene is a hydrocarbon found in appreciable quantities in shark liver oil but in small amounts in most other tissues By a process of condensation and rearrange ments squalene is transformed to cholesterol Each of the many steps in this biosynthetic sequence is catalysed by a different enzyme present in the cell Cholesterol formation has been observed to occur in surviving tissue outside the animal in whole cells and in broken cell systems under suitable experimental conditions *See* STEROID *see also* CARBOHYDRATE METOBOLISM LIPID METABOLISM PROTEIN METABOLISM

Distribution Cholesterol is present in all tissues of the animal body both in free form and esterified with long chain fatty acids through the hydroxyl (OH) group at carbon atom 3 The proportion of free to esterified cholesterol varies with the tissue The average total cholesterol content in percentage values of dry tissues is as follows

Tissue	*Dry weight %*
White matter brain	14
Gray matter brain	6
Kidney	1 6
Spleen	1 5
Skin	1 3
Liver	0 93
Mammary gland	0 70
Whole blood	0 65
Smooth muscle	0 55
Diaphragm	0 35
Skeletal muscle	0 25

Cholesterol is obtained commercially by acetone extraction of beef spinal cord In this and other tis sues cholesterol is accompanied by 1–2% of choles tanol Highly purified cholesterol with a melting point of 150°C is prepared by formation of dibro mocholesterol separation from cholestanol by re crystallization and removal of bromine [I Z]

Choline

A compound considered essential to the animal or ganism as a precursor of acetylcholine and as a source of methyl groups for the synthesis of amino acids It is a strongly basic hygroscopic substance with the following structural formula

$$(CH_3)_3N—CH_2—CH_2OH$$
$$|$$
$$OH$$

Choline

It is questionable but not important whether this very necessary metabolite should be considered a vitamin Choline is determined microbiologically by using a mutant of the mold *Neurospora crassa*

A choline deficiency has been produced in a num ber of animal species The degree of deficiency achieved depends on the amount of choline pre-cursors particularly methyl donors such as me-thionine present in the diet Choline deficiency is associated with fatty livers poor growth and renal lesions It is a lipotropic agent There is no direct evidence of disease in man due to choline defi ciency although there have been suggestions that some of the liver kidney or pancreas pathology seen in various nutritional deficiency states may be related to choline insufficiency Choline is found in acetylcholine which is necessary for nerve im pulse propagation and in phospholipids

There is no evidence that choline acts as a coen zyme Choline functions as a donor of methyl groups to quaternary nitrogen and sulfonium com pounds

Human beings eat 50–600 mg of choline per day but only excrete 2–4 mg Consequently conven tional load tests are of no value in studying choline requirements and no knowledge of human choline requirements exists *See* ACETYLCHOLINE VITA MIN [S N G]

Industrial production Choline trimethyl β hydroxyethylammonium hydroxide is a quater nary compound which is made by the reaction of trimethylamine and ethylene oxide in either an aqueous or an alcoholic solvent If choline salts are desired the reaction can be carried out with the corresponding trimethylamine salt or the base can be neutralized with the corresponding acid The choline salts in common use are choline chloride choline bitartrate choline dihydrogen citrate and tricholine citrate

Choline salts are sold both as liquids and solids The liquids such as a 65% solution of tricholine citrate are prepared by the aqueous quaterniza tion procedure decolorized with charcoal and then evaporated to the desired strength The solid types are prepared in either aqueous or alcoholic media and are crystallized by cooling concen trated solutions [R J T]

Chondrichthyes

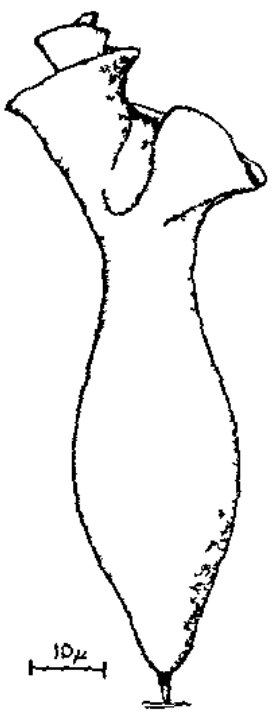
The cartilaginous fishes one of the three classes of Recent fishlike vertebrates including the sharks rays and chimaeras The class Chondrichthyes is similar to the Osteichthyes or bony fishes and differs from the Agnatha in possessing jaws paired nostrils true teeth paired pectoral and pel vic fins and girdles and primitively scales The Chondrichthyes contrast with the Osteichthyes in

lacking a bony skeleton in the absence of a swim bladder and of a true gill cover and in having placoid scales or denticles (sometimes secondarily absent) that like teeth have a mesodermal core and an ectodermal surface Fertilization is always internal being effected by means of pelvic fin claspers Cartilaginous fishes were long regarded as more primitive than and ancestral to bony fishes largely because of their unossified skeleton They appear later in the fossil record in Middle Devonian time and are now regarded as constituting a separate evolutionary line The cartilaginous skeleton is likely a derived condition rather than primitive Dermal spines scales or small plates may be found on the surface of the body or fins but there are no bony plates *See* AGNATHA OSTEICHTHYES SCALE (ZOOLOGY)

The Chondrichthyes are classified in two subclasses the Elasmobranchii or sharks rays and skates and the Holocephali or chimaeras The former group is larger and better known consisting of 500–600 species most of which are marine shore fishes The chimaeras include only about 24 species that occur chiefly in deep marine waters *See* ELASMOBRANCHII HOLOCEPHALI PISCES (ZOOLOGY) [R M B]

Chonotrichida

An order of the Holotricha This is a small group of curious vase shaped ciliates commonly found as ectocommensals on marine crustaceans They at



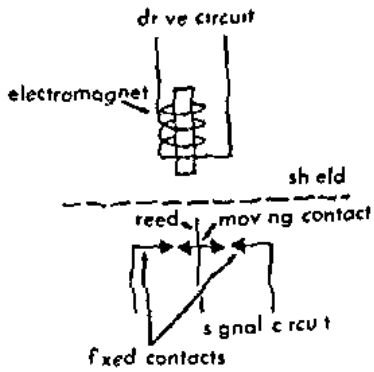
Spirochona an example of a chonotrichid

tach to their hosts by a short secreted stalk, and their bodies are practically devoid of ciliature *Spirochona* (see illustration) is a common example of this order *See* HOLOTRICHA [J O C]

Chopper

Usually an electromechanical component that synchronously switches a signal circuit By extension the term chopper is also applied to photoelectric electronic and transistor circuits adapted to perform the same function as a mechanical chopper An older related device is an optical shutter arranged to sequentially pass and interrupt or chop a light beam

Fundamentally a chopper serves as a suppressed carrier square wave modulator Such a component is shown schematically in the diagram An electromagnet driven by a source of alternating current (typically 60 or 400 cps although higher frequencies may be used) sets a reed into vibration The reed carries a moving contact that alternately contacts one and the other of two fixed contacts in a signal circuit Thus the signal (typically in the order of 1 milliwatt or less at 1 volt) is periodically interrupted



Basic chopper structure

A usual chopper application is the inversion of a slowly varying signal into a rapidly varying one the latter being the more readily amplified An electrostatic shield and other design precautions minimize coupling between drive and signal circuits A frame supports the parts usually with some degree of vibration isolation *See* VIBRATOR [F H R]

Chopping

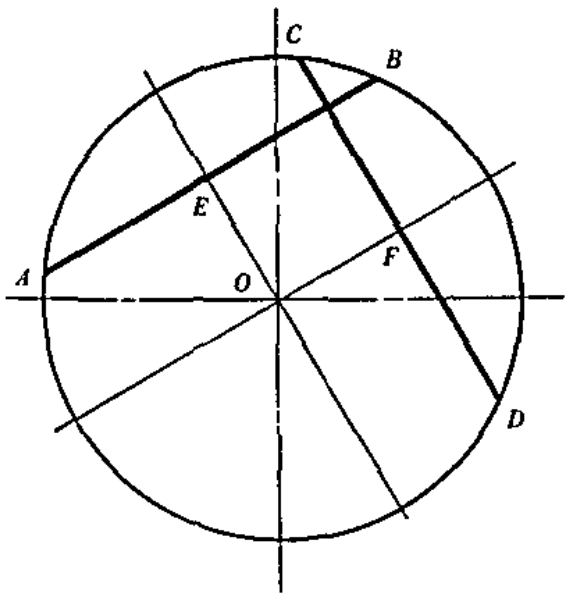
The act of interrupting an electric current beam of light or beam of infrared radiation at regular intervals This can be accomplished mechanically by rotating fan blades in the path of a beam or by placing a vibrating mirror in the path of the beam to deflect it away from its intended source at regular intervals

A current can be chopped with an electromagnetic vibrator having contacts on its moving armature A current can also be chopped electronically by passing it through a multivibrator or other switching circuit

Chopping is generally used to change a direct current signal into an alternating current signal that can more readily be amplified Control systems for guided missiles make extensive use of chopping *See* MULTIVIBRATOR VIBRATOR [J MR]

Chord

A line segment whose end points are points of a circle (*see illustration*) A chord subtends two (conjugate) arcs of the circle Equal chords of a circle subtend equal arcs, and of two unequal chords, the greater subtends the greater arc The chord of maximum length passes through the cen ter of the circle and is called the diameter A diam



Two intersecting chords *AB* and *CD*

eter perpendicular to a chord bisects it Equal chords of a circle are equally distant from the cen ter of the circle, and conversely An angle formed by two chords that intersect inside the circle is measured by half the sum of the intercepted arcs, and the product of the segments of one chord equals that of the other *See* ARC (MATHEMATICS), CIRCLE [L M BL]

Chordata

The highest phylum in the animal kingdom It in cludes the tongue worms, tunicates, and lancelets and the vertebrates such as the lampreys, sharks and rays bony fishes, amphibians, reptiles, birds, and mammals Members of the first three groups, the lower chordates are small and all marine Verte brates are free living and include animals of me dium and large size up to giant sharks and whales, although some are small, as the mice humming birds frogs and fishes

Chordate characteristics. Three distinctive chordate characteristics are the notochord, nerve cord [illegible]

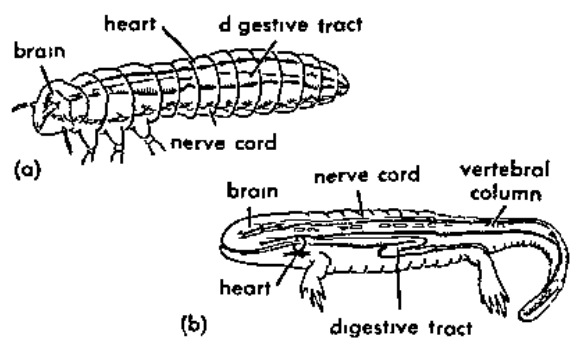
primitive gut In tunicates it occurs only in the tail of the larvae In the lancelets (amphioxus) and all higher forms it extends from the head region through the tail In lampreys and lancelets, it per sists as the axial support for the body throughout life but in fishes to mammals it is later replaced or surrounded by segmental vertebrae of the spinal column

Nerve cord The nerve cord forms on the upper surface of the early embryo and by infolding be comes a hollow tubular cord The forward end en larges slightly in larval tunicates and amphioxus but in vertebrates thickens and folds to become the brain, progressively larger and more complex in higher animals From the lampreys onward, the nerve cord later is surrounded by neural arches of the vertebrae that form a flexible segmental conduit to protect it from injury The brain is enclosed in the brain box or cranium, giving vertebrates the name "craniates"

Gill slits Paired gill slits develop on the sides of the embryonic pharynx, a part of the digestive tract The typical development is seen in a shark or fish where each slit becomes margined with many fine filaments containing blood vessels to form a gill Water carrying dissolved oxygen passes through the mouth and pharynx and out over the filaments, where the blood takes up oxygen and discharges carbon dioxide in respiration Aquatic chordates from tongue worms to amphibians respire by gills Frogs, toads, and salamanders that change from aquatic larvae to air breathing adults lose their gills and slits at transformation Reptiles, birds and mammals have paired gill slits early in embryonic life but these never function and soon close All later acquire lungs for breathing

Chordate origin. The origin of the chordates is unknown The notochord and gill slits are unknown among invertebrates some of which have ventral, solid, double nerve cords unlike those of chordates Various theories seek to derive chordates from an nelid, arachnid or echinoderm stocks, but none is satisfactory

Fossil record No chordate remains are known from Cambrian rock strata where animal fossils first became common The earliest were probably soft bodied unlikely to persist as fossils The first verte brates were fishes of Silurian and Ordovician time Thereafter vertebrates are common, often dominant in the fossil record Sharks and bony fishes appear first in fresh water deposits then both groups in



Basic differences between (a) a nonchordate (insect) and (b) a chordate (salamander) as to location of the nervous system digestive tract, and heart, diagram matic (*T I Storer and R L Usinger, General Zoology 3d ed , McGraw Hill, 1957*)

vaded the sea Ancient amphibians began in the Devonian while salamanders date from the Cretaceous and frogs from the Jurassic Reptiles appeared in the Permian During the Mesozoic Era they expanded into a great variety of forms living on land in fresh water and the sea These included both herbivorous and carnivorous types Most died out at the end of the Cretaceous The first bird *Archaeopteryx* comes from the Upper Jurassic The mammals derived from reptiles began in the Triassic blossomed widely during the early Tertiary period and form a dominant group today despite the fact that more than half the known orders are known only as fossils and all the others contain many extinct forms

Environmental adaptations The vertebrates exhibit a progressive advance from an aquatic to a terrestrial habitat This has been achieved by successive development of special structural and functional characteristics All gill breathers are of necessity confined to the water but damp skinned lung breathing amphibians can occupy moist terrestrial environments The reptiles birds and mammals are fitted for life on dry land although some such as turtles some birds whales and seals have reverted to a water habitat In these three groups there are special embryonic membranes surrounding and conserving moisture for the delicate growing embryo In consequence dry shelled eggs of reptiles and birds can produce living young in dry land environments Most mammals show a further advance in reproduction by growth of the embryo within the body of the maternal parent Another notable achievement in birds and mammals is acquisition of a high sustained body temperature commonly above that of the environment This is related to the presence of an insulated body covering of feathers fur or fat

The lower chordates today are minor elements in the sea whereas the vertebrates dominate both land and water throughout the world because of their greater size mobility and activity The chordate species number only about 51 000 (fishes 25 000, amphibians 3000 reptiles 10 000 birds 8600 mammals 4400) among the estimated 1 000 000 of all living animals *See* ANIMAL KINGDOM EVOLUTION ORGANIC GEOLOGY PALEONTOLOGY [TIS]

Chorion

The outermost of the several extraembryonic membranes in amniotes (reptiles birds and mammals) enclosing the embryo and all of its other membranes The chorion or serosa is composed of an outer layer of ectoderm cells and an inner layer of mesoderm cells, collectively the somatopleure Both layers are continuous with the corresponding tissue of the embryo The chorion arises in conjunction with the amnion another membrane that forms the outer limb of the somatopleure which folds up over the embryo in reptiles, birds and some mammals The chorion is separated from the amnion and yolk sac by a fluid filled space the extraembryonic coelom or body cavity In those mammals in which the amnion forms by a process of cavitation in a mass of cells, instead of by folding, the chorion forms directly from the trophoblastic capsule the extraembryonic ectoderm which becomes gradually underlain by extraembryonic mesoderm

In reptiles and birds the chorion fuses with another extraembryonic membrane the allantois to form the chorioallantois, which lies directly below the shell membranes An extensive system of blood vessels develops in the mesoderm of this compound membrane which serves as the primary respiratory and excretory organ for gaseous interchanges In all mammals above the marsupials, the chorion develops special fingerlike processes (chorionic villi) extending outward from its surface To a varying degree in different species of mammals the villous regions of the chorion come into more or less intimate contact with the uterine mucosa or uterine lining of the mother thereby forming the various placental types *See* ALLANTOIS, FETAL MEMBRANE GERM LAYERS [NTS]

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Choristida

An order of sponges of the class Demospongiae subclass Tetractinomorpha in which at least some of the megascleres are tetraxons usually triaenes Monaxonid spicules may occur as well Triaenes characteristically lie in tracts which radiate from the center of the sponge to the periphery with the three shorter rays lying just below or in the cortex In some cases the three shorter rays extend beyond the dermis to form a spicule flush with the protruding monaxonid spicules Microsclere types are chiefly asters streptasters, or sigmas A well

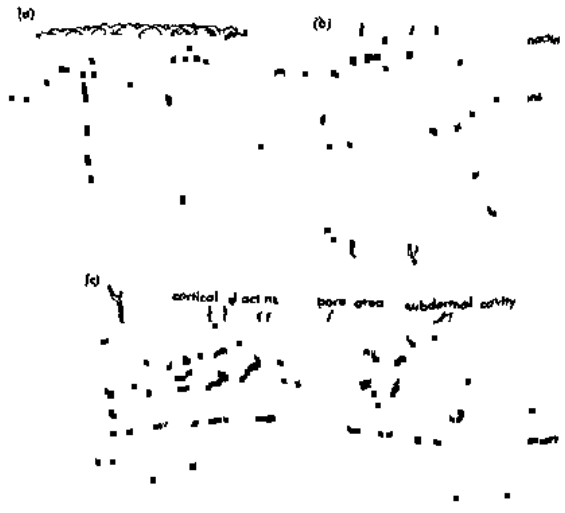


Fig 1 (a) Section through *Ancorina* showing spicule arrangement (b) Section through *Pachastrella* showing spicule arrangement (c) Section through *Geodia* showing skeletal arrangement (after *Sollas* 1888) (From *Hyman* 1940)

developed cortex comprising an outer gelatinous layer and an inner fibrous layer is often present *Geodia* has a stony cortex formed of numerous closely packed spiny spherical microscleres

Many choristidan sponges are radially symmetrical spherical or ellipsoidal shapes are common Others are encrusting or massive, very few form branching colonies Some species have basal tufts or mats of long thin spicules which serve to anchor them in mud or sand on the sea bottom

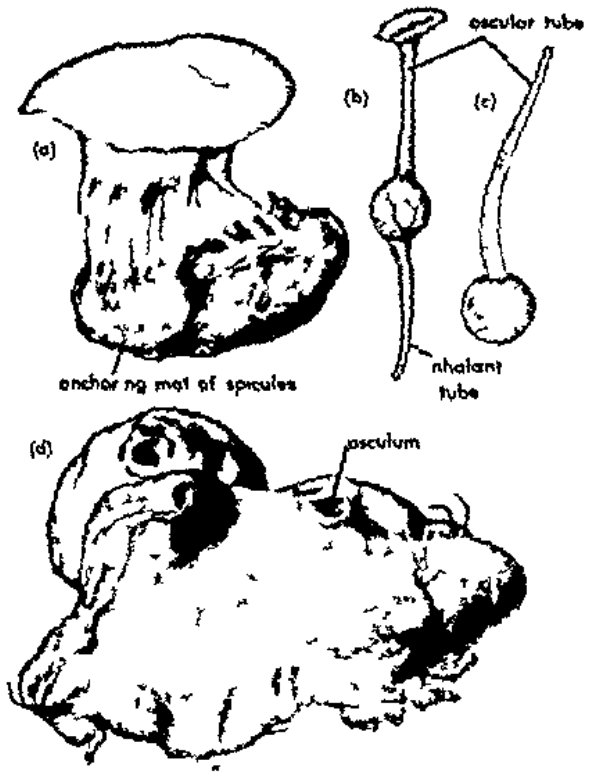


Fig 2 Representative choristidan sponges (a) Theneo wyv ll w ith basal mat of spicules (after Sollas 1888) (b) Tr beach on schmidt with long osculor tube (c) Dysyringo d ssimilis with separate osculor and inhalant tubes (from Hyman 1940 after Sollas 1888) (d) Geodia g bberosa (after Sollas 1888)

Choristidans are common in tidal regions and shallow waters of all seas and some species extend down to depths of at least 3500 meters Sponges with spicules similar to those of existing choristidans are scattered through the fossil record from Carboniferous times onward *See* DEMOSPONGIAE TETRACTINOMORPHA [W O H]

Chromadoroidea

A superfamily of small to moderate sized free-living nematodes with spiral or kidney shaped amphids and a striated and punctate cuticle Most species are marine but members of two families occur in soil and fresh water A few species occur in hot springs and some are adapted to running water Several species are predatory but most feed on algae and microorganisms. Some authorities consider the marine species to be the most primitive existing nematodes *See* NEMATODA [H E W]

Chromate

The CrO_4^{2-} ion derived from the unstable acid H_2CrO_4 Chromic oxide CrO_3 gives instead of the expected H_2CrO_4 condensed or polyacids such as $H_2Cr_2O_7$ and $H_2Cr_3O_{10}$ in acid solutions However, the solid chromates are stable and are the most important salts of the series The dichromates are also well known *See* DICHROMATE

The chromates are easily converted to dichromates by the addition of acid This is accompanied by a color change from yellow to orange and can be represented by the following equation

$$2CrO_4^{2-} + 2H^+ \rightleftharpoons Cr_2O_7^{2-} + H_2O$$
Yellow Orange

Most of the solid chromate salts are also yellow an exception being silver chromate which is red

The chromates of calcium strontium mercury(I) silver barium and lead are insoluble and are used for identifying the chromate ion However these salts dissolve in strong acid to form dichromates

Chromates are good oxidizing agents They are used in paints as pigments and in the tanning of leather *See* CHROMIUM OXIDIZING AGENT PIGMENT [E E W R]

Chromatic aberration

A type of error in an optical system in which the formation of a series of colored images occurs even though only white light enters the system Chromatic aberrations are caused by the fact that the refraction law determining the path of light through an optical system contains the refractive index n which is a function of wavelength λ Thus the image position and the magnification of an optical system are not necessarily the same for all wavelengths nor are the aberrations the same if the light traversing the system is not monochromatic

In this article the chromatic aberrations of a lens system are discussed For information on other types of aberration see ABERRATION OPTICAL *See also* REFRACTION OF WAVES

Dispersion formula When the refractive index of glass or other transparent material is plotted as a function of the square of the wavelength the result is a set of dispersion curves which appear to have an asymptote in the near ultraviolet region and a straight portion in the near infrared (up to 1 μ) In glass catalogs the indices are given for selected wavelengths between 0.365 and 1.01 μ, which are the absorption (emission) bands of certain chemical elements For an extended discussion of dispersion see ABSORPTION (ELECTROMAGNETIC RADIATION) *See also* OPTICAL MATERIALS

For the visible region, the Hartmann formula

$$n = a/(\lambda - b) \qquad (1)$$

where a and b are constants for a g
been much used However if an
apply it to the near ultraviolet or

Values of the four universal functions $a(\lambda)$ for various wavelengths

λ	a	a_2	a_3	a_4
1.0140	0.000000	0.000000	0.000000	+1.000000
0.7682	+0.031522	−0.276197	+1.053935	+0.192687
0.6563	0.000000	0.000000	+1.000000	0.000000
0.6438	0.001774	+0.021075	+0.966511	−0.012813
0.5893	−0.024932	+0.376222	+0.741598	−0.015919
0.5876	0.000349	+0.330338	+0.673480	−0.016326
0.5461	−0.033080	+0.597792	+0.479019	−0.013761
0.4861	0.000000	+1.000000	0.000000	0.000000
0.4800	+0.009340	+1.036699	−0.022699	+0.006659
0.4358	+0.143980	+1.193222	0.391269	+0.022036
0.4047	+0.366779	+1.414864	−0.487631	+0.075791
0.3650	+1.000000	0.000000	0.000000	0.000000

it proves to be insufficient Over this more extended range n can be given as a function of the wavelength by the formula

$$n = a + b\lambda^2 + \frac{c}{\lambda^2 - 0.028} + \frac{d}{(\lambda^2 - 0.028)^2} \quad (2)$$

This formula in which c and d are additional constants enables one to compute n for any wavelength if it is given for four An equivalent formula is

$$n = n_1 a_1(\lambda) + n_2 a_2(\lambda) + n_3 a_3(\lambda) + n_4 a_4(\lambda) \quad (3)$$

where $a_1(\lambda)$ $a_2(\lambda)$ are functions of the form (1) which assume for λ_1 λ_2 the values 1 0 0 0 0 1 0 0 0 0 1 0 and 0 0 0 1 respectively Choosing $\lambda_1 = 0.365 = \lambda_n$ $\lambda_2 = 0.4861 = \lambda_F$ $\lambda_3 = 0.6563 = \lambda_C$ $\lambda_4 = 1.014 = \lambda^*$ one finds in the table the four universal functions $a(\lambda)$ tabulated for different values of λ Note that for any wavelength

$$a_1 + a_2 + a_3 + a_4 = 1 \quad (4)$$

Instead of giving the indices of a glass for the wavelengths specified one can specify the glass by the refractive index n_F at one wavelength F the dispersion $\delta = n_F - n_C$ and the partial dispersions in the ultraviolet and infrared defined respectively by

$$P_m = \frac{n_m - n_F}{n_F - n_C} \qquad P^* = \frac{n_F - n^*}{n_F - n_C} \quad (5)$$

The partial dispersion for an arbitrary wavelength λ is then given by

$$P = P_m a_1(\lambda) + a_2(\lambda) + P^* a_4(\lambda) \quad (6)$$

In the literature the Abbe number

$$\nu = (n_D - 1)/(n_F - n_C) \quad (7)$$

where n_D is the mean index for the D lines of sodium is frequently used to designate optical glass

In Fig 1 $(n_F - 1)$ is shown plotted against $(n_F - n)$ for various optical materials

Color correction A system of thin lenses in contact is corrected for two wavelengths λ_A and λ_B if the power of the combination is the same for both wavelengths

$$\phi_A = \phi_B = \Sigma(n_A - 1)K_s = \Sigma(n_B - 1)K_s \quad (8)$$

where the K s are the differences between the first and last curvatures of the lenses and the summation is over all the lenses each with its particular value of n_A n_B and K_s

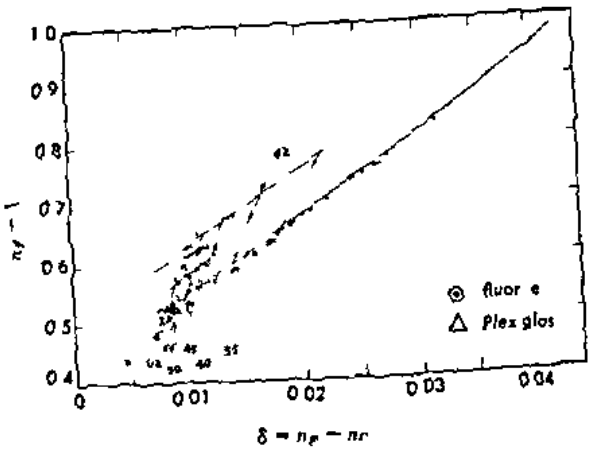


Fig 1 Plot of $(n_F - 1)$ vs δ for selected glasses largely from the Schott Catalog 350-E and for fluorite and Plexiglas The numbers on the lines dividing the glasses into groups represent ν-values

Two cemented lenses are corrected for wavelengths C and F for instance if

$$\phi_1 + \phi_2 = \phi$$
$$\phi_1/\nu_1 + \phi_2/\nu_2 = \phi_C - \phi_F = 0 \quad (9)$$

See LENS OPTICAL

The two lenses are corrected for a third wavelength λ only if moreover $P_1 = P_2$ where P_1 and P_2 are given by Eq (6)

A system corrected for three colors is called an apochromat (in microscopy this term traditionally demands freedom from asymmetry in addition) An apochromat for the ultraviolet portion of the spectrum is possible only if the two glasses in Fig 2 have the same P_m value For the infrared the glasses must have the same P^* value (Fig 3) The ν values for the two glasses should lie as far apart as possible to give low values for the powers

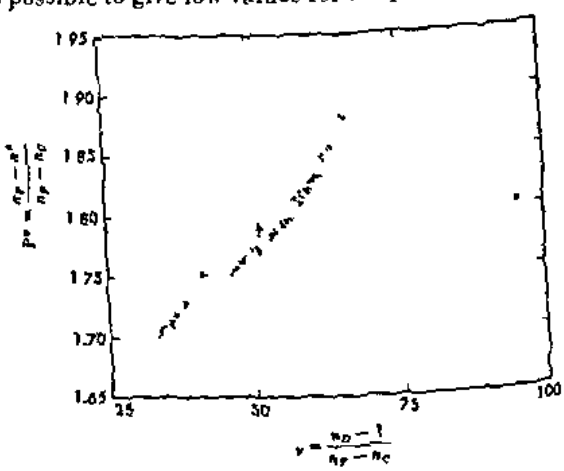


Fig 2 Plot of P^* vs ν for materials of Fig 1

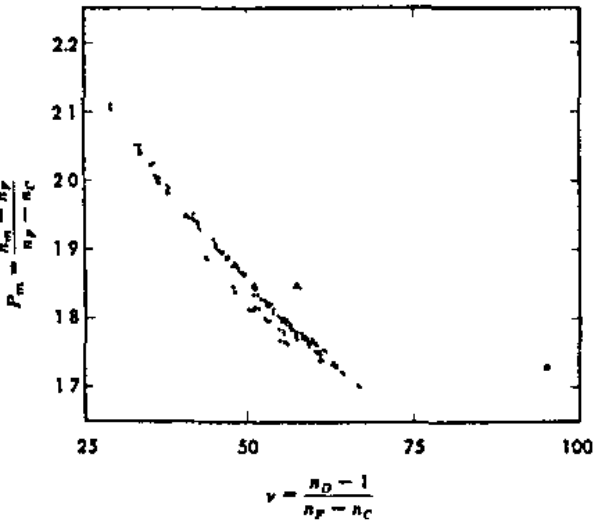


Fig 3 Plot of P_m vs ν for materials of Fig 1

Three lenses can be corrected for four wavelengths and therefore practically for the whole spectrum if the glasses lie on the straight line on the plot of P_m against P^* (Fig 4) Such a system may be called a superchromat

In lenses with finite focal distances, there are in Gaussian optics two errors to be corrected One is longitudinal aberration, which means that the Gaussian images do not lie in the same plane, and the other is lateral aberration, which means that the images in different colors have different magnifications

In the presence of longitudinal aberration, it is best to balance lateral aberration so that the apparent sizes of the images as seen from the exit pupil coincide

A system of two uncorrected lenses, such as a simple ocular, with one finite distance, cannot be corrected for both color errors Two finite distances are needed to balance both color errors at the same time

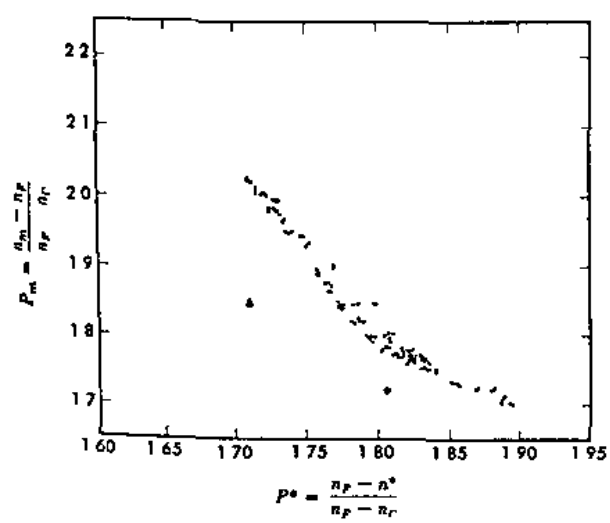


Fig 4 Plot of P_m vs P^* for materials of Fig 1

In a general system, all image errors are functions of the wavelength of light However, in a lens system corrected for color, it is easily possible, with a small adjustment, to balance the aperture rays (spherical aberration) with respect to color by introducing a small amount of lateral color aberration

If only two colors can be corrected the choice of the colors depends on the wavelength sensitivity of the receiving instrument For visual correction, *C* and *F* are frequently brought together Some optical systems contain filters to permit only a narrow spectral band to pass the instrument This makes correction for color errors easier

If light of a large band of wavelengths traverses the instrument, it is frequently desirable to use catadioptric systems, such as the Schmidt camera (*See* SCHMIDT CAMERA) The mirror or mirrors of these systems are used to obtain the necessary power without introducing color errors and an afocal lens system can be added to give the monochromatic correction [M H]

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Chromatography

A method of separating and analyzing mixtures of chemical substances A flow of solvent or gas causes the components of a mixture to migrate differentially from a narrow starting zone in a special porous, insoluble, sorptive medium

Chromatography serves primarily as a tool for the examination and separation of mixtures of chemical substances It facilitates the purification, isolation, and comparison of the components It may be employed with all kinds of volatile and soluble substances organic and inorganic polar and nonpolar, and it may be adapted to use with various quantities under many different conditions It has been modified in many ways by the use of various wash liquids and wash gases and by the use of diverse sorptive media

Chromatographic procedure. Chromatographic separations are usually made in columns of carefully selected, sorptive powders, or in sheets or strips of fibrous media such as paper A small quantity of the mixture is placed at one end of the chromatographic medium and washed with fresh solvent or gas Owing to their selective sorption, the constituents of the mixture migrate in the solvent or gas stream at different rates and separate from one another as a series of zones

As an example of chromatographic procedure, the successive steps in the chromatographic examination of the pigments from green leaves are shown in Fig 1 For this separation, the pigments were extracted from fresh leaves with a mixture of methanol and petroleum ether and were transferred to the petroleum ether by the addition of aqueous salt solution The petroleum ether layer was separated

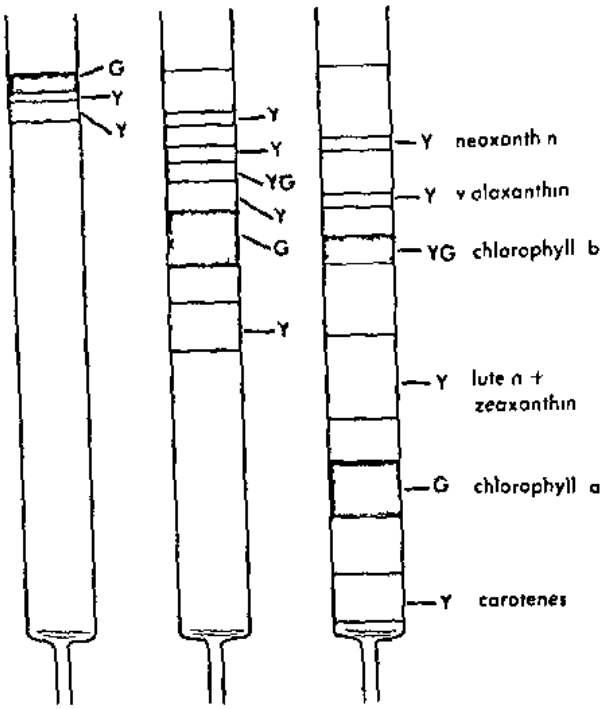


Fig 1 Successive steps in the formation of a chromatogram of the pigments of a green leaf G signifies green Y yellow YG yellow green

from the heavier salt solution by decantation and was washed with water to remove residual methanol which reduces the sorbability of the pigments With the aid of suction a little of the green petroleum ether solution was drawn into the upper portion of a column of powdered sugar formed by pressing small portions of confectioners powdered sugar into a constricted glass tube loosely plugged with cotton This narrow zone of the sorbed pigments was then washed with petroleum ether containing 0 5% *n* propanol This produced rapid migration and separation of the mixture as shown in the figure The carotenes which are not adsorbed on powdered sugar were not separated from each other Similarly the lutein and zeaxanthin the molecules of which differ from each other only in structural regions not attracted to the powdered sugar were not separated from each other *See* CAROTENOID

For isolation of the separated pigments, the colored zones were removed separately from the column and each pigment was eluted from the sugar with ethanol Alternatively the pigments were washed through the column and were collected separately in the percolate

In these chromatographic separations, both the sorbent and the solvent play critical roles For example if the leaf extract as utilized in Fig 1, is sorbed in a column of activated magnesium oxide (mixed with nonsorptive heat treated siliceous earth to improve filtration) and is washed with petroleum ether containing about 1% acetone, the carotenes are sorbed and are readily separated from each other and from the very strongly sorbed chlorophylls and xanthophylls as shown in Fig 2a If the same mixture of pigments is sorbed in a magnesia (magnesium oxide) column and washed with petroleum ether containing 25% acetone the carotenes are not sorbed and migrate rapidly through the column but the xanthophylls are moderately sorbed and are separated from one another and from the strongly bound altered chlorophylls as shown in Fig 2*b*

Another common modification of chromatography with paper as the sorbent is shown in Fig 3 Here a mixture of ferric cadmium cupric, and silver ions was added as a narrow zone near one end of a strip of soft paper The end of the paper strip was then dipped into a 4 *M* solution of ammonium hydroxide in a covered vessel (to restrict evaporation) As the ammonia solution was drawn into the paper by

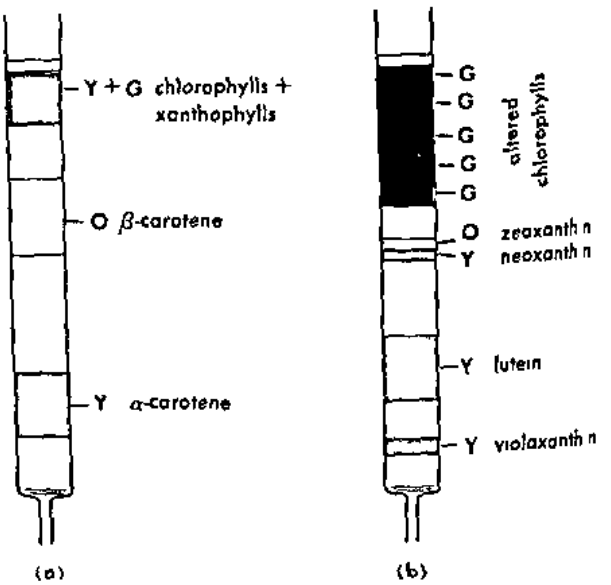


Fig 2 (*a*) Separation of carotenes by adsorption on activated magnesium oxide (*b*) Separation of xanthophylls by adsorption on activated magnesium oxide *G* signifies green O orange, Y, yellow

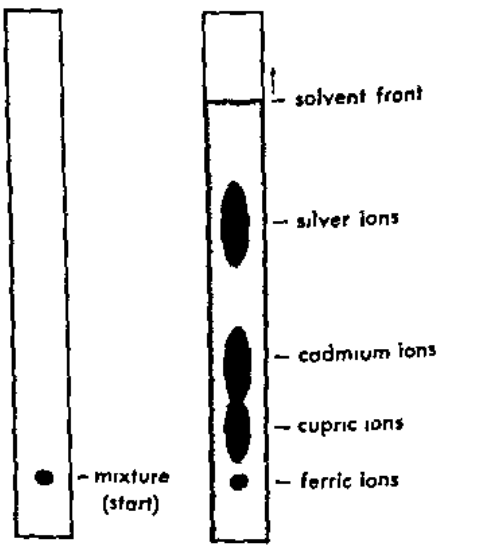


Fig 3 Paper chromatography of a solution of ferric cadmium, cupric, and silver ions

capillarity the ions were carried along at different rates and separated from one another To locate the ion zones the paper was sprayed with ammonium sulfide which converted the ions into the colored sulfides

Nomenclature of chromatography The chromatographic procedure with flow of fresh solvent to separate the constituents of mixtures was first utilized for the separation of the carotenoid and chlorophyll pigments from leaves Described by the botanist M Tswett in 1903 and 1906 this method was shown to depend upon the selective adsorption of the pigments upon surface active solids such as powdered inulin and precipitated chalk (*see* Adsorption) The method was called therefore chromatographic adsorption analysis a name indicative of adsorption and of color Even then it was recognized that colorless substances also separate as distinct zones in the adsorption columns Later other sorption processes such as ion exchange and partition between immiscible liquids were made the basis of chromatographic separations hence the name was contracted to chromatographic analysis and to chromatography Synonymous terms are sorptographic analysis and sorptography

The pattern formed by the zones of the separated pigments is called a chromatogram a term applied to the zones of colorless substances as well as to those of colored substances The separation of these zones by washing with fresh solvent is the formation or the development of the chromatogram The treatment of a chromatogram of colorless substances with reagents to yield colored zones has also been called development of the chromatogram because it is analogous to the development of a photograph

The observed migration of a chromatographic zone relative to the flow of the wash liquid is called the R or the R_f value Ranging from 0 for firmly sorbed substances to 1 0 for nonsorbed substances the R value serves for the description and identification of the separated materials

As the chromatographic method has been modified and applied to various kinds of substances numerous refinements of the terminology have been introduced With respect to the wash medium there are solution chromatography and gas chromatography With respect to the geometrical arrangement of the sorbent there are column chromatography and various forms of paper chromatography With respect to the nature of the sorption process there are adsorption chromatography ion exchange chromatography and partition chromatography With regard to the kinds of substances that have been examined there are many other terms such as amino acid chromatography and carbohydrate chromatography There are also many modifications of these terms some of which are noted in subsequent sections

Many decades before the invention of the chromatographic adsorption procedure for the separation of leaf pigments the flow of solutions through porous sorptive media such as paper and columns of soil and sorptive powders was employed for the partial resolution of mixtures Because each constituent is retarded in its migration through the sorbent the number of leading boundaries of the migrating substances indicates the number of the components of mixtures This technique has been called capillary analysis break through analysis frontal analysis and retardation analysis

Uses of chromatography Chromatography serves for the purification and isolation of various substances Chemical species isolated from mixtures by chromatographic methods are said to be chromatographically pure Because the purification of substances is prerequisite to the determination of their properties chromatography has become an indispensable tool in all branches of science concerned with chemical substances and their reactions Besides their use for the resolution of mixtures chromatographic techniques also serve for the description and comparison of chemical substances Chemical species may be compared and described not only with respect to their migration relative to that of the wash liquid or wash gas (R values) but also by their migration relative to that of other substances such as various reference substances or conspicuous constituents of mixtures In exploratory investigations a knowledge of the sequences in which substances separate is particularly useful for their description and comparison

The chromatographic sequence of sorbed substances is related to their atomic and molecular structures With suitable precautions and with reference substances of known structures the chromatographic sequence provides information about the atomic and molecular architecture of related substances With similar substances such as the rare earths the actinide elements and homologous organic compounds the chromatographic sequence provides clues to the nature of new members of the series In homologous series for example sorbability usually increases with the number of the carbon atoms and with the polarity of the functional groups But with variation of molecular types with changes of the functional groups and with variation of the location of the functional groups the sorbability of substances often varies unpredictably Similar unpredictable modifications of the sorbability and the sorption sequence occur with variation of the solvent and the sorbent It is impossible therefore to determine molecular structure from the chromatographic behavior alone There is likewise no simple relationship between the chromatographic and chemical classification of substances

Chromatographic methods are frequently employed to detect the alteration or metabolism of chemical substances A change in a chemical substance produced by a chemical or biological reaction usually alters the sorbability the relative migration rate and the sequence relative to reference substances

Characteristics of chromatographic methods. Relative to chemical methods of analysis

matographic methods have many unique features They depend upon physical reversible processes hence they do not alter or change the substances during the separation Unlike chemical methods of separation chromatographic techniques do not require specific reagents for particular components of the mixtures They facilitate the resolution of complex mixtures even when the components are undescribed substances whose presence is unknown or unsuspected

Separations by chromatography are extremely economical For most separations simple apparatus and inexpensive sorbents and solvents may be employed The recovery of the separated substances can usually be achieved by elution followed by removal of the solvent or wash liquid

Chromatographic methods are among the most sensitive separatory techniques They are effective with the smallest quantities of substances that can be detected by the most sensitive tests

Detection methods Most of these depend upon the properties of the separated substances They vary with the substances being separated and with their condition that is whether they are in gaseous form or in solution A common method of detection depends upon the conversion of colorless substances into colored products so that the zones are readily visible in the migration medium as described relative to the separation in Fig 3

Properties that serve for the detection and estimation of various separated substances fall into four principal categories nuclear properties (use of tracers and neutron activation analysis) physical properties (thermal conductivity of gases ionization of gases and spectral absorption or color) chemical properties (usually the formation of colored or other easily detectable products) and biological properties (as influence on growth or cell division)

Some of the detection methods employed with gas chromatography (thermal conductivity the gas density balance and ionization techniques) are applicable to virtually all kinds of gases and vapors They are also extremely sensitive As a consequence virtually all the components of most gaseous mixtures can be separated located and estimated by the technique of gas chromatography combined with a single detection technique Many commercial instruments have been designed for the practical utilization of these detection techniques with gas chromatography They are of great importance in the chemical process industries particularly in petroleum refining *See* GAS CHROMATOGRAPHY

With solution chromatography which is most useful with nonvolatile substances a great variety of detection techniques has been employed These techniques must be selected in relation to the properties of the substances being separated because no single detection procedure is both useful with all kinds of dissolved substances and sensitive in the presence of the solvent

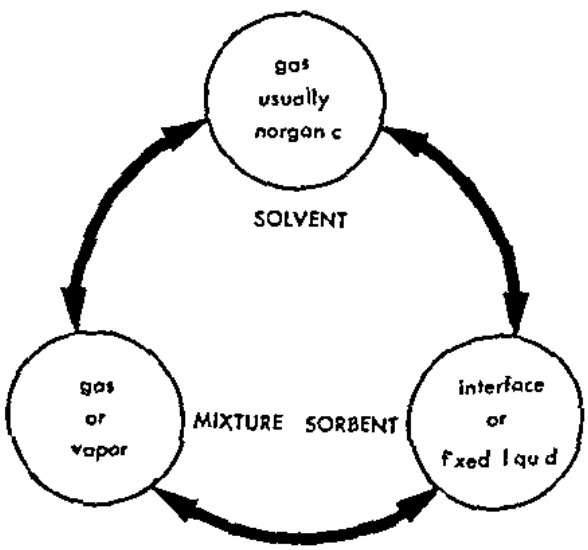
Chromatographic systems In all chromatographic separations there is a delicate reversible interaction among the solvent the sorbent and the constituents of the mixture This combination of sorbed substances solvent and sorbent is the chromatographic system

For the separation of a particular mixture the solvent and the sorbent must be chosen so that there is not only reversible sorption of the components of the mixture but so that there is also selective sorption of the components of the mixture Frequently several solvents and sorbents may be employed in various combinations to resolve a particular mixture This selection of solvent and sorbent is a highly specialized and empirical art the ramifications of which are incompletely understood

The separability of substances the migration rate and the chromatographic sequence vary often unpredictably with the solvent and the sorbent (Figs 1 and 2b) Description of the separability relative migration rates (R or R_f values) and sequence requires specification of the sorbent particularly with respect to chemical composition preparation treatment particle size porosity sorption capacity selectivity and arrangement It also requires specification of the solvent or wash gas usually with respect to chemical composition and purity The quantity and concentration of the mixture the size of the initial zone and the distance of migration are sometimes significant

Chromatographic systems have been varied in so many ways that it is virtually impossible to provide a comprehensive systematic survey of all the modifications Some significant variations of the solvent and the sorbent in gas chromatography and in solution chromatography are shown by the diagrams of Figs 4 and 5

Mixtures For their separation or chromatographic examination substances must be in an ionically or molecularly dispersed state as in a solution a vapor or a gas Mixtures may be classified



Fg 4 Pr ncipal interact ons in gas chromatography

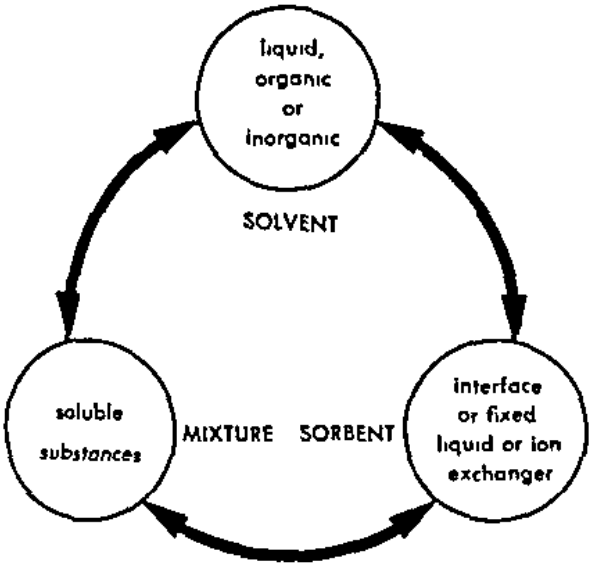


Fig 5 Principal interactions in solution chromatography

with respect to their volatility and their polarity, or degree of ionization Volatile, nonpolar substances such as hydrocarbons may be examined by gas adsorption or gas partition chromatography Nonvolatile polar substances may be examined by solution adsorption chromatography Weakly polar substances such as alcohols, ketones, and esters are examined by adsorption or partition chromatography Ionized substances such as acids bases, and salts are examined by partition or ion exchange chromatography Because polarity and ionization are affected by the solvent, particular substances may often be examined by various modifications of the chromatographic procedure

Solvents. These should not only permit reversible and selective sorption of the components but also detection and recovery of the separated substances Because soluble substances are much more abundant than volatile and gaseous substances solution chromatography is much more widely applicable than gas chromatography

Solvents have a great effect upon the sorbability and separability of mixtures The sorbability of a given substance usually increases as solvents of decreasing polarity are employed, and vice versa Small amounts of much more polar solvents may be added to a weakly polar wash liquid to decrease sorbability and thereby accelerate formation of the chromatogram By selective displacement of sorbed substances these polar solvents may improve the separation of mixtures (Compare Fig 1 with 2*b* and 6*a* with 7*b*)

Sorbents. The porous substances employed as sorbents must sorb the components of mixtures selectively and reversibly They should permit the recovery of the sorbed substances preferably without change or alteration and they should facilitate uniform flow of the wash liquid, thereby ensuring the formation of well defined uniform zones of the separated substances

Many different sorptive effects have been utilized for chromatographic separations With flow of gas for formation of the chromatogram, both selective adsorption by a surface-active powder and preferential dissolution by a nonvolatile liquid fixed in a porous support have been widely employed These systems provide gas adsorption chromatography and gas partition chromatography. (See Fig 4)

With flow of liquid for formation of the chromatogram, adsorption by powdered solids (liquid solid interfaces Figs 1, 2, 3, and 6) and by surfaces of fixed liquids (liquid liquid interfaces) has been utilized (Fig 5) Figure 6 shows the separation of the pigments in a petroleum ether extract of green leaves by adsorption in a strip of paper using petroleum ether or petroleum ether plus 0 5% *n* propanol as the solvent In dry paper, the pigments are sorbed at the cellulose petroleum ether interface, whereas in the paper moistened with glycerol, the pigments are sorbed at the glycerol petroleum ether interface Note the effect of the addition of 0 5% *n* propanol in Fig 6*b*

Preferential dissolution by a fixed polar liquid immiscible with the less polar wash liquid provides the so-called partition chromatography (See Fig 7*a*) With the phases reversed, that is with the polar phase as the wash liquid and the less polar phase fixed in the support, the method is known as reversed phase partition chromatography It provides a chromatographic sequence the inverse of that produced by partition chromatography (See Fig 7*b*)

Ion exchange processes by zeolites and by synthetic resins provide ion exchange chromatography (*see* ION EXCHANGE) Ion exchangers fall into two principal classes, those with acid groups which ex

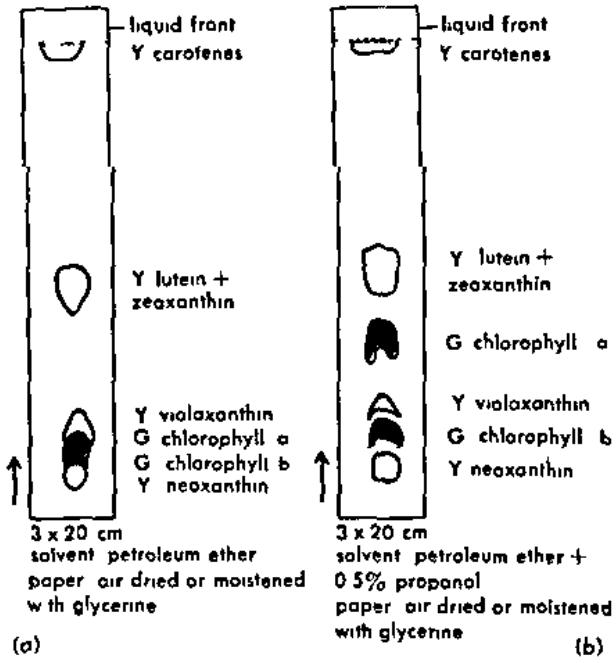


Fig 6 (a b) Effect of mixed solvents on chromatogram G signifies green, Y, yellow

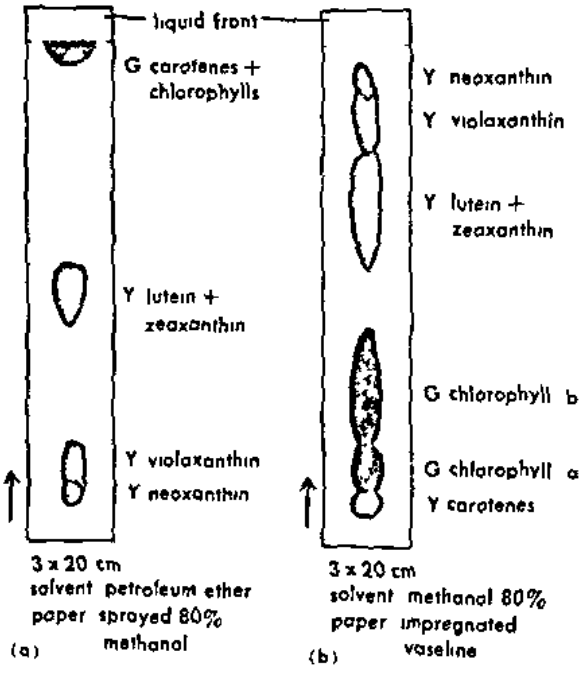


Fig 7 (a) Partition chromatography (b) Reversed phase partition chromatography G signifies green, Y, yellow

change or sorb cations and those with basic groups which exchange or sorb anions However cations may be complexed with various anions and chelate forming reagents so that they are sorbed by anion exchange resins Variation of these reagents and of the pH of the solution may be employed to modify the sorbability and the separability of many ions

Arrangements of the sorbent The packed column as in columnar chromatography is the most common because it permits the use of a great variety of powdered sorptive substances It may also be used with various gases and wash liquids and it may be adapted to micro and macro separations

Columns may be prepared in several ways depending in part upon the properties of the sorbent Sorbents of small dense round particles may be packed dry by jarring them in the tube Noncompressible dry powders may be tamped into the tube in small successive portions whereas compressible powders such as siliceous earth and powdered sugar may be pressed firmly into the tube with a plunger only slightly smaller than the tube itself Finely powdered sorbents may be mixed with a filter aid such as heat treated siliceous earth before they are packed into the tube thereby improving the filtration rate (Fig 2) Many sorbents may be made into a slurry with the solvent and poured into the tube

Several arrangements of the sorbent have been devised with paper, the uses of which make up the category of paper chromatography The paper has been employed as sheets or strips providing *one way paper chromatography* (See Figs 3 6 and 7) The paper has also been employed with migration from a spot in a sheet so that the zones separate as a series of concentric rings (Fig. 8) This use of paper is called circular paper chromatography and radial paper chromatography. A paper sheet may also be employed with migration from a spot near one corner followed by migration in a transverse direction with a solvent that is different from that employed for the first migration This two-way paper chromatography (Fig 9) provides high resolving power for complex mixtures. It has been widely employed for the separation and characterization of amino acids

All these arrangements of paper are adaptable for use in adsorption chromatography, partition chromatography, and reversed phase partition chromatography They also permit the convenient addition of various detection reagents for location of the substances separated in the paper But with respect to the mechanism of the sorption process, there is no difference between the separations in paper and those carried out with cellulose packed in columns

Differential migration. All separations by chromatography depend upon the differential migration of the components of mixtures For the migrations, a driving force in the form of flow of gas or solvent is required The sorption of the migrating substances provides a resistive action to their migration The driving force is nonselective; the resistive action is selective and determines the effectiveness of the separations As indicated already, the sorption and the resultant resistive action are a function of the solvent and the sorbent

Regarded as a differential migration phenomenon chromatography resembles a number of analogous differential migration procedures such as differential sedimentation, differential electrical migration, and mass spectrometry Chromatography has served as a model for the design and improvement of other differential migration methods of

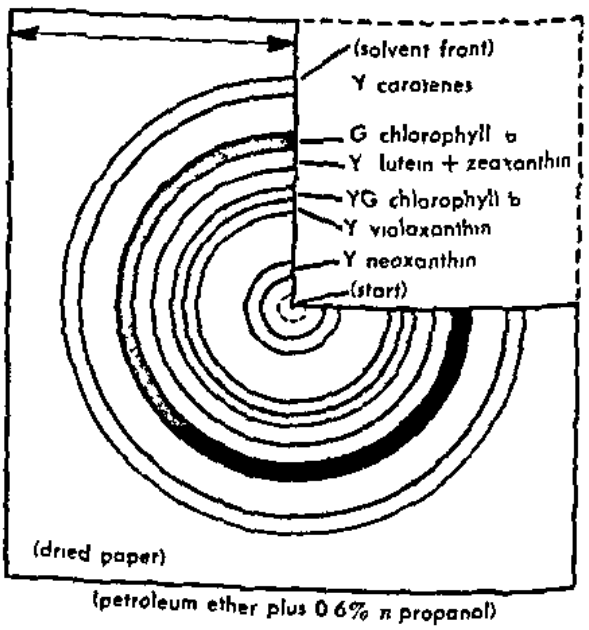


Fig 8. Radial, or circular, paper chromatography G signifies green, Y, yellow

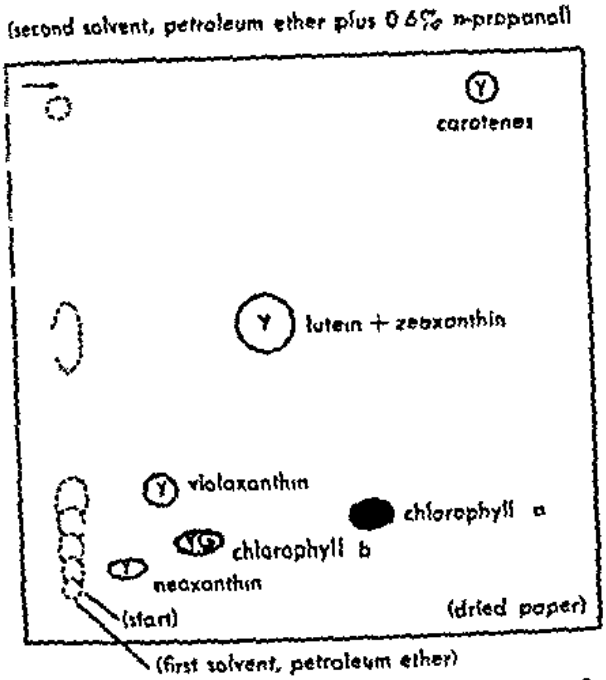


Fig 9 Two-way paper chromatography G signifies green, Y, yellow, YG, yellow-green

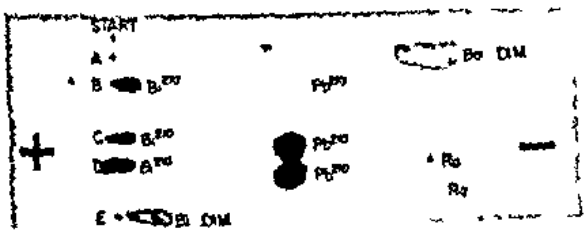


Fig 10 Chromatogram obtained by electrochromatography

analysis One of these methods, *differential* electrical migration in solutions stabilized in paper is remarkably similar to paper chromatography

Electrochromatography. Differential electrical migration of the components of mixtures from a narrow zone in a stabilized, background electrolytic solution provides an effective separatory technique variously known as electrochromatography, zone electrophoresis, electropherography and ionography In this technique, the background solution may be varied in many ways as by the use of buffers and various complex forming and chelating reagents. The stabilizing media may be gels, porous columns, and paper Of these, paper is the most common and has been employed in various grades and thicknesses as well as in various forms such as strips, sheets, and pads These uses of electrical migration with paper as the stabilizing medium are known as paper electrochromatography, paper electrophoresis, and electropherography

In electrochromatography, dc electrical potential is the driving force The migrating particles may encounter resistive action in the viscosity of the background solution and through sorption on the stabilizing medium Separations may depend upon the selectivity of the driving force upon the selective effect of the resistive action, or upon both

Electrochromatography is especially useful for the examination of ionized substances such as acids, bases, and salts It is also useful for the resolution of proteins and it finds extensive use in biochemical and clinical applications Figure 10 shows the chromatogram obtained in the separation of various cations in 0 1 *M* lactic acid stabilized in soft paper. Five separate migrations were carried out in parallel at 7 volts/*cm* for 7 hours, the barium ions migrating a distance of some 66 *cm*, the radium ions, 63 cm In the photograph, the hatched zones indicate initial concentrations of 0 01 *M* solutions The barium zone was located with rhodizonate, the bismuth with sulfide The dark zones are the radiographs of radium and its principal decay products, which were present in minute quantities

Differential electrical migration in one background solution may be followed by transverse migration in a second different solution providing two-way electrochromatography analogous to the two-way paper chromatography illustrated by Fig 9 Electrical migration in one direction has been combined with transverse flow of solvent to provide continuous separations of mixtures added as a narrow stream of solution This method, known as continuous electrochromatography and continuous zone electrophoresis is one of the few methods that may be employed for the continuous resolution of mixtures In Fig 11 is shown the chromatogram obtained in the separation of cobaltous and ferric ions by continuous electrochromatography The mixture of these ions each 0 005 *M*, was added continuously through the narrow wick The background wash liquid 0 05 *M* malonic acid in 0 1 *M* acetic acid flowed downward through the paper The dc electri

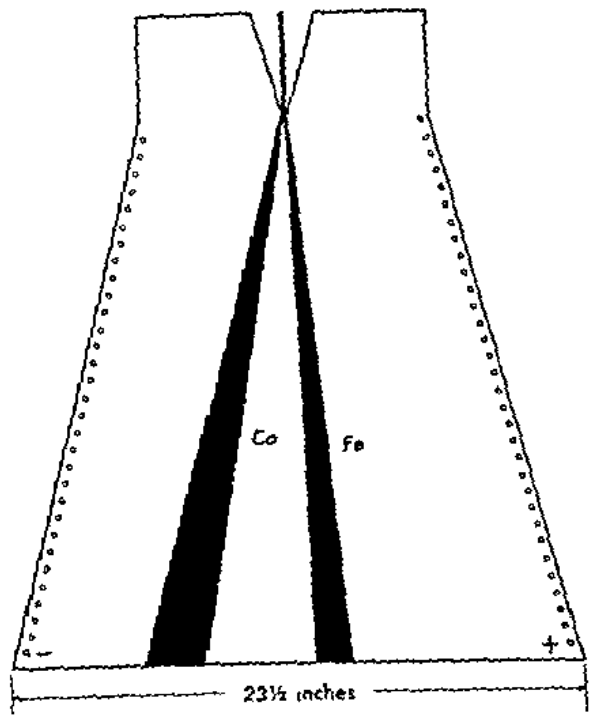


Fig 11 Chromatogram obtained by continuous electrochromatography

cal potential 50 volts was applied to platinum wire electrodes laced through the holes in the paper The paths followed by the ions are shown by the dark zones They were located by spraying the paper with ammonium sulfide

Many of the techniques for the detection and estimation of substances separated by chromatography are readily applicable to the location and determination of materials resolved by electrochromatography *See* SEPARATION (CHEMICAL AND PHYSICAL) {H H SR}

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Chromatophore

A color bearing cellular structure in organisms Chromatophores are mainly pigment cells especially those having movable pigment that occur in the skin and in certain deeper tissues of animals In cells of some plants having large or complex colored plastids such chromoplasts and chloroplasts for example those of the green alga *Spirogyra* have often been called chromatophores (*see* CELL PLASTIDS) In animals nearly all chromatophores are themselves single cells having distinctive pigment produced and contained either dispersed or aggregated in the cytoplasm which typically forms many branching protrusions In cephalopod mollusks however the chromatophores mature as miniature organs each composed of a round sac like pigment cell and an encircling ring of radially attached muscle cells Chromatophores contribute to the coloration and pattern of the many different animals by their presence and abundance and according to their localization They bring about more or less rapid changes in the color of these animals by spreading their pigment over larger areas or compacting it into smaller areas exposed to view In performing these functions they also according to the nature of their pigment absorb or reflect light and heat and thus modify the penetration of radiant energy into deeper parts

Occurrence Chromatophores capable of effecting color change by movement of their pigment are also called pigmentary effectors They are known to occur in some polychaete worms echinoderms and insects as well as many leeches cephalopods crustaceans fishes amphibians and reptiles Pigment cells not demonstrably capable of effector activity are found in birds and mammals including

[illegible]

are quite like active chromatophores in origin and other respects those found in various species exclusive of birds and mammals can also be practically regarded as chromatophores In this broad sense chromatophores occur in more animals than already indicated notably in most insects and other arthropods in slugs and many other gastropod mollusks and in virtually all fishes amphibians and reptiles

Chromatophores of cephalopods Chromatophores which occur in the octopus cuttlefish and squid are the fastest acting When stimulated their several long muscle cells radially arranged in the plane of the skin and contracting synchronously stretch the central spheroidal pigment cell into a disk 2-60 times greater in diameter in a fraction of a second (Fig 1) Although not striated the muscle fibers contract almost as rapidly as some striated muscle When the fibers relax the elastic membrane of the color cell instantly reverts to its spheroidal form and pinpointlike diameter rendering the pigment it contains practically invisible to

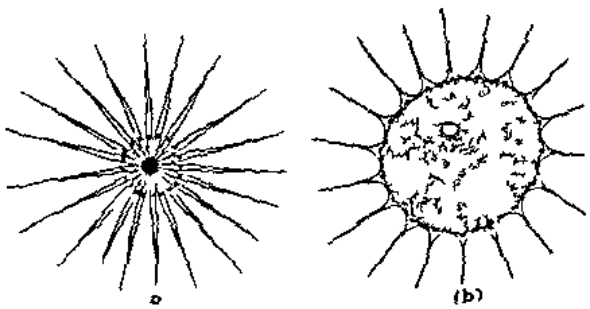


Fig 1 Chromatophores of a squid (a) Radial muscle cells relaxed pigment contracted (b) Radial muscle cells contracted pigment expanded (From E Bozler Z vergleich Physiol 7 407–435 1928)

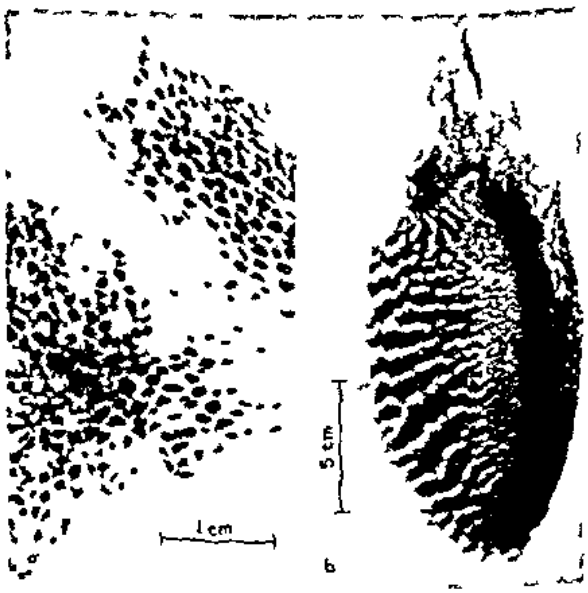


Fig 2 (a) Skin of a squid with pigment cells contracted except in two areas affected by electrical stimulation (b) Living cuttlefish with alternate crossbars of expanded and contracted chromatophores on the left side and with a broad black longitudinal band on the right where nerves were cut 5 days previously (From F B Hofmann Pflugers Arch ges Physiol 132 1910)

the naked eye The chromatophore muscle cells are controlled through nerve fibers extending to them from nerve cells lying in lobes of the subesophageal ganglia These *immediate motor neurones* are subject to excitation and inhibition by adjustor neurones grouped in control centers in lobes of the supraesophageal ganglia Environmental stimuli *are transmitted to these ganglia from* the eyes and other receptors This system is *subject to hormonal* modification of its operation by substances in the blood that directly and indirectly affect chromatophore activity Thus the animal is able not only to display flashes *and waves of color change but* also to assume and maintain various patterns shades and hues as some of its different chromatophores are locally or generally expanded or contracted Three types of color cell *are* usually present the largest *are* blackish or brown and *lie deepest* others have orange or red pigment and the smallest are yellow and occupy a shallower layer under the epidermis Interspersed among them and also forming a deeper *reflecting layer are numerous* small glistening doubly refractive cells called iridophores, or iridocytes They show no movements but provide a pearly white backdrop that *in* interacting optically with the different reactive chromatophores *produces* additional hues

The chromatophores of animals *other* than cephalopods differ in details of form pigment and reactions in each species or group

Types of chromatophores Several types of chromatophores are *distinguished by their* color The most common are black or brown *and are* called melanophores They are the type which have been studied most often and are most thoroughly known Others are yellow red white or iridescent and are *generally known* as *xanthophores erythrophores leucophores and iridophores* respectively Typical iridophores differ from most other chromatophores especially melanophores which are usually the most active in not displaying *movements* of *their* pigment Leucophores *iridophores and intergrading types form* a broader category for which another name antaugophore meaning reflecting chromatophore has been coined Unlike the yellow and the red all of these are grayish or dull light brownish as viewed by light *transmitted through them No* lastingly blue chromatophores are known *but* a *diffuse* water soluble blue pigment *a carotenoid* conjugated with an albumin originating in chromatophores of other color appears in the surrounding tissues in some animals including *many* crustaceans In addition blue green *or other colors occur as interference effects of* light diffracted or refracted by the pigment crystals or intervening films in iridophores or from iridophore colors mingling with the colors of other cells

A partly different set of *chromatophore* types is predicated *on the chemical nature of their* pigment Melanin a class of *insoluble black* and brown pigments characterizes the predominant type which accordingly retains the designat[illegible]

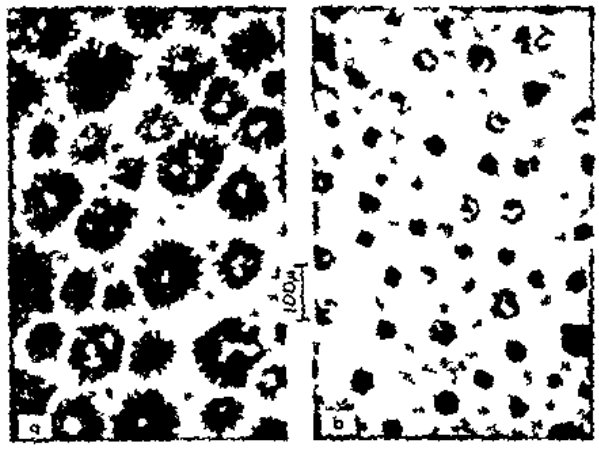


Fig 3 Skin of the back of a killifish (Fundulus) after removal of scales with melanophores (black) xanthophores (numerous, small gray) and iridophores and leucophores (both white) (a) Pigment dispersed in the melanophores hiding all leucophores but not all iridophores (among branches of melanophores) (from J M Odorne *Proc Natl Acad Sci U S* 1975 1933) (b) Pigment concentrated in the melanophores exposing leucophores with white pigment dispersed in spreading branches (by J M Odorne)

phore Most yellow and red chromatophores contain lipochrome a *fat* soluble carotenoid pigment and *have therefore been called lipophores* Some chromatophores contain a red pigment different from that of the lipophores and these have been called allophores The term pteridophore has been introduced *for certain* yellow *chromatophores which owe their color to pteridine rather than* carotenoid pigment *Confirmed* evidence that the white and iridescent material on the scales of some fishes is guanine led to the classification of all chromatophores *of leucophore* or *iridophore* appearance as guanophores *but the chemical* assumption *implicit* in such *broad* use of this word has proved untenable More recent analyses have shown that other substances with the same optical properties including double refraction supplement or supplant gua

[illegible] es Melores are

differentiated during embryonic development from amebоid cells Nevertheless it is generally agreed *that* contrary *to* former views they do not protrude *and retract their* branches like pseudopodia in the *adult but* retain at all times the characteristic and for the most part elaborately branched form that is manifested whenever their granular pigment is fully dispersed into all their parts Evidence *indicates that the branches are* simply emptied *of pigment and become* transparent and invisible to ordinary microscopic inspection (in some species they appear more slender) when the pigment is displaced toward the cell center and compacted into a globose mass (Fig 4) The nucleus *is usually close to* this concentrated *pigment* but may occupy a more *remote* position in a branch Some melanophores have more than one nucleus Ch

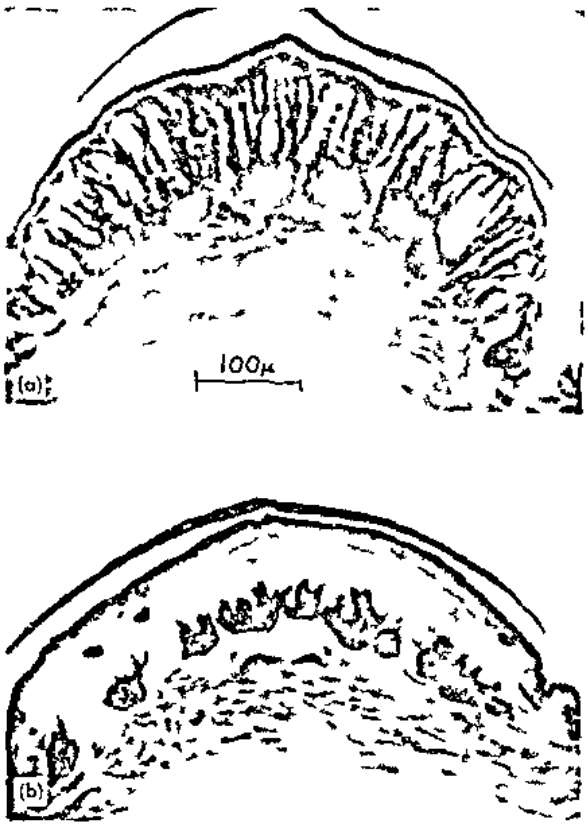


Fig 4 Vertical sections of lizard skin (extent of one scale) showing black pigment (a) Pigments dispersed in melanophore branches that pass through layers of *pale chromatophores* and spread over them (b) Pigments withdrawn into melanophore bodies (From L H Kleinholz *J Expll Biol* 15 474 1938)

tophores of other colors are believed to resemble melanophores in most structural essentials but in some especially xanthophores the pigment is not only less grossly and obviously granular but may appear liquid In antaugophores the reflecting pigment is mostly crystalline owing iridescence to the larger size regular shape and arrangement of its platelets in iridophores or appearing white because of light scattering by its more minute non uniform or irregularly arranged particles in leucophores

Most vertebrate chromatophores appear monochromatic but close analysis has revealed the presence of more than one pigment in some Dichro

[illegible] crustaceans But at least in some cases chromatophores seemingly of that nature are actually compound each comprising two or more chromatophores intimately combined Such multiple units often called *chromatosomes* are common in fishes (Fig 3)

Chromatophore effector activity involves change in the colloidal state of the cytoplasm In melanophores at least the dispersion of the melanin granules appears to be linked to the conversion of inner cytoplasm from gel to sol and there is evidence that the reverse migration and clumping of the granules depends upon gelation and contraction of a connecting protein network Experiments with hormones and drugs indicate how glycolysis and oxidative metabolism in the chromatophores may participate in energy transfers required for these changes of state

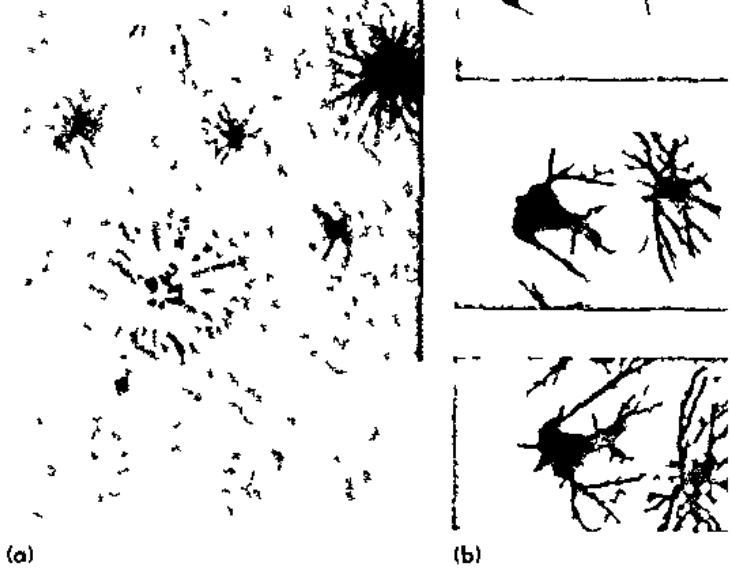
Factors influencing pigmentary activity Environmental conditions that affect the dispersion and concentration of chromatophore pigment chiefly involve light but in some cases other external factors are decisive either of themselves or by evoking a nervously excited state

Nervous excitement Induced by mechanical visual or other stimuli which may originate from an enemy or mate nervous excitement initiates a striking concentration of dark pigment "excitement pallor in various reptiles and fishes A darkening or mottling change however, results in some other forms

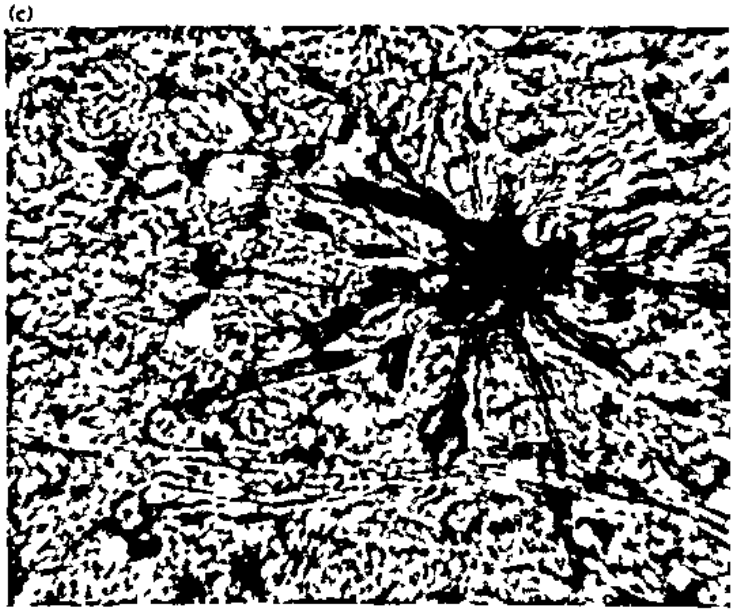
Humidity Little general effect on chromatophores results from humidity, but walking stick insects and frogs darken in moisture and become pale under drier conditions

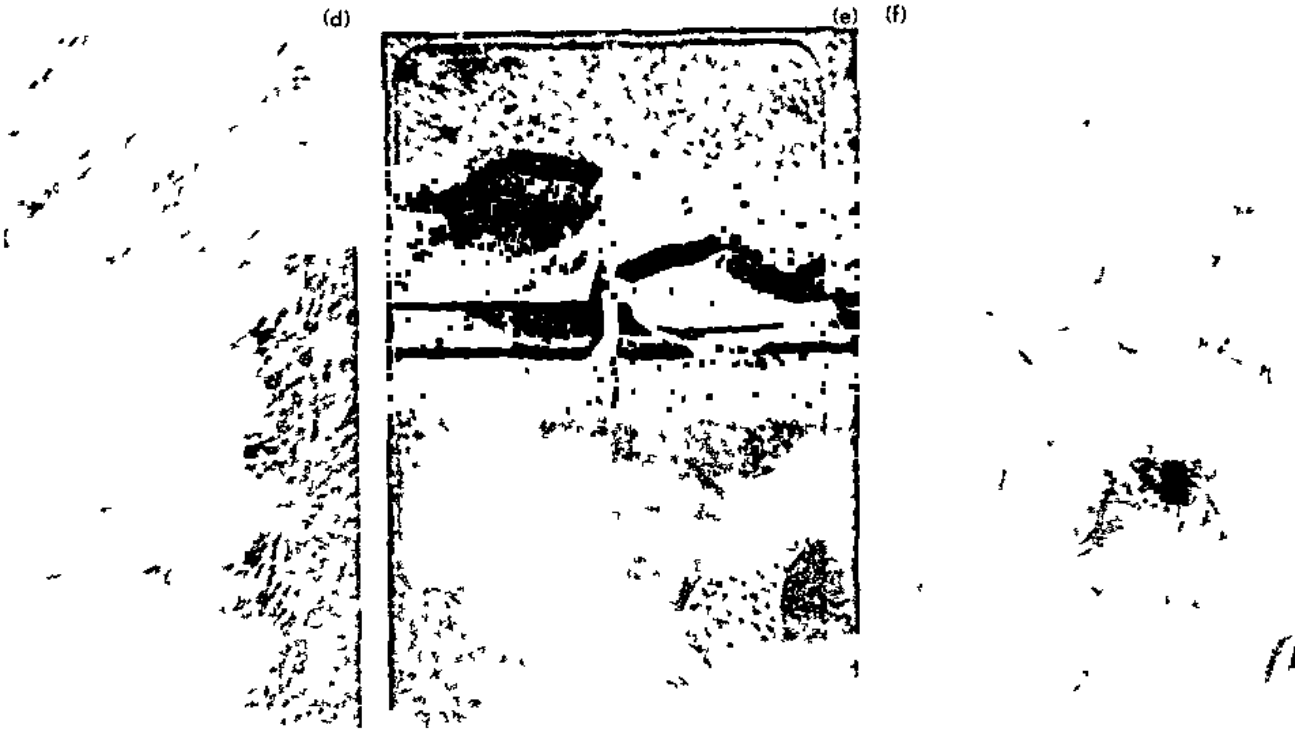
Temperature Temperature does not often determine chromatophore change when it is in the normal range for vertebrates But, as a rule above 30–35°C or near the extremes of warmth tolerable to the species melanophore pigment concentration occurs in the cold blooded vertebrates that have been tested Their melanin disperses in the near freezing cold of 1–5°C This rule holds for the chameleon various other lizards, and some snakes among the Reptilia the common frog and certain salamanders among Amphibia, and for certain fishes in Pisces Exceptions to it however have been found in all three classes Color change in certain grasshoppers caused by opposite migration of two kinds of pigment granules depends on temperature, not on humidity, light or the visual field They become almost black below 15°C and greenish blue above 25°C reflecting more light and retaining less heat

Light In some cases, light affects pigment movement without help from eyes or structures of true visual function In various crustaceans light appears to act directly on the chromatophores themselves which in blinded animals respond as independent effectors Both white and darker pigments disperse when brightly illuminated and become concentrated in total darkness Similar responses to light by melanophores have been observed in various fishes amphibians and reptiles after blinding or in the absence of local nerves or before embryonic development of means of visual mediation In some such instances light acts indirectly, exciting responses through hormonal reflexes initiated not in the eyes but in the skin or the pineal body The latter is a receptor for light in various lower vertebrates and as such controls the responses of melanophores in larval lampreys It also appears



(a–c) Skin of a prawn (*Leander serratus*), with red and white chromatophores showing (a) *pigment mostly dispersed in the branches of* one white and several red cells, (b) successive stages in dispersal of pigment in two red cells, (c) twofold effect of injecting prawn with sinus-gland extract—red pigment becoming less dispersed and some converted into a blue dif fused outside the chromatophore (*From F G W Knowles, Endeavour, 1499, 1955*)
(d) Skin of a squirrelfish (*Holocentrus ascen sionis*) with chromatophores as seen by trans-*mitted light a few large finely branched* melanophores and many small erythrophores (seen as balls of concentrated red) over a screen of larger oval iridophores (looking grayish and granular) and a deeper and more evenly spaced layer of nearly parallel elon-gate reflecting bodies (appearing straw-col ored) (*By H B Goodrich, at Lerner Marine Laboratory, Bimini, B W I*)
(e) Young flounders (*Parophrys velulus*), origi *nally indistinguishable in color, showing adap* tive coloration attained during prolonged periods of time (43 days) over a given bottom color such as black, red, blue, or white (*By E F B Fries at Hopkins Marine Station, Paci fic Grove, Calif*)
(f) Parrotfish skin with chromatophores as seen *by reflected light melanophores, with black* pigment widely dispersed in their branches, and smaller, less sharply defined, yellow to-orange xanthophores over meshed chains of brightly whitish iridophores (*By H B Good rich, at Lerner Marine Laboratory, Bimini, B W I*)





able to mediate the effect of light on chromatophore activity in at least some lizards and true fishes

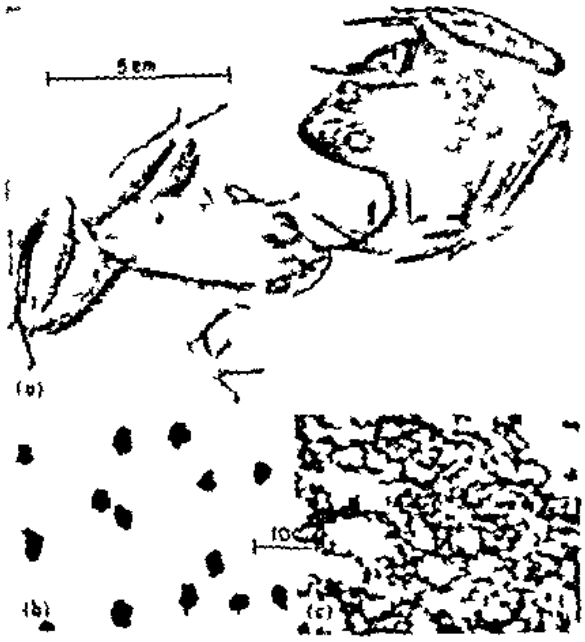


Fig 5 (a) Frogs turned pale in response to a white background and dark to a black one (b) Concentrated pigment in melanophores of the pale frog (c) Dispersed pigment in melanophores of the dark frog (From M E Pearce J Exptl Zool 89 293–295 1942)

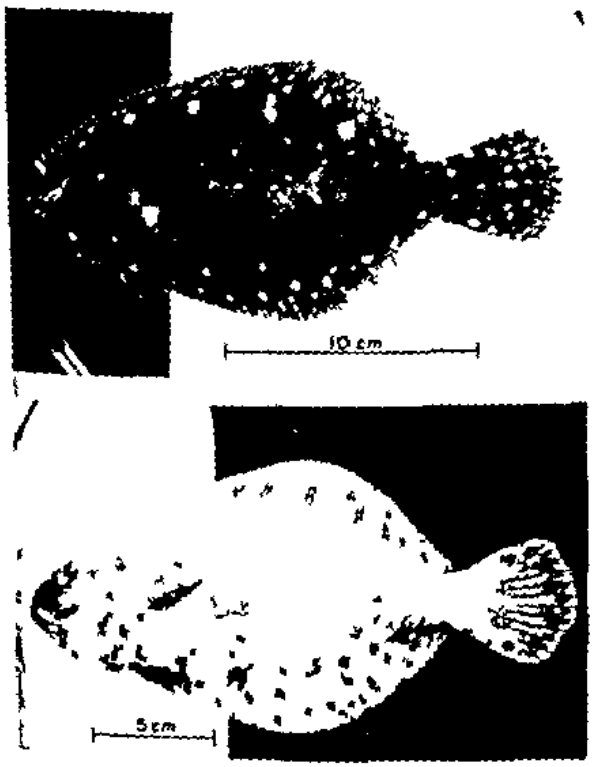


Fig 6 Darkening and paling reactions of a flounder having only its eyes and forepart kept (about 2 hours) over black and white respectively (From S O Mast Bull U S Bur Fisheries 821 1916)

Visual background The chief environmental factor influencing postlarval chromatophore activity is light entering the eyes from the surroundings or background of the animal The responses to this background light depend primarily upon its quantitative relation to the light entering the eyes from overhead or passing to the retinal parts normally exposed to direct light from the sky or main source Relatively pale illuminated backgrounds that is those diffusely reflecting much of the light falling on them evoke only pigment concentration in dark chromatophores and pigment dispersal in leucophores, whereas relatively dark or light absorbing backgrounds evoke only the opposite effects (Fig 5) Though far from universal the ability to turn paler or darker by such pigmentary responses and thus to conform visibly to the shade of the background is widespread in the classes of chromatophore possessing animals that have eyes (Fig 6) In addition adaptive changes of actual color effected by differential chromatophore responses to the hue apart from the shade of the background occur in many of these species especially in some decapod crustaceans and bony fishes that lack conspicuous pattern markings and that frequent habitats presenting fairly uniform backgrounds For example when certain mutually identical prawns or killifishes are placed over backgrounds as contrasting *in hue as red and green or deep yellow and* light blue but of equal shade they change color within 3 hours each assuming a hue more or less corresponding to its given background In effecting such color changes the different chromatophores respond independently of each other Thus xanthophores disperse their pigment in response to yellow or brown backgrounds and concentrate it in response to blue whether pale or dark whereas melanophores adapt simply to the pallor or darkness of the background hues

Diurnal rhythm A diurnal rhythm of pigment movements that persists for weeks or months independently of the afore discussed factors characterizes certain marine isopod and decapod crustaceans and such widely representative vertebrates as the lamprey European minnow frog and chameleon It is evinced particularly under constant darkness but it may be detected under constant illumination because by day it slows or reduces and in the night facilitates the chromatophoral adaptation to a white background In fiddler crabs there is a noticeable strong rhythmic tendency to darken by day *and turn pale at night* This largely masks the influence of illuminated pale or dark backgrounds

Chromatophore control systems These systems vary strikingly among different animals and at first were found to involve nerves in the chameleon and certain bony fishes but hormonal control occurs in other animals

Arthropods In crustaceans and insects chromatophore responses to factors affecting them indirectly depend entirely upon the blood's supply of hormones, secreted under visual or other stimulation transmitted through the nervous system [7]

or more such substances having various dispers ing and concentrating effects on the different chro matophore pigments arise by neurosecretion being formed by certain nerve cells In shrimps and other decapod crustaceans two are released from the sinus glands on the eyestalks and at least one from other neurohemal bodies (corpora allata) be hind the brain *See* INSECT PHYSIOLOGY

Vertebrates Among vertebrates both blood borne melanophore hormones and nerve fibers di rectly innervating the melanophores function prominently in certain elasmobranch dogfishes and probably most bony fishes and reptiles in cluding horned toad lizards Though some evidence of a direct nerve supply to chromatophores has been reported for the lizard *Anolis* and for frogs and toads color changes in these animals and other amphibians are governed predominantly by hor mones Only hormonal mediation of chromatophore control has been shown in some relatively primitive vertebrates including lampreys and such elasmo branchs as skates and the dogfish *Scyllium* At the other extreme in the chameleon and certain bony fishes notably the killifish *Fundulus* which include species showing the fastest vertebrate color changes the melanophores are controlled entirely or pre dom nantly through direct innervation This may be a more recent evolutionary specialization than hor monal control systems which cannot act so rapidly

Generally vertebrate melanophore nerves are pigment concentrating in action but in some cases pigment d spersing nerves are also present This is true of various bony fishes including species with partly hormonal systems as well as others with predominantly direct nervous control The action of the pigment dispersing nerves appears to be cho*linergic that is mediated locally* by the neurohor mone acetylcholine Most melanin concentrating *nerves appear* to be adrenergic exerting their ef fect by local release of a neurohumoral substance *identical with* or closely similar to adrenaline

The *vertebrate* chromatophore hormones include one that is usually called intermedin It occurs in *the intermediate or* posterior lobe of the pituitary gland in all species When *obtained from hogs it*

melanin d spersal in the many species subject to its action Another hormone *opposite in effect* has been found in other pituitary tissue in some bony fishes and may occur also in amphibians and pos s l l y in elasmol ranchs Experiments *on Asiatic* cat fish indicate that like some other pituitary hor mones it is a neurosecretion *produced in nearby* cells of the thalamus of the brain and *released from* their f ber endings in the gland Another hormone having pigmentary effects is *adrenalin which* in opposition to intermedin concentrates melanin in horned toads Adrenalin has this *effect* also when injected into amphibians and some *species of* bony fi hes l ut has the opposite effect in other species In either event it is difficult to *prove the part* that adrenalin plays in normal control of melanophores because the probability of chemical transmission of impulses from adrenergic nerves complicates the problem

The red yellow, and white chromatophores of vertebrates have been studied very little but availa ble data indicate that their reflex responses are mediated by control systems like those of the mela nophores The systems governing the different chromatophore species are probably never wholly identical For example xanthophores of the com mon killifish (*Fundulus*) though innervated in the same manner as the melanophores are affected mainly by the supply of pigment dispersing hor mone from the pituitary The xanthophores of a very closely related species of *Fundulus* although affected by this hormone are dominated by their nerves although less completely than the melano phores The leukophores in these two species re spond adaptively to pale and dark backgrounds more slowly than the melanophores and maintain their responses when drug treatment blocks melano phore responses although they can do so inde pendently of pituitary secretion

Physiological color change This term desig nates any relatively transitory color change that under visual or other stimulation results from pig mentary effector activity or redistribution of mov able pigment already present in existing chroma tophores of an animal

Morphological color change In contrast to the physiological morphological color change is any intrinsically longer lasting quantitative change in pigmentation that results from increase or decrease in the total number of chromatophores or from syn thesis or destruction of pigment in preexisting chromatophores or from both together Measurable change of this kind commonly occurs in conse quence of continuance for an extended period of some of the same conditions often involving the blood s hormone content that are effective sooner in evoking the corresponding physiological color change Several species of bony fishes when they stay several days or longer over an ill uminated background of a particular color at first more or less closely match that color This is accomplished within mere minutes or hours by appropriate posi tioning of the pigments in their chromatophores The first color then becomes enhanced by change in the number or content of their different chro*matophores* This change has been determined spe cifically for not only melanophores but also xantho phores and antaugophores Decrease of melano phores or xanthophores takes place by degenera tion by ingestion of their pigment by phagocytes and by extrusion of the pigment through the epidermis Many kinds of animals that undergo morphological color change show no physiological color change The latter may be a more advanced outcome of evolution

Genetics of chromatophores The ability to synthesize the pigments varies in different animals the types of chromatophores and the characteristic



Fig 7 Swordtail platyfish hybrid with red and black pigment-cell tumors on the head Overgrowth of melanophores has also blackened the tail but left gleaming patches of iridophores exposed on the flank (*From R F Nigrelli, S Jakowski, and M Gordon, Brit J Cancer, 5 54–68, 1951*)

sizes and forms they assume vary even more, and the distinctive patterns of chromatophore distribution in the body vary most of all These various traits are inherited transmitted from parent to offspring by genes segregated in the sex cells and recombined in the embryo in accordance with Mendelian principles Some combinations of these genes in hybrids of common aquarium fishes result in pigmentary overgrowth and even malignant pigment cell tumors (Fig 7) *See* GENETICS, PIGMENTATION

Embryonic origin in vertebrates As the result of repeated experiments, it has been known since the early 1930s that the melanophores of amphibians develop from cells that originate in the neural plate (ectoderm giving rise to the nervous system) They migrate thence to final sites in the skin or deeper membranes Later studies regarding various pigment cells in fishes birds and mammals support the significant generalization that whatever their pigment, both pigmentary effectors and unreactive pigment cells of all vertebrates come from an equivalent part of the early embryo

Functional significance of chromatophores. Aristotle observed that the octopus reaps advantage from its changeable coloring, which conceals it, or confuses its prey or enemies Modern experiments have confirmed that color change in certain animals has survival value as camouflage, they add grounds for belief that color adaptation to the background contributes importantly to protection from predators or to capture of prey In addition, instances of physiological and of morphological color change linked to breeding are found in most of the major groups of chromatophore possessing animals Transitory color displays are elements of male mating behavior in some reptiles, fishes, and invertebrates *Bright nuptial coloring distinctive of sex develops* for the breeding season in many vertebrates, but chromatophores often serve a more fundamental function as screens excluding or absorbing radiation Thus they can protect inner tissues against harmful illumination In many reptiles they evidently counteract loss of needed heat by increasing their absorbing area and protect against too high temperature by decreasing that area and affording more reflection *See* ENDOCRINE MECHANISMS, PROTECTIVE COLORATION [E F B F]

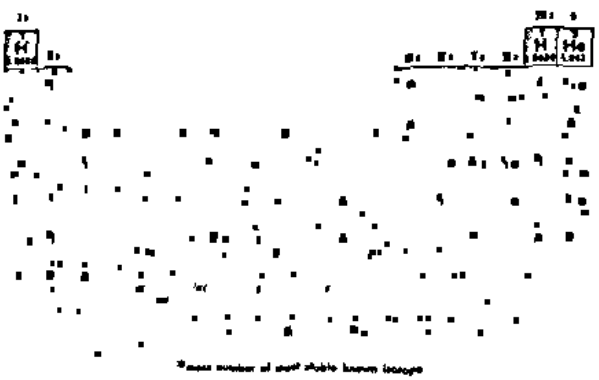
Bibliography· G H Parker, *Animal Colour Changes and Their Neurohumours*, 1948, G E Pickford and J W Atz, *The Physiology of the Pituitary Gland of Fishes*, 1957, C L Prosser (ed), *Comparative Animal Physiology*, 1950

Chromite

The only important ore mineral of chromium Chromite crystallizes in the isometric system but crystals are rare and it usually is massive The hardness is 5 5 (Mohs scale) and the specific gravity 4 6 The luster is submetallic and the color iron black to brownish black Pure chromite with composition $FeCr_2O_4$ is rare because magnesium usually substitutes for some ferrous iron, and aluminum and ferric iron substitute for chromium Chromite is a common constituent of peridotites and serpentines and in some is present in large masses Major producing countries are Turkey, the Union of South Africa, Russia, the Philippines, and Rhodesia *See* CHROMIUM, PERIDOTITE, SERPENTINE [C S HU]

Chromium

Chemical element number 24, chromium, Cr, is a silver white hard brittle metal Chromium was discovered in 1798 by N L Vauquelin The principal uses for chromium are production of noncorrosive, high strength heat resistant characteristics in alloys or as an electroplated coating



Natural occurrence. Elemental chromium, as such is not found in nature The most important mineral occurrence of chromium is in the form of chromite $FeOCr_2O_3$ which is never found in pure form Some of the FeO is always replaced isomorphically by MgO, and some Cr_2O_3 by Al_2O_3 It also contains silica in varying quantities, and small amounts of other minerals The chemical composition is usually represented by the formula *(Mg Fe) (Cr,Al Fe)$_2$O$_4$ or more simply as MgO* $FeO\ Cr_2O_3\ Al_2O_3\ Fe_2O_3$ Some high grade chromites containing up to 65% Cr_2O_3 are found in nature but these are extremely rare

The usual high grade ore contains 48% Cr_2O_3 with a Cr Fe ratio of approximately 3 1 The iron content is found in widely varying amounts

pentines chlorites and peridotite frequently occur as gangue constituents of the natural chromites The principal chromite-producing countries are the United States Canada Cuba Guatemala and Brazil in the Western Hemisphere Albania Bulgaria Greece Portugal and Yugoslavia in Europe Cyprus Indochina India Japan Pakistan the Philippines Turkey and Russia in Asia Sierra Leone Rhodesia and the Union of South Africa in Africa and New Caledonia Minor occurrences or presently undeveloped reserves have been found in other countries

Metallurgical extraction Chromium is produced in the form of an iron alloy ferrochromium by the reduction of chromite ores with carbon or silicon in the electric furnace Ferrochromium is also produced from chromite by a silicothermic reaction in the presence of a suitable oxidizing agent such as calcium chromate $CaCrO_4$ sodium nitrate $NaNO_3$ or manganese dioxide MnO_2 The latter reaction is exothermic in nature Chromium metal may also be produced by the exothermic reduction (Goldschmidt) of chemically produced Cr_2O_3 using powdered aluminum as the reductant The silicothermic reaction is generally employed to produce ferrochromium of controlled low carbon content (0 03–0 1% C) although low carbon ferrochromium is also produced in quantity by the reduction and removal of the carbon of normal high carbon ferrochrome in a vacuum furnace employing iron oxide chromic oxide or silica The ferrochrome produced by this method is usually of very low carbon content (0 01–0 03%) *See* FERRO ALLOY

Chromium metal is also produced on a commercial scale by electrolysis of an ammonium chromium alum solution prepared either from chromium ore or from high carbon ferrochromium

Chromium metal is produced in more limited quantities by the thermal dissociation of chromium(III) iodide in contact with a suitable heated deposition surface under vacuum conditions (the Van Arkel–de Boer process) This is the purest form of chromium presently available and it generally brings a premium price of $85 125/lb A high purity product is also produced on a commercial scale by the hydrogen reduction of electrolytic chromium

Chromium can be plated electrolytically from chromic acid containing a small amount of sulfuric acid It is also plated by thermal decomposition of [illegible]

[illegible]

by the hydrogen reduction of $CrCl_2$

Uses and alloys One of the principal and most important uses of pure chromium is in its applications for chromium plating Many household appliances are chromium plated as are decorative parts of other manufactured items including automobiles Tools plug gages rolls drum dryers chemical equipment dies mandrels electric appliances gears food machinery kettles pans packing machinery, and many hundreds of other articles are chromium plated where brightness beauty and resistance to wear and rust are necessary or desirable *See* ELECTROPLATING OF METALS

Chromium is used extensively for alloying with iron to form stainless steels special high strength steels (ferritic) and electrical resistance wires with nickel and iron to form nickel stainless steels (austenitic) and with manganese and iron to form chromium manganese stainless steels In steel it prevents corrosion caused by atmospheric conditions corrosive waters acids and high temperature conditions It is insoluble in nitric acid for example *See* STAINLESS STEEL

Chromium is alloyed with nickel in varying quantities to form special heat resistant alloys The composition of these alloys is usually 15 28% Cr and 5–78% nickel

Nickel base alloys of chromium are of particular importance because of their high strength and unique resistance to high temperatures Other metals can be added to the nickel base alloys such as iron Fe titanium Ti columbium (niobium) Cb cobalt Co copper Cu molybdenum Mo and tungsten W to produce modified alloys for specialty uses

Chromium forms with nickel the well known electrical resistance alloy Nichrome which has made possible the large number of modern home appliances such as electric ranges and water heaters

Chromium is alloyed with cobalt for use in producing cutting tools and some tungsten vanadium and carbon are usually added for these applications Stellite is probably the best known commercial form of this type of alloy These materials also possess desirable high temperature properties

Chromium is also used to alloy to a lesser extent with metals such as copper aluminum and titanium *See* ALLOY IRON ALLOYS

Physical properties There are four naturally occurring isotopes of chromium namely Cr^{50} Cr^{52} Cr^{53} and Cr^{54} The crystal structure of chromium is body centered cubic although it transposes to face-centered cubic at 1830°C (3325°F) Other reported structures have turned out to be hydrides

Potentially chromium is ductile at room temperature when pure Pure chromium is difficult to produce however because of its great affinity for oxygen carbon nitrogen and other contaminating elements

Electroplated and polished chromium is bright bluish white Its reflecting power is 77% that of silver

Chromium has a density at 20°C (68°F) of 7 19 g/cm^3 (0 26 lb/in^3)

Electrical properties These properties are largely concerned with the electrical conductivity resistance and current carrying capacity of chromium

The electrical conductivity is 22 2% of that of copper when measured on the basis of the metal in a very pure and annealed form The specific resist

ance at 20°C is 13 0 microhm cm for annealed and electrodeposited chromium

The electrochemical equivalents are for valence of 6 0 08983 valence of 3 0 17965 and valence of 2 0 26940

Mechanical properties These properties relate to the strength and workability of chromium including among others its hardness tensile strength and forging rolling and drawing characteristics Chromium has relatively poor forging rolling and drawing properties However when absolutely free of oxygen hydrogen carbon and nitrogen it is relatively ductile and can be forged and drawn It is difficult to keep it free from these elements Chromium normally demonstrates brittle characteristics which heretofore have led many to believe it to be an inherently brittle metal but more recent work has shown that its brittleness is probably a function of its purity

Chromium has a Brinell hardness (as cast) of 110–170 that of electrodeposited chromium is 550–1250 depending on the hydrogen content Its hardness is 70–90 when annealed

Ch

fourths that of babbit on babbit (sliding)

For powder metallurgy the best hot working temperature is 1250°C (2280°F) and 40 000 psi is the best pressure for compacting

Sintering is best effected at 1300°C (2370°F) in vacuum until gas free followed by heating in an inert atmosphere such as argon at 1600–1700°C (2990–3090°F) to maintain high purity

Typical compositions of chromium from various processing techniques are as follows iodide chromium 99 99+% Cr electrolytic chromium 99 00% thermit chromium 97 00% and electric furnace chromium 97 00% Cr 0 03–0 5% C and 1% Fe

Thermal properties The thermal properties of chromium are generally viewed as those which have to do with its melting point boiling point heat capacity (in the solid liquid and gaseous states) vapor pressure and heat conductivity

Chromium has a melting point of 1930 ± 10°C (3505 ± 20°F) its boiling point is 2480°C (4500°F) at 760 mm mercury Its heat capacity is

or 0 11 cal/

capacity is

The latent heat of fusion is 4 20 cal/mole (80 75 cal/g) The latent heat of vaporization is 76 635 cal/mole (1470 cal/g) The vapor pressure at 2097°C (3807°F) is 10^{-1} atm The thermal conductivity of chromium at 20°C (68°F) is 0 16 cal/(sec) (cm) (°C)

Chemical properties These properties include the principal chemical characteristics of chromium and its typical reactions with other elements and compounds Chromium forms three series of compounds with other elements these can be represented in terms of the chromium oxides

Chromium valence 2 CrO chromium (II) or chromous oxide
Chromium valence 3 Cr_2O_3 chromium (III) or chromic oxide
Chromium valence 6 CrO_3 chromium (VI) or chromic acid

Chromium metal reacts readily with hydrochloric acid and chlorine to form chlorides The metal is soluble in sulfuric acid but insoluble in nitric acid It is oxidized by water vapor at high temperatures and by carbon monoxide at 1000°C It reacts at high temperatures with nitrogen and is attacked by fused alkalies The metal reacts with sulfur vapor and SO_2 at 700°C, and with hydrogen sulfide at 1200°C and it attacks porcelain at 1600°C Electrolytic chromium absorbs 250 times its volume of hydrogen

Chromium and hydrogen form chromium hydride CrH_2 a black powder having a density of 6 77 g/cm³ The heat of formation is 3800 cal/mole of hydrogen It decomposes at 350°C (660°F) and at room temperature on long standing CrH is also formed

Chromium and nitrogen form two nitrides Cr_2N and CrN The solubility of nitrogen in liquid chromium is approximately 4% by weight

Chromium and carbon form three positively known carbides of chromium $Cr_{23}C_6$ Cr_7C_3 and Cr_3C_2 The properties of Cr_3C_2 are well known and it has considerable commercial use It has a hardness (nominal) of 88_A (equivalent to 72 Rockwell C) density of 7 g/cm³ transverse rupture of 100 000 psi and an abrasive resistance much higher than steel but not as high as tungsten carbide Its corrosion resistance is excellent at 1800°F Its electrical conductivity is 2 2% of that of copper at 20°C Its electrical resistance is 80 microhms/(cm) (cm²) at 20°C It is nonmagnetic It is resistant to salt spray and sulfuric and nitric acids and it can be ground and lapped

Chromium and silicon readily form chromium silicides in the electric furnace They vary from soft to hard and brittle depending on the silicon content They are resistant to all acids except hydrofluoric acid

The known borides of chromium Cr_3B_2 CrB CrB_2 and Cr_3B_4 are attacked by acids

Chromium is known to alloy with many metals including aluminum antimony beryllium bismuth carbon cobalt copper gold iron lead manganese molybdenum nickel palladium platinum silicon silver tin titanium vanadium zinc and zirconium

Principal compounds Chromium is capable of forming compounds with other elements in oxidation states of II III and VI The table lists the typical compounds of each valence state with oxygen

Peroxides perchromic acid and perchromates are also known The most widely known compounds include ferrous chromite ($FeOCr_2O_3$) lead chromate ($PbCrO_4$) barium chromate ($BaCrO_4$) so-

Valence states of chromium

Compound	Formula	*Valence* state of Cr
Chromous oxide	CrO	2+
Chromous hydroxide	$Cr(OH)_2$	2+
Chromic oxide	Cr_2O_3	3+
Hydrous chromic oxide (chromic hydroxide)	$Cr_2O_3 \cdot xH_2O$	3+
Chromites	$(CrO_2)^3$	3+
Chromic anhydride	CrO_3	6+
Chromates	$(CrO_4)^2$ and $(Cr_2O_7)^2$	6+

dium chromate (Na_2CrO_4) sodium dichromate ($Na_2Cr_2O_7$) potassium chromate and potassium dichromate (K_2CrO_4 $K_2Cr_2O_7$) chromic acid (H_2CrO_4) and zinc chromate ($ZnCrO_4$) Almost all metals form chromate compounds with chromium Some have extensive use in the production of chromium metal pigments tanning agents textile dyestuffs and dye-fixing agents chromium plating preparations and in numerous organic derivatives

Sulfides of chromium are known but are not used extensively by industry The chromium sulfate $Cr_2(SO_4)_3$ is a common salt of chromium and finds use in the tanning industry The sulfate as well as other chromium salts forms many coordination compounds with H O and NH_3

The halides (chlorides fluorides bromides and iodides) of chromium are fairly common compounds of this metal The chloride for example has been used to some extent in the production of chromium metal by the hydrogen reduction of chromous chloride ($CrCl_2$) The iodide is used to produce very pure chromium metal by application of a modified Van Arkel–de Boer technique

Nitrogen containing chromium compounds include the chromic cyanides such as $(NH_4)_3[Cr(CN)_6]$ the azides $Cr(N_3)_3$ chromic amide $Cr(NH_2)_3$ and chromous nitrate $Cr(NO_3)_2$ The industrial uses of these compounds are somewhat limited

Carbon containing chromium compounds include the carbonate of chromium ($CrCO_3$) the ammonium carbonate $(NH_4)_3Cr(CO_3)_2$ chromium carbonyl $Cr(CO)_6$ and the thiocarbonate $[Cr_2(CS)_3]_3$ which possess limited industrial usefulness

Chromium borates of indefinite composition have also been reported They consist of Cr O_3 and B_2O_3 in varying proportions

Both chromous and chromic salts of acetic acid formic acid oxalic acid and tartaric acid are known and have varying commercial importance

Analytical methods Chromium can be detected and identified via the chromate ion by precipitation as barium chromate ($BaCrO_4$) or lead chromate ($PbCrO_4$) It is also detected by the change in coloration of the chromate ion from orange to bluish green when a solution of chromate is treated with ferrous ammonium sulfate More modern methods of detection include the spectrograph x ray analysis polarographic analysis and flame photometry

There are several principal methods in use today for determining chromium (1) the gravimetric method by precipitation and weighing as $BaCrO_4$ or by precipitation and weighing as Cr_2O_3 (2) volumetric methods such as the ferrous ammonium sulfate titration of a chromate with back titration of the excess ferrous ammonium sulfate with potassium permanganate it can also be determined volumetrically by the iodometric method in which [illegible] bromate sol[illegible]

Chromium in small amounts may be detected by the colorimetric method using s-diphenylcarbazide as indicator *See* TRANSITION ELEMENTS [M.J.U]

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Chromomycosis

A cutaneous fungus infection of man also known as chromoblastomycosis It is usually seen on the legs feet and occasionally the arms Three fungi are most frequently associated with this disease *Hormodendrum pedrosoi Hormodendrum compactum* and *Phiolophora verrucosa*

The lesion begins as an itchy papule slowly developing into a reddish warty nodule which eventually becomes pedunculated As the disease progresses secondary nodules develop and often coalesce to give rise to a large lesion cauliflower like in appearance Chromomycosis is most frequently seen in agricultural workers probably because of their repeated contact with the soil and frequent trauma to the skin The etiological agents are believed to reside in soil and on plants If the lesions are seen in an early stage of development they may be removed by surgical excision The injection of an antibiotic Amphotericin B into the lesions has been reported to be successful in some instances *See* ANTIBIOTIC MONILIALES MYCOLOGY MEDICAL [L.D.H]

Chromosome

A threadlike structure of complex organization which is part of the nucleus in animal and plant cells and carries in linear order the Mendelian factors of inheritance or genes Chemically it consists of deoxyribonucleic acid combined with certain basic proteins and in most cells variable amounts of a more complex protein and ribonucleic

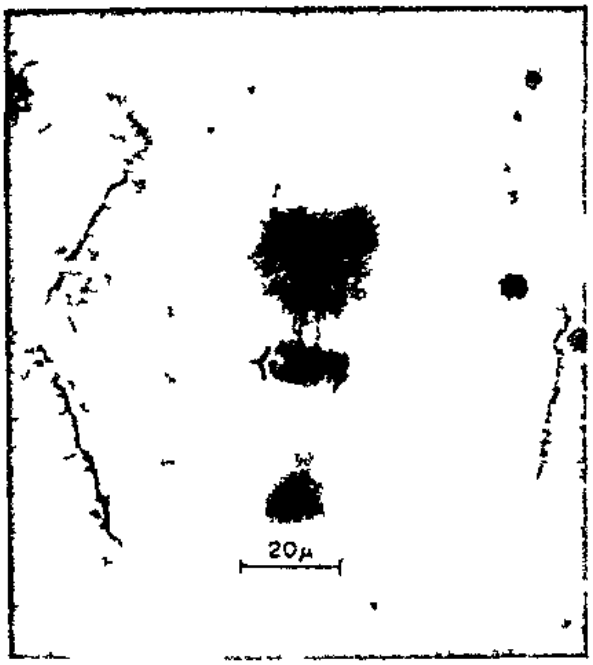


Fig 1 Early anaphase separation of chromosomes during cleavage of a whitefish egg

acid New chromosomes originate only through duplication of preexisting ones This usually occurs just prior to cell division During mitosis chromosomes coil up into compact rodlike bodies Daughter chromosomes are moved by special cell structures to opposite sides of the cell (Fig 1) where they swell and uncoil again to form the nuclei of the daughter cells (*see* MITOSIS)

Chromosome number Each species has a characteristic set of chromosomes making up its karyotype and representing the whole of its genetic endowment or genom Examples of chromosome numbers are listed below Each type of chromosome contains a definite group of genes known as a linkage group Every cell must normally contain at least one chromosome of each type that is one complete set of chromosomes if it is to live and develop In sexually reproducing organisms the fertilized egg and the cells derived from it generally contain two sets of chromosomes one derived from the egg nucleus the other from the sperm Each chromosome is consequently matched with a homologous chromosome The gametes the egg and sperm have only one set A cell containing one set of chromosomes is called haploid (n) if two sets are present it is diploid ($2n$)

Man	46	Lily (*Lilium* spp)	24
Rhesus monkey	42	Onion	16
Cebus monkey	54	*Icerya* (scale insect)	4
Cattle	60	Fruit fly (*Drosophila melanogaster*)	8
Rat	42	Radiolaria	over 800

Sex chromosomes In many sexually reproducing forms so as to assure a regular inheritance of maleness and femaleness the sex factors are located on a special chromosome pair A mixing of the sex factors is prevented through mechanisms that bar recombination between these chromosomes and therefore they often develop structural differences Usually one of the partners is larger It is *called the X chromosome and carries the factors* for femaleness The smaller one is the Y chromosome (Fig 2) The male determiners may be located in the Y chromosome as apparently in man or in one or several of the other chromosomes or autosomes as in the fruit fly In many species where maleness is determined by autosomes the Y has been lost

The sex is generally determined by a balance in sex factors that is by the ratio of X to Y chromosomes or X to autosomes Since the female carries two X chromosomes all the eggs contain one X The male being XY forms two types of sperm cells those carrying an X and those carrying a Y Chance fusion of eggs and sperm thus results in equal numbers of females (XX) and males (XY) In a few groups of animals such as moths amphibians and birds the situation is reversed and the males are XX and produce only one type of sperm cell In this case the males are the homogametic sex while the female is XY or XO and forms two types of eggs that is to say is heterogametic *See* SEX DETERMINATION

Chromosome morphology Most characteristic of chromosomes in general is a variable degree of helical coiling ranging from a loose irregularly twisted thread to a tightly packed helical coil Also in general chromosomes are least coiled in the nondividing cell and most tightly coiled during cell division In the latter stage they are most clearly seen and individually recognized They vary in size from one below visibility in the light microscope to about $3 \times 30\ \mu$ Large chromosomes are found in salamanders grasshoppers lilies and spiderworts



Fig 2 The 46 chromosomes in a human male Squash of dividing cell X and Y are the sex chromosomes (*From J H Tjio and T T Puck Proc Natl Acad Sc 44 1229 1958*)

The thinnest coiled thread that is shown by the light microscope is called the chromonema In large chromosomes two or even four chromonemata are visible within a single chromosome Each half chromosome is called a chromatid These are the units of genetic recombination, by means of crossing over, during meiosis

The basic morphology of a chromosome at metaphase of mitosis is shown in Fig 3 Figures 4 and 5 illustrate the coiling cycle during cell division In early stages a large number of small gyres is seen As the chromonema slowly unwinds, the gyres get wider and decrease in number, and the chromosome becomes thicker and shorter until the gyres are so tightly packed that the chromosome looks uniformly dense After they have moved apart the daughter chromosomes unravel and the helix becomes an irregularly wound thread Figures 6–8 show plant chromosomes treated to reveal the helical structure In some cells two such coiling cycles may overlap and the chromosomes are then doubly coiled (Fig 6) The fine small turns of the fiber form a minor coil which is itself helically coiled to form the major coil The chromonemata within a chromosome are coiled so that they can separate and do not interlock (a paranemic coil Fig 9a) Sometimes chromatids may be wound around each other to form a relational coil (Fig 9b) The direction of coiling is either clockwise or counterclockwise and may change within a chromosome arm Nothing is known about the causes of this coiling The degree of coiling along the chromosome is not constant but is often variable Certain regions remain tightly coiled even in the nondividing nucleus and appear there as darkly staining clumps among the fine throng of unravelled strands These regions of chromosomes are called heterochromatin (Figs 4 and 5) Euchromatin is that part of chromosomes which regularly unravels at the end of cell division Since heterochromatin represents specialized chromosome regions that are clearly recognizable, at least morphologically there has been much interest in its genetic and physiological significance Though there are indications that genetically and biochemically its activity is different from that of

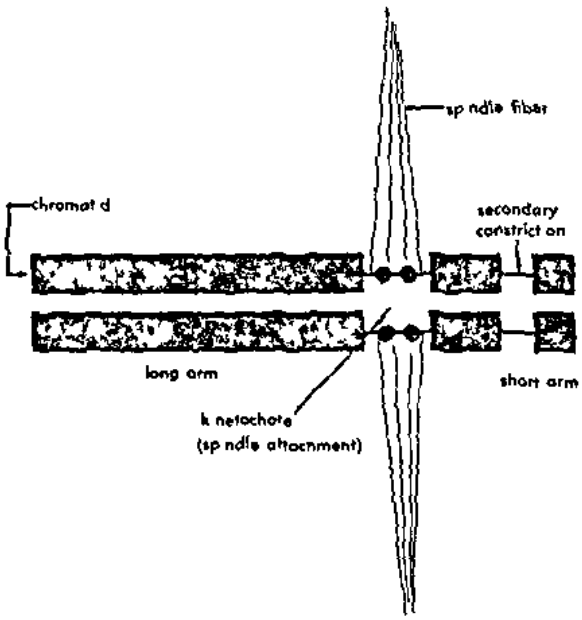


Fig 3 Diagram of a metaphase chromosome

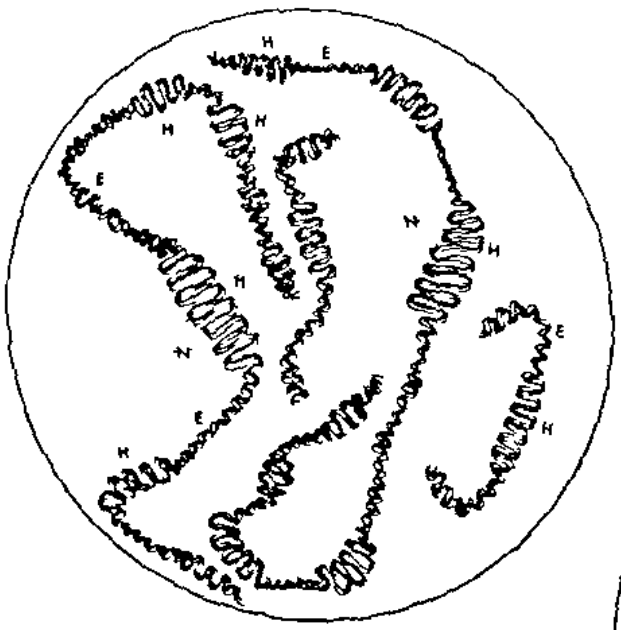


Fig 4 (Above) Diagram of an interphase nucleus (nondividing cell) N is nucleolus H is heterochromatin E is euchromatin

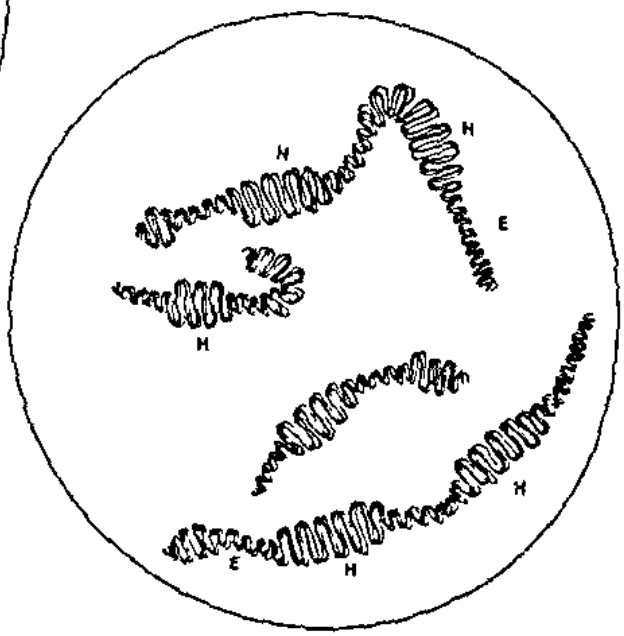


Fig 5 (Right) Diagram of nucleus in early prophase H is heterochromatin E is euchromatin

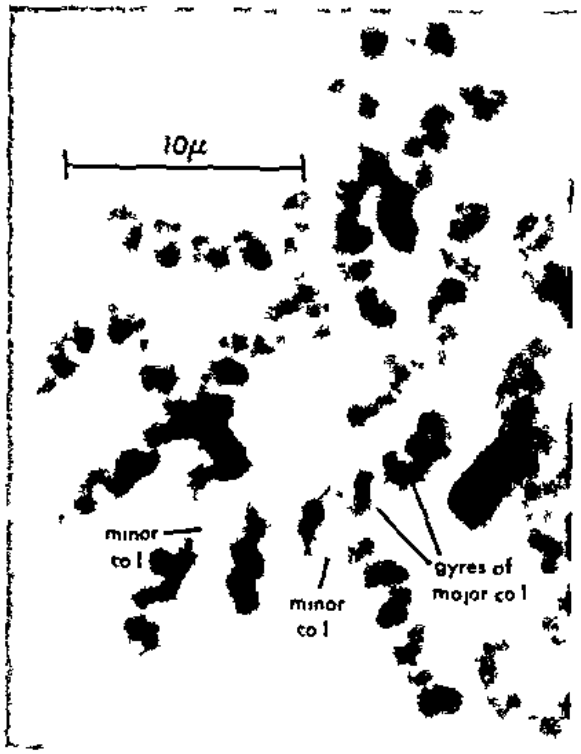


Fig 6 Chromosomes from a microsporocyte division in *Lilium* Pretreated to reveal coiling

the euchromatin, not enough is known to make any definite statements about the significance of these chromosome regions

In the early stages of coiling during prophase of mitosis many chromosomes show small beadlike structures which are short, tightly coiled areas of the chromonema and are called chromomeres The pattern of chromomeres along a chromosome is rather constant for any single type of cell and is an expression of a basic differentiation along the length of the chromosome which reveals itself under certain conditions in a differential degree of coiling However, this pattern is not always present and the chromonemata may be completely straightened out, as in the sperm nuclei of some animals (Fig 11)

Chromosome chemistry. The chemical composition of chromosomes is studied either by cytochemical methods in microscopic preparations or by chemical analysis of chromosomes isolated from nondividing cells of various tissues by mechanically breaking up cells and nuclei and separating out the chromosomes by differential centrifugation Chromosomes contain mainly deoxyribonucleic acid (DNA), ribonucleic acid (RNA), histones or protamines and a fraction of large complex proteins (residual protein) With very few exceptions such as in egg cells DNA occurs only in the chromosomes and is always present in them It is made up of smaller units the nucleotides which themselves consist of a sugar (deoxyribose) a phosphate residue and a nitrogenous base Four different nitrogenous bases, two purines and two pyrimidines are present and there are therefore four different nucleotides In some organisms a fifth base is found in small concentrations Many hundreds of nucleotides are combined to form a long chain In the DNA molecule two such chains are coiled around each other and form a double helix All the evidence indicates that the genetic properties of the chromosomes reside in the DNA molecules and that the genetic specificities along the chromosome are based on the specific pattern in which the four

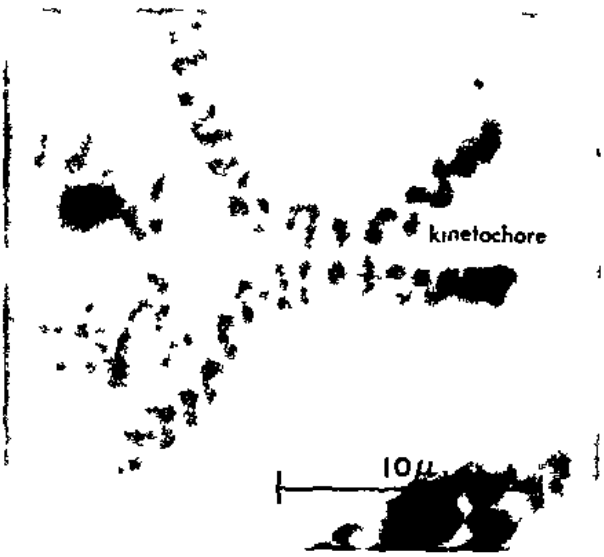


Fig 7 Chromosome from microsporocyte division in *Trillium*

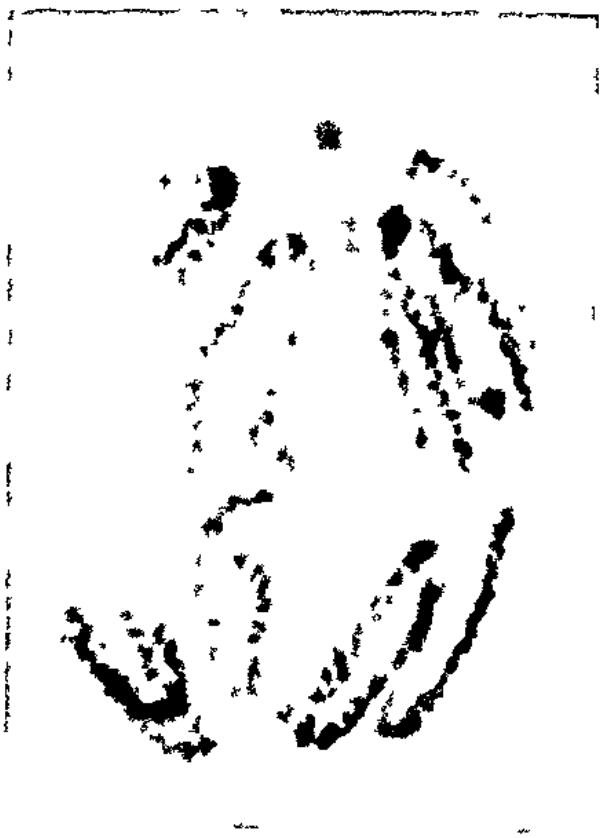


Fig 8 Anaphase in microsporocyte division of *lium* showing coiling of chromosomes.

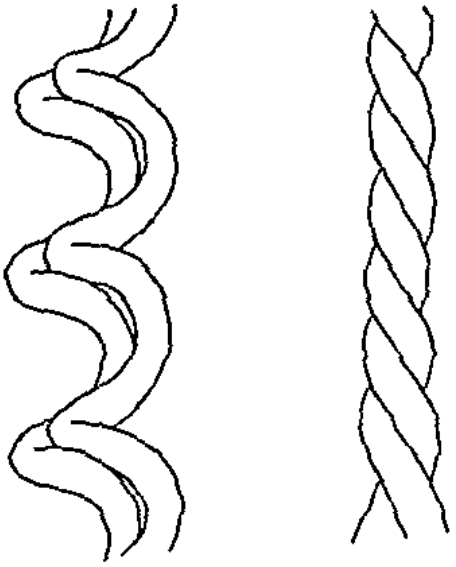


Fig 9 Diagram of chromosome coils (a) Paranemic coils such that the strands can separate (b) Relational coil such that strands must untwist in order to separate

nucleotides follow each other The DNA content of chromosomes is determined cytochemically by measuring the absorption in the ultraviolet with the ultraviolet microscope (ultraviolet cytospectrophotometry) or measuring the amount of DNA combined in the Feulgen reaction The DNA content of entire nuclei is obtained from chemical determinations based on a known number of isolated nuclei The synthesis of new DNA is detected by giving the cells a precursor of DNA labeled with a radioactive element (C^{14} P^{32} or H^3) and visualizing the presence of the label by means of autoradiography As a rule the amount of DNA per chromosome set is constant for a species and new DNA is made only during chromosome reproduction The characteristic DNA content of the diploid nucleus in some animals is listed below in billionths of a milligram Once formed the DNA molecule is

Sponges	0 12	African lungfish	100
Limpet	1 0	*Amphiuma* (salamander)	168
Squid	9 0	Frog	15
Crab	*28*	Turtle	5 0
Shark	6 5	Domestic fowl	2 3
Shad	2 0	Rat	6 1
		Man	6 2

stable and breaks down only with death of the cell The histones are basic proteins combined with the DNA by twisting around the DNA double helix In sperm cells of many animals the histones are replaced with smaller and more basic *proteins the* protamines The total amount of histones per chro*mosome* set is also relatively constant *See* DEOXYRIBONUCLEIC ACID

The residual protein fraction and the RNA which seems to be combined with it on the other hand vary in amounts depending on the physiological state of the cell More is present in cells with active synthesis Sperm nuclei contain a minimum and in some species none at all *See* AUTORADIOGRAPHY NUCLEIC ACID

Fine structure of chromosomes X ray diffraction studies suggest that the histone or protamine is wound around the DNA double helix the basic residues of the protein bound to the phosphoric acid residues of the DNA These nucleoprotein molecules are about 4000 A long and 40 A thick and are lined up end to end to form long fibers These fibers are visible in electron micrographs of nucleohistone preparations and in the nucleus of developing sperm cells (Fig 10) Two such fibrils are always associated to form a larger unit In the presence of residual protein these two fibrils appear as a solid unit about 100 A thick and this seems to be the basic element of all chromosomes (Fig 11) It is likely that these fibrils run through the entire length of the chromosome, several of them seem to be present so that the chromosome is generally multistranded Figure 12 shows an electron micrograph of a chromosome in early prophase of a plant microsporocyte (*Tradescantia*), and Fig 13 represents a wire model of such a chromosome In Fig 12 the multistranded chromosome consists of two bundles or chromatids each containing about 16 fibrils 100 A thick These are associated in pairs which show up as single coiled fibrils about 200 A thick The whole chromosome contains about 64 DNA double helices with associated protein The chromosome fibrils are most

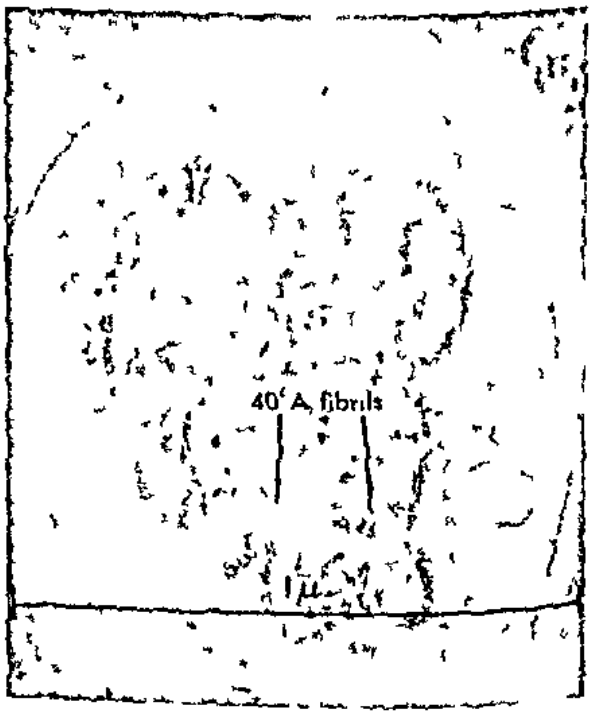


Fig 10 Electron micrograph of a thin cross section through the nucleus of a developing sperm in the water scorpion *Ranatra* Note the pairs of 40 A fibrils (arrows)



Fig 11 Electron micrograph of a longitudinal section through a developing sperm of the octopus Note oriented microfibrils 100 A thick in the nucleus

visible in the developing sperm cells of some animals where they are unraveled and are oriented parallel to the long axis of the nucleus (Fig 11)

Special chromosomes. Salivary gland chromosomes and lampbrush chromosomes are discussed in this section

Salivary gland chromosomes In larval tissues of dipteran insects one finds chromosomes of unusually large size They are most conspicuous in the salivary glands, where they may reach 300 μ in length and 20 μ in width Their constant and specific banding pattern (Fig 14) has made it possible, in the fruit fly *Drosophila*, to correlate genes with specific regions of chromosomes in greater detail than in any other organism Chromosome maps have been developed in which hundreds of genes are allocated to specific bands on the chromosomes It is not completely understood how these chromosomes develop from the more ordinary ones in the cells of very young larvae where mitosis still occurs Certainly involved is a repeated reproduction of chromosomes without cell division, a process known as endomitosis The many chromonemata produced in this way remain together in a multistranded bundle They are therefore called polytene chromosomes Multistranded chromosomes occur in other forms, for instance, in the antipodal cells of female gametophytes and in the endosperm of flowering plants But only in dipteran chromosomes is there that close association of homologous chromosome regions which is responsible for the regular banding pattern

Lampbrush chromosomes Another type of chromosome of unusual size is found in oocytes of many animals especially in fishes, amphibians, reptiles, and birds The structure of the lampbrush chromosomes, however, is very different from that of

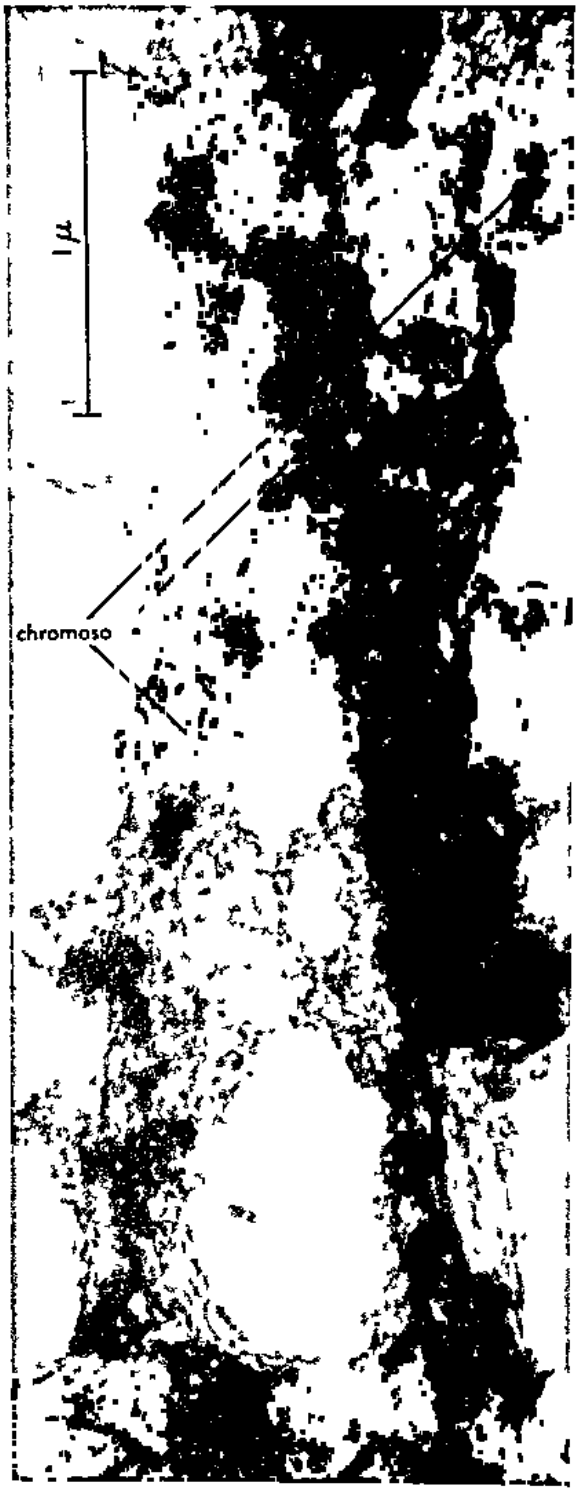


Fig 12 Electron micrograph of three intact chromosomes from a microsporocyte of *Tradescantia* in early prophase They were squeezed out of the cell after fixing

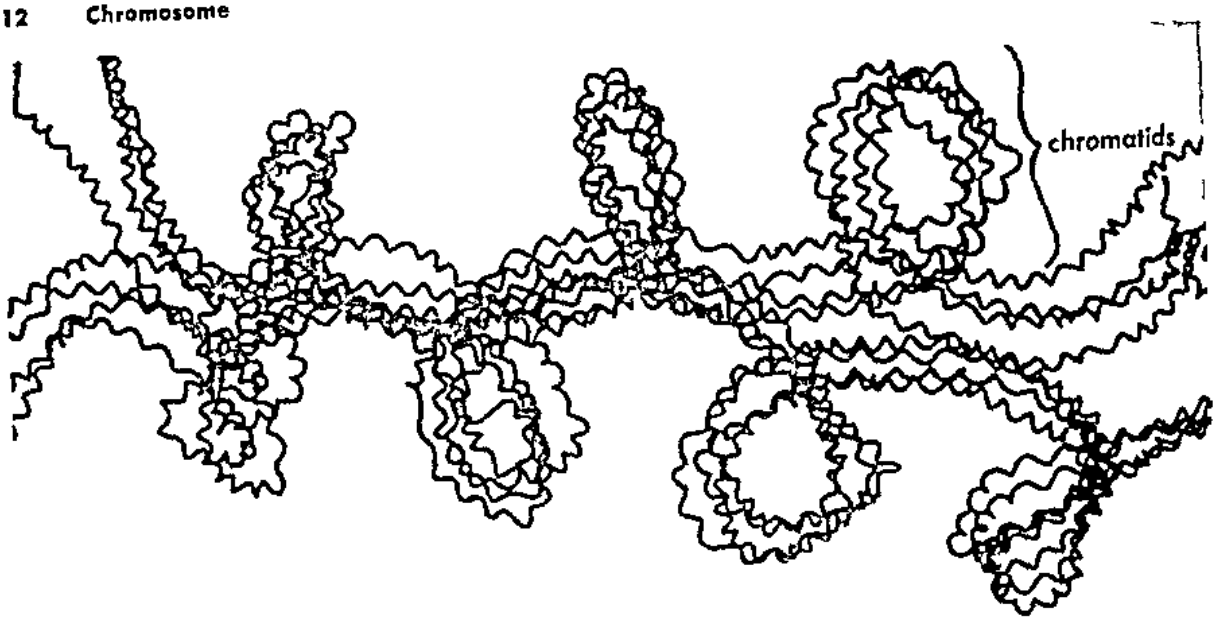


Fig 13 Wire model of a chromosome in early prophase to show the coiled microfibrils and the two coiled bundles

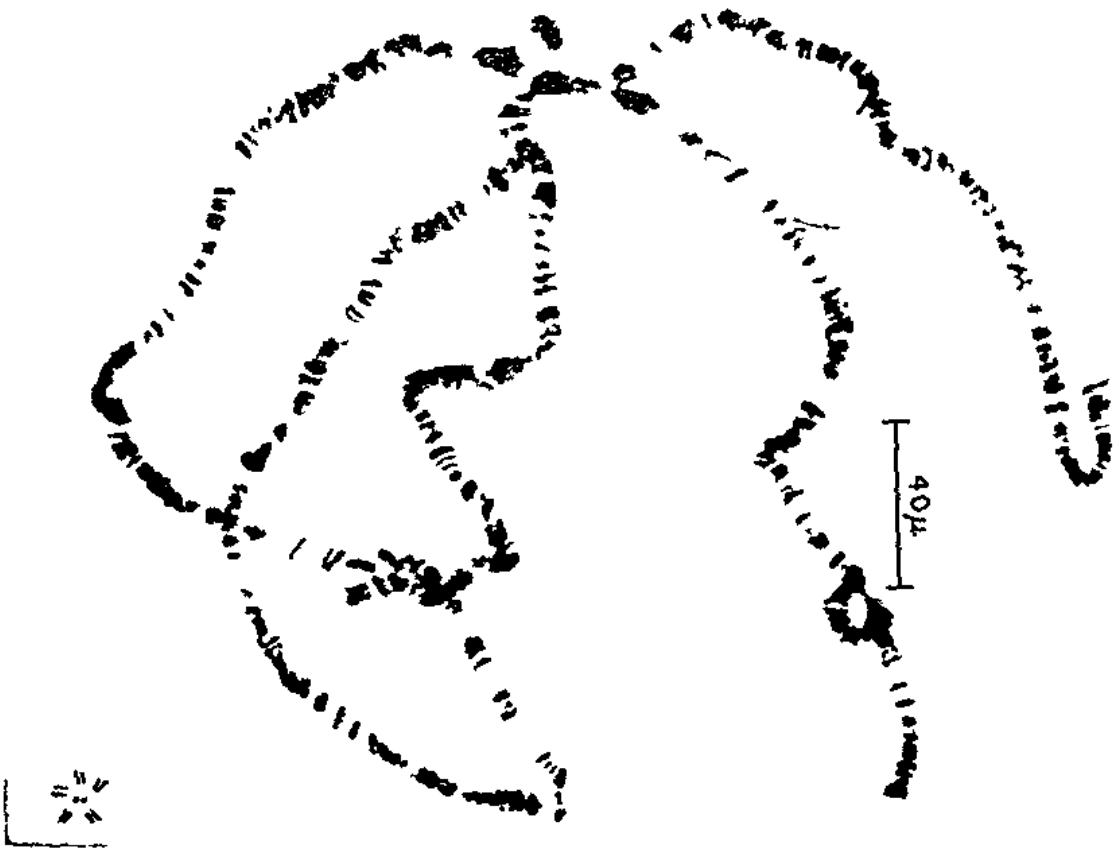


Fig 14 Salivary chromosomes of *Drosophila virilis*, showing five long and one short chromosome pairs The nucleus was squashed to flatten and straighten out the chromosomes The drawing in the corner shows the metaphase chromosomes in a normal diploid cell at the same magnification



Fig 15 Piece of a lampbrush chromosome from the oocyte nucleus of a salamander, *Pseudotriton* (*From J G Lafontaine and H Ris J Biophys Biochem Cytol, 4 99, 1958*)

dipteran salivary gland chromosomes No chromosome reproduction or DNA synthesis takes place during their growth Their increase in size, which is many hundred fold, is instead related to an increase in residual protein and RNA This seems to involve an enormous growth in length of the chromonemata, which develop into loops of various sizes between darkly staining heterochromatic parts The chromosomes thus attain a definite brush like appearance This growth of the chromosomes occurs during meiotic prophase as the egg cells grow

the chromosomes reflects their involvement in the work of the cell The lampbrush chromosomes are paired and show chiasmata, because their maximal size is reached in the diplotene stage Figure 15 shows such a chromosome pair from an oocyte of the salamander *Pseudotriton* As the growth of the egg cell draws to a close the chromosomes decrease in size again until, in the first maturation division, they may be reduced to one thousandth of their maximal volume Just as the salivary gland chromosome is most useful to relate the genetic sequence along the chromosome to a morphological *pattern, so the lampbrush chromosome may be of* help in understanding how intense metabolic activity expresses itself in chemical and structural modifications of chromosomes *See* CYTOLOGY, GENE, GENETICS [H RI]

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Chromosome aberration

A change in the normal complement (karyotype) of chromosomes This may occur either by heteroploidy, which is the modification of the basic chromosome number, or by structural changes within chromosomes

Heteroploidy. The chromosome number may be altered by entire sets of chromosomes or by the addition or subtraction of one or more individual chromosomes These modifications are summarized below

Types of heteroploidy

1 Euploidy variation by entire chromosome sets triploid ($3n$), tetraploid ($4n$), , 10 ploid, and so on
   - *a* Polyploidy chromosome number in germ cells, and therefore basic number in the entire organism, is changed
   - *b* Polysomaty germ cells are not affected, cells in many tissues have variable multiples of the diploid number

   Origin chromosome duplication without a succeeding nuclear division (endomitosis), inhibition of cell division and fusion of daughter nuclei, producible experimentally by treatment with colchicine
2 Aneuploidy variation by one or more individual chromosomes
   - *a* Polysomy variation is regular and affects germ cells and therefore entire organism
     Example aa *bbb*, cc, dd, ee single trisomic
     aa, bbb, cc, dd, eee double trisomic
   - *b* Somatic aneuploidy irregular variation in a few cells of a tissue, occurs commonly in tumors and in cells grown in tissue culture, constant reproduction from an altered cell can give rise to a mass of cells with a new chromosome number

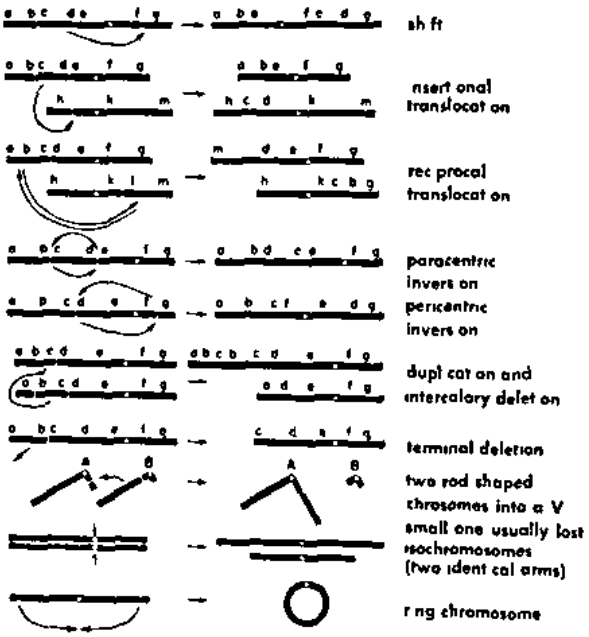


Fig 1 Common chromosomal alterations

Origin accidents during cell division—daugh ter chromosomes failing to separate and becom ing included in one daughter nucleus or being left out of both daughter nuclei

Structural changes The karyotype of an animal or plant may be altered not only by entire chromo somes or chromosome sets but also by structural changes within chromosomes These are brought about through fracture of chromosomes and the rejoining of broken ends in new combinations Chromosome breaks are caused by a variety of agents They occur spontaneously that is because of unknown factors and can be increased in fre quency by experimental means such as radiation (x rays electrons protons neutrons ultraviolet) or by certa

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tachments and thus are torn apart during chro mosome movement

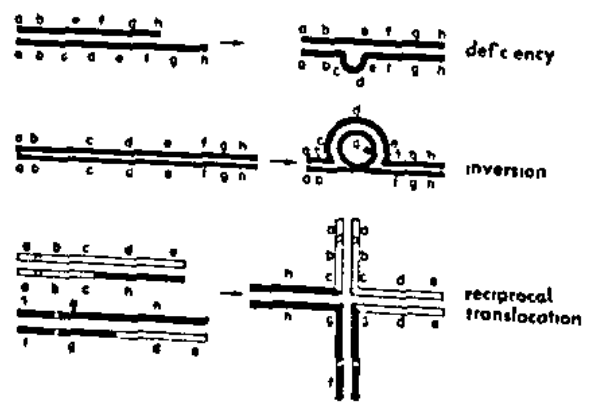


Fig 2 Abnormal chromosomal pairing patterns caused by chromosomal alterations

Broken ends are unstable and tend to rejoin either in the old alignment, or, if more than one break is present, in new combinations The most common chromosomal alterations are shown in Fig 1 These changes in the karyotype can be detected either genetically, since the linear ar rangement of certain genes will be altered or, in favorable cases cytologically by examination of the chromosomes themselves The salivary chromo somes of dipterans with their detailed banding pattern are best suited for this purpose In some organisms the pachytene pattern of chromomeres can show such structural changes on a coarser scale Furthermore since the pairing of chromo somes in prophase of meiosis is highly specific, any change in sequence will show up in chromosome pairs where one partner is normal and the other changed (structural heterozygote) The same holds true where pairing occurs in somatic cells, as in the larvae of flies Figure 2 illustrates some of the abnormal pairing patterns caused by chromosomal alterations Numerical and structural chromosome alterations have been a very important tool of the geneticist to test the chromosome theory of in heritance It has also been shown that together with gene mutations they play a major role in evolution In every population of organisms such altered karyotypes exist in variable frequencies and form a source of genetic variability which is a basis for the development of new types of organ isms *See* CHROMOSOME [H RI]

Chromosome theory of heredity

W S Sutton and T Boveri postulated in 1902 that the behavior of chromosomes at meiosis pro vides a physical mechanism for the segregation and independent assortment of Mendelian factors if it is further assumed that the genes are in or form a part of the chromosomes This postulate has been substantially verified and proof has been derived from a number of parallelisms between the behav ior of genes and chromosomes as well as by proof that specific genes are located on specific chromo somes *See* CHROMOSOME, GENE, MEIOSIS, MEN DELISM

As part of the general problem of sexual repro duction it is recognized that the egg and sperm form the physical bridge between generations, that sperms and eggs contribute equally to the genotype of the offspring as demonstrated by the similarity of F_1 individuals from reciprocal crosses, that the sperm is largely nuclear, and consequently, that the nucleus is the physical site of hereditary de terminants, and that of the nuclear components only the chromosomes are distributed in an exact and meticulous way during cell division and gam ete maturation A search for genetic and cytologi cal parallels reveals a number of suggestive coin cidences (1) genes occur in pairs in a sexual individual as do chromosomes, with the paired genes and chromosomes derived from paternal and maternal sources, (2) members of a gene

pair segregate when the gametes are formed as do members of chromosome pairs (3) certain genes segregate at random from other genes and a similar behavior is exhibited by chromosomes of different pairs (4) linkage studies show the genes to be arranged in linear order while the chromosome can be observed to be physically differentiated along its length and (5) the number of linkage groups in any organism never exceeds the number of pairs of chromosomes *See* LINKAGE GENETIC

Specific proof that the chromosomes are the physical carriers of hereditary determinants has been obtained from studies involving the inheritance of a genetic trait associated with sex in *Drosophila melanogaster* and the distribution of a pair of chromosomes known to be concerned with sex determination Females of this species possess a pair of sex determining chromosomes designated as XX males have only one of these chromosomes the other being replaced by a Y chromosome carrying no comparable genes The males chromosomal composition therefore is XY When a cross is made (Fig 1) the transmission of the genes determining eye color [red (W) versus white (w)] among the phenotypes of the F_1 and F_2 generations is exactly that expected according to the distribution of the X chromosomes and the dominancy and recessiveness of genic expression The reciprocal cross in which the female is homozygous for red eyes (WW) and the male is white eyed (wY) gives a different F_2 population but again the parallelism

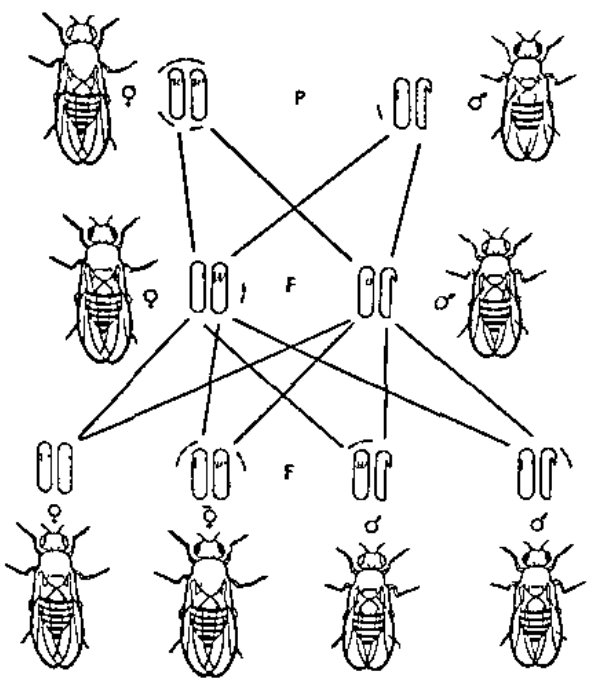


Fig 1 Cross of a white-eyed female (♀) *Drosophila melanogaster* with a red-eyed male (♂) Illustrating the transmission of a gene located in the X chromosome (From E W Sinnott L C Dunn and T Dobzhansky *Principles of Genetics 5th ed* McGraw Hill 1958)

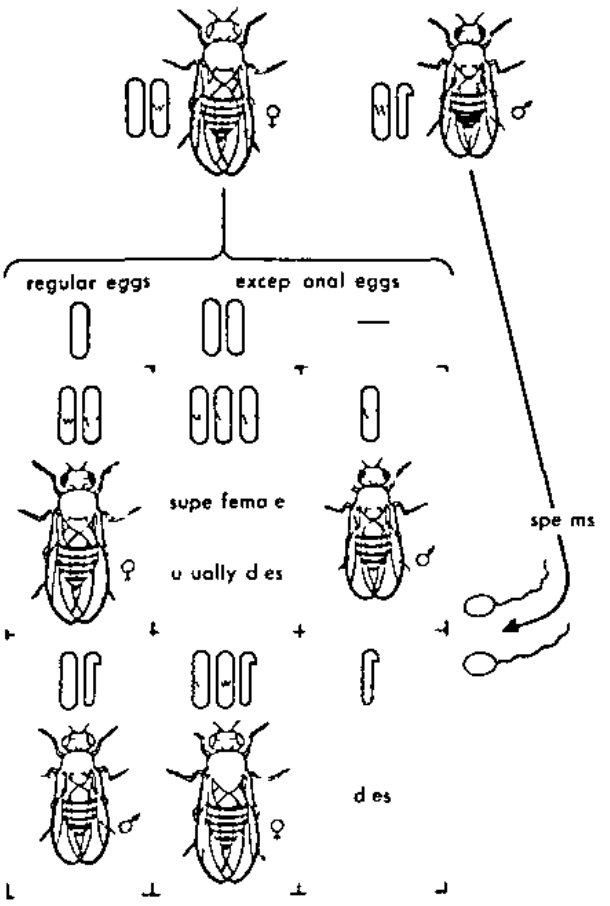


Fig 2 Diagram of E B Bridges nondisjunction studies which prove that the W gene is located on the X chromosome (From E W Sinnott L C Dunn and T Dobzhansky *Principles of Genetics 5th ed* McGraw Hill 1958)

between the segregation of eye color and the distribution of X chromosomes is exact *See* SEX DETERMINATION SEX LINKED INHERITANCE

Further proof was provided by C B Bridges in 1915 (Fig 2) Using the same cross indicated in Fig 1 Bridges noticed an occasional red eyed male

eggs carrying either two X chromosomes or none The phenomenon was called primary nondisjunction Normal fertilization of a two X egg would give either a superfemale with three X chromosomes or a white eyed female with a Y chromosome in addition to two Xs An egg lacking an X chromosome would give a red eyed male if fertilized by an X bearing sperm a nondeveloping zygote if fertilized by a Y bearing sperm In each exceptional male or female the predicted chromosomal composition was found to establish beyond reasonable doubt that the gene determining eye color was located in the X chromosome Similar studies in other organisms have yielded the same explanation *See* GENETICS *see also* BREEDING (ANIMAL) BREEDING (PLANT) [C P SW]

Chromosphere

A transparent tenuous layer of gas in the atmosphere of the Sun resting on the visible surface or photosphere The chromosphere is between 10 000 and 20 000 kilometers (km) thick It is a thermal buffer zone between the low temperature at the top of the photosphere (4400°K) and the high temperature of the corona (1 or 2×10^6°K) The structure of the chromosphere consists of a homogeneous atmosphere with a negative height density gradient in which are embedded forests of hairy spikes known as spicules The spicules are conspicuous above the 4000-km level where they are much brighter than the homogeneous background *See* SUN [J W E]

Chronograph

An instrument that records time intervals It is useful in timing events in a laboratory in timing the transit of celestial bodies in astronomical observatories and in timing races In its most common form it consists of a drum rotated at constant speed often by means of a weight The drum carries a sheet of paper and an electromagnetic stylus impresses a signal upon the chart for reference

In Europe a stop watch is often called a chronograph *See* TIME INTERVAL MEASUREMENT [W G B]

Chronometer

A large and strongly built watch especially designed for precise timekeeping on ships at sea The name is sometimes loosely applied to any fine watch

The features that distinguish a chronometer from a watch are (1) a heavy balance wheel the axis of which is kept always vertical by mounting the entire instrument within two concentric rings so pivoted as to permit the chronometer to remain undisturbed despite considerable tilting of the box containing it as the ship rolls and pitches (2) a balance spring wound in cylindrical shape instead of a nearly flat helix (3) a special escapement, and (4) a fusee by means of which the power of the mainspring is made to work through a lever arm of continuously changing length being shortest when the spring is tightly wound and longest when it has run down thus regulating the transmitted power so that it is approximately constant at all times

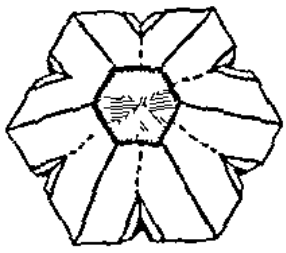
Ocean going ships during a voyage formerly relied completely on chronometers keeping Greenwich mean time as a means for determining longitude The broadcasting of radio time signals that became widespread in the decade 1920–1930 has made Greenwich mean time available to mariners at almost any time of day and chronometers are no longer indispensable for determining longitude at sea *See* CLOCK [G M C]

Chronoscope

An instrument that indicates short time intervals Essentially a laboratory instrument, it may be based upon the vibrations of a tuning fork the rate of decay of a capacitance, or other means *See* TIME INTERVAL MEASUREMENT [W G B]

Chrysoberyl

A mineral having composition $BeAl_2O_4$ and crystallizing in the orthorhombic system Chrysoberyl crystals are usually tabular parallel to the front pinacoid and frequently in pseudohexagonal twins (see illustration) There is good prismatic cleavage The hardness is 8 5 (Mohs scale) and the specific gravity is 3 7–3 8 The luster is vitreous and the color various shades of green, yellow and brown There are two gem varieties of chrysoberyl Alexandrite one of the most prized of gem stones is an emerald green but in transmitted or in artificial light is red Cat's eye or cymophane is a green chatoyant variety with an opalescent luster When cut en cabochon it is crossed by a narrow beam of light This property results from minute tabular cavities that are arranged in parallel position



Orthorhombic pseudohexagonal twinned crystals of chrysoberyl (*From* C S Hurlbut, Jr , *Dana's Manual of Mineralogy, 16th ed , Wiley, 1952*)

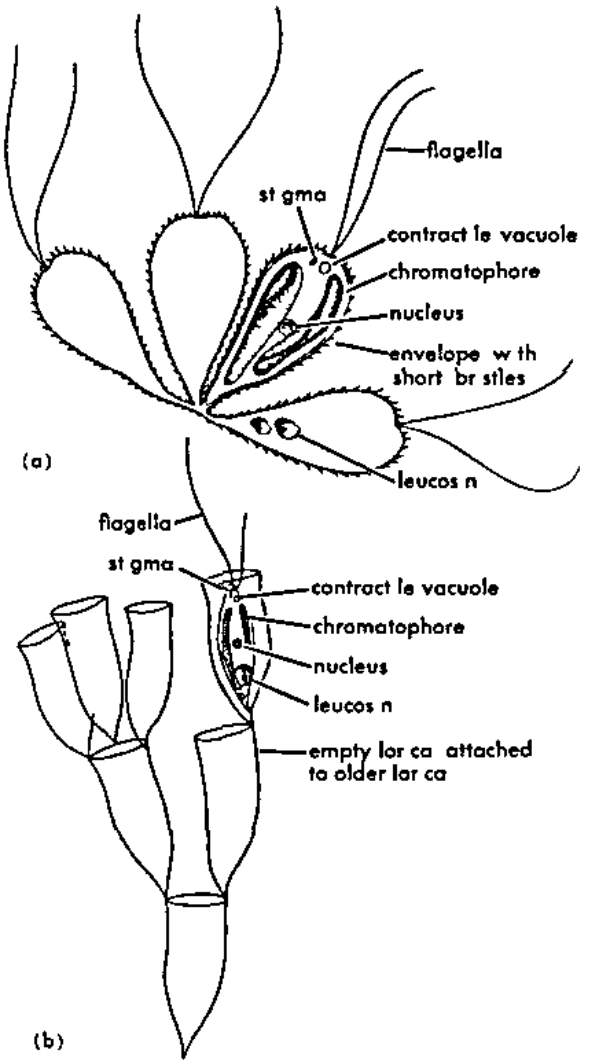
Chrysoberyl is a rare mineral found most commonly in pegmatite dikes and occasionally in granitic rocks and mica schists Gem material is found in stream gravels in Ceylon and Brazil The alexandrite variety is found in the Ural Mountains In the United States chrysoberyl is found in pegmatites in Maine Connecticut, and Colorado *See* BERYLLIUM, GEM [C S HU]

Chrysocolla

A silicate mineral composition $CuSiO_3 \cdot 2H_2O$ Small acicular crystals have been observed but it ordinarily occurs in impure cryptocrystalline crusts and masses with conchoidal fracture The hardness varies from 2 to 4 on Mohs scale, and the specific gravity varies from 2 0 to 2 4 The luster is vitreous and the color normally green to greenish blue may be brown to black when impure Chrysocolla is a secondary mineral occurring in the oxidized zones of copper deposits where it is associated with malachite azurite native copper and cuprite It is a minor ore of copper [C S HU]

Chrysomonadida

An order of the class Phytomastigophorea Chrysomonads also known as Chrysomonadina are usually small flagellates *Mallomonas* being about the



(a) Port on of colony of *Synura uvella* Cells vary from 20 to 40 μ colon es from 100 to 400 μ (b) *D nobryon sertular a* show ng colony organ zat on Ind v dual cells measure 30–44 μ

largest They are yellow to brown because of phycocrysin in the usual one or two chromatophores but some lack chromatophores *Uroglena* colonies may be quite large Many species form d agnostic siliceous cysts Palmelloid colonies (*Hydrurus*) consist of a tough gelatinous matrix holding many nonflagellate cells Starch is not formed but fats are and the refractive carbohydrate leucosin is common The flagella are usually two rarely three and are subequal Nuclei are small

Synura and *Dinobryon* are colonial types which produce enough oil to be a source of tastes and odors in drinking water *Dinobryon* often shows large numbers of cysts in the open ends of empty tests of old colonies Chrysomonads may ingest food through the area near the flagellar base Chrysomonadida are common in cooler fresh water and certain types (Coccolithophora Silicoflagellata) abound in the ocean *See* COCCOLITHOPHORIDA PHYTOMASTIGOPHOREA SILICOFLAGELLATA

[J B L]

Chrysophyta

A phylum of plants often called the golden brown algae because they have a yellow green or golden brown color The pigments localized in the plastids (chromatophores) are chlorophyll carotenes and xanthophyll The predominance of the last two pigments named is responsible for the color of these algae (*see* CAROTENOID CHLOROPHYLL) Instead of forming starch the cells of these algae produce and store the excess photosynthate (food) as droplets of oil and as granules of an insoluble carbohydrate called leucosin

Morphology Structurally these plants range from predominantly unicellular to colonial species but in a few cases multicellular individuals occur which may be coenocytic Usually the cell wall is composed of two overlapping halves frequently impregnated with silica Motile vegetative cells bear flagella which may be equal or unequal in length (Fig 1) For the most part reproduction is asexual by means of cell division zoospores (swimming spores) or immobile spores In many genera there is formed a unique silicified resting cyst the statospore which appears in no other group of algae Sexual reproduction is commonly isogamous but oogamy occurs in a few species

Classification The phylum is made up of three classes—the Xanthophyceae or yellow green algae the Chrysophyceae or golden brown algae and the Bacillariophyceae or diatoms These three classes are known to include more than 300 genera and 6000 mainly microscopic species three fourths of which are fresh water forms and one fourth marine The suggestion that the three classes are related was first made in 1914 Since that time accumulated data have shown that the common features are widespread and the grouping into the phylum Chrysophyta is generally accepted

Yellow green algae These are predominantly fresh water organisms but others may be found on moist terrestrial habitats a few are marine and some have been isolated from subterranean soil samples Since there is an array of parallel genera showing similar body types many members of this class were formerly classified among the green algae (*see* CHLOROPHYTA) One group includes primitive unicellular types such as *Botrydiopsis* or the motile *Chlorochromonas* another group produces an unbranched filamentous form such as *Tribonema* and a third branch ends in the development of the siphonaceous habit such as *Botrydium* and *Vaucheria* This tendency to produce parallel life forms is rather common in evolution and does not always indicate a close relationship between the two groups However the yellow green algae (Xanthophyceae) are readily separated from the green (Chlorophyta) on the basis of pigmentation lack

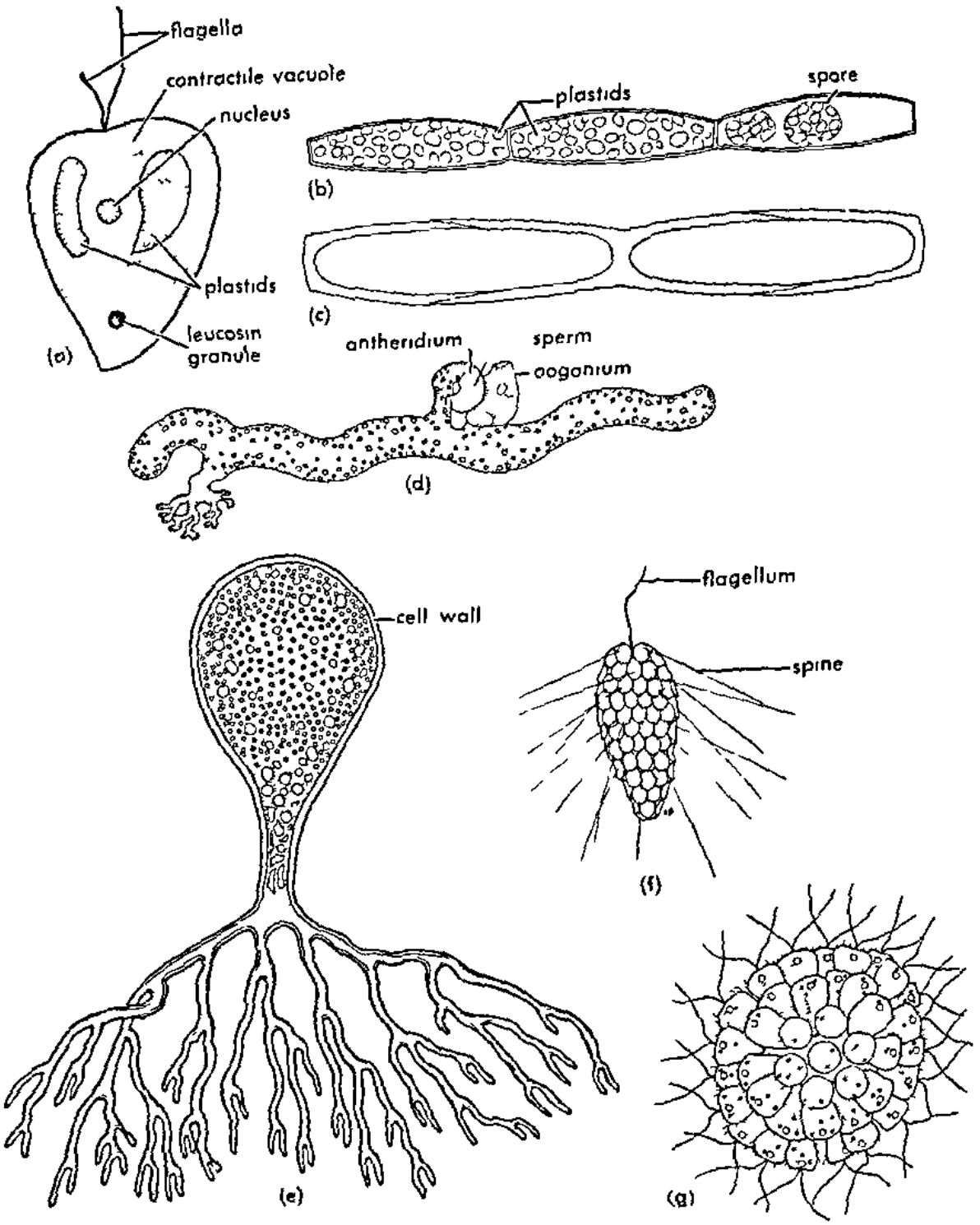


Fig 1 Kinds of Chrysophyta (a) *Chlorochromonas*, with two unequal flagella anterior contractile vacuole, central nucleus two curved plastids and a posterior leucosin granule (b) *Tribonema*, portion of filament with plastids and reserve food and one cell containing spores (c) *Tribonema*, overlapping cell walls in cells, each of which consists of two halves (d) *Vaucheria* showing tubular body or coenocyte bearing an antheridium and an adjacent oogonium (e) *Botrydium*, with globose, aerial portion (with thick cell wall and many nuclei, plastids, oil droplets, and leucosin granules), and subterranean, rootlike portion (f) *Mallomonas*, a chrysomonad, with single, anterior flagellum and many overlapping siliceous scales or plates which bear spines (g) *Synura*, a colonial golden brown alga (*From H J Fuller and O Tippo, College Botany, rev ed , Holt, 1954*)

of starch, unequal flagellations, and the overlapping construction of the cell walls in many genera.

Golden brown algae. Although widely distributed in both fresh and salt water, these algae are usually not found in great abundance. Many are planktonic and are found only in cold water or during the colder portions of the year. The motile cells vary from those with a single flagellum to those with two flagella of either equal or unequal length. One group contains unicellular forms which have ameboid movement and carry on holozoic nutrition (ingestion of solid, complex food materials), which is an animal attribute. The body cells are uninucleate and reproduction, though largely asexual, may be isogamous. Small siliceous scales often ornament the surface of the protoplast.

The resting spore in some members consists of two siliceous parts of unequal size. The larger portion is shaped like a flask and the smaller portion is like a stopper to the flask. Upon germination the protoplast escapes from the flask through the unplugged pore.

Diatoms (Bacillariophyceae). These are the best known and most numerous members of this phylum with over 5000 species (Fig. 2). They are usually found wherever there is water and an adequate amount of light. All diatoms are unicellular but some species are linked together to form chains or pseudocolonies, others may be enclosed in mucous sheaths and appear as small filamentous forms. They are divided into two orders on the basis of symmetry which is clearly shown by the pattern of markings on the valves.

1. Centrales, in which the form is often circular and the markings on the valves are radial. The plastids are small and numerous. These organisms are nonmotile in vegetative condition and occur predominantly in the ocean.

2. Pennales, in which the form is elongate or boat shaped and the markings of the valves are bilateral. In this order, there are two plastids which are large, frequently irregular, and embedded in the peripheral layer of the protoplasm. Many of these diatoms move by a series of jerks and all having such motility possess a raphe or complicated longitudinal cleft extending along the median line of the valve. Cytoplasmic streaming exerts an influence through the raphe which sets up water currents causing the movements. These algae occur predominantly in fresh water.

In most diatoms the nucleus occupies a more or less central position in the cytoplasm. When division occurs, the nucleus divides in a plane perpendicular to the plane of the valves. Usually a division of the plastids and other cell inclusions accompanies that of the nucleus. As the two valves separate, each daughter cell forms a new wall on the inside of the old one. This results in one cell being the same size as the parent and the other being smaller. This reduction in size may continue for several divisions, but eventually a minimum size is reached. At this stage auxospores are produced. These give rise to vegetative cells which restore the maximum size for the species.

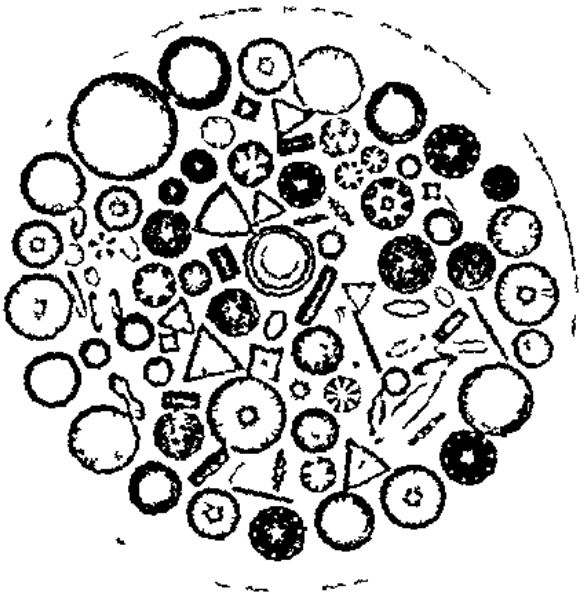


Fig. 2. Diatoms of assorted shapes and sizes. (*General Biological Supply Company*)

When diatoms decay or are consumed by animals, the siliceous valves remain and may accumulate in large quantities at the bottom of any body of water. Fossil deposits of these diatom shells going back to the Cretaceous are found in various areas of the world and have given rise to a diatomaceous earth industry. *See* DIATOM; GEOLOGY.

[P A V]

Bibliography. *See* THALLOPHYTA.

Chuckwalla

A large sluggish lizard *Sauromalus obesus*, of the southwestern desert of the United States, easily recognized by its size, blunt tail, small scales, and short, thick claws. It is rather variable in color



The chuckwalla, *Sauromalus obesus*, length to 1 ft. (*From E. L. Palmer, Fieldbook of Natural History, McGraw-Hill, 1949*)

shading from gray to black, with a tail that may be dark or light banded or plain. The body is sometimes marked with red blotches. The chuckwalla is a staple food of Indians within its territory, the flesh being tender and tasty. It is commonly 10 in. long, sometimes longer, and is abundant within its habitat where it frequents hot sand and rocks. It is herbivorous in diet.

The chuckwalla seldom bites, but for protection relies on its ability to wedge tightly into a crev-

when the lungs are punctured the technique used by Indians in hunting it

There are eight similar species of the same genus in Mexico *See* SQUAMATA [J D B]

Ciconiiformes

An order of predominantly long legged long necked birds including the herons storks ibises spoonbills and their relatives The flamingos (Phoenicopteridae) have been traditionally placed in the Ciconiiformes but also show many strong resemblances to the waterfowl (Anseriformes) some authors recognize an intermediate order Phoenicopteriformes for them Most ciconiiform birds feed on aquatic or subaquatic animals but many nest or even feed far from water Only the flamingos have the toes webbed Bill shape varies with food habits spearing prey probing in mud or straining water or silt Most species build tree nests but some nest on the ground flamingo nests are mounds of mud The order is virtually cosmopolitan in distribution and particularly well represented in the tropical regions *See* AVES [K C P]

Cidaroida

An order of Perischoechinoidea in which the narrow ambulacra comprise two columns of simple plates and each broad ambulacral plate carries only one primary tubercle They are unique among echinoids as the only Paleozoic order surviving to the present day The earliest representatives were the Carboniferous Archaeocidaridae with a flexible test and more than two columns of plates in the interambulacra Neoteny in the Permian and Triassic families led to forms with only two columns in the interambulacra and in the Jurassic the test assumed the rigid globular shape it has in modern forms After the Mesozoic cidaroids waned in northern faunas but they have remained prominent and beautiful elements in Indonesian and Australasian faunas *See* NEOTENY PERISCHOECHINOIDEA *see also* ECHINODERMATA [H B F]

Ciliata

The single class of the subphylum Ciliophora This group has the characteristics of those given in the subphylum The class is divided into the subclasses Holotricha and Spirotricha *See* CILIOPHORA HOLOTRICHA SPIROTRICHA [J O C]

Ciliophora

A subphylum of the Protozoa The ciliates are a fairly homogeneous group of highly differentiated unicellular organisms Some 5000 species have been described and many more surely exist, but remain to be discovered Typically ciliates are larger than most other Protozoa They range in size from 10 to 3000 μ or about $\frac{1}{2500}$ to $\frac{1}{8}$ in Some larger species are easily visible to the naked eye The majority of them are free-living forms found abundantly in a variety of fresh and salt water habitats although a few entire groups live in association with other organisms generally only as harmless ecto or endocommensals Their principal value to man lies in their wide usage as the experimental animal in a host of investigations concerned with fundamental problems of biology

Systematics The classification of ciliates followed here differs slightly from that which is usually given by other authorities since there are indications today that the scheme here adopted may receive wide usage in future reference works Separate articles appear on each group included in the following classification Subordinal divisions in some of the orders are commonly recognized by protozoologists

Subphylum Ciliophora
- Class Ciliata
  - Subclass Holotricha
    - Order Gymnostomatida
      - Trichostomatida
      - Chonotrichida
      - Hymenostomatida
      - Thigmotrichida
      - Peritrichida
      - Suctorida
      - Apostomatida
      - Astomatida
  - Subclass Spirotricha
    - Order Heterotrichida
      - Odontostomatida
      - Oligotrichida
      - Tintinnida
      - Entodiniomorphida
      - Hypotrichida

The Protociliata or opalinids (Fig 1) are entirely excluded They are considered members of the subphylum of flagellates the Mastigophora Major reasons advanced for this opinion are the possession of only one type of nucleus a symmetrogenic rather than a homothetogenic type of binary fission and true syngamy or sexual reproduction with anisogamous gametes rather than conjugation There are four genera of opalinids which are large mouthless multiflagellated forms found almost exclusively as saprozoic commensals in the posterior end of the alimentary tract of frogs and toads *See* MASTIGOPHORA

The number of major subdivisions of the ciliates is reduced to two the Holotricha and Spirotricha Within the first are included several groups formerly accorded a high level independent taxonomic status These are the Suctorida the Peritrichida and the Chonotrichida

Characteristics of the Ciliophora The usual ciliate life cycle is fairly simple An individual feeds, undergoes binary fission and the resulting filial products repeat the process Some of the commensal or parasitic forms have a more complicated life history but it is never as involved as that of such members of the subphylum Sporozoa as the malarial species (*see* HAEMOSPORIDIIDA) Some ciliates including free living species have a cystic stage in their cycle This stage as is the case in other kinds



Fig 1 *Opalina ranarum* an opalinid Not considered a ciliate by the author

of Protozoa as well often serves as a protective phase during adverse environmental conditions such as desiccation or lack of food It also may be important in distribution and thus possibly in preservation of the species

There are six major characteristics which aid in distinguishing the ciliophora from other protozoan groups Not all of these are entirely unique but when taken together they are definitely distinctive of ciliates

Mouth Most Ciliophora possess a true mouth or cytostome often associated with a buccal cavity containing compound ciliary organelles However some ciliates are completely astomatous that is mouthless Nutrition incidentally is heterotrophic in ciliates Some species are solely or primarily herbivorous since they are bacteria or algae eaters some are carnivorous or even cannibalistic with other Protozoa and occasionally small aquatic invertebrate Metazoa serving as food some are omnivorous others live a saprozoic or saprobic existence obtaining all their nutritive needs from materials dissolved in the medium The process of stomatogenesis or new mouth formation which must take place before the completion of binary fission of the ciliate's body is a morphogenetic phenomenon of great interest to students of the Protozoa Various modes of stomatogenesis exist in different ciliate groups Their study helps in postulation of phylogenetic interrelationships within this subphylum of highly differentiated unicellular animals

Ciliation The Ciliophora possess simple cilia or compound ciliary organelles often in abundance in at least one stage of their life cycle Morphologically cilia are relatively short and slender hair like structures The ultrastructure of these is now known from electron microscope studies to be composed of nine peripheral and two central fibrils Compound ciliary organelles include the undulating membrane (the UM) which is essentially a single sheet of fused cilia the membranelle a more or less fused block of cilia 2 4 rows wide and of greater length and the cirrus a tuft of closely opposed cilia which is approximately circular in cross section near its base or proximal end but tapered or even fimbriate at its distal end Functionally cilia and cirri serve principally as locomotor organelles Membranes and membranelles are characteristically associated with the mouth or buccal areas and serve to bring food into the oral opening although they sometimes aid in locomotion as well Membranelles are typically arranged as an adoral zone (AZM)

Infraciliature The presence without exception of some sort of infraciliature located at a subpellicular level in the cortex is another characteristic of Ciliophora The infraciliature consists essentially of the basal granules or kinetosomes associated with cilia and ciliary organelles at their bases plus certain more or less interconnecting fibrils The basal granules are argentophilic in that they readily stain with silver stains They are the most important components of the so called silverline system present in all ciliates (see Fig 2) Various argentophilic fibrils the contractile vacuole pores and the cell anus called the cytoproct or cytopyge are also included in this system The controversial are definitely not argentophilic Much remains to be learned of the function of this structure

Nuclear apparatus Ciliophora possess two kinds of nuclei and at least one of each is customarily present The smaller or micronucleus contains recognizable chromosomes and behaves much as the single nucleus in cells of metazoan organisms Its mitotic divisions however appear to be acentric (without centrioles) The larger or macronucleus does not show mitosis but is considered indispensable in controlling metabolic functions and it has recently been implicated as having genic control over all phenotypic characteristics of ciliates (*see* GENETICS) Micronuclei are typically spherical or ovoid and show little variety in shape Macronuclei vary in different species from compact bodies to C or E shaped forms or from nodulated chains which look like a string of tiny linked sausages to bizarre dendritic configurations In fission both nuclei divide but in sexual phenomena new macronuclei arise from what may be considered micronuclear origin

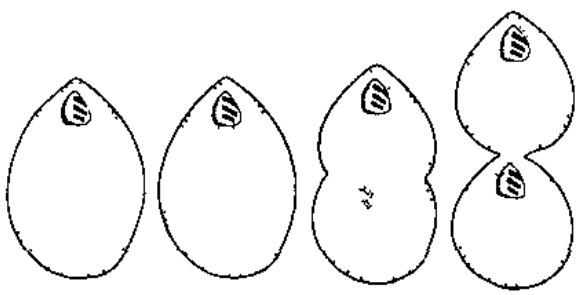


Fig 2 Binary fission and stomatogenesis in the ciliate *Tetrahymena* showing argentophilic basal granules silver line forming a part of the system and [illegible] ture

Fission Ciliophora exhibit a type of binary fission commonly known as transverse division In ciliates the splitting results in two filial organisms the anterior or proter and the posterior or opisthe which geometrically speaking show homothety with respect to identical structures possessed by each (Fig 2) Thus homothetogenic is both a broader and more exact descriptive term Indeed in a number of groups the fission is more nearly longitudinal than transverse Some ciliates show a budding type of asexual reproduction, some regularly reproduce within a cystic membrane

Reproduction Ciliophora lack true sexual reproduction Ciliates do not show syngamy, with fusion of free gametes Processes such as conjugation are considered to be sexual phenomena, since meiosis and chromosome recombination are involved, but not sexual reproduction In addition to conjugation certain ciliates exhibit forms of sexual phenomena known as autogamy and cytogamy (*see* REPRODUCTION ANIMAL)

Evolution of the ciliates. The ciliated Protozoa, by virtue of their universal possession of *an infraciliature and relatable patterns of somatic and buccal ciliature appear to be the most compact group* in the phylum Protozoa They also seem to lend themselves most readily to interpretation of their own phylogenetic interrelationships, that is, their own evolutionary history from the conjectured time of the first recognizable ciliate on the phylogenetic tree of the animal kingdom Handicaps to study include lack of a usable fossil record their dent of the ciliated Protozoa may still recognize, with a certain amount of reasonable, if indirect, supporting evidence certain evolutionary lines or trends among the several orders Most fruitful lines of such investigation have involved comparative study of life cycles, of the infraciliature and of mouth parts and of the morphogenetic phenomenon of stomatogenesis A possible genealogical tree of the Ciliophora is presented in Fig 3 The change in somatic and buccal ciliature in the evolution of ciliates is emphasized in three present day forms which, allegedly, are representative of the most primitive, intermediate, and most highly evolved orders (Fig 4) [J O C]

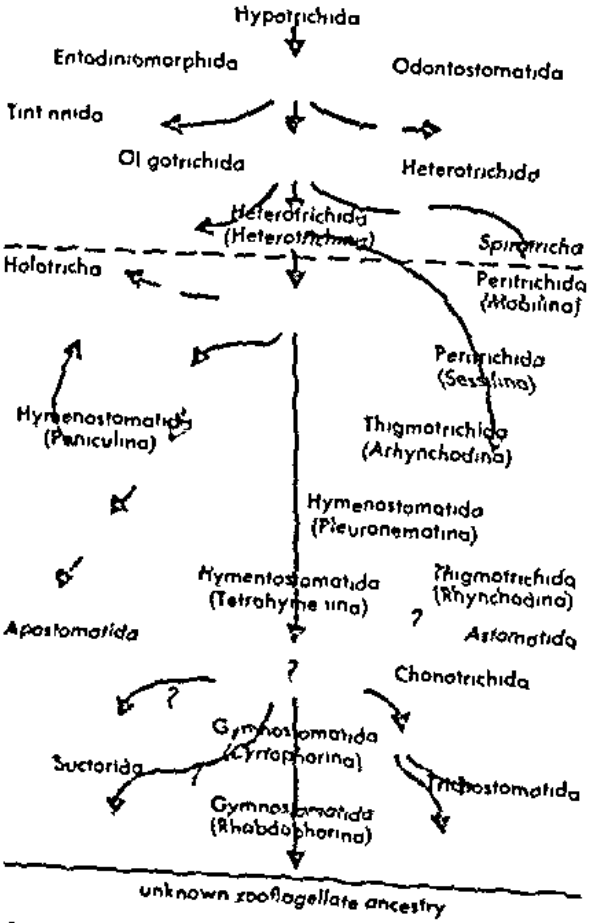


Fig 3 Phylogenetic tree of the Ciliophora

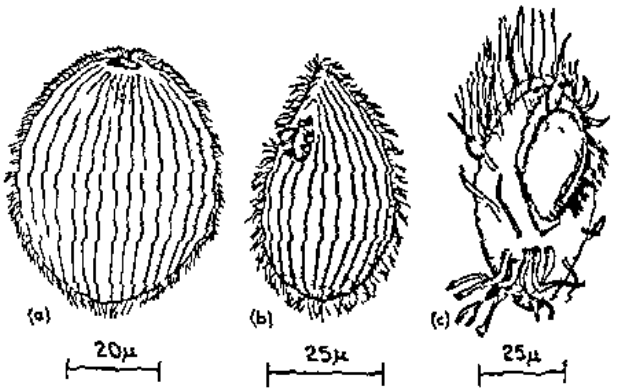


Fig 4 Representative ciliates (a) A primitive form *Holophrya* (b) Intermediate form, *Tetrahymena* (c) Highly complex form, *Diophrys* Not drawn to the same scale

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Cinchona

A genus of trees belonging to the madder family (Rubiaceae), occurring indigenously in the cool cloud forests of the Andes from Colombia to Peru Many species have been described, most of which may be variants of *Cinchona pubescens* or *C officinalis* The bark contains several alkaloids the most important of which is quinine This bitter substance is the most specific drug used in the treatment of malaria The great demand for quinine and the wasteful methods used in collecting the materials threatened extinction of the plants, therefore cultivation was begun Now there are extensive cinchona plantations in India, Java, Ceylon Australia, and Jamaica *See* QUININE, RUBIALES [P D S]

Cinematography

The process of producing the illusion of a moving picture Cinematography includes two phases the taking of the picture with a camera and the showing of the picture with a projector The camera captures the action by taking a series of still pictures at regular intervals the projector flashes these pictures on a screen at the same frequency thus producing an image on the screen that appears to move This illusion is possible only because of the persistence of vision of the human eye The still pictures appear on the screen many times a second and although the screen is dark equally as long as it is lighted by the projected image they do not seem to be a series of pictures but appear to the viewer to be one continuous picture

This article discusses motion picture cameras motion picture projectors and wide screen processes For related information *see* CAMERA LENS OPTICAL MAGNETIC RECORDING OPTICAL RECORDING PHOTOGRAPHIC MATERIALS PHOTOGRAPHY PHOTOGRAPHY COLOR PROJECTION SYSTEMS OPTICAL STEREOPHONIC SOUND

CAMERAS

Still photographs are taken by motion picture cameras (movie cameras) at the rate of 24 per second even faster at times The photographs are sharp and clear and if they were superimposed on one another would be found to be extremely uniform with respect to position This last feature is essential in order to have the image appear steady on the screen

A motion picture camera consists of five basic parts the lens the shutter the gate the film chamber and the pull down mechanism

Lens The lens in a motion picture camera collects the light from the scene being photographed and focuses it on the photographic emulsion in the camera aperture The lenses used vary in focal length the normal lens for the 35 mm camera has a focal length of 50 mm Other lenses in common use vary from wide angle (25–40 mm) through long focal length (60–100 mm) to telephoto (150 mm and longer) The lenses of shorter focal length have a wider angle of view those of longer focal length give greater image size Variable focal length lenses (zoom lenses) are also used on motion picture cameras especially in photographing sporting events With all of these lenses the image recorded on the film is inverted top to bottom and right to left *See* TELEPHOTO LENS ZOOM LENS

Some cameras have turrets on the front of them which hold three or four lenses at one time making it a simple matter to change from a lens of one focal length to one of another The lenses come in focusing mounts which allow them to be focused at various distances These mounts screw into the front of the camera and position the lens in its proper place with respect to the film The lenses also have an iris diaphragm which can be opened and closed to control the amount of light reaching the film

Shutter The shutter in a motion picture camera rotates and exposes the film according to its angle of opening When the shutter is open to its widest angle the film receives its maximum exposure Many cameras have variable shutters that is the angle of opening can be changed while the camera is running Such shutter openings usually vary from 170° when the shutter is wide open to 0° when it is closed Some cameras have a variable shutter which opens to 235° at its widest opening The shutter in a motion picture camera is almost always located between the lens and the film

Gate The aperture called the gate is the passageway through which the film is channeled while it is being exposed It consists of the aperture plate which is in front of the film and masks the frame or picture the pressure plate which is in back of the film and holds it firmly against the aperture plate and the edge guides which keep the film stable laterally

Film chamber This holds the unexposed film at one end and collects the exposed film at the other *Although some motion picture cameras have* an interior film chamber it is usually a separate piece of equipment called the film magazine Magazines come in 400-ft and 1000-ft capacities One thousand feet of film exposed at the normal speed of 24 frames per second and with a four perforation pull-down lasts slightly more than 11 min The magazines are loaded with film in a darkroom or in a lightproof changing bag They are fitted on the camera as they are needed making loading of the camera an easy and rapid operation

Pull down mechanism The part of the pull down mechanism called the intermittent movement pulls the film down through the gate of the camera one frame at a time in a conventional 35 mm camera each frame is four perforations high Some wide screen cameras have frames five or six per *forations high The pull down claw engages the* perforations and pulls the film down into place to be exposed At the bottom of its stroke the claw remains stationary for a moment to position the film then disengages itself and returns to the upper portion of the stroke to pull another frame into place During the time the claw is returning to the top of its stroke the film is stationary and the shutter opens and exposes the film Some of the more expensive cameras have registration pins which engage the film while the picture is being taken This ensures that the film is perfectly still and is in exactly the same position as each frame is being exposed

Blimp When sound is being recorded cameras must be absolutely quiet If a camera is noisy it must be put in a sound enclosure called a blimp Most cameras have to be blimped although the Mitchell BNC is self blimped and is quiet enough to be used on a sound stage For this reason the

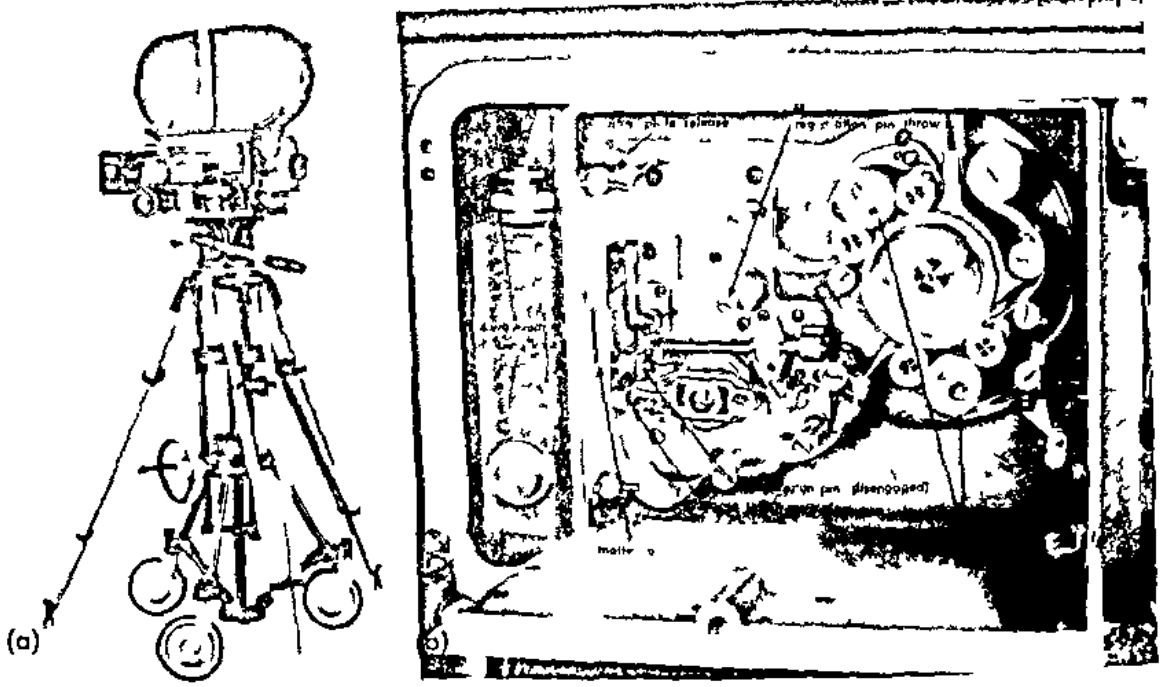


Fig 1 Mitchell Studio Camera (BNC) (a) Over-all view (b) Film moving mechanism (*Mitchell Camera Corporation*)

BNC has become the standard sound camera the world over and is used to make more feature films than any other make of camera (Fig 1)

Film The film used in the standard motion picture camera is 35 mm (1 378 in) wide and is perforated along both edges There are 64 perforations (or sprocket holes) to each foot of film

Motion picture film consists of a cellulose acetate base approximately 0 006 in thick and coated with a light sensitive emulsion In color film several layers of emulsion are applied each of three of the layers is sensitive to one of the three primary colors of light blue green and red The film is made in large rolls about 40 in wide and as long as 1000 ft It is slit into 35 mm strips perforated and packed in lightproof bags and cans in rolls 100 400 and 1000 ft in length

Substandard film such as 16 mm is not used professionally for feature pictures for theatrical release many television features however particularly documentary and travel films are shot on 16-mm film

Aspect ratio The picture taken in standard 35 mm motion picture cameras is masked by the aperture plate which varies according to the camera The silent aperture that is the aperture used on cameras that do not leave room on the film for a sound track is almost the entire width of the film between perforations slightly less than 1 in and approximately $\frac{3}{4}$ in high This gives an aspect ratio (the ratio of its width to its height) of 1.33 1 ($\frac{4}{3}$) Sound apertures are masked down to a width of 0 868 in to allow room for the sound track and a height of 0 631 which gives an aspect ratio of 1 37 1

PROJECTORS

The projector in a modern motion picture theater has four main assemblies the optical sound head which reproduces optical (photographically recorded) sound the projector head which projects the image onto the screen, the lamphouse which furnishes the illumination for the picture, and the shutter On some projectors there is a second sound head for the reproduction of magnetic (magnetically recorded) sound The release print of a picture as contrasted with the negative and the original which are never projected in a theater is usually mounted on a 2000 ft reel It is placed in the upper film magazine and the film is threaded through the projector head down through the optical sound head and on to the takeup magazine

Optical sound head. This consists of an exciter lamp and a photoelectric cell The optical sound track is 20 frames ahead of the picture on 35 mm film (26 frames ahead on 16 mm film) If the film has a magnetic sound track in addition to the optical one it is first threaded over the magnetic sound head which is above the projector head (see Fig 2) The magnetic sound track is 28 frames behind the picture on 35 mm film (26 frames ahead on 16-mm film, the same as optical sound)

Projector head This consists of the projection lens and the projector intermittent The projection lens is located in the front of the projector head between the aperture and the screen The film is put in the projector aperture upside down and with the sound track on the right The image is inverted by the lens and appears right side up on the screen. The sound track if it were visible would appear

on the left side of the screen The focal length of the lens is determined by the size of the image desired on the screen and the distance between projector and screen The lens usually has a fixed speed of $f/2$ and has no iris diaphragm

The projector intermittent uses a Geneva movement to pull the film through the gate This movement drives a 16 toothed sprocket one quarter of a revolution at a time With each movement a new frame is pulled into place The film is wrapped around this sprocket wheel and its perforations on both sides engage four or five teeth on the wheel at all times This distributes the stress caused by the acceleration and deceleration over many perforations and results in less wear and tear on the film substantially increasing its life A framing device is incorporated in the projector head so that the frame can be moved up or down to position the picture correctly and put the frame lines at the top and bottom of the screen

Lamphouse This is located behind the projector head Its light is created by a carbon arc which operates on direct current at about 60 volts A concave reflector behind the arc collects the light and concentrates it on the film in the projector aperture Because a great amount of heat is collected at the aperture water cooled gates are often used to carry the heat away The current consumed by these arcs varies from 40 amp in those used in some smaller theaters to 180 amp used in large theaters and drive ins

Shutter A projector has a two bladed shutter located between the lamphouse and the gate in the projector head The shutter cuts off the light to the screen while the film is being moved down from one frame to the next and opens when the new frame has been moved into place It then closes and opens a second time before another frame has been brought into position This makes two exposures per frame or 48 light impulses hitting the screen in 1 sec even though the picture was shot at 24 frames per second This reduces the flickering effect that would be noticeable if only 24 light impulses per second were flashed on the screen

Universal types Many of the new projectors are universal projectors They can show 35 mm prints both normal (VistaVision) and anamorphic (CinemaScope) with optical sound four track magnetic sound or both They can also show 70 mm normal (Todd AO) and anamorphic (M G M Panavision) with six track magnetic sound The 35 mm sprockets are between and below the 70 mm sprockets and either film can be run by selecting the correct lens and threading the film through the gate and through the appropriate sound head

WIDE SCREEN PROCESSES

Until 1952 the motion picture industry as a whole used film and equipment that was well standardized Film was 35 mm wide the aspect ratio was 1 33 1 and the camera had a four perforation pull down mechanism These standards had been in effect since early in the twentieth century Since the advent of sound in 1926 standard camera speed has been 24 frames per second and most sound tracks have been reproduced optically Since 1952 however many new processes have been introduced which depart from these standards and have introduced a multiplicity of film sizes aspect ratios and types of sound tracks Some processes which continue to employ 35 mm film use either a means of getting more picture on the film or use multiple strips of 35-mm film projected to form a single large picture Four track six track and even seven track magnetic sound has become fairly common The motion picture industry has been changed to a larger extent in the years from 1952 to 1960 than at any other time since 1926

Cinerama The first of the wide screen processes to receive any great recognition and by far the most radical was Cinerama invented and developed by F Waller It was first shown to the public in 1952 The system uses three lenses to take the entire picture and records the scene on three strips of standard 35 mm film The Cinerama camera is actually three cameras mounted in one body It has three lenses three intermittent movements and uses three strips of film from three magazines simultaneously The lenses are mounted in the camera body with an angle of 48° in a horizontal plane

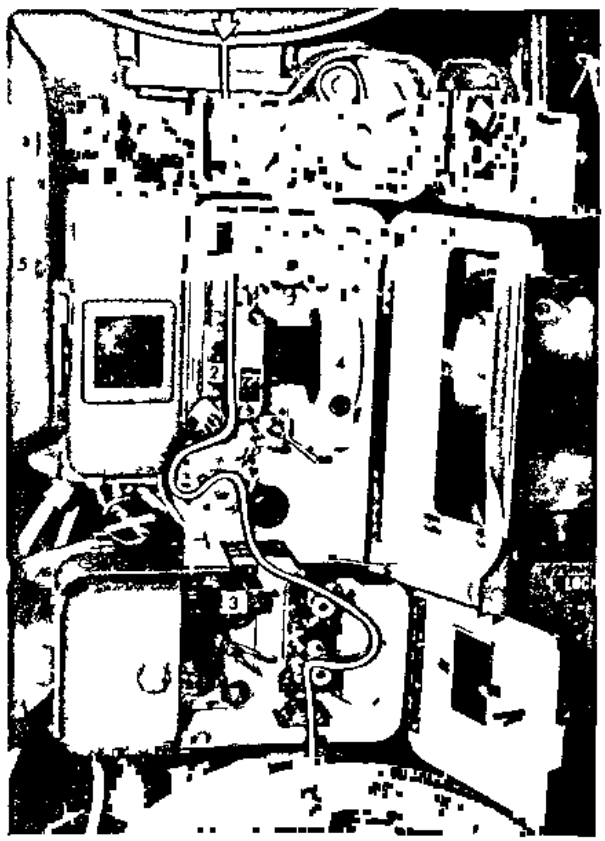


Fig 2 Motion picture projector White ribbon shows path of film from feed magazine 1 over the magnetic sound head 2 down through the projector head 3 bypassing the optical sound head on its way to the takeup magazine 4 lens and 5 lamp house (*Twentieth Century Fox*)

between each of the adjacent lenses The focal length of the lenses is 27 mm they are not interchangeable because of the 48° angle established in the construction of the camera They have a vertical angle of view of 55° and a horizontal angle of view of 50° Adjacent lenses overlap 2° at the two match lines giving a total horizontal angle of view for the entire system of 146° The lens on the right hand side of the camera points to the left, the one in the center points straight ahead and the one on the left points to the right The central axes of these lenses cross at a point less than 1 in in front of the

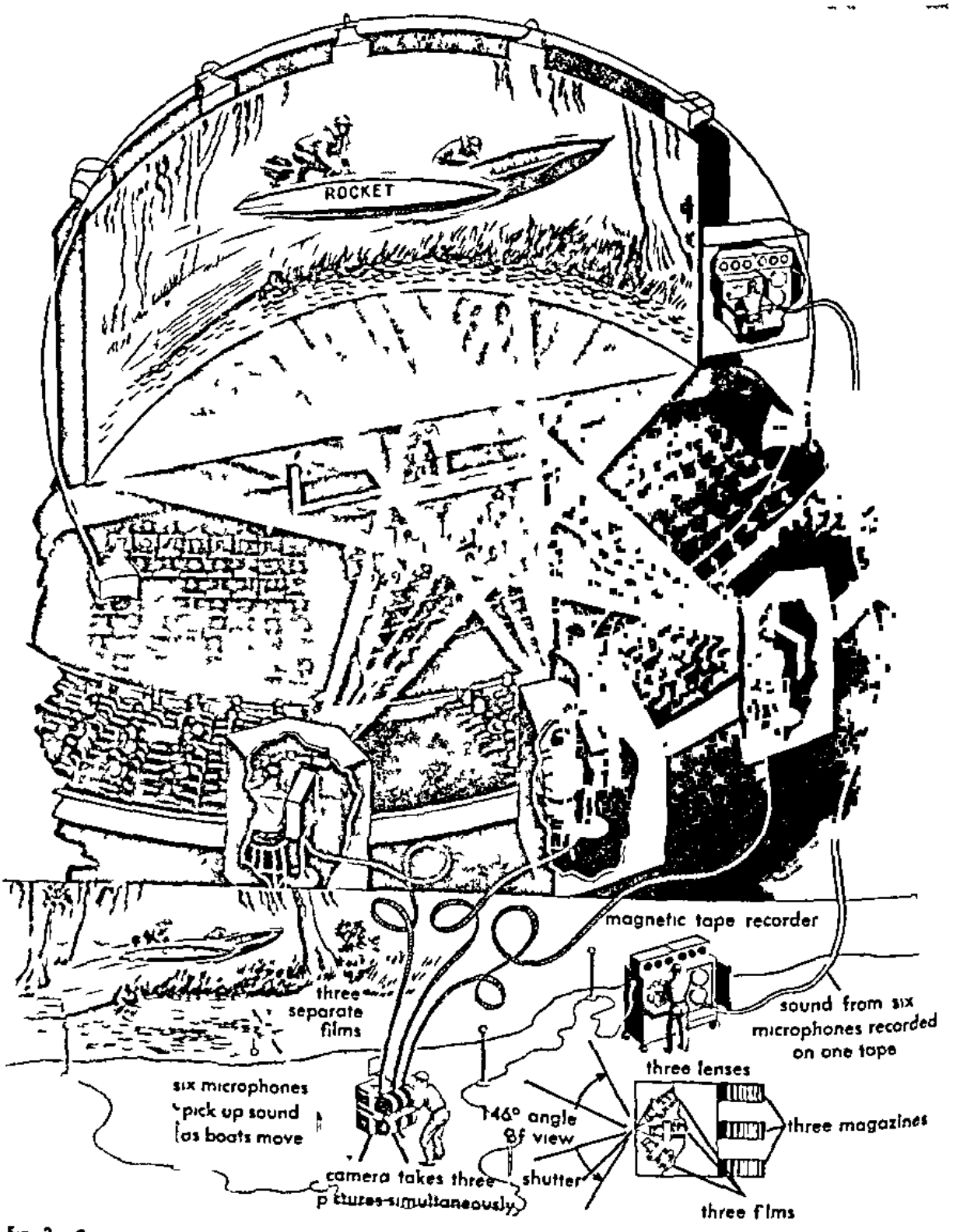


Fig 3 Cinerama This picture shows how the scene is recorded on three strips of film how the sound is recorded on a separate sound track and how sound and picture are reproduced in the theater (*Cinerama Inc*)

len es and the shutter is located in front of the lenses at this cross-over point so that all three len ses and subsequently all three strips of film are exposed at the same instant

The frame is six perforations (1¼ in) high and the intermittent movement has a six perforation pull down instead of the usual four In order to reduce the flicker that is apparent because of peripheral vision and because of the extremely wide angle taken in by the camera both the camera and the projector run at 26 frames per second in stead of the usual 24

Focusing of the lenses is done with a system of gears and cams and all of the lenses are focused simultaneously with one knob The lens apertures are also controlled with one knob Three chambers each of which houses a gate and an intermittent movement and holds a film magazine are removable for loading

Cinerama is shown on a deeply curved screen which is made up of over 1500 louvers ¾ in wide This wrap around screen combined with the ex tremely wide angle of view gives an illusion of depth to the picture and produces a feeling of audience participation in the action

The Cinerama camera uses the entire area of the film between perforations The image is vignetted that is tapered off to blend with the adjacent pic ture in the projector

The sound is on a separate piece of 35 mm mag netic tape with seven separate sound tracks re corded stereophonically Five of the tracks are played to five speakers behind the screen Two tracks play to speakers on each side of the theater There is an eighth speaker in the back of the house which is cued in for special effects (see Fig 3) The aspect ratio varies with viewing posi tion it is 2 06 1 viewed from the center projector

CinemaScope This is a wide screen process which was developed by Twentieth Century Fox It combines stereophonic sound and a wide screen picture on a single piece of film and was first used to make *The Robe* (1953) CinemaScope uses a lens called an anamorphic lens on a standard 35 mm camera to compress or squeeze the image on the film horizontally A similar type of lens is used on the projector to unsqueeze" the image in projection thus restoring the image to its original size and shape (Fig 4) This lens was based on earlier work of the French physicist H Chretien The first CinemaScope lens was an extra lens mounted in front of the regular camera lens Both lenses had to be focused simultaneously This sys tem was later improved by Bausch and Lomb Com pany which developed a lens system incorporating both of these lenses in one unit This improved the lens optically and simplified the focusing proce dure

The CinemaScope release prints are on film 35 mm wide The perforations on the film are made narrower than standard to allow room on the film for four magnetic sound tracks for stereo

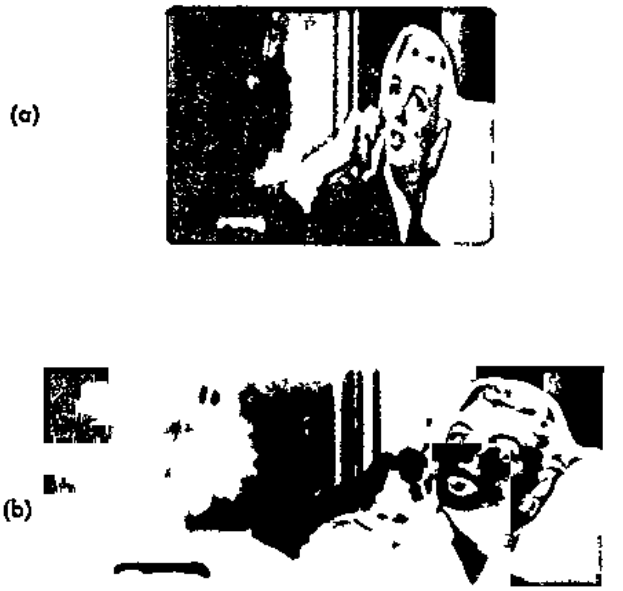


Fig 4 Action of CinemaScope anamorphic lens (a) The image squeezed onto the film by an ana morph c lens (b) The unsqueezed image as it ap pears on the screen (*Twent eth Century Fox*)

phonic sound Three of the sound tracks feed loud speakers behind the screen, the fourth is used for special effects in various parts of the theater The aspect ratio of the projected image for magnetic sound prints is 2 55 1 Magoptical CinemaScope prints which carry both magnetic and optical sound tracks on the same film are also available (Fig 5) This makes it possible for the print to be shown in theaters which are equipped with standard optical reproducers only as well as in those which are equipped to handle four track stereophonic sound This same print is also re leased bearing only the optical sound track The aspect ratio of the prints with optical sound tracks is smaller (2 34 1) than those with magnetic tracks only because optical tracks occupy some of the picture area of the film

CinemaScope 55 Another Twentieth Century Fox development CinemaScope 55 uses a special film 55 625 mm wide The picture area on this film is twice as wide and twice as high as the picture area on 35 mm film This 2 1 reduction can be made from a 55 mm negative to a 35 mm positive print which will have a regular CinemaScope aspect ratio of 2 55 1 This reduction results in better pic ture quality in terms of definition because of the reduced magnification factor *Carousel* premiered in 1956 was the first picture made in Cinema Scope 55 it was released on 35 mm film only

VistaVision The process called VistaVision was developed by Paramount Pictures The first Vista Vision release was *White Christmas* in 1954 The outstanding innovation of the VistaVision process is that standard 35 mm film runs through the camera horizontally from right to left The frame is eight perforations wide and almost 1 in high giving twice the area of a standard 35 mm frame

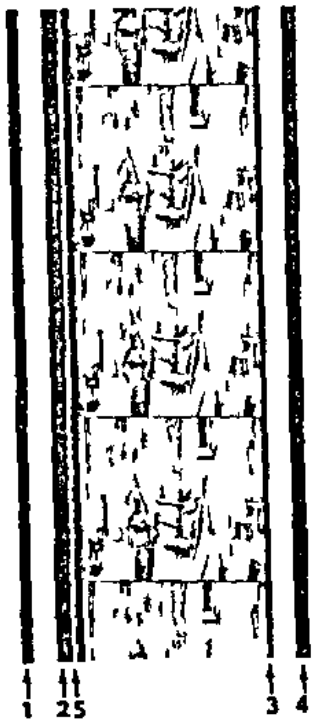


Fig 5 Magoptical CinemaScope release print with four magnetic tracks designated by 1 2 3 4 and an optical sound track designated by 5 (*Twentieth Century Fox*)

This double frame picture because of its increased area results in a high quality negative Prints made from this negative have an aspect ratio of 1 96 1 Horizontal projection of prints made directly from the negative is used only at special showings because it requires special projection

negative and can be shown on standard projection equipment The photographic reduction from the large negative to the standard release print results in sharper picture images The aspect ratio of the standard release print varies from 1 33 1 to 2 1 with 1 85 1 recommended The aspect ratio is controlled by the size of the projector aperture

Superscope 235 This is a variable type of anamorphic projection system used by RKO Pictures Inc I and J Tushinsky developed the process which was first used by United Artists to make *Vera Cruz* shown in 1954 The first RKO picture in Superscope was *Underwater* released in 1955

Superscope is photographed in the normal way with a 35-mm camera All the picture area of the film between the perforations is used care is taken however to mask the camera view finder top and bottom to the CinemaScope format so that important features in the picture will not be lost in printing or projection Anamorphic lenses are used in the printing to make a release print which can be shown on any CinemaScope projector

Todd AO The first of the current wide screen processes to depart from the standard 35 mm film Todd AO uses 65 mm film in the camera and is printed on 70 mm film the additional width in the print is used for six magnetic sound tracks The first picture in Todd AO was *Oklahoma* first shown in 1955

The system uses a single lens camera and a single projector The special lenses were designed by B O Brien and are classified according to angle of coverage rather than focal length They cover angles of 37° 48° and 64° and the special bug eye lens covers an angle of 128° The aspect ratio of the projected image is 2 2 1 The film carries six magnetic sound tracks two outside the perforations on each side and one inside the perforations on each side

Technirama This is a process developed by the Technicolor Corporation The first picture made in the medium was *Monte Carlo Story* first shown in Italy in 1956 The first Technirama feature shown in the United States was *Night Passage* (1957) Technirama uses a double frame image on standard 35 mm film which goes through the camera horizontally from right to left It is similar to Vista Vision in dimensions and image size except that it uses an anamorphic lens with a 1 5 1 compression ratio in the camera and takes in 50% more of the scene horizontally The horizontal negative with a squeeze of 1 5 is printed vertically on 35 mm film with an additional anamorphic compression of 1 33 1 thus making a total squeeze of 2 1 Technirama prints can be projected on equipment designed for CinemaScope and prints with a magnetic sound track will have the CinemaScope aspect ratio of 2 55 1 on the screen Technirama sound tracks can be four track magnetic or single-track optical The print with the optical sound track has an aspect ratio on the screen of 2 34 1

MGM 65 Metro Goldwyn Mayer developed this method of motion picture production which uses 65 mm film in the camera Like Todd AO it has a picture height of five perforations but uses a special lens developed by Panavision Inc which gives an anamorphic compression of 1 33 to the width Contact prints 70 mm in size are made and projected in a 70-mm projector which has a lens with a 1 33 1 decompression ratio By reducing the negative image in printing and giving it an additional 1 5 squeeze prints can be made on 35-mm film which can be shown on equipment made for CinemaScope These 35 mm prints can have a single optical sound track a magoptical sound track with one optical and four magnetic tracks or four magnetic tracks only

The first complete picture made in M G M 65 was *Raintree County* premiered in 1957 *Raintree County* was released on 35 mm prints *Ben Hur* was shown during its first engagement (1959) on 70-mm film It was later released in 35 mm

Cinemiracle This is a three strip process similar to Cinerama It uses three lenses three camera

movements, and three pieces of film simultaneously to take the picture The cameras have six perfora tion pull downs, and the frame is six perforations high Each of the three lenses has a vertical angle of view of 55° and a horizontal angle of view of 50° with a 2° overlap between them Mirrors are used to reflect the images into the two side lenses The lens on the left photographs the left hand portion the center lens the center portion and the right hand lens the right hand portion of the scene

The Smith Dietrich Corporation developed the camera, and the National Theatres Corporation was responsible for developing the projection equipment The film is vignetted in the printing The screen is deeply curved with a radius of 80 ft

The first picture made in Cinemiracle was *Wind jammer* (1958) Cinemiracle uses seven track mag netic sound on a separate 35 mm tape Five speak ers are behind the screen, and there are other speakers at the sides and rear of the auditorium Aspect ratio of the projected picture is 2 33 1

Kinepanorama. This is a Russian motion picture process similar to Cinerama and Cinemiracle It was developed by E M Goldovsky of the Moscow Institute of Cinematography It uses standard 35 mm film and has a frame size six perforations high and 1 in wide It uses three lenses three camera movements, and three strips of film to take the picture and three projectors to show it There is a separate sound film with nine sound tracks A film in Kinepanorama was shown in the Russian exhibit at the Brussels World Fair in 1958 Two films *Great is My Country* and *The Magic Mirror*, were shown at the Mayfair Theater in New York City in 1959 The vignetting can be done either in the printing or in the projector The prints can be shown on either the Cinerama or Cinemiracle pro jection equipment [W G F]

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Cinnabar

A mineral having composition HgS Cinnabar is the only important ore of mercury It crystallizes in the hexagonal system but crystals are rare usually of rhombohedral habit and often in pene tration twins It most commonly occurs in fine, granular, massive form There is perfect prismatic cleavage, the hardness is 2 5 (Mohs scale) and the specific gravity is 8 10 When pure cinnabar has an adamantine luster and vermillion red color, when impure the luster may be dull and the color brownish red

Metacinnabar is polymorphous with cinnabar and the two minerals occur together It is isometric, with hardness 3, specific gravity 7 6, and color grayish black It inverts to cinnabar, the stable form, on heating to 400–500°C

Cinnabar occurs in mineable deposits at compara tively few localities It is commonly found in veins and impregnations deposited near the surface and appears to be genetically associated with recent volcanic rocks and hot springs Important localities for the occurrence of cinnabar are at Almaden, Spain, Idria, Italy, and in Kweichow and Hunan Provinces China In the United States it was early found at New Almaden and New Idria in California It also has been mined in Nevada Utah, Oregon Arkansas Texas, and Idaho *See* MERCURY (ELE MENT) [C S HU]

Cinnamon

This plant *Cinnamomum zeylanicum*, is an ever green shrub or small tree of the laurel family (*Lauraceae*) *A native of Ceylon the plant is now* in cultivation in southern India, Burma, parts of



Cinnamon (*Cinnamomum zeylanicum*) (USDA)

Malaya West Indies and South America In culti vation, the trees are cut back and long, slender suckers grow up from the roots The bark is re moved from these suckers, dried and packaged for shipping Cinnamon is a very important spice for flavoring foods It is used in confectionery, gums incense dentifrices and perfumes Cinnamon oil is used in medicine and as a source of cinnamon ex tract *See* MYRTALES, SPICE AND FLAVORING [P D S]

Circle

The curve that is the locus of points in a plane with equal distance (radius) from a fixed point (center) In elementary mathematics circle often refers to the finite portion of the plane bounded by a curve (circumference) all points of which are equidistant from a fixed point of the plane that is a circular disk Circles are conic sections (*see* CONIC SECTION) and are defined analytically by certain second degree equations in cartesian coordinates (*see* ANALYTIC GEOMETRY) They were extensively studied by the ancient Greeks who formulated the famous problem of squaring the circle that is to construct with compasses and unmarked straightedge only a square whose area is equal to that of a given circle It was not until 1882 that this was shown to be impossible In that year F Lindemann proved that the ratio of the length of a circle to its diameter (denoted by π) is not the root of any algebraic equation with integer coefficients That π is irrational (that is not the quo

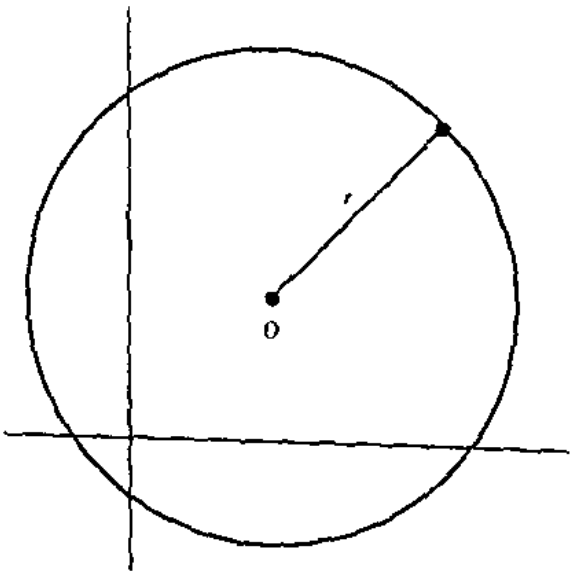


Fig 1 Circle of radius r and center O

tient of two integers) was shown by A M Legendre in 1794 Numerous approximations of π appeared *quite early* for example 3 (*Book of Kings*) $3\frac{1}{8} > \pi > 3\frac{10}{71}$ (Archimedes) $\sqrt{10}$ (*Ch ang Hong* 78 139) 3 1416 (Aryabhata 476–550) Electronic computers have calculated π to over 10 000 decimal *places* Interesting expressions for π are

$$\pi = 4(1 - \tfrac{1}{3} + \tfrac{1}{5} - \tfrac{1}{7} + \quad)$$

and

$$\pi = 2\ 2(2\ 1\ 3\ 3)(4\ 6/5\ 5)(6\ 8/7\ 7)$$

The area of a circle (circular disk) with radius r is πr^2 the length (circumference) is $2\pi r$ The area enclosed by a circle is *greater than* that bounded by any other curve of the same length If a circular disk can cover each three points of an arbitrary plane set then the disk can cover the whole set It is moreover the only disk that has this property A great many properties of the circle are in relation to a given triangle Such for example is the nine point circle theorem [L M BL]

Nine point circle Let the altitudes of any triangle ABC intersect each other in the orthocenter H and intersect the opposite sides in D E and F respectively Then the circle DEF passes through the midpoints of each of the six segments AB BC CA AH BH CH It is called the nine-point circle of the triangle ABC and also of each of the triangles HBC HCA HAB, whose orthocenters are A B C respectively Feuerbach's theorem states that this nine point circle is tangent both to the inscribed circle and to the three escribed circles of each of these triangles

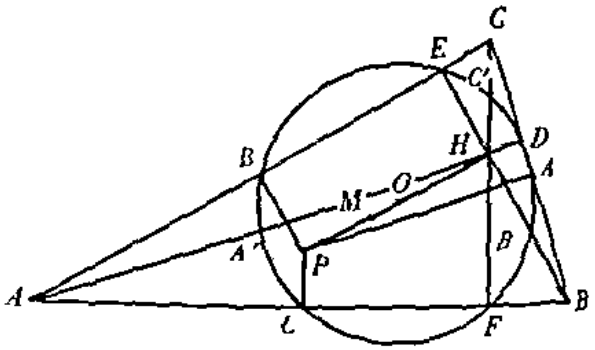


Fig 2 Nine point circle and Euler line PMH

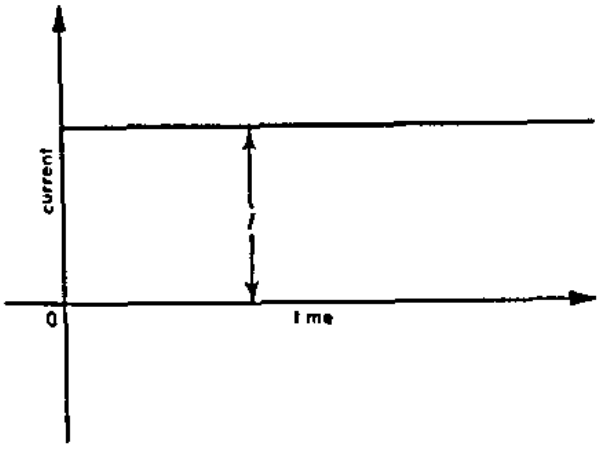
The center O of the nine point circle of any triangle lies midway between the orthocenter H and the circumcenter P on the so called Euler line that passes through these points and the centroid M [J S F]

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Circuit, electric

A general term referring to a system or part of a system of conducting parts and their interconnections through which an electric current is intended to flow A circuit is made up of active and passive elements or parts and their interconnecting conducting paths The active elements are the sources of electric energy for the circuit they may be batteries direct current generators or alternating current generators The passive elements are resistors inductors and capacitors The electric circuit is described by a circuit diagram or map showing the active and passive elements and their connecting conducting paths

Electric circuits are used to transmit power as in high voltage power lines and transformers or in low voltage distribution circuits in factories and homes to convert energy from or to its electrical form as in motors generators microphones loudspeakers and lamps to communicate information as in telephone telegraph radio and televis on



Fg 1 D rect current

systems to process and store data and make logical decisions as in computers and to form systems for automatic control of equipment

Electric circuit theory This includes the study of all aspects of electric circuits including analysis design and application In electric circuit theory the fundamental quantities are the potential differ ences (voltages) in volts between various points the electric currents in amperes flowing in the sev eral paths and the parameters in ohms or mhos which describe the passive elements For a dis cussion of these parameters *see* ADMITTANCE CONDUCTANCE, IMPEDANCE ELECTRICAL REACT ANCE RESISTANCE ELECTRICAL SUSCEPTANCE Other important circuit quantities such as power energy and time constants (*see* TIME CONSTANT) may be calculated from the fundamental variables

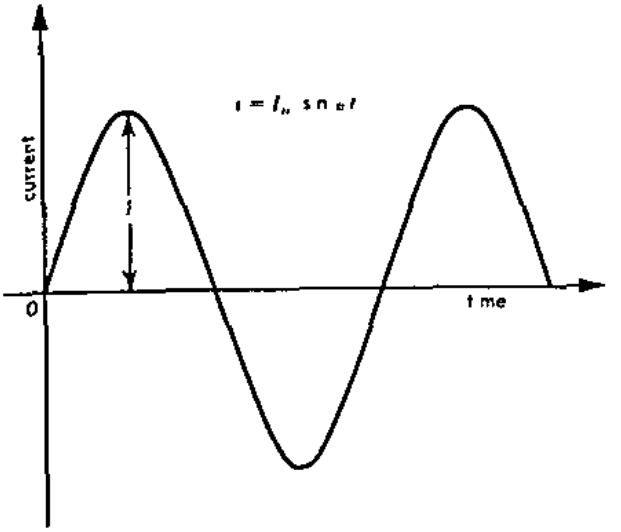
Electric circuit theory is an extensive subject and is often divided into special topics Division into topics may be made on the basis of how the voltages and currents in the circuit vary with time examples are direct current alternating current nonsinusoidal and transient circuit theory An other method of classifying circuits is by the ar rangement or configuration of the electric cur rent paths examples are series circuits parallel circuits series parallel circuits networks coupled circuits open circuits and short circuits

Direct current circuits In dc circuits the volt ages and currents are constant in magnitude and do not vary with time (see Fig 1) Sources of di rect current are batteries dc generators and recti fiers Resistors are the principal passive element For a discussion of direct current circuits *see* DIRECT CURRENT CIRCUIT THEORY

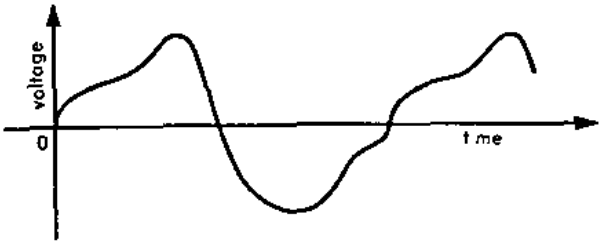
Magnetic circuits Magnetic circuits are similar to electric circuits in their analysis and are often included in the general topic of circuit theory Magnetic circuits are used in electromagnets re lays magnetic brakes and clutches computer mem ory devices and many other devices For a detailed treatment of magnetic circuits *see* MAGNETIC CIR CUITS

Alternating current circuits In ac circuits the voltage and current vary sinusoidally with time For example the alternating current in Fig 2 may be expressed by $i = I_m \sin \omega t$ Sinusoidal sources are ac generators and various types of electronic and solid state oscillators passive circuit elements include inductors and capacitors as well as resis tors The analysis of ac circuits requires a study of the phase relations between voltages and currents as well as their magnitudes Complex numbers are often used for this purpose For a detailed discus sion *see* ALTERNATING-CURRENT CIRCUIT THEORY

Nonsinusoidal wave forms These voltage and current variations vary with time but not sinusoi dally as in the ac circuit (see Fig 3) Such non sinusoidal variations are usually caused by non linear devices such as saturated magnetic circuits electron tubes and transistors Circuits with non sinusoidal waveforms are analyzed by breaking the waveform into a series of sinusoidal waves of dif ferent frequencies known as a Fourier series Each frequency component is analyzed by ac circuit techniques and the results are combined by the



Fg 2 Alternat ng current



Fg 3 Nons nusoidal voltage wave

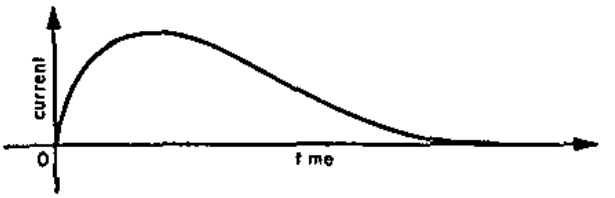


Fig 4 Trans ent electr c current

principle of superposition to give the total response For a detailed discussion, *see* WAVEFORM NONSINUSOIDAL

Electric transients. Transient voltage and current variations last for a short length of time and do not repeat continuously (see Fig 4) Transients occur when a change is made in the circuit such as opening or closing a switch or when a change is made in one of the sources or elements For a discussion of dc and ac transients *see* TRANSIENT ELECTRIC

Series circuits In a series circuit all the components or elements are connected end to end and carry the same current as shown in Fig 5 *See* SERIES CIRCUIT

Parallel circuits Parallel circuits are connected so that each component of the circuit has the same potential difference (voltage) across its terminals as shown in Fig 6 *See* PARALLEL CIRCUIT

Series parallel circuits In a series parallel circuit some of the components or elements are connected in parallel and one or more of these

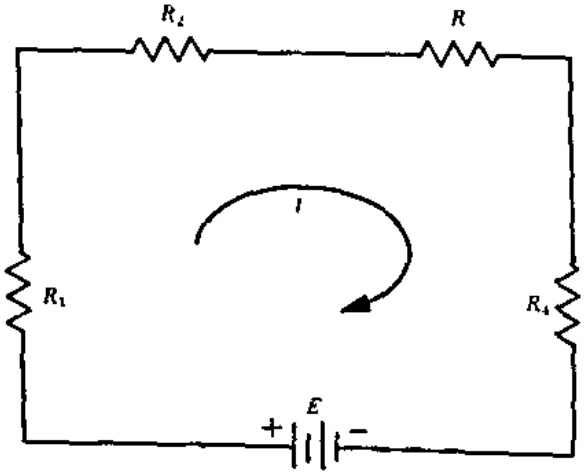


Fig 5 Series circuit

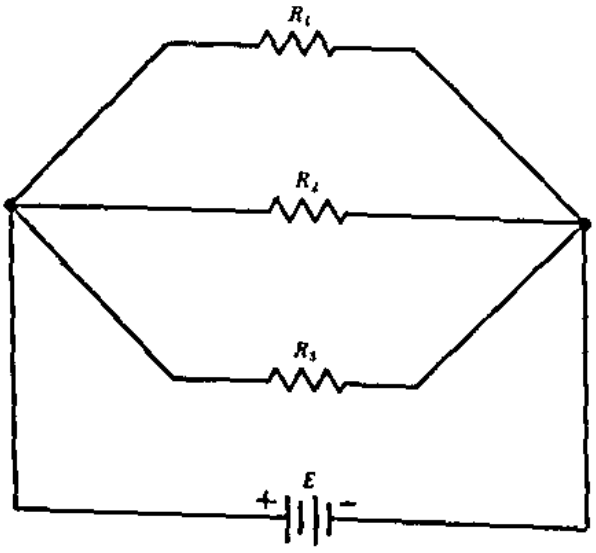


Fig 6 Parallel circuit

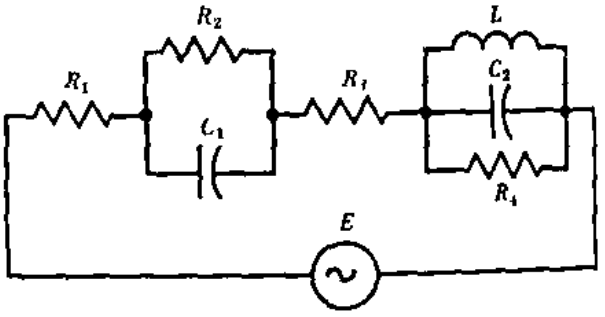


Fig 7 Series-parallel circuit

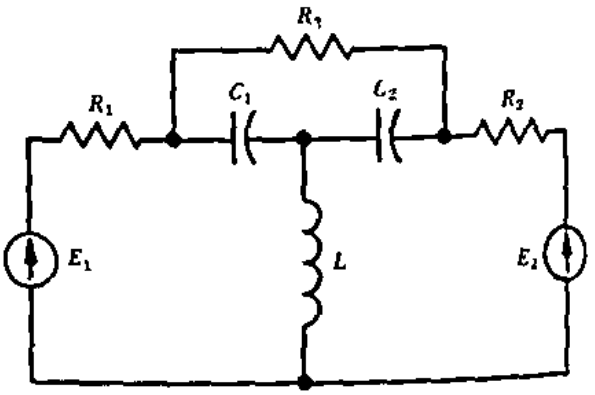


Fig 8 A three mesh electric network

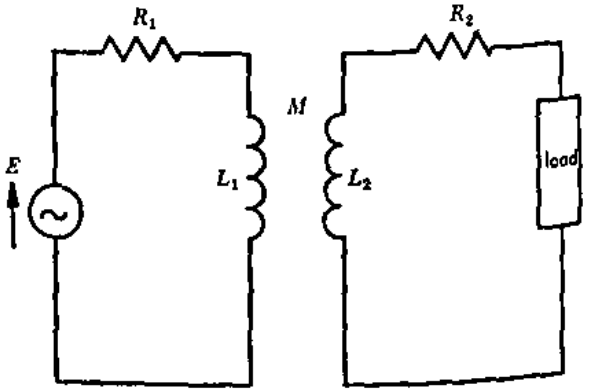


Fig 9 Inductively coupled circuit

parallel combinations are in series with other components of the circuit as shown in Fig 7

Electric network. This is another term for electric circuit, but it is often reserved for the electric circuit that is more complicated than a simple series or parallel combination A three mesh electric network is shown in Fig 8 For a discussion of theorems used in solving electric networks, *see* NETWORK THEORY ELECTRICAL.

Coupled circuits. A circuit is said to be coupled if two or more parts are related to each other through some common element The coupling may be by means of a conducting path of resistors or capacitors or by a common magnetic linkage (inductive coupling), Fig 9 *See* COUPLED CIRCUITS

Open circuit. An open circuit is a condition in an electric circuit in which there is no path for current flow between two points that are normally connected *See* OPEN CIRCUIT

Short circuit This is the existence of a zero-impedance path between two points of an electric circuit *See* SHORT CIRCUIT [C F G]

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Circuit, electronic

An electric circuit in which some of the components are classified as electronic components These are the identifying feature of electronic cir cuits and their characteristics determine the char acteristics and the function of the circuit Follow ing an introduction to electronic components this article discusses the more important considerations in electronic circuit design

Electronic circuits are classified by their func tion specific electronic circuits will be found in this encyclopedia under titles describing these functions *See* AMPLIFIER COUNTING CIRCUIT DE TECTOR MODULATOR OSCILLATOR POWER SUP PLY ELECTRONIC RECTIFIER SWEEP GENERATOR SWITCHING CIRCUIT TIME DELAY CIRCUITS WAVE SHAPING CIRCUITS

Electronic circuits find application in all branches of industry and in the home Because of their low power dissipation and fast response they are excellent control circuits Computers and navigation systems use many types of electronic circuits *See* COMMUNICATIONS ELECTRICAL COM PUTER CONTROL SYSTEMS NAVIGATION SYS TEMS ELECTRONIC

ELECTRONIC COMPONENTS

For an electric circuit to be classed as an elec tronic circuit some of its components must be able to switch currents or voltages without mechanical switches or to amplify or control voltages or cur rents without mechan cal command Such devices as electron tubes transistors magnetic ampl fiers diodes quartz crystals resistors capacitors induc tors transformers and ferrite devices are electronic components tube sockets interconnecting wires chassis strictly are not although they form a part of the electronic circuit For a discussion of typical components *see* CAPACITOR DIODE SEMICONDUC TOR ELECTRON TUBE FERRITE DEVICES INDUCTOR PIEZOELECTRIC CRYSTAL RESISTOR SEMICONDUC TOR TRANSFORMER TRANSISTOR

Typ cally electronic components have the capa bility of dissipating controlling or storing elec tric energy or some combination of these func tions In addition the current and voltage applied to the component may bear a relatively linear rela tion to each other (such as a resistor) a nonlinear relation as a function of current and voltage (such as a d ode transistor electron tube or saturable reactor) a nonconstant relation as a function of frequency (such as an inductor capac itor or transformer) a time-controlled switching function (such as a thyratron) or a combination of the relations Although a component is intended to introduce only one or two of the voltage-current relations or characteristics into a given circuit certain undesired or parasitic characteristics are also introduced Because of the wide range of power levels at which electronic components must function from less than 10^{-5} watts to 10^{7} watts and the wide range of frequencies from direct current to 10^{11} cycles per second (cps) the para sitic characteristics are of great importance to cir cuit behavior Noise generated in the components is important in low power circuits *See* NOISE ELECTRICAL

Some classes of electronic components such as those for military service are packaged to protect them from environmental conditions whereas ordi nary components are given little protection Spe cially packaged components that are used in equipment required to give reliable operation must also be used conservatively that is at frac tions of their rated values of voltage current and power d ssipation This is a function of circuit de sign and is discussed later in this article [K.A P]

ELECTRONIC CIRCUIT DESIGN

There are many factors that enter into the design of an electronic circuit in addition to that of choos ing the proper values for the resistors capacitors inductances and so on in the circuit Failure to con sider these additional factors may often result in circuits that will perform their expected function for only a short time or not at all The circuit de signer learns these factors by experience Some of these considerations will be discussed in the fol lowing material

Circuit specifications The expected perform ance of an electronic circuit is stated in the speci fications which cover the electrical behavior and in addition may include mechanical and thermal limits within which the circuit is expected to give satisfactory performance For example the specifi cations for an audio amplifier might state that the bandwidth shall extend from 20 to 20 000 cps and at the maximum power output the total harmonic distortion shall be no more than 3% Other specifi cations may also be given such as limits on the allowable intermodulation distortion

In many situations electronic circuits are ex pected to give satisfactory performance over a wide range of environmental temperatures For example complex military electronic equipment must operate as well in the arctic regions as in the tropical regions The specifications must include the permissible change in the behavior of the cir cuit over a wide temperature range

Mechanical disturbances such as vibration shock and acceleration to which electronic equip ment can be subjected can affect the electrical be havior Electronic equipment in space satellites must be expected to withstand cons derable ac celeration while function ng properly Vibration

and shock can affect the performance of circuits using vacuum tubes

From the above brief discussion it follows that the specifications placed upon the performance of a circuit are important factors in the design There are additional factors such as cost maintenance and reliability Textbooks and handbooks often give only a cursory treatment if any of other than purely electrical factors that affect the design of circuits The design of circuits to meet mechanical thermal and other requirements is a problem in experimentation testing and the employment of empirical data *See* SYSTEMS ENGINEERING

Reliability considerations The reliability of a given circuit in the performance of the expected function is an important consideration in the design There are cases on record of the failure of a complex expensive system because of the failure of an inexpensive component The reliability of a circuit is of course determined by the reliability of the resistors capacitors vacuum tubes semiconductors and other components Therefore the most reliable circuit is made from the most reliable components To increase the reliability of the components the circuit is often designed to use the

mum the power dissipated as heat in a resistor might be 50% of the maximum or the voltage on a capacitor may be only one third the rated value In addition some components are specifically designed for situations where reliability is essential the cost of the component being increased accordingly *See* RELIABILITY OF EQUIPMENT

Component ratings The components in electronic circuits are rated so that if the rating is exceeded for a period of time the component will fail One of the common ratings is the amount of power that the component can safely dissipate as heat This is the usual rating for resistors vacuum tubes and semiconductors Adequate provision must be made for the conduction convection and radiation of this heat to ensure the maintenance of proper operating temperatures (*see* HEAT TRANSFER) Another rating is the maximum voltage that can be placed across the element For example if the voltage rating of a capacitor is exceeded the dielectric may be punctured and the capacitor ruined It follows then that the components must be used in a given circuit in such a way that the rating will not be exceeded

Environmental factors The environment under which the circuit is used is an important factor in the design The considerations involved in the design of a circuit that will be used only in a laboratory are much different from those for a circuit that may have to operate reliably over a temperature range from −50 to 150°F and an altitude of from sea level to 50 000 ft Furthermore the circuit may have to operate reliably in locations where the humidity is excessive The choice of components and the design which will assure that the circuit will operate in the expected environment often can be learned only by experience and experimentation

Stability of circuit The stability of the performance of a circuit is of extreme importance Since vacuum tube characteristics change somewhat with use a circuit may have different characteristics after an extended period of use Other components in the circuit also age with a resulting alteration of the performance To counteract these effects the circuit is designed with components that are stable with time Vacuum tube characteristics can be stabilized somewhat before they are put into the finished circuit by operating them at some fraction of the rating for a period of time say 100 hours Other components in the circuit can also be put through an aging cycle before they are installed The end result is that the performance can be made quite stable with time [HFK]

ELECTRONIC CIRCUIT TESTS

Between the time an electronic circuit is designed on paper and the time the equipment embodying the circuit is finally discarded many tests may take place The number kind and severity of the tests depend upon the nature and purpose of the equipment

A home radio receiver to be sold at a low price and in intense competition may be tested only to see if it will function when placed in the home A piece of military equipment on which the success of a mission or the lives of personnel may depend undergoes much more extensive and rigorous tests

Breadboard model After a circuit is designed on paper the first step toward manufacture of the equipment is to make a breadboard model This may consist simply of mounting the components on a base board or panel (in the early days on an actual wooden breadboard) on which the selection placement and mounting of the components may bear little relation to the final manufactured models

The purpose of such preliminary models is to determine if the paper circuit design performs the desired function The parts are usually arranged for easy removal and substitution

Prototype model After the breadboard model performs properly (in electronic terms when it has the bugs removed) a prototype model is carefully constructed to conform to the way the designer envisions the final manufactured product

This model is tested to determine if the components are satisfactory and to test out the effects that various voltages currents temperature rises and other factors may have on equipment operation The prototype also may be life tested to actual failure

Military equipment tests Not only are the individual parts which go into a piece of military equipment tested individually prior to acceptance and placement into the equipment but the final production models must undergo lengthy and stren

uous tests to determine if the equipment lives up to its specifications

Acceptable quality level The specifications that describe and define a piece of military eq ipment usually state that only standard parts may be used These are parts that have undergone qualifi cation tests by the military services In such tests the parts are examined for proper functioning under such environmental conditions as tempera ture humidity and shock and vibration The com ponent part specification allows a certain number of units to fail these tests If the tested parts pass the requirements the manufacturer s name is put on a Qualified Parts List (QPL) which indicates that he has made at least one batch of parts that passed the tests at the required Acceptable Quality Level (AQL)

If for a particular function the designer can find no standard part he may get a waiver from the military service to use a nonstandard part but such waivers are discouraged

Reliability Specifications for military electronic equipment now include reliability clauses which require the manufacturer of the equipment to per form tests to ensure that the equipment will per form the desired function for the desired time Out of such tests comes a measure of the mean time between failures which shows how long on the average such equipment will function before it is likely to require repair

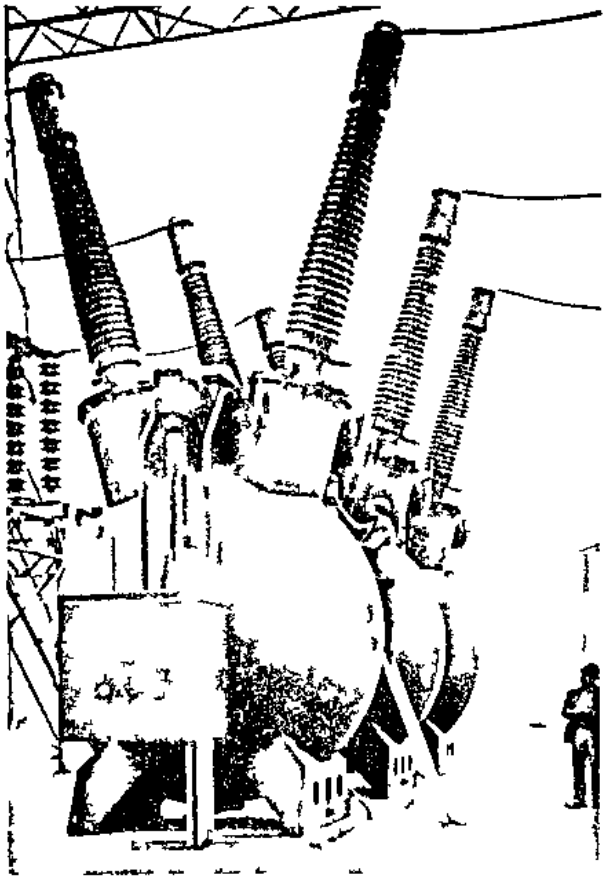
Radio service testing No electronic equipment is so perfect that it will never fail When the equip ment refuses to function service is required Most often an electron tube has failed and a simple substitution of a good tube for the bad one will put the equipment back into effective use

Other components also occasionally fail and it becomes necessary to determine which of the many parts is at fault Service personnel are now equipped with symbolic circuit diagrams of radio and television receivers marked with the resistances and voltages that should appear at certain points if the equipment is functioning properly The service man equipped with a volt ohmmeter can easily check out the receiver and locate the offend ing component

More complex equipment for industrial or mili tary uses is often constructed of replaceable units each un t containing a functional circuit such as an amplifier When trouble is traced to such a unit the entire unit is removed and another is sub stituted The unit at fault can then be repa red at a rear echelon shop where more time and better facilities are available These units are often modu lar in form *See* MAINTAINABILITY OF EQUIPMENT PACKAGING OF EQUIPMENT [K HE]

Circuit breaker

A device which opens an electric power circu t whenever excessive current develops thereby pro tecting the circuit s apparatus and surroundings from the potentially disastrous consequences of



Fg 1 O l c rcu t breakers hav ng an nterrupt ng rat ng of 42 000 amp at 345 000 volts (*General Elec tr c* Co)

sustained excessive current Excessive currents usu ally are the result of short circuits caused by l ght ning accident or deterioration of equipment For another means of protection against excessive cur rent *see* FUSE In addition circuit breakers often are used in place of switches to close and open circuits in the normal course of power system op eration *See* SWITCH ELECTRIC

The opening of a circuit carrying excessive cur rent always generates a potentially destructive electric arc at the point of opening The circu t breaker must extinguish this arc quickly and harmlessly dissipate its enormous energy The essential elements of a circuit breaker are one or more assemblies of contacts and arc extinguish ing devices known as interruptors (*see* CONTACT ELECTRIC) Necessary accessory elements are the contact operating mechanism conta ners for the arc ext nguishing medium (o l air or gas) and the insulating supporting and protective struc ture

C rcuit breakers are used in pract cally all kinds of electric power transmission and distribution sys tems from small isolated farm generating plants to the largest public utilities and industrial plants In physical size they range from that of a small two story house to that of a package of cigarettes They are rated according to their ability to

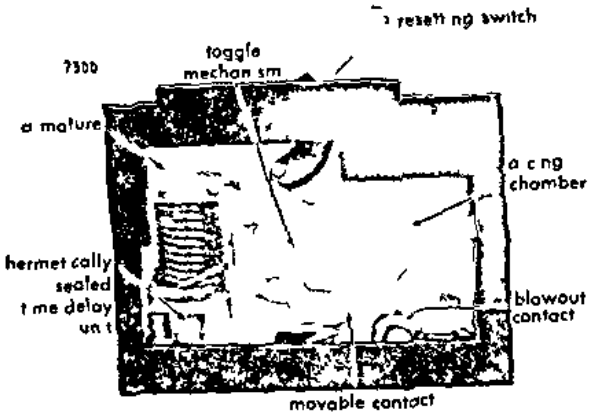


Fig 2 Working parts of a small electromagnetic cir cu t breaker with magnetic arc quenching (*Heinemann Electric Co*)

rupt short circuit current from a few amperes at less than 100 volts to over 40 000 amperes at 345 000 volts and 150 000 amperes at 240 volts

According to the method used to extinguish the arc they are classified as (1) oil in which the arc is drawn and extinguished in insulating oil (2) air blast in which the arc is extinguished by a blast of compressed air directed between the open contacts (3) magnetic air in which the arc is forced by a magnetic field along diverging con ductors into a labyrinth of cooling baffles (*see* BLOWOUT COIL) and (4) gas in which arc ex tinction takes place in a dielectric gas other than air

Circuit breakers are required to interrupt the circuit in a very short time ranging from about 0 01 to 0 1 sec after excessive current appears Many types are also required to reclose in as little as 0 3 sec Powerful mechanisms are often neces sary to drive the contacts at high speeds and with sufficient force to overcome the high magnetic forces occurring when high short circuit currents develop during the closing operation

Electric solenoids compressed air and pre compressed springs are the most frequently used means of actuating these mechanisms

Protective relays give the tripping signal to most high voltage breakers (*see* ELECTRIC PROTECTIVE DEVICES) Low voltage breakers (750 volts and be low) are provided with built in current sensitive devices (electromagnetic or thermal) which sense the presence of excessive current and trip the breaker These devices are similar in operation to electromagnetic and thermal relays *See* RELAY

[W N G]

Circuit testing, electrical

The testing of electric circuits to determine and lo cate any of the following circuit conditions (1) an open circuit (2) a short circuit with an other conductor in the same circuit (3) a ground which is a short circuit between a conductor and ground (4) leakage (a high resistance short cir cuit) and (5) a cross (a short circuit or leakage between conductors of different circuits) Circuit testing for complex systems often requires exten sive automatic checkout gear to determine the faults defined above as well as many quantities other than resistance

In cable testing the first step in fault location is to identify the faulty conductor This is done with a continuity tester such as a battery and flashlight bulb or buzzer (Fig 1), or an ohmmeter

Murray loop test Useful for locating faults in relatively low resistance circuits the Murray loop is shown in Fig 2 with a ground fault in the cir cuit under test If the fault is a cross, the battery should be connected to the second faulty conductor rather than to ground From a knowledge of the conductor size and resistance per unit length the location of the fault can be calculated from the ratio relationship

Varley loop test This is similar to the Murray loop test except for the inclusion of the adjustable resistance R The Varley loop (Fig 3) is used for fault location in high resistance circuits

Open circuit An ac capacitance bridge can be used for locating an open circuit as shown in Fig 4

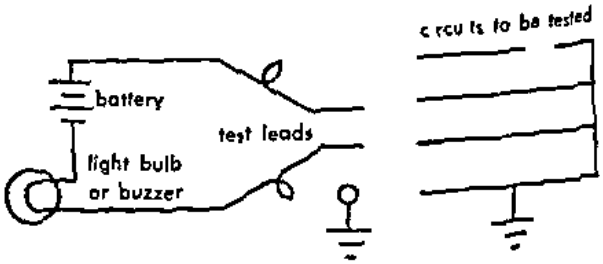


Fig 1 Simple continu ty test equipment

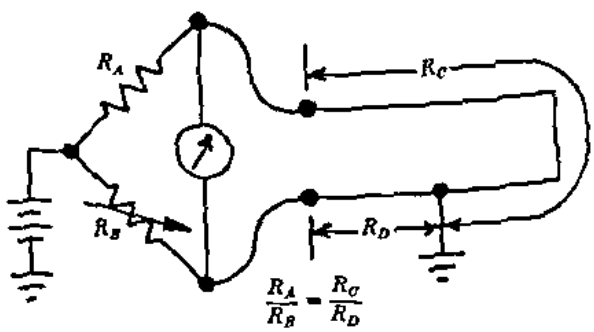


Fig 2 Murray loop test circuit

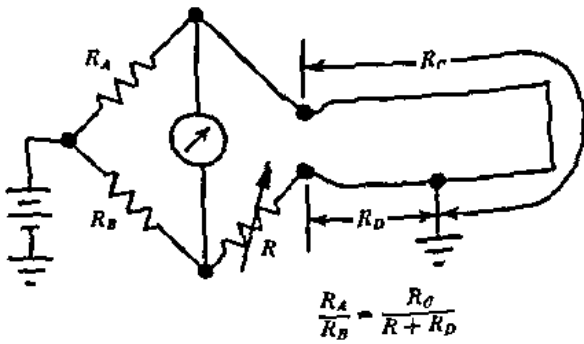


Fig 3 Varley loop test circuit

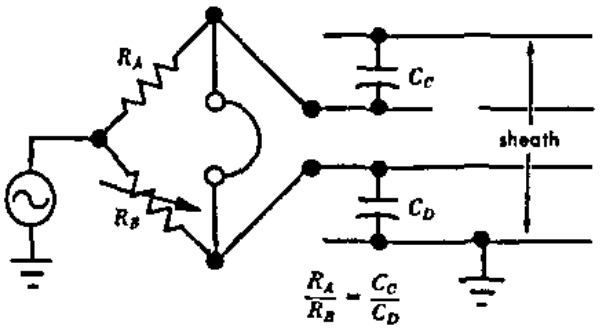


Fig 4 Capacitance bridge for locating open circuits

The location of the cable break can be calculated from a knowledge of the cable length and the bridge ratio setting

Equipment for circuit testing A wide variety of instruments is used for circuit tests Where resistance is the property to be tested the ohmmeter and the Wheatstone bridge for fault location are most often used *See* OHMMETER WHEATSTONE BRIDGE

The fault location bridge is a specialized version of the Wheatstone bridge with switching arranged to obtain the various loop test circuits required for fault location testing *See* CIRCUIT ELECTRIC RESISTANCE MEASUREMENT [C E A]

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Circulation

The movement of blood in a closed circuit from a muscular pump or heart to the body tissues and back to the heart By extension the term is applied to other fluid transport systems in multicellular animals although a circular path is not always involved Circulatory systems function in the transport of foodstuffs wastes gases and internal secretions among the organs and tissues of the body The experimental proof of the circular movement of the blood in the vertebrates published in 1628 by William Harvey is regarded as the first major achievement of modern physiology For a discussion of the function of blood in gas transport *see* RESPIRATORY PIGMENTS

FLUID TRANSPORT SYSTEMS

The basic elements of fluid transport systems in animals are the heart blood vessels and circulating fluids

Blood vessels These are hollow tubes of connective tissue which often include a muscular layer Vessels which carry blood from the heart to the tissues are called arteries those carrying blood from the tissues to the heart are called veins Blood is forced from the ventricle into a large artery typically called the aorta this vessel then undergoes branching usually dichotomous as the distance from the heart increases The diameters of the individual branches are generally less than that of the main artery from which they arise but the total cross sectional area of the arterial system increases as it passes from the aorta to the smaller branches or arterioles which terminate in capillaries These are thin walled vessels connecting the arterioles with the smallest branches of the veins the venules The venous branches finally unite into one or two major veins known in the vertebrates as caval veins or venae cavae leading into the atrium In certain invertebrates the smaller branches of the arteries do not end in capillaries but open freely into tissue spaces or sinuses Body fluid is then collected from the sinuses into the veins The heart itself is not supplied with blood vessels except in mammals where special vessels the coronary arteries arise from the aorta and ramify through the heart tissue the coronary veins empty into the atrium

Circulating fluid The circulating fluid or blood is an aqueous solution of salts proteins and other organic substances containing in suspension cells of various types The term blood is sometimes restricted to a circulatory fluid containing erythrocytes or red blood cells and contained wholly within the vessels of a closed circulatory system The circulating fluid in open systems is then called hemolymph In the closed type of circulatory system the tissues are bathed by a fluid known as lymph which is outside the blood vessels and is largely formed by transudation of the noncellular portion of the blood through the capillary walls Lymph is returned to the blood vascular system along special channels which ultimately unite to form lymphatic vessels leading into a main lymph vessel such as the thoracic duct of mammals which drains into the vena cava Some vertebrates such as the frog have lymph hearts which aid in this return *See* BLOOD

Heart The heart is a hollow muscular organ capable of rhythmic contraction and usually provided with valves which permit flow through the organ in only one direction In some animals accessory hearts occur in addition to the main or systemic heart The heart may be divided into two or more chambers A chamber which receives blood coming from the tissues is called an atrium one which forces blood out of the heart toward the tissues is called a ventricle The term auricle is sometimes used instead of atrium but should be used only for the mammalian atrium Contraction of the muscle decreases the volume of the heart cavity or lumen and thus forces blood out of the lumen The simplest form of heart is seen in the contractile dorsal blood vessel of certain annelid worms In this vessel the contraction begins at the posterior end and progresses anteriorly in a peristaltic wave which moves the blood toward the head A similar arrangement is found in some insect larvae and in primitive chordates such as the amphioxus Most hearts were probably derived from such contractile vessels

The heart of arthropods is a dorsal tubular structure the lateral walls of which are pierced by openings or ostia The heart is enclosed in a peri

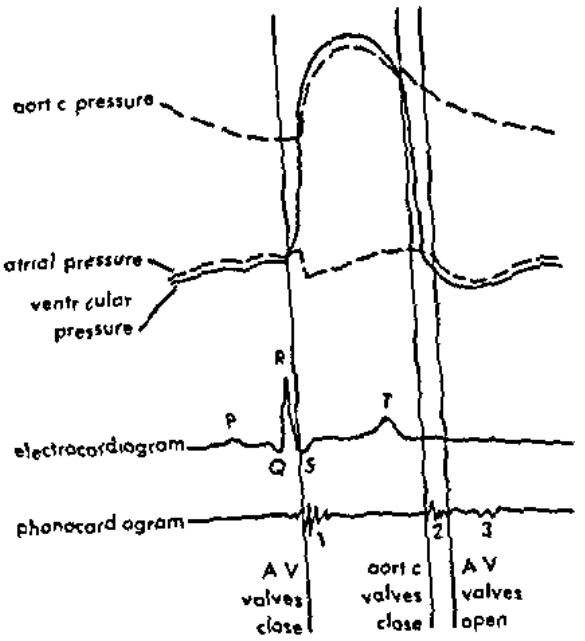


Fig 1 Events in the mammalian cardiac cycle (*From J F Fulton A Textbook of Physiology 17th ed. Saunders 1955*)

cardial cavity and a large blood vessel or aorta arises from either end of the heart The pericardial cavity receives blood through veins leading from the gills in crustaceans or body sinuses in insects The ostia are provided with valves permitting flow only from the pericardial cavity into the heart The heart is suspended in the pericardial cavity by elastic ligaments or in some insects by muscles When the heart contracts blood is forced into the aorta and the suspending ligaments or muscles are stretched When the contraction ends the heart is returned to the resting condition by elastic recoil of the ligaments or contraction of the suspensory muscles This return is accompanied by aspiration of blood into the heart through the ostia (Fig 1)

Contraction cycle The contraction cycle of the vertebrate heart begins with the heart in diastole, the musculature is relaxed the atrioventricular valves are open and the semilunar valves in the aorta are held closed by the pressure of the blood in the aorta Blood flows into the heart passively from the great veins, filling atrium and ventricle The electrocardiogram (ECG) obtained by recording from two points on the body surface the small changes in electrical potential which arise when the heart is excited and the wave of excitation is conducted through the tissues of the heart, shows a steady line of constant potential in diastole

[illegible]

of the heart This excitation arises spontaneously in a bundle of specialized heart tissue at the point where the great veins joined to form the sinus venosus enter the atrium This bundle is known as the sinoatrial node (SA node) Immediately following excitation the atrial contraction begins, and the pressure in the atrium and ventricle begins to rise The atrial contraction is weak, and serves merely to empty the blood which has collected in the atrium into the ventricle, thus increasing the ventricular volume somewhat This movement of blood can be detected with the stethoscope as a soft rushing sound

Before the atrial contraction is complete, the wave of excitation has reached the boundary separating atrium from ventricle Here there is another bundle of specialized tissue known as the atrioventricular node (AV node) The wave of excitation is delayed here, because of the special arrangement of cells, until the atrial contraction is well along The excitation then spreads rapidly in the mammalian heart, along a bundle of special conducting tissue, the bundle of His, to the apex of the ventricle, whence it spreads more slowly back up toward the base of the ventricle through the musculature Birds have a similar conducting tissue but in the lower vertebrates conduction occurs only through the musculature itself

The passage of the excitation wave along the bundle of His is accompanied by a sharp three phase deflection in the ECG, called the QRS wave this wave ends just as ventricular contraction begins As the ventricle fills during atrial systole the large valves separating atrium and ventricle flop out toward their closed position, the beginning ventricular contraction slams the valves shut with a distinct sound which may be characterized the syllable "lub" At once, the ventricular pressure begins to rise until it exceeds the pressure the aorta, at this point, the semilunar valves forced open and the ejection of blood into aorta begins

During the brief period when both sets of valves are closed, called the isometric period, the ventricular volume remains unchanged As the maximum contraction is attained, and relaxation commences there is another small deflection on the ECG T wave The pressure in aorta and ventricle begins to fall, when it falls below the back pressure in the aorta the semilunar valves are forced shut with a sound characterized as "dup" During the ejection phase of ventricular contraction has again begun to flow into the atrium the veins As the ventricular pressure falls below the pressure in the atrium, the AV valves open and the cycle is complete

Muscular activity. The heart exhibits the common property of muscles whereby the force of the contraction is proportional to the length of the muscle before contraction The force of each contraction of the heart is therefore determined by the amount of blood which has flowed in during diastole All the blood contained in the heart is in a normal organ forced out with each contraction Consequently, the amount of blood which is pumped out of the heart per minute (minute volume or cardiac output) is always exactly equal to the amount entering the heart from the veins per minute (cardiac input) This relation output equals input, is Starling's law of the heart

Heart excitation. The excitation of the heart is a spontaneous phenomenon similar to spontaneous activity in other tissues (*see* NERVOUS SYSTEM) The mechanism of such excitation is poorly understood In all hearts, the excitation typically arises in a localized region known as the pacemaker The position of the pacemaker may be changed experimentally by local increases in temperature, whereupon the warmed region becomes the pacemaker When an isolated heart is separated into fragments the region of the pacemaker shows a higher rate of spontaneous beating than do other regions This suggests that the pacemaker region has the highest metabolic activity of any part of the heart In a few animals such as ascidians, the pacemaker activity may shift from one end of the heart to the other at intervals, resulting in a reversal of the heart beat, and hence of the circulation In most animals the pacemaker is in the heart tissue itself and is either typical muscle tissue or tissue obviously derived from muscle

When the beat arises in muscular tissue it is spoken of as myogenic In a few animals notably the higher crustaceans insects, and the xiphosuran *Limulus*, the horseshoe crab, the beat originates in a nervous ganglion attached to the heart, and is referred to as neurogenic The drug acetylcholine generally acts to slow or stop the beat of myogenic hearts, and accelerates the beat of neurogenic hearts *See* ENDOCRINE MECHANISMS

Rate of beat The rate of beating of most hearts is under external control by nervous influences The control may be excitatory, inhibitory, or both The inhibitory nerves of the vertebrates and of the quahog clam, *Venus mercenaria*, act by liberating acetylcholine from their endings, and are called cholinergic The accelerator nerves of the vertebrates act by liberating noradrenaline, and are called adrenergic Other mediators of nervous excitation and inhibition undoubtedly exist in the invertebrates, but have not been identified The excitatory and inhibitory nerves of the vertebrates and probably of other animals as well, are under reflex control

TYPES OF SYSTEMS

The major types of fluid transport systems in animals are the closed circuit, the open circuit, and the ebb-and flow systems (Fig 2)

The closed circuit. *This system is typical of vertebrates*, many annelid worms, cephalopod mollusks and a few other invertebrates The blood flows in its entire circuit in vessels, and comes in contact with the tissues only across the thin walls

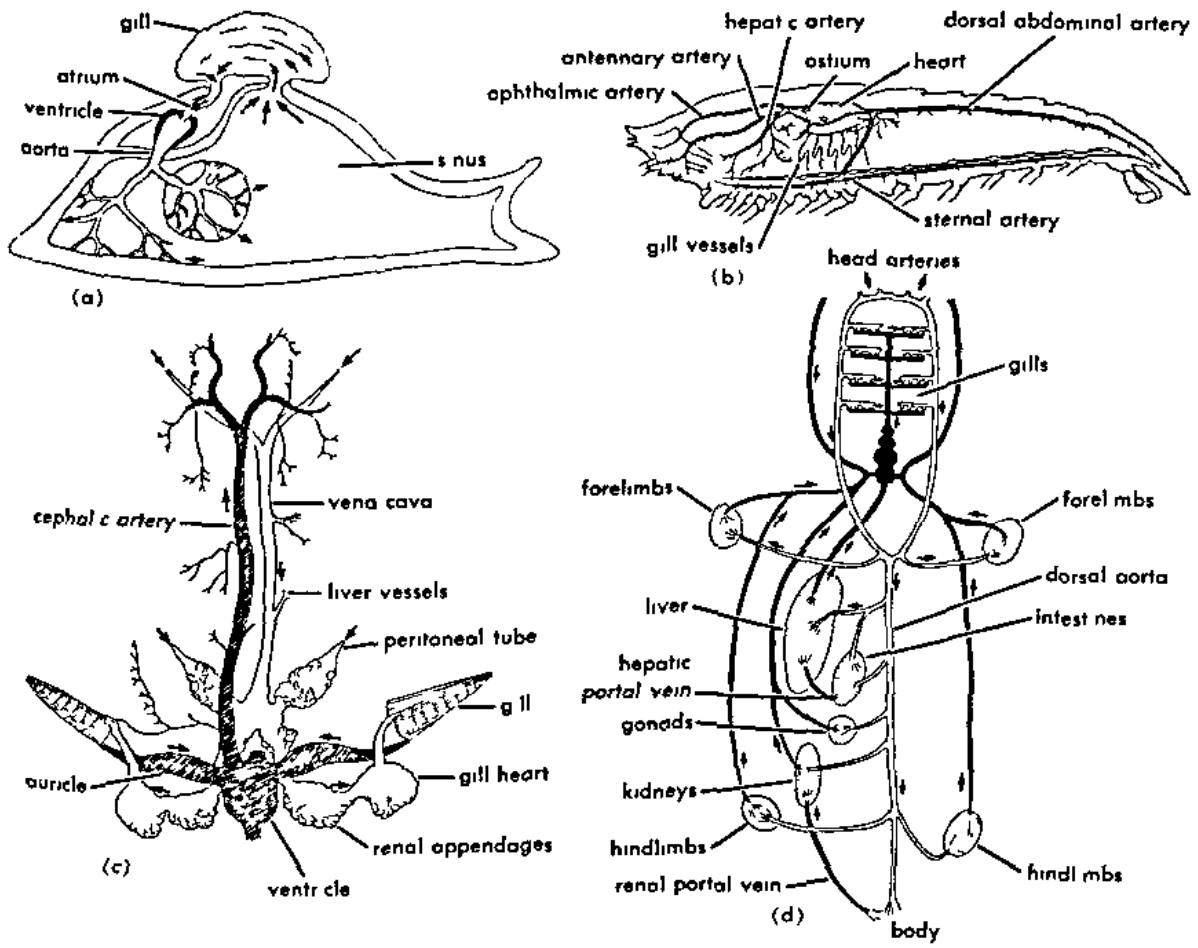


Fig 2 Patterns of blood flow in open and closed circulatory systems (a) Sea slug *Aplysia* open system (b) A crayfish, open system (c) An octopus closed system (d) A fish, closed system (*From B T Scheer Comparative Physiology, Wiley, 1953*)

of capillaries or enclosed sinuses Systems of this type generally contain a small volume of blood 2 10% of the body weight under relatively high and constant pressure 10–150 millimeters (mm) of mercury

The open circuit This type is typical of arthropods and most mollusks The hemolymph flows out of the open ends of the arteries into spaces known as sinuses The sinuses collectively make up the hemocoele and are not lined with mesodermal tissue The hemolymph is generally large in volume 10–60% of the body weight and the blood pressure is low and variable

Ebb and flow system The ebb and flow type of system is found in nematodes rotifers and entoprocts In such systems there are no blood vessels and the hemolymph is moved through a hemocoele a pseudocoelom or a true coelom by general body movements This type of system serves an important secondary function as a hydrostatic skeleton giving purchase to the muscles in burrowing movements

It appears likely that the closed system is the primitive type and that the other systems are derived from it by degeneration of blood vessels in the course of evolution

DYNAMICS

The dynamics of blood flow are determined by the action of the heart and by the arrangement and diameters of the blood vessels The blood ejected from the heart passes first into the aorta or a similar large artery The effect of the sudden ejection against the inertia of the blood already in the vessel is to stretch the elastic walls of the artery in a bulge This bulge is then propagated mechanically along the arterial system as the pulse wave *The blood* in the arteries is under hydrostatic pressure The blood pressure may be measured experimentally by inserting a tube or needle into an artery and connecting the tube with a manometer *or other device* for measuring pressure Clinically the measurement is made by inflating with *air a cuff placed around a limb* and determining the air pressure required to stop the flow of blood completely (systolic pressure) or to stop *the flow* momentarily only at the lowest point of the pulse wave (diastolic pressure) The blood pressure *is* ordinarily expressed in terms of the pressure exerted by a column of mercury *hence in millimeters* of mercury and given as systolic diastolic The accepted normal pressure for man is 120/80 The difference between systolic and diastolic *pressures* 40 mm in man is called the pulse pressure

Blood pressure The blood pressure is the resultant of the force exerted by the contraction of the heart acting against the *frictional resistance* to blood flow offered by the blood vessels The force of contraction is directly related *to the cardiac* output or minute volume this in turn is the product of the output per beat or stroke *volume by the* heart rate in beats per minute Because input and output are always equal any change in heart rate must be accompanied by a corresponding change in stroke volume in the opposite sense and the output is determined solely by the input not by the rate An increased input may be accommodated either by an increased rate or by an increased stroke volume or by both

Frictional resistance The frictional resistance to blood flow as in any hydraulic system is inversely proportional to the diameter of the vessel In consequence the bulk of the frictional resistance is concentrated in the smallest vessels of the system Pressure decreases in vessels which become progressively smaller and farther from the heart the greatest drop occurs in the arterioles The major factor in the normal variation in blood pressure is also the arteriolar diameter which can be varied considerably by contraction or relaxation of smooth muscle fibers arranged circularly in the vessel wall The frictional resistance in the arterioles also determines the amount of blood flow to various regions In a set of parallel channels the volume of blood flow in each will be inversely proportional to its frictional resistance Blood may thus be diverted from one body region to another in mammals by a change in arteriolar diameter and a consequent change in local resistance

Resistance in open systems In the open type circulatory system of certain invertebrates there are no arterioles or capillaries and frictional resistance within the system is consequently low The major factor determining blood pressure in such a system is probably body movements which, by local compression of blood in a part of the hemocoele aid in moving blood from one part of the body to another Measurements of pressure in different parts of an open system have revealed higher pressures in the hemocoele than in the heart in many instances indicating that in such systems the body movements are the main force in moving the blood and that the heart serves only to give direction to the flow through the vascular part of the system and possibly to move the blood sluggishly when the animal is inactive

Control of arteriolar diameter The control of arteriolar diameter and hence of blood pressure *and blood flow* in the vertebrates involves *both* nervous and humoral factors The basic control of *total blood* pressure involves a *feedback reflex* mechanism centered in a cardiovascular center in the medulla oblongata of the brain This center exerts a continuous or tonic control over the heart rate through the vagus nerve and over arteriolar diameter through vasoconstrictor fibers connected *with* the sympathetic portion of the nervous system

The heart is under a continuous inhibitory influence through the vagus and the arterioles are in a state of continuous partial constriction under the influence of the constrictor fibers The activity of the cardiovascular center is in turn influenced by nervous impulses arising in receptors located in the gill vessels of fishes and in the carotid sinus and aorta of higher vertebrates These receptors are normally stimulated by stretching of the ves-

sels that is by an increase in arterial pressure The effect of stimulation is an increase in vagal activity hence slowing of the heart and a decrease in activity of the vasoconstrictors hence dilation of the arterioles The change in heart rate is without effect on the blood pressure but the dilation of the arterioles results in a fall of blood pressure The effect of this reflex system is to maintain total blood pressure within normal limits and thus in turn to maintain the heart rate within normal limits

Cardiac output The total blood flow or cardiac output, is as noted earlier determined entirely by the cardiac input or venous return The blood flow to particular organs and tissues is determined by the total flow and by local arteriolar diameter The local arteriolar diameter is determined by a balance between nervous vasoconstrictor effects and local vasodilator effects The most important of the latter are caused by products of tissue activity which diffuse from the cells and cause dilation in proportion to concentration which is in turn in proportion to tissue activity In insects there are often local hearts at the bases of the limbs which facilitate the flow from the hemocoele into these structures it is not known whether the activity of these hearts varies according to local muscular activity

Reflex controls There are in the vertebrates numerous reflex controls on blood flow to particular regions The reflexes originating in the carotid sinus at the bifurcation of the major arteries leading to the head region serve to maintain blood pressure at a level adequate to provide a constant flow of blood to the brain under all normal circumstances (*see* AORTIC BODY CAROTID BODY) The emergency reflexes of the sympathetic nervous system mediating the flight or fight response to fear rage and other strong emotions result in vasoconstriction in the splanchnic area and in the skin thus diverting considerable quantities of blood into the brain and muscles This reflex mechanism is augmented by the discharge of adrenaline into the blood from the medulla of the adrenal glands Adrenaline has actions similar to the noradrenaline liberated from the vasoconstrictor fibers

In birds and mammals and especially in man the skin plays an important part in temperature regulation and the blood flow to the skin is under reflex regulation from the thermoregulatory center in the hypothalamus In general blood flow to the skin is increased when the body temperature tends to rise and decreased when the temperature tends to fall In diving birds and mammals a reflex with receptors in the nasal region acts to produce widespread vasoconstriction throughout the body when the nostrils are wet The effect is to shut off the circulation to all parts of the body save the brain and thus to permit prolonged submergence with the oxygen in blood and lungs used only to supply the needs of heart and brain the remaining tissues *function* anaerobically

Venous pressure The return of blood to the heart through the veins depends on a variety of factors In most animals the venous pressure is the primary factor in venous return The venous pressure is the residual blood pressure after passage through the capillaries or hemocoele plus the pressure produced by compression of veins or hemocoele by muscular activity Dilation of the arterioles will permit a larger fraction of the arterial pressure to be transmitted to the veins and thus increase venous flow Muscle activity will increase the massaging effect and thus increase venous flow In the mammals respiratory movements aspirate blood into the great veins of the thoracic cavity In man and certain other animals the heart is located well above the bulk of the active tissue of the body and the venous return must be accomplished against a considerable hydrostatic pressure In man this return is facilitated by the presence of valves in the veins which effectively prevent flow away from the heart and thus conserve any contribution of body movements or respiratory movements to venous flow In cephalopod and pelecypod mollusks there are gill hearts which aid in pumping blood from the hemocoele through the gills to the heart [BTS]

Circulation disorders

The function of the circulatory system is to transport and distribute substances either used or produced by cells or both Excluded are those materials that are discharged directly from sweat glands digestive glands and renal tubule cells This includes however nutritive and metabolic substances hormones waste products water and heat

The circulating fluids are distributed between the heart blood vessels capillaries intercellular spaces lymphatics and within the cells The blood and body fluids are in a constant state of dynamic equilibrium Blood flows through the vessels to the capillaries where some fluid passes through the endothelium to the intercellular spaces to bathe the cells Fluid with contained electrolytes and metabolic substances can then pass into and out of the cells At the distal end of the capillaries most of this fluid passes back into the vascular compartment A portion of this fluid returns to the circulation via the lymphatics

Vascular disturbances Disturbances in this pattern can either result in or from disease conditions An example is edema which is an abnormal accumulation of fluid in the cells tissue spaces or cavities of the body There are three main factors in the formation of generalized edema and a fourth which plays a role in the formation of local edema They are the permeability of the capillary wall the colloid osmotic pressure of the plasma proteins and the hydrostatic pressure in the capillaries The fourth factor which is of importance in local edema formation is lymphatic obstruction

An example of edema formation secondary to a decrease in the colloid osmotic pressure of the plasma proteins is nephrotic edema In Bright s disease there is a mar
m n and the plasma protein

Cardiac edema follows the generalized venous congestion of cardiac failure and is an example of edema formation resulting from increased hydrostatic pressure in the capillaries

Increased permeability of the capillary walls plays an important role in the formation of inflammatory edema the edema of severe infections metabolic intoxications asphyxia anaphylactic reactions secondary shock and acute nephritis *See* EDEMA

Deficiencies A deficiency of circulating blood volume both cellular elements and fluid is called oligemia This may be the result of an acute blood loss or it may be of a chronic nature such as an anemia combined with dehydration Anemia or oligochromemia is a deficiency of circulating red cell volume or more specifically hemoglobin content This is the oxygen carrying component of the circulating red blood cell The normal value for the adult human is 14 16 g/100 ml of blood The norm for most domestic animals is 10–12 g/100 ml of blood except for the dog which is 13 g

Anemia can result from a variety of causes It may be secondary to a chronic nutritional deficiency with an inadequate intake of iron Iron is a necessary substance used by the blood forming tissues to make hemoglobin Anemia can also result from a defect in the blood forming tissue (the bone marrow) so that it is unable to use the materials available to make red blood cells It can also be the result of a displacement of blood forming tissue as from a tumor It may also follow periods of acute blood loss These are just a few examples of the causes of anemia *See* BLOOD HEMATOPOIESIS

Pancytopenia or oligocythemia is a deficiency of all circulating blood cellular elements This is usually the result of a deficiency of the blood forming tissue the bone marrow

Ischemia The decrease of blood flow to an organ or tissue is known as ischemia This can be sudden as when a vessel is ligated when a thrombus or blood clot forms or when an embolus comes to lodge in the vessel A gradual occlusion can follow arteriosclerotic changes in the vessel wall with resulting diminution of the lumen and blood carrying capacity of the vessel The effect of a sudden occlusion depends to a great extent on the collateral circulation to the organ or tissue involved If an adequate collateral circulation comes to be established the tissue survives if not it dies and an infarct results

An infarct is a region of necrosis resulting from a vascular obstruction The usual cause is occlusion of an artery or vein by a thrombus or embolus If the vessel is the sole source of blood supply the tissue dies *See* INFARCTION

Plethora An excess of blood is referred to as plethora This increase may be the result of an increase in the size or the number of red blood cells The increase in red cell volume may be a poly

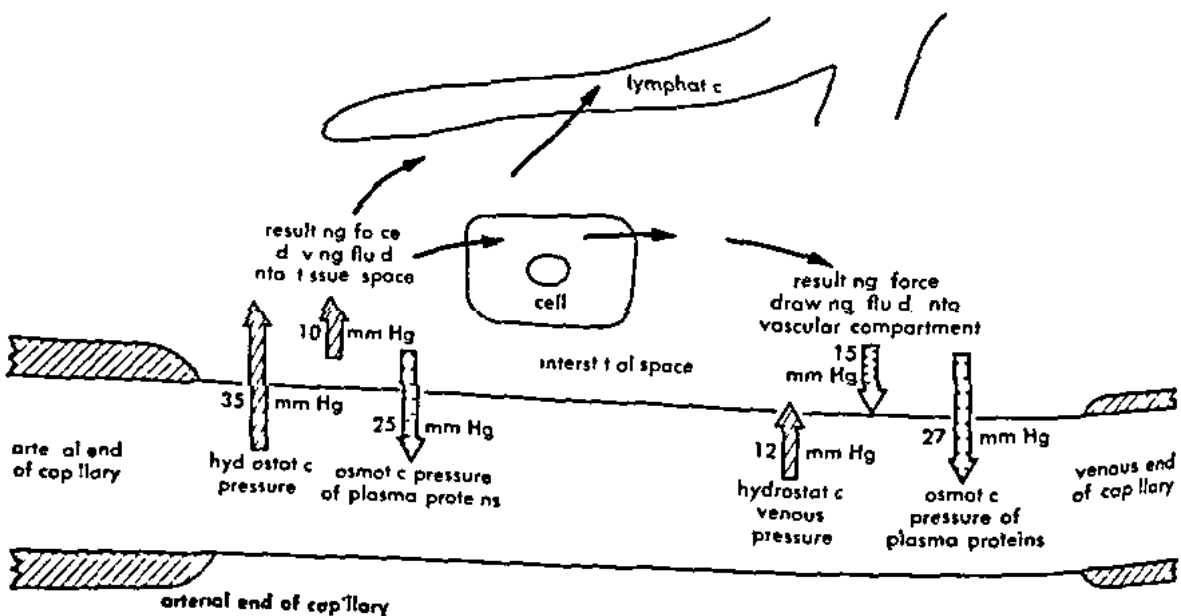


Fig 1 Fluid movements at the capillary level

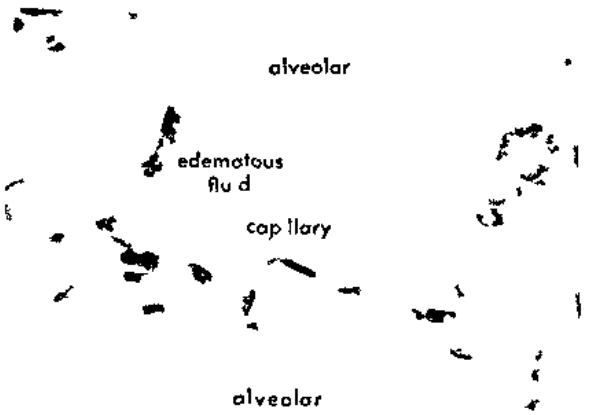
cythemia vera or true polycythemia which is a primary increase in the numl er of red l lood cells with no regard to the needs of the organism Poly *cythemia or erythrocytosis is usually a secondary* increase in red cells following conditions of chronic hypoxia such as congenital heart disease emphysema or residence at high altitudes Serous plethora is an increase in the watery part of the blood

Hyperemia Hyperemia or congestion refers to an excess of blood within an organ or tissue This condition may be localized or generalized Active hyperemia is congestion which is caused by an ac tive dilatation of arterioles and capillaries This oc c irs under certain physiological conditions such as in the muscle when there is an increased need for blood during exercise It also occurs in patho logical states such as inflammation *See* INFLAM MATION

Passive hyperemia or congestion is a condition which results in an accumulation of blood in the venous system It may be generalized or localized and can result from any obstruction or hindrance to the o tflow of blood from the venous circuit The generalized form can result from valvular diseases of the heart such as mitral or aortic stenosis or in sufficiency or myocardial failure from any cause Tricuspid valvular disease is slightly more fre quent in animals *See* HEART DISORDERS

Diseases of the lungs such as emphysema fibro sis or pulmonary hypertension of any origin can result in right ventricular failure and generalized venous congestion The late stages of the above-mentioned conditions can result in cor pulmonale which is a hypertrophy and dilatation of the right ventricle secondary to an obstruction to the pul monary blood flow associated with a generalized venous congestion

Localized venous congestion results when a main vein from a region is occluded either by a thromb is or some extrinsic pressure such as a tumor or en larged lymph nodes



Fg 2 Pulmonary cap llary congest on The cap llary s d lated and full of red blood cells A small quan tity of edematous flu d s seen adjacent to the vessel A r filled alveolar spaces are also evident

In congestion the organ is usually wet and bloody Microscopically there is an enlargement of the veins and capillaries associated with edema *formation*

Hemorrhage The escape of blood from within the vascular system is hemorrhage This process can be the result of trauma to or disease of the vessel wall Diapedesis is the passage of the cor puscular elements of the blood through an intact vessel wall

The trauma which results in hemorrhage may be direct such as a cut from a knife or it may be in direct such as a blow to the head resulting in a tearing of cerebral or meningeal vessels

The causes of hemorrhage other than trauma can be divided into three main groups In the first group are those conditions in which there is a dis ease process affecting the vessel wall such as arte riosclerosis or aneurysm formation An infarct or tissue death from any cause can result in hemor rhage

In the second group are conditions in which there is an acute process affecting the vessel wall such as in septicemia poisoning by heavy metals or even anoxia

The third and last group consists of those condi tions in which there is a defect in the blood itself which results in hemorrhage Under this heading are included the blood clotting disorders thrombo cytopenia leukemia and pernicious anemia

Apoplexy or stroke is an acute vascular lesion of the brain This can be the result of hemorrhage or *thrombosis in* or *embolism* to a cerebral vessel *See* HEMORRHAGE

Thrombosis Thrombosis is the formation of a thrombus which is a solid body formed during life and composed of the elements of the blood plate lets fibrin red cells and leukocytes

Thrombosis is essentially platelet deposition and may occur on a vessel wall anywhere that the endo thelium is damaged However because the plate lets release thromboplastinogen which activates *the clotting mechanism thrombosis and* blood co agulation may occur together Platelets normally exhibit a tendency to stick together This tendency is increased if their number is increased as in thrombocytosis if the velocity of the stream is de creased below a certain speed or if the endotheli m is roughened These are the same factors which promote thrombus formation *See* THROMBOSIS

Thrombi may form in the veins arteries capil laries or within the heart The most common sites for the formation of thrombi are in the veins

The venous thromboses can be divided into two groups venous thrombosis (phlebothrombosis) and thrombophlebitis Phlebothrombosis is *the* most important and is often a sequela of general ized circulatory failure trauma or prolonged bed rest from any cause

Thrombophlebitis is the formation of a thro secondary to inflammation in the wall of Arterial thrombosis is usually the re uses such as arteriosclerosis of

Embolism The sudden blocking of an artery or vein by a clot or other substance which has been brought to its place by the blood current is an embolism The material carried in the circulation in this process is an embolus Emboli may be composed of thrombi fat air tumor cells masses of bacteria or parasites bone marrow amniotic fluid or atheromatous material from the vessel wall

Emboli originating in the right side of the heart or the great venous system of the body come to lodge in the lungs those from the portal system in the liver and those from the pulmonary veins or left side of the heart in some segment of the peripheral arterial tree

One of the dire consequences of an embolus is infarction or death of the tissue supplied by the occluded vessel This occurs if the collateral circulation is inadequate to supply the tissue with blood *See* EMBOLISM [RAV]

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Circulatory system

The circulatory system of vertebrates actually includes two systems of ramifying tubes the cardiovascular (blood vascular) and lymphatic systems The tubes provide the pathway for the circulating fluids which transport food water oxygen and other necessary materials to the cells and aid in the removal of waste products

Cardiovascular system The circulating fluid is the blood which is pumped throughout the body by a muscular contractile heart From the heart the blood enters the arteries of the arterial system which subdivide into smaller vessels the arterioles Arterioles branch into minute vessels the capillaries and these empty into the venules of the venous system The capillary network is the area in which diffusion of nutrients and oxygen into the tissues and elimination of waste products from the tissues occur The capillaries alone are sufficiently thin walled to permit this and they ramify into every organ and tissue Anastomoses of venules result in the veins which return blood to the heart Pulmonary and systemic divisions of the arterial system are recognized The pulmonary division carries blood to the lungs the systemic to other parts of the body In addition to pulmonary and systemic divisions of the venous system all vertebrates have an hepatic portal system Additional forms of lower vertebrates also have a renal portal system which is present in the embryos of higher vertebrates *See* BLOOD CARDIOVASCULAR SYSTEM

Lymphatic system Lymph circulates through the lymphatic vessels which originate from a network of fine lymph capillaries These capillaries which are closed or terminate blindly at their free ends drain the tissue spaces Lymph is a clear watery fluid while in the capillaries It becomes turbid as a result of its passage through the spongy lymph nodes where it receives large numbers of cells the lymphocytes These lymph nodes are located along the larger lymph vessels The flow of lymph is much slower than that of the blood because propulsion is largely dependent upon muscular and visceral movements The lymph vessels have valves which prevent a backflow Some organisms have lymph hearts which are located at the junctions of lymph vessels and veins *See* LYMPHATIC SYSTEM LYMPHANODE [CBC]

Cirque

An amphitheaterlike depression in a mountain side or at the head of a valley Toward the mountain it is very steep with cliffs forming a headwall Formation of such abnormal slopes resulted from the



Cirque amphitheater or bowl shaped glacial valley head in mountain terrain Yosemite area California northeast of Mount McGee (*Photograph by F E Matthes U S Geological Survey*)

breaking up of the bedrock and its attrition and removal by glacial motion Breaking was largely caused by frost action in the crack (bergschrund) between ice and rock In the lower part of many cirques glacial grinding has also excavated a basin later containing a postglacial lake (tarn) Cirques also have been produced by local glaciers in regions of continental glaciation where valley glaciers occurred before or after the larger ice sheet *See* GLACIATED TERRANE [FTT]

Cirrhosis

Any one of several types of liver disease all of which are characterized by an increased proportion of connective tissue in the organ Although the term cirrhosis refers to a yellowish or orange color not all the forms display such discoloration Common usage has also diverted the term to include scarring or fibrosis and when used alone to denote the most common form that of nutritional cirrhosis *See* LIVER

Various classifications of cirrhosis are in use but none is universally accepted because etiologic factors are sometimes difficult to isolate or identify

Nutritional cirrhosis is also known as alcoholic Laennec's and portal cirrhosis. Middle aged persons are most often affected especially males. The true etiology is not specifically known despite the association with alcoholism. Dietary deficiencies metabolic defects and other factors must be considered in view of clinical and experimental findings.

In the early stage of cirrhosis the liver is enlarged loaded with fat and smooth. Progressive disease eventually leaves a typical nodular shrunken organ which is largely scar tissue with an irregular pattern of regenerating liver lobules. Hepatic insufficiency associated disease coma and death may follow a progressive course in a surprisingly high number of cases which are free of severe symptoms until the terminal stage.

Other common forms of cirrhosis which display characteristic features fall into a few major categories. Biliary obstruction and some forms of cardiac disease produce biliary and cardiac cirrhosis respectively. In addition liver cell damage from specific infections chemicals and other agents may lead to postnecrotic cirrhosis characterized by massive destruction of liver tissue. Syphilitic cirrhosis is marked by characteristic lesions; other less common types are also recognized. *See* SYPHILIS. [E. G. ST.]

Cirripedia

A subclass of the Crustacea which are permanently fixed in the adult stage. The carapace consists of a fleshy mantle with or without calcareous plates. Typically the body is indistinctly segmented with six pairs of biramous thoracic appendages (cirri) and a vestigial abdomen. Attachment is by means of the antennules. Compound eyes and antennae are absent in the adult; a heart is lacking and these organisms are usually hermaphroditic. The female orifices are on the first thoracic segment while the male openings are at the posterior end of the body. Development is by metamorphosis and includes two larval stages, the nauplius and cypris.

In addition to the well-known barnacles, the Thoracica, the subclass includes one closely related order, the Acrothoracica, the members of which live in holes bored in shells, and three highly modified orders, the Rhizocephala, Ascothoracica, and Apoda, which are parasitic in invertebrates.

Ecology. Although the Thoracica are not parasitic, many species are associated with other invertebrates such as sponges, coelenterates, mollusks, crustaceans, and echinoderms, as well as with such vertebrates as fish, sea snakes, turtles, and whales (Fig. 1*a*). A few species are limited to a single host or even to certain areas of the body. Some species are partially imbedded in the shell or skin of the host. Many species associated with animals are also found on rocks, pilings, or floating objects, including ships and buoys (Fig. 1*b*). The fouling of ships and other marine structures costs the shipping industry millions of dollars annually. Barnacles are one of the commonest animals on rocky shores and occur in large numbers to the edge of the continental shelf; however, they also are found at great depths. They are widely distributed in tropical and warm temperate waters, but

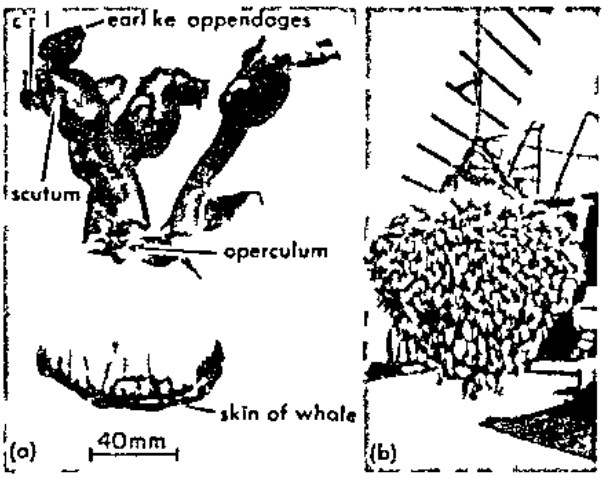


Fig. 1. (*a*) *Conchoderma auritum* (L.) on *Coronula diadema* (L.) from a humpback whale (*Photograph by V. B. Scheffer, U.S. Fish and Wildlife Service*). (*b*) Glass ball, formerly a Japanese fishing float, heavily fouled with *Lepas anatifera* Linnaeus (*Photograph by R. Shomura, Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu*).

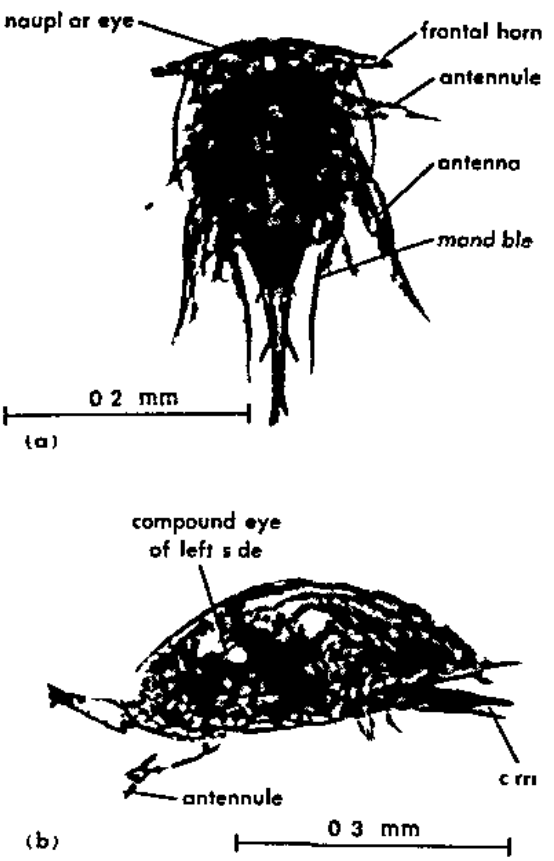


Fig. 2. (*a*) Nauplius of *Balanus*. (*b*) Cypris of *Balanus* (*Photographs by D. P. Wilson*).

relatively few species occur in the Arctic and Antarctic Geologically the earliest cirripede was found in the Carboniferous but apparently the group was not abundant until the Upper Cretaceous

Development Usually the egg hatches as a free swimming nauplius distinguished from other nauplii by the presence of frontal horns on the carapace After several molts the last nauplius stage gives rise directly to the cypris stage so called because of the superficial resemblance to the ostracod *Cypris* (Fig 2) When a substratum is found the cypris larva attaches by the antennules cement is secreted and many internal changes occur including the formation of the five primary valves (paired scuta and terga and a carina) and of a deep inward fold of the mantle At the next molt this fold opens and the metamorphosed animal assumes the characteristic position of the adult It attaches by the preoral region with the ventral side at right angles to the surface of attachment and the posterior end directed upwards *See* ACROTHORACICA CRUSTACEA THORACICA [D P H]

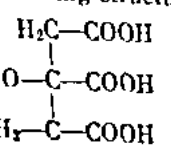
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Citrate

A salt or ester of citric acid Citrates are formed by replacing the acidic hydrogens of citric acid by a metal or an organic radical One two or all three of the carboxylic hydrogens can be replaced to produce an extensive series of salts esters and mixed (double) salts Many salts and a few esters have commercial uses as anticoagulants for blood saline carthartics (sodium) effervescent medicines (magnesium) and other pharmaceutical uses (iron and calcium) in blueprinting (iron) as plasticizers in plastics and as resins (simple esters) *See* CARBOXYLIC ACID CITRIC ACID ESTER [E H H]

Citric acid

An organic acid with a formula $C_6H_8O_7\ H_2O$ It is used in the pharmaceutical food confectionery and textile industries The compound produced commercially by fermentation has a melting point of 153°C and the following structural formula



This commercially useful tricarboxylic fruit acid formerly was recovered from cull citrus fruits but virtually all of the production today which is in excess of 50 000 000 lb per year in the United States employs a sugar fermentation process under controlled conditions, followed by extraction and recovery of crystalline citric acid *See* FERMENTATION FOOD FOOD ENGINEERING

Fermentation The preferred microbial agent is a strain of the filamentous ascomycetous fungus *Aspergillus niger* selected for (1) outstandingly high yields of citric acid from high concentrations of cheap carbohydrate sources under simulated production conditions (2) relatively rapid growth (3) abundant (asexual) conidiospore formation (4) tolerance to exceptionally high acidity and (5) absence of significant amounts of other fermentation products Citric acid weight yields of 50–70% of added sugar are obtained Economics dictates the use of molasses in final sugar concentrations of 10–20% Cane and blackstrap molasses contain impurities and so are less suitable than beet molasses Beet molasses itself ordinarily must be pretreated with either potassium ferrocyanamide or cation exchange resins to remove interfering mineral impurities such as iron manganese zinc and copper

Salts of these metals are added to the medium to produce final concentrations predetermined as optimal for the process under the particular conditions Optimal levels of inorganic phosphate are also added Concentrations of these elements are critical in general highest yields of citric acid are produced at metal concentrations that are deficient for optimal growth of the fungus Ammonium nitrate and magnesium sulfate also are added in predetermined optimal amounts The medium is adjusted initially to pH 3.0–4.5 with hydrochloric or phosphoric acid Sterilization is achieved by heating at 100°C for 15–30 min (*see* STERILIZATION) Dry conidiospores asexual spores are produced on an appropriate medium and used to inoculate production batches of medium

Surface process In the surface process the medium is distributed in aluminum or coated metal trays (2 3 meters on a side) to a depth of 5–8 centimeters The trays are arranged in tiers in closed fermentation chambers After inoculation with spores a mat or mycelium of mold growth develops covering the surface of the medium in 1 2 days Temperature is maintained at 25–33°C according to the mold strain Filter sterilized humidified air is passed continuously through the fermentation chambers at a rate of one volume of air per volume of medium each few minutes The mycelial mat thickens and becomes heavily wrinkled and covered with black spores Incubation time is 7 14 days

Submerged process In the submerged process which is more economical to conduct not counting capital investment costs the fermentation is conducted in 1 000 to 10 000-gal or larger stainless steel fermentors in which the medium is continuously agitated and aerated under aseptic conditions The mold growth is homogeneously distributed throughout the medium The large capa

of fermentors and the shorter fermentation time of 3–6 days give this process a cost advantage over the surface process

In both processes the conversion of sugar to citric acid takes place most efficiently after the mold growth is at a maximum

Recovery The mycelium is filtered and its press juice added to the fermentation liquor Calcium citrate is precipitated by neutralization with calcium oxide or calcium carbonate at 80–90°C and then filtered off The calcium citrate is decomposed by addition of dilute sulfuric acid in slight excess over the theoretical amount required The insoluble calcium sulfate is filtered off The citric acid liquor is concentrated under reduced pressure crystallization of citric acid is induced by cooling and agitation The crystals are recovered by centrifugation Recrystallization results in an essentially pure product The mother liquors from the crystallizations are concentrated and the citric acid is recovered *See* INDUSTRIAL MICROBIOLOGY [J W F]

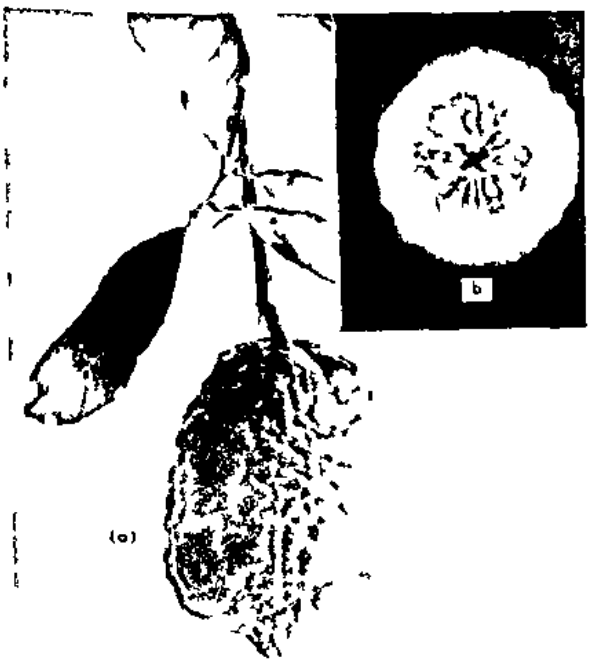
Citron

A species of true citrus *Citrus medica* citron is grown almost exclusively in the Mediterranean region It is probably the oldest cultivated form of citrus being known as long ago as 4000 B C

The citron is an evergreen shrubby tree of irregular growth habit The fruit is rather large oblong or oval and yellow and fragrant when ripe The rind is very thick constituting most of the fruit volume

This fruit is not grown commercially in the United States partly because the tree lacks cold hardiness but chiefly because other familiar types of citrus are more profitable The largest citron plantings are in southern Italy Greece and France

The citron crop is used chiefly in the production of candied peel for cakes and confections The United States imports annually over 3 000 000 lb for this use *See* FRUIT (BOTANY) FRUIT (TREE) [F E C]



(a) Foliage and fruit of commercial citron *Citrus medica* (approximate natural size) (b) Cross section of fruit showing thick rind (*From J Horace McFarland Company*)

Citronella

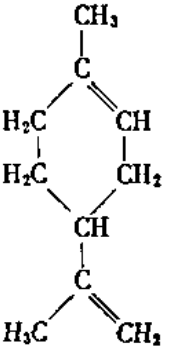
A tropical grass *Cymbopogon nardus* from the leaves of which oil of citronella is distilled This essential oil is pale yellow in color inexpensive and much used in cheap perfumes and soaps It is perhaps best known as an insect repellant A large acreage is devoted to the cultivation of this grass in Java and Ceylon *See* GRAMINALES [P D S]

Citrus flavoring

Food flavoring derived from the aromatic principles of fruit of the citrus family Principal members of the family used include orange lemon lime tangerine and grapefruit Citron is seldom used Flavoring is compounded from the oils of citrus fruits coloring and synthetic flavor

Citrus oils These are found in the skin of the fruit and the usual commercial source is from canning or processing by products Citrus oils occur in oval balloon shaped sacs located in the outer rind of the fruit The percentage present based on fruit weight is usually 0 11–0 58%

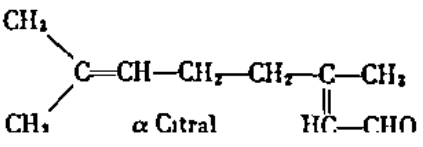
Citrus oils are high in terpenes A member of this family which occurs heavily in the citrus group is *d* limonene



d Limonene

In general *d* limonene is subject to an undesirable change in the presence of air and light resulting in a turpentinelike odor and flavor This is called terpeniness by the industry The change is best avoided by excluding light and air and occasionally chemical materials called antioxidants are added which greatly delay its development

The characteristic odor of most citrus oils is due to oxygenated compounds especially citral



α Citral

Since these compounds are present at a low level of 2 5% and since the terpenes are unstable it is common practice to remove the terpenes to produce terpeneless oils Terpenes are removed either by fractional vacuum distillation selective solvents or a combination of both

Distilled oil is also obtained as a by product of the citrus juice operation In juice manufacture there is an upper limit of oil content for desirable juice Surplus oil is removed in a deoiler essentially a vacuum still operating at 130–190°F

Citrus flavors usually compounded from the above oils with synthesized flavor and color additives are used extensively in the food industry Primary outlets include candy and carbonated beverage industries as well as the baking and ice cream trades A large market also is found in the detergent field —citrus aromas make wash day more pleasant

Methods of extracting oil These include (1) Pipkin roll (2) screw press (3) Fraser Brace extractor and (4) Pipkin juice extractor All methods give a water and oil emulsion which is separated by a two stage centrifugation to yield a clear polished oil Oil is then stored in steel tanks at 32–40°F to allow waxy materials to separate out This process is called winterizing

without rasping the peel Striations in the rollers extract the oil without further contact with the peel lest it be reabsorbed

Screw press method squeezes the crushed peel against a perforated screen thereby forcing out the oil Screws may be vertical or horizontal and water may or may not be added

Fraser Brace extraction utilizes a machine which is basically an abrasive peeler Abrasive carborundum rollers rasp the peel from the fruit under a water spray The water and peel mixture is screened and settled to allow oil separation

The Pipkin juice extractor is used where both oil and juice are required Whole fruit is fed into *cups which exert* a squeezing action to extract juice and oil which are caught in separate troughs

[REM]

Bibliography E Guenther and D Althausen *The Essential Oils* vols 1–6 1948–1952 J W Kesterson and R Hendrickson, *Essential Oils from Florida Citrus* Univ Florida Agr Expt Sta Bull 521 1953 J L Simonsen et al *The Terpenes* 5 vols 2d ed 1947 1958

Civet

Africa They are characterized by musk glands which produce a strong long lasting sweetish scent the civet of commercial perfume manufacture captive civets are stripped for the valuable liquid musk



The civet cat Bassariscus astutus; length 15 in (From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd London)

Civets also called civet cats are similar in size and form to the house cat and are usually spotted Although they may be tamed the wild animals are fierce active and mostly nocturnal predators

The spotted skunk and other spotted carnivores are often called civet or civet cat *See* CARNIVORA SKUNK

[JDB]

Civil engineering

The planning design construction and maintenance of the fixed structures and ground facilities for transportation for the use and control of water and for occupancy

The men who planned and directed the building of such projects as the Egyptian pyramids the Roman highways and aqueducts bridges canals and harbors were given the title architect meaning chief builder The early architect thus was responsible not only for what is now included under architecture but for what is included under engineering as well

During this same period the men who constructed roads bridges and other such works for the armies were called *ingeniarii* by the Romans and until the sixteenth century the term engineering meant military engineering About the eighteenth century men who devoted themselves to planning and constructing public works began calling themselves civil or civilian engineers The first man to advertise himself as a civil engineer was John Smeaton an Englishman who in 1761 designed and built the Eddystone lighthouse

Buildings The civil engineer plans designs and constructs the skyscrapers and large industrial buildings without which large cities could not exist Although the skyscraper is often assumed to be an architectural rather than an engineering triumph its existence is due largely to advances in engineering Its great height was made possible through the development of skeleton frame construction in which a stable system of structural steel members is used to act as a frame to support curtain walls as well as the floor and roof loads The Empire State Building with its 102 stories is the world's tallest building (1472 ft including the television tower)

The civil engineer plans the space structure and equipment to produce the environment and facilities for efficient production in industrial buildings To create a plant with optimum working condi ons

he must carefully consider such items as site selection parking facilities public transportation cafeterias sanitary facilities light heat air conditioning and acoustics *See* BUILDINGS STRUCTURES (ENGINEERING)

Transportation The civil engineer develops transportation and terminal facilities allowing passengers and goods to move freely within and between cities with a minimum of inconvenience and expense Transportation development consists of the planning location and design of highways expressways and parking facilities of rapid transit systems and railways of transmission systems and pipelines of airports and of the improvement of waterways and harbors

The design of highways and expressways is dictated by terrain features the degree of development of the area to be traversed availability of right of way and the existing and potential traffic volumes Adequate sight distances must be provided and sharp curves eliminated in order that traffic may operate safely and economically at reasonably high speeds *See* HIGHWAY ENGINEERING TRAFFIC ENGINEERING

The civil engineer plans designs and constructs bridges To eliminate hazardous intersections on modern highways bridges pass either over or under streets or railways It is estimated that more than one bridge per mile of road will be necessary to complete the vast network of highways linking all parts of the United States *See* BRIDGE

The civil engineer designs constructs operates and manages canals locks dams ports harbors and navigational facilities No one engineering structure has benefited trade and commerce as much as the Panama Canal Built in the period 1903–1914 to link two oceans its construction presented an unprecedented challenge to the American civil engineer

The main feature of air travel is speed requiring airports to be located so that they are easily and quickly accessible from the cities they serve It is the responsibility of the civil engineer to plan design construct and maintain civil and military airports *See* AIRPORT ENGINEERING

Water An adequate and safe supply of water and the disposal of human and industrial wastes are as essential to community life and urban development as office and industrial buildings and transportation systems The civil engineer who plans designs and constructs a sanitary and water supply system to collect treat and distribute public water supplies and to handle household and factory wastes plays an important role in the safeguarding of public health So important is this branch of civil engineering to public health that it is sometimes combined with the related field of preventive medicine to form a specialty designated as public health engineering *See* SANITARY ENGINEERING

Many localities are dependent on the importation of water from outside the immediate area Modern civil engineering design has made it practicable to transport large quantities of water over considerable distances The Colorado River aqueduct will eventually carry 1 000 000 000 gallons of water per day from the Colorado River to Los Angeles 250 miles away

Reclaiming arid lands and controlling rivers for agricultural and power purposes require a great diversity of structures such as dams power plants canals and associated facilities The Grand Coulee Dam and the Columbia Basin project exemplify the planning ability and the creative imagination of the civil engineer This project provides for the irrigation of 1 000 000 acres involves the world's largest hydroelectric power plant and is a potent factor in controlling the floods on the Columbia River *See* DAM HYDRAULICS

Other fields Many structures that challenge the skill and ingenuity of the civil engineer are buried from sight The deepest building foundation is that of the tower of the Cleveland Union Terminal Building whose supporting piers rest on rock 262 ft below the curb *See* FOUNDATIONS SOIL MECHANICS *See also* ENGINEERING GEOLOGY

The civil engineer is concerned with the problems accompanying advances in atomic energy He designs and builds the structures necessary to develop atomic power He has the responsibility of protecting workmen and the public against atomic radiation through the design of shielding structures He provides for the safe treatment and disposal of atomic wastes He designs structures to shield the public from the effects of radioactive fallout and structures to withstand the blast of atomic explosions [C N G]

Cladding

An old jewelry art recently developed on an industrial scale to add the desirable surface properties of an expensive metal to a low cost or strong base metal In the process a clad metal sheet is made by bonding or welding a thick facing to a slab of base metal the composite plate is then rolled to the desired thickness The relative thickness of the layers does not change during rolling Cladding thickness is usually specified as a percentage of the total thickness commonly 10%

Gold filled jewelry has long been made by this process the surface is gold the base metal bronze or brass with the cladding thickness usually 5% The process is used to add corrosion resistance to steel and to add electrical or thermal conductivity or good bearing properties to strong metals One of the first industrial applications about 1930 was the use of a nickel clad steel plate for a railroad tank car to transport caustic soda by 1947 stainless clad steels were being used for food and pharmaceutical equipment Today corrosion resistant pure aluminum is clad to a strong duralumin base and many other combinations of metals are widely used in cladding a recent development includes a technique for cladding titanium to steel for jet engine parts

Cladding supplies a combination of desired properties not found in any one metal A base metal can be selected for cost or structural properties and another metal added for surface protection or some special property such as electrical conductivity Thickness of the cladding can be made much heavier and more durable than obtainable by electroplating The following clad materials are in common use

Stainless steel on steel Provides corrosion resistance and attractive surface at low cost for food display cases chemical processing equipment sterilizers and decorative trim

Stainless steel on copper Combines surface protection and high thermal conductivity for pots and pans and for heat exchangers for chemical processes

Copper on steel Adds electrical conductivity and corrosion resistance needed in immersion heaters and electrical switch parts also makes soldering easier

Nickel or Monel on steel Provides resistance to corrosion and erosion for furnace parts blowers chemical equipment toys brush ferrules and many mechanical parts in industrial and business machines more durable than electroplating

Titanium on steel Supplies high temperature corrosion resistance Bonding requires a thin sheet of vanadium between titanium and steel

Bronze on copper Usually clad on both sides for current carrying springs and switch blades combines good electrical conductivity and good spring properties

Silver on copper Provides oxidation resistance to surface of conductors for high frequency elec

ding sometimes is in form of stripes or inlays with silver areas serving as built in electrical contacts

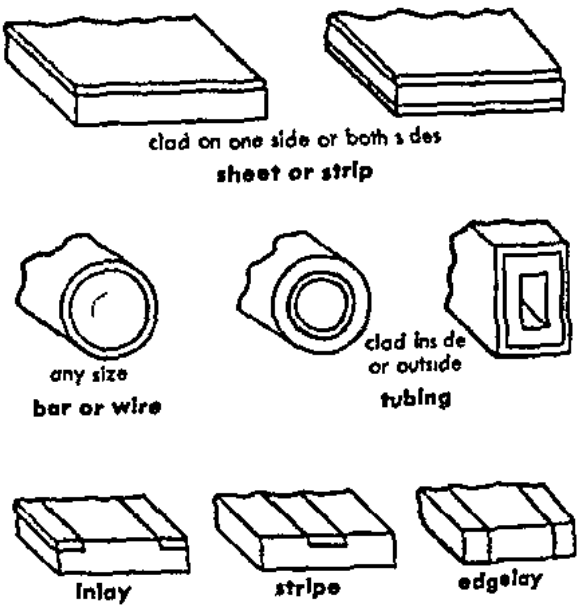
Gold on copper Supplies chemical resistance to a low cost base metal for chemical processing equipment

Gold on nickel or brass Adds chemical resistance to a stronger base metal than copper also used for jewelry wrist bands watch cases

Cladding can be added to both sides of a sheet or strip of base metal Tubing can be supplied with a clad surface on inside or outside round and rectangular wire can also be clad by the same process

is needed to form an electrical contact with no waste of costly metal

Another related form of cladding is found in thermostatic bimetals in which equal thicknesses of low and high expansion metals are bonded together With a change in temperature differing expansion rates of the two metals causes the composite material to bend and thus operate valves in automobile cooling systems or electrical contacts in room thermostats



Types of cladding

Clad wires with properly chosen proportions of materials of different thermal expansion rates can match the thermal expansion of types of glass used for vacuum tight seals for conductors in lamp bulbs and hermetically sealed enclosures

In making parts from clad metal the composite material can be bent drawn, spun, or otherwise formed just the same as the base metal without breaking the bond The maximum service temperature is limited by the melting point of the material at the juncture of the two metals, annealing temperatures during manufacturing are similarly limited

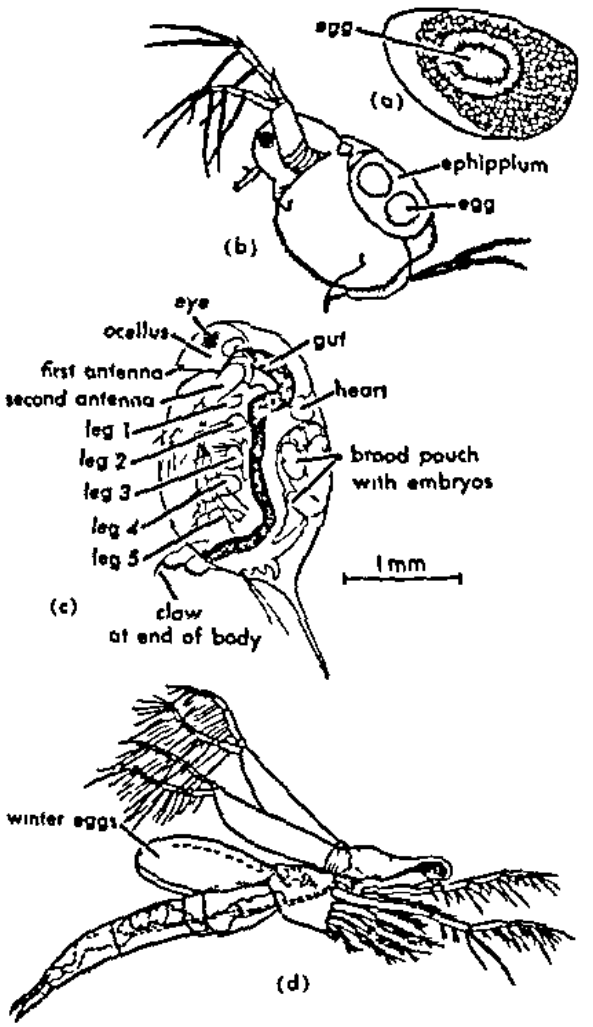
Cut edges of clad sheets expose the base metal and thus may require special protection Welding of thick clad sheets sometimes offers special problems in maintaining the integrity of the protective surface but joining methods are generally the same as for the base metal *See* ELECTROPLATING OF METALS METAL COATINGS, NUCLEAR FUELS

[R W CA]

Cladocera

An order of small crustaceans commonly known as water fleas found mostly in fresh water Usually they possess a bivalve shell which covers the body and trunk limbs but leaves the head and antennae free The best known species is *Daphnia magna* which is bred in large numbers to provide living food for aquarium fishes

Owing to the transparent nature of their bodies when alive Cladocera have long been favorite objects for study under the microscope The workings of the heart and other organs can be seen clearly including the corpuscles of the blood as it is pumped through the heart or courses by intri-



Examples of some Cladocera (a) Ephippium of *Moina daphnia rectirostris* (Leydig) (b) *Moina macrocopa* Straus with ephippium (c) *Daphnia magna*, female with advanced embryos (d) *Leptodora kindti* (Focke), adult female with winter eggs (a, b, and d from R W Pennak, *Fresh Water Invertebrates of the United States*, Ronald, 1953)

cate routes, through channels and spaces in the limbs

Like other Crustacea, Cladocera have two pairs of antennae The first pair is small and sensory in function, while the second pair is large and two branched Most Cladocera swim in a characteristically jerky way by beating the water with these second antennae The limbs of the trunk are usually enclosed in the valves of the shell They are flattened leaf shaped organs fringed with setae, whose rhythmic movements create currents of water through the shell which bring oxygen and particles of food to the animals

Most species feed in this way either on microplankton or on particles of detritus stirred up from the bottom or from the surfaces of weeds

There is a separate group of Cladocera in which there is no shell apart from remnants forming the brood pouch, and the limbs are free, prehensile, and used for capturing small planktonic animals, including other Cladocera The marine species *Podon* and *Evadne* are planktonic Their fresh water relatives, including *Leptodora*, the largest of all Cladocera (1 cm and more long), are planktonic in lakes

The temporary nature of many of the fresh waters in which Cladocera live is overcome by the production of resting eggs which can withstand both drying and freezing In *Daphnia* and some other genera, the resting eggs are carried in special saddlelike pouches on the back of the female, known as ephippia, which are cast off with the eggs inside them when the animal molts The resting eggs are produced sexually, but only females hatch from them, these give rise to a number of purely female generations by parthenogenesis In this way large populations are rapidly built up (*see* REPRODUCTION, ANIMAL) Under favorable conditions 20 or more young may hatch every few days Under adverse conditions as for example when a pond begins to dry up, males make their appearance together with ephippial females, and fertilized resting eggs are produced

The fertilized "winter egg" of *Leptodora* hatches as a nauplius larva so characteristic of diverse groups of Crustacea but all other Cladocera, whether they come from resting eggs or from the parthenogenetically produced "summer" eggs, hatch as miniatures of the adult, the embryos developing in a brood pouch formed in the hollow between the body and the dorsal arch of the shell

One consequence of the ability of the winter eggs to withstand desiccation for long periods may be the very wide geographical distribution of most species of Cladocera As an example, there are more species in the United States and the U S S R which are common to both countries, than there are species present in one and absent in the other

Cladocera are comparatively feeble swimmers and are preyed upon by fishes and various fresh water invertebrates, including *Hydra* and some of the larger Protozoa

Anchistropus is remarkable, for not only is it the only known parasitic cladoceran, but the animal it parasitizes is *Hydra*, whose stinging cells are fatal to very much larger Cladocera *See* CRUSTACEA

[J P HA]

Cladocopa

A suborder of the order Ostracoda which includes those organisms having a shell that is without a permanent aperture Both heart and eyes are lacking and there are only two pairs of postoral appendages The body terminates in a lamelliform process that is provided with clawlike spines The first and second antennae are used for swimming, both the endopodite and the exopodite are developed for locomotion

The Cladocopa has a single family, the Polycopidae A distinguishing characteristic of the genus *Polycope* is the almost completely circular,

smooth glistening shell Representatives of this suborder have been collected from Norway the British Isles the Cape of Good Hope and the North Atlantic *See* OSTRACODA [E F]

Bibliography W L Tressler Marine Ostracoda from the Gulf of Mexico *U S Fish Wildlife Serv Fishery Bull* 55 429–437 1954

Cladoselachii

An order of extinct elasmobranch fishes including the oldest and most primitive of sharks Best known is *Cladoselache* of the Late Devonian of which complete specimens including even muscle and other soft tissues have been obtained from shales in the region of Cleveland Ohio Primitive features are broad based paired fins amphistylic jaw support and absence of claspers The teeth termed



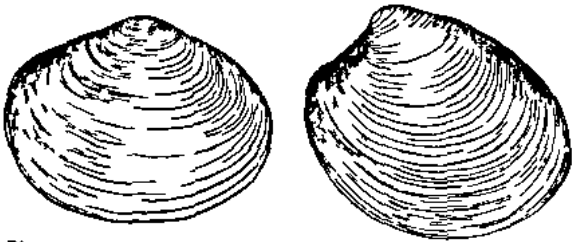
Cladoselache a Late Devonian sharklike fish Original specimens range from about 1½ to 4 feet in length (*After Harris and Dean*)

Cladodus when found separately and the *Ctenacanthus* spines borne by some cladoselachians are found in Carboniferous and Permian as well as Devonian deposits but whether they pertain to true cladoselachians or to hybodont sharks descended from them is generally doubtful *See* ELASMOBRANCHII FOSSILS HYBODONTOIDEA [A S R]

Clam

Any of a wide variety of marine species of the class Pelecypoda phylum Mollusca For distinction marine species are usually considered clams and fresh water forms mussels although the names are often used interchangeably

In general the anatomy of the clam is similar to the fresh water mussel The food of both is detritus and plankton harvested from the environment as water and passed over their gills However reproduction in the marine Pelecypoda is unlike that in the fresh water forms Large numbers



Clam (a) Fresh water *Sphaerium stamineum* shell about ½ in long (b) Quahog *Mercenaria mercenaria* 5¼ by 4½ by 3 in (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

Common species of clam

Name	Size in	Distribution and characteristics
Quahog or Venus	5½	Atlantic Coast mostly Cape Cod to South Carolina sandy or muddy sea bottoms tide level to 50 ft valuable as food animal
Soft shelled clam	4	Atlantic and Pacific Coasts, Europe between tide lines in shallow water and on mud flats *Mya arenaria* most valuable commercial species
Pismo clam	7	Mid California Mexico on open, surf beaten beaches, above low water mark slow growing 11 years to reach legal size important commercial species
Butter clam	5	West Coast between tide marks in sand and gravel valuable food form
Hard shelled clam	3	West Coast in gravel not in mud round lead shell some commercial value
Sea clam	6	Arctic to Pismo Calif canned in Alaska and Washington more abundant in southern part of range
Surf giant, or hen clam	7	Labrador to North Carolina largest Atlantic Coast bivalve excellent food lives in shallow water

(sometimes several million) of eggs are produced and expelled into the sea where they are fertilized by free swimming sperm Each egg soon hatches into a minute pelagic larva the veliger In a few days this free swimming animal starts developing a shell and gradually sinks to the bottom where transformation into the adult form is completed Clams may be hermaphroditic or may have separate sexes

Some clams burrow deeply into the mud and extend long incurrent and excurrent siphons to the surface others must live near the surface

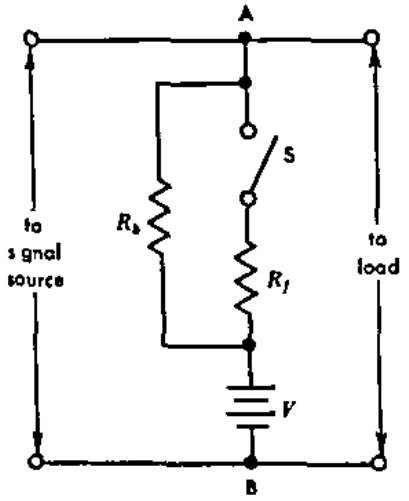
Tridacna the giant clam of the South Pacific is among the largest of the invertebrates and attains a length of 5 ft and a weight of 500 lb

Many species of clam are prized for food *Mytilus edulis* the blue mussel is a valuable marine species There is a substantial commercial fishery in the United States with both East Coast and West Coast species being marketed in quantity For [illegible] more [illegible] mer [illegible] nds more being harvested by amateur clam diggers for sport and food The table shows size distribution and characteristics of some of the more common species *See* MUSSEL PELECYPODA [J D B]

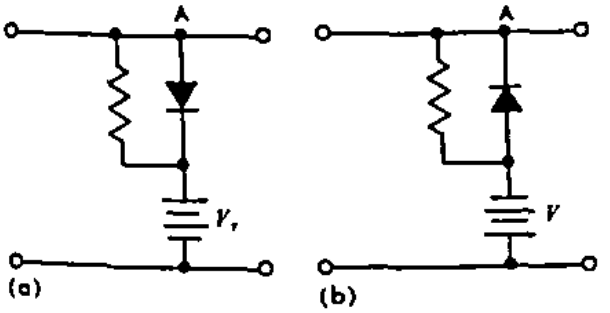
Clamping circuit

An electronic circuit that effectively connects a signal point to a fixed reference voltage level either at a specific time interval or at some prescribed amplitude of the signal The circuit is also called simply a clamp Clamps are frequently used to reset the starting level of sweep generators and are used in many frequency and voltage comparison and control circuits

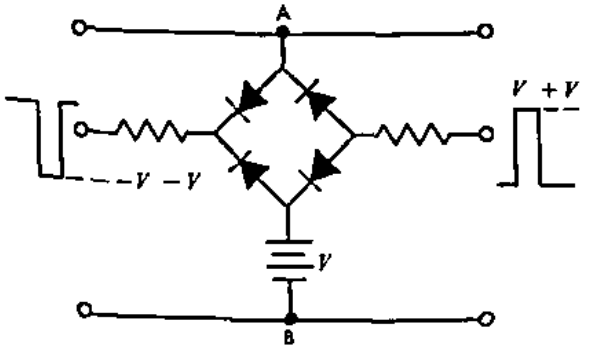
The basic elements of a clamping circuit are shown in Fig 1 The clamp l etween terminals A and B is shown as a switch S in series with the ref erence voltage V, which is in series with a small resistance R_f when the switch is closed and a much larger resistance R_b when the switch is open



Fg 1 Elements of a clamp



Fg 2 (a b) S ngle-d ode clamp circu ts



Fg 3 Four-d ode b d rect onal keyed clamp

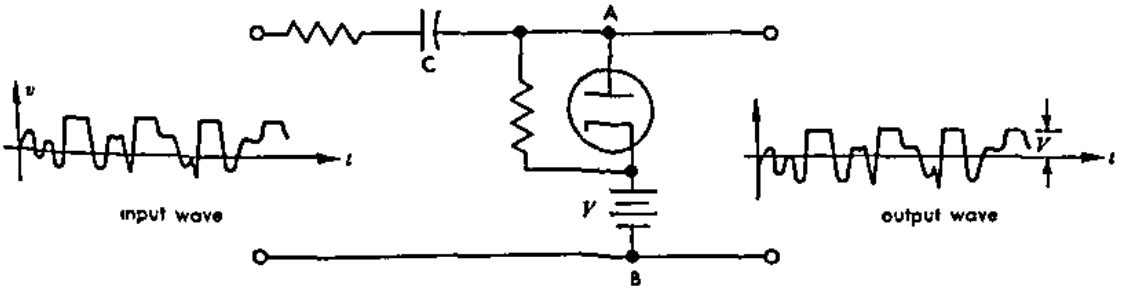
Voltage controlled clamp In Fig 2*a* the diode functions as a clamp whenever the potential at point A starts to rise above V Then the diode is in its forward biased condition and acts as a low re sistance Such a clamp is referred to as a voltage controlled or continuous clamp The circuit of Fig 2*b* is similar except that the polarity is re versed Point A is connected to V, through a low impedance whenever the potential at point A starts to fall below V These circuits function only when a fixed polarity of signal with respect to V appears at point A therefore they are referred to as uni directional clamps

Keyed clamp If a clamp functions at specific time intervals controllable from external signals and not from the signal source itself it is a syn chronous or keyed clamp Such a keyed clamp may be unidirectional but more often it is a bi directional clamp defined as a clamp that func tions at a prescribed time period irrespective of the polarity of the signal source at the time the clamp control pulses are applied

A bidirectional clamp using four diodes with two control pulses of opposite polarity is shown in Fig 3 The peak of the negative pulse is estab lished at a level less than V by a potential V and that of the positive pulse above V by the same po tential Thus at the time the pulses are applied the two lower diodes are forward biased At the same time one or the other of the two upper diodes will be forward biased or conducting depending upon whether point A is above or below V Between clamping pulse intervals all of the diodes will be reverse biased and the signal point is essentially disconnected from the reference voltage

In form the bidirectional clamp is similar to the key element in the diode transmission gate (*see* GATE CIRCUIT) and the voltage controlled diode clamp is the main element of the limiter (*see* LIM ITER CIRCUIT)

DC restorer A dc restorer is a clamp circuit used to establish a dc reference level in a signal without modifying to an important degree the wave form of the signal itself To perform this function the signal must have a self contained reference *which repeats at periodic intervals* An example of such a waveform applied to a single diode volt age controlled clamp is shown in Fig 4 Restora



Fg 4 D ode clamp as dc restorer

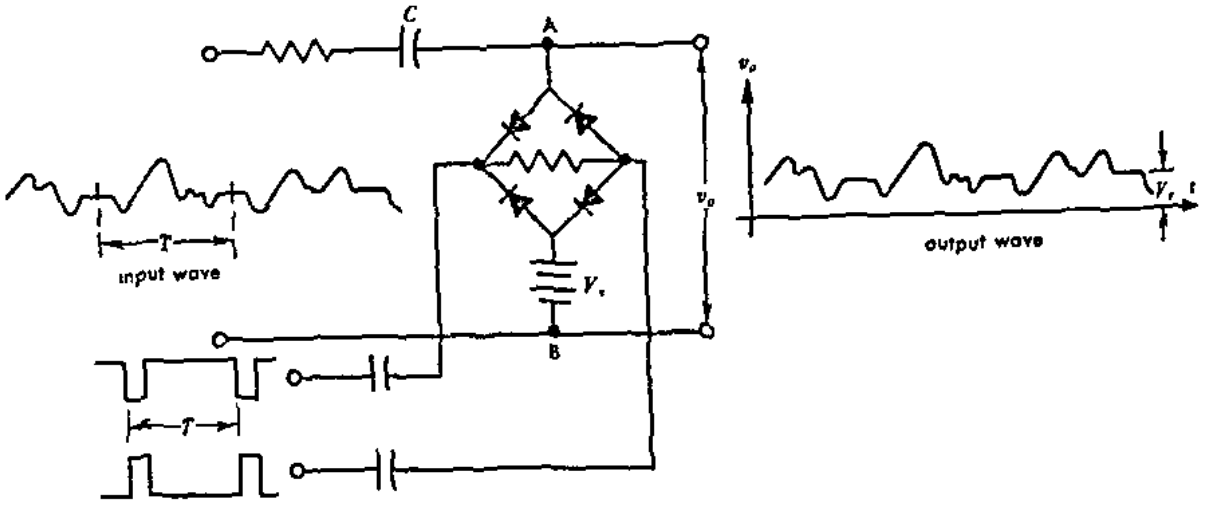


Fig 5 Keyed clamp as dc restorer

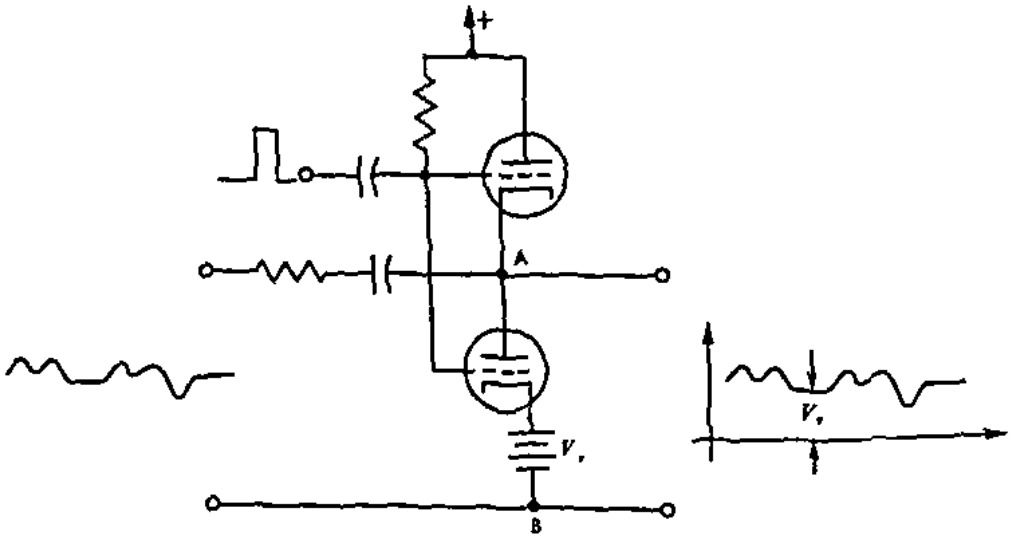


Fig 6 Two-triode clamp

tion of the peak of the waveform to the level of V_r depends upon current flowing through the capacitance in the forward conduction mode of the diode when the input level is above V_r The capacitance becomes charged during such successive peaks, and the peak level is finally established at V_r The circuit would not operate if the peak of the input waveform were not above V_r to begin with

The waveform of Fig 5 requires a bidirectional keyed clamp to function This clamp is similar to that of Fig 3 except that the clamping pulses are capacitance coupled to the circuit, a preferable arrangement for periodic waveforms A keyed clamp thus establishes the recurrent reference level in the signal at the dc reference level, regardless of the excursions of the signal between clamping intervals

Triodes may also be used as keyed clamps in the manner shown in Fig 6 At the time clamping pulses are applied one or the other of the two triodes conduct heavily thus establishing a low impedance from the signal point to the reference potential [C M C]

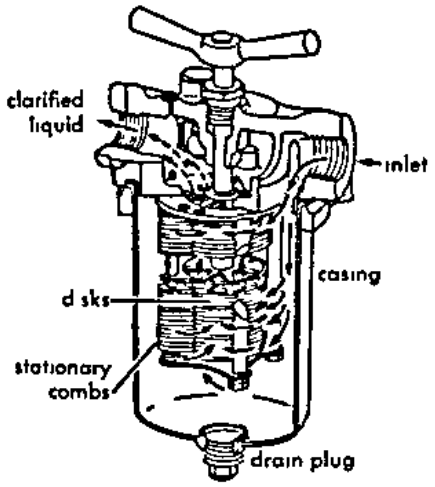
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Clarification

The complete removal of small amounts of solids from liquids Clarification is one of the operations in the generic group of mechanical separations Its major applications are in the cement, metallurgical, and chemical industries, in water purification and in sewage treatment

The methods of clarification include filtration sedimentation, and centrifugation Clarification is differentiated from other applications of these techniques in that in clarification the ratio of solid to liquid is low, and the separation of solids is complete Also, the particle size is usually relatively large In other applications of these general methods, solid liquid ratios are larger, particle sizes are smaller, and sometimes an incomplete separation between solid and liquid is desired

Clarifying filters may be any of the standard filter types modified to take account of the small



Cartridge filter (W L McCabe and J C Smith Unit Operations of Chemical Engineering McGraw Hill 1956)

solid liquid ratio Some types of filter are especially adapted to clarification One such type is the sand filter, which is widely used especially for the clarification of water A sand filter consists of a tank either open or closed containing a grid or false bottom on which is placed a layer of coarse gravel On the gravel is a thick bed of fine sand which acts as the filter medium The turgid water is pumped over the top of the bed The water percolates through the bed and the solids are retained in the sand Clear water is drawn from the bottom of the tank An open filter operates under gravity In a closed filter, pressure from a pump is available for forcing flow Periodically in a sand filter, the flow of water is interrupted and the filter bed backwashed by a stream of water forced through the bed from bottom to top This removes the solids, which leave the filter with the backwash through the top of the unit, and cleans the filter for the next cycle *See* FILTRATION

Another specialized filter for clarification of process liquids containing small amounts of solids is the cartridge filter An example is shown in the illustration The filtering cartridge consists of a series of thin metal disks, 3–10 in in diameter assembled in a vertical stack with narrow uniform gaps between them The disks are supported by a hollow vertical shaft and fit into a closed cylindrical casing Turgid liquid is pumped into the casing under pressure The liquid flows inward between the disks to openings in the central shaft and clarified liquid leaves through the top of the filter The solids are trapped between the disks and remain in the filter Periodically, the solids are removed from the cartridge by a half turn of the cartridge, given by the external handle The stationary teeth of a cleaning comb pass between the disks and dislodge the solids which drop to the bottom of the casing They are removed through the drain at fairly long intervals

Gravity settling in continuous thickeners is a common method of clarification In combination with thickening, settling produces, in addition to the clear liquid, a concentrated slurry containing the solid *See* SEDIMENTATION (INDUSTRIAL), THICKENING

Centrifugal force is used in clarifying centrifuges (*see* CENTRIFUGATION) Centrifuges of this type which are specially designed to treat liquids carrying very small concentrations of solids, are used when gravity is too weak to give a practicable settling rate to remove sludges and solid contaminants from viscous liquids, such as varnish, fuel oil, and lubricants *See* SEPARATION (MECHANICAL)

[W L M]

Bibliography W L Badger and J T Banchero, *Introduction to Chemical Engineering* 1956, W L McCabe and J C Smith, *Unit Operations of Chemical Engineering*, 1956, J H Perry (ed), *Chemical Engineers' Handbook*, 3d ed, 1950

Classification, biological

The systematic arrangement of animals or plants into groups or categories such as phyla (or sometimes in botany divisions), classes orders, families, genera, species, and varieties The classification of living or fossil organisms is based primarily on natural relationships including similarity of characteristics and complexity of structure *See* ANIMAL SYSTEMATICS, BACTERIA, TAXONOMY OF, FUNGI, PALEOBOTANY, PALEONTOLOGY, PLANT TAXONOMY, PROTOPHYTA, SCHIZOMYCETES

[J F F]

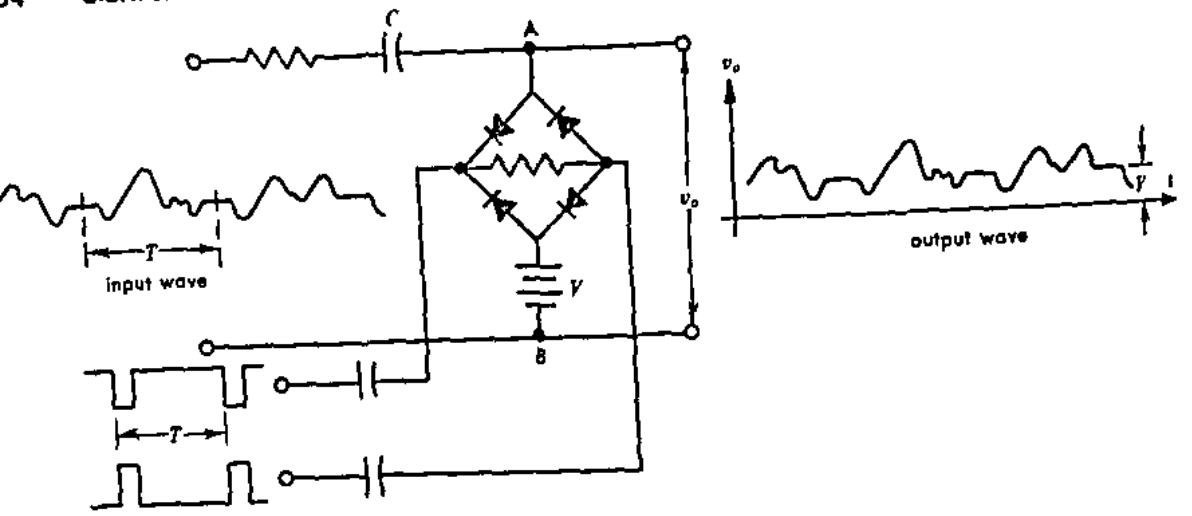
Classification, mechanical

A sorting operation in which mixtures of particles of mixed sizes, and often of different specific gravities are separated into fractions by the action of a stream of fluid Water is ordinarily used as the sorting fluid but other liquids or air or other gas may be used

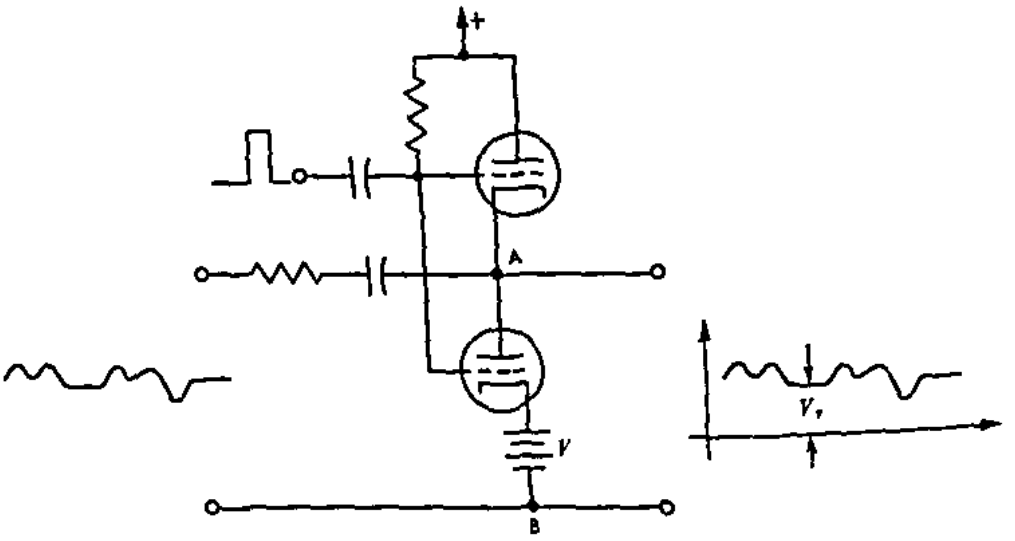
The main objective of classification is to separate the particles according to size This function is identical to that of screening, but classification is applicable to smaller particles especially those undersize For small particles it is more economical than screening In classification the oversize and undersize are called sands and slimes, respectively

Material also may be mechanically classified by specific gravity, a method that separates substances differing in chemical composition This is called hydraulic separation Such classification is based on the fact that, in a fluid, particles of the same specific gravity, but of different size or shape, settle at different constant speeds Large, heavy, round particles settle faster than small light needlelike ones If the particles also differ in specific gravity, the speed of settling is further affected This is the basis for the separation of particles by kind rather than by size alone

Mechanical classifiers utilize the differences in settling velocities by bringing the feed mixture into contact with a continuous stream of fluid and allowing the particles to reach their settling velocities



Fg 5 Keyed clamp as dc restorer



Fg 6 Two triode clamp

tion of the peak of the waveform to the level of V depends upon current flowing through the capacitance in the forward conduction mode of the diode when the input level is above V The capacitance becomes charged during such successive peaks and the peak level is finally established at V The circuit would not operate if the peak of the input waveform were not above V to begin with

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rates) In biological systems, inclusion compounds may play an important role

Inclusion compounds can be subdivided into (1) lattice inclusions (inclusion compounds within a lattice which, as such is built up from smaller single molecules), (2) molecular inclusion compounds (inclusion into larger ring molecules with holes), and (3) inclusion compounds of macromolecules (clay minerals molecular sieves adsorption compounds of proteins, and blue starch iodine color) Besides general chemical and physicochemical methods, x ray structural analysis is of special importance for evaluation of the structure of inclusion compounds (see table)

The best known lattice inclusion compounds are the urea and thiourea channel inclusion compounds which are formed when one mixes hydrocarbons carboxylic acids, or long chain fatty alcohols with solutions of urea Urea in this case the host lattice crystallizes in the presence of the other molecules in a particular crystal structure which

Inclusion compounds

Host substance	Shape of the cavity	Foreign substance
Crystalline inclusion compounds		
Urea	Channel	Derivatives of straight-chain hydrocarbons
Thiourea	Channel	Branched-chain and cyclic hydrocarbons
Deoxycholic acid	Channel	Paraffins, fatty acids, aromatic hydrocarbons
Dinitrodiphenyl	Channel	Diphenyl derivatives
Hydroquinone, phenol	Cage	Hydrogen chloride sulfur dioxide acetylene
Gas hydrates	Cage	Halogens, inert gases, low molecular weight hydrocarbons
Trithymotide	Cage	Benzene chloroform
Nickel dicyanobenzene	Cage	Benzene chloroform
Substance which produces the blue iodine inclusion compound	Channel	Polyiodine chains I_x
Molecular inclusion compounds		
Cyclodextrin	Channel (in a crystal)	Hydrocarbons, iodine halogenated hydrocarbons and aromatic hydrocarbons
Bis(N N' alkyl benzidines)	Cage	Benzene dioxane
Inclusion compounds of macromolecular substances		
Clay minerals, molecular sieves	Cage or sheet	Hydrophilic substances
Graphite	Sheet	Oxygen bisulfate ion, alkali metals
Cellulose	Channel	Water hydrocarbons, dyes, iodine
Starch	Channel	Fatty acids, iodine
Protein nucleic acids	?	Dyes, lipids, ions

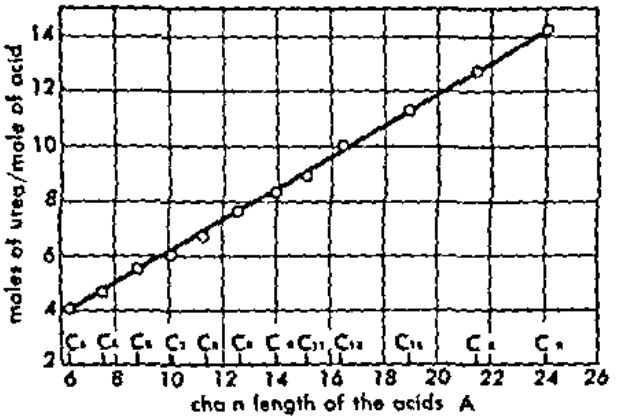


Fig 1 Carboxylic acid–urea addition compounds Dependence of composition on chain length (After W Schlenk, Jr, Organic occlusion compounds, Fortsch chem Forsch, 2 92–145, 1951)

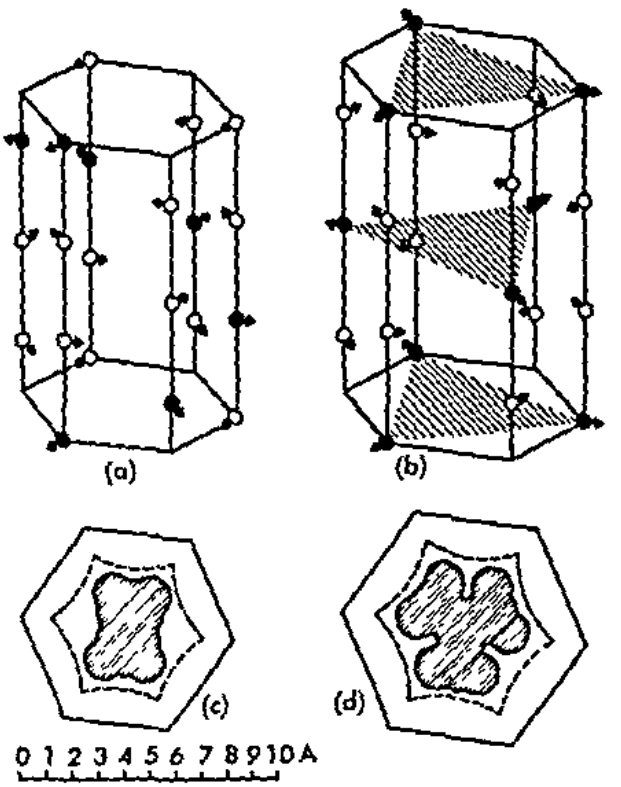
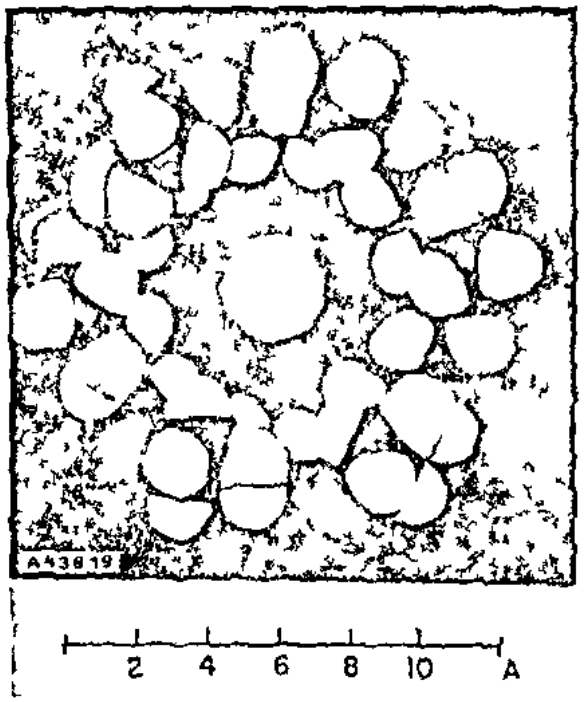


Fig 2 Lattices of inclusion compounds (a) Urea (b) Thiourea Space filled by paraffin chains (c) Unbranched (d) Branched

contains long channels or tubes 4–5 angstroms (A) in diameter The hydrocarbons are accommodated in these channels, but only unbranched molecules find enough space to fit into the urea channel The molar ratio of urea to hydrocarbon is simply determined by the lengths of the hydrocarbon molecule not by any functional group The longer the paraffin chain the more urea is necessary in order to envelope the paraffin (Fig 1) Thiourea has a similar lattice structure but a larger diameter of



Fg 3 Molecular model of α-dextr n iod ne com pound seen n the d rect on of the c ax s that is in the d rect on of the iod ne cha n

cannot be held rigidly (principle of closest pack ing) as shown in Fig 2

Other representatives of lattice inclusion com pounds are the choleic acids which are inclusion compounds of *deoxycholic acid* with fatty acids and other lipoic substances Most likely these compounds play a role in the digestion process by emulsifying or dissolving fat and fat soluble substances

Hydroquinone and phenol as well as some other *aromatic hydroxy* compounds form an open crystal lattice which can accommodate *smaller gas and* solvent molecules (clathrates in the *stricter* sense of the word) The gas hydrates which have been known since about 1810 (for example $Cl_2 \cdot 6H_2O$) are inclusion compounds of gases in a somewhat expanded ice lattice The gas or solvent molecules are inserted into defin te places within the ice *latt ce* and are surrounded by water molecules on all sides

Several cyclic anhydrides of *phenol carboxylic* acids such as *o* trithymotide and *tetrasalicylide* form inclusion compounds with smaller mole cules

The cyclodextrins belong to the *group of molec* ular inclusion compounds They are cyclic degrada tion products of starch which contain six seven or eight glucose residues and have the *shape of large* ring molecules the diameter being 6–10 *A Here* one can prepare a great number of *inclusion com* pounds with various kinds of molecules for exam ple with gases

α Cyclodextrin forms a blue iodine *inclusion* compound in which the iodine posesses the same structure as in the starch iodine complex (blue iodine is made up of polyiodine chains) The iodine chains lie in channels (Fig 3)

The starch iodine compound which belongs to the class of inclusion compounds of macromole cules is built by the same principle The blue iodine inclusion compound of polyvinyl alcohol ex hibits a strong dichroism in stretched states Th s is used technically to make (light) polarizing sheets and spectacles

Some clay minerals are made up of di tinct silicate layers Between these layers some free space may exist in the shape of channels Smaller hydrocarbon molecules can be accommodated re versibly within these channels This phenomenon is used in some technical separation processes for separating hydrocarbons (molecular sieves) *See* MOLECULAR SIEVE

Proteins form loose addition compounds con taining numerous molecules some of which do not carry functional groups for salt formation Such molecules are probably bound in the same manner as are inclusion compounds This however deserves further study In biochemistry one discusses tem plate systems or lock and key mechanisms in order to explain the astonishing specificity of biochemical reactions In principle the bond type here may be the same as in other inclusion compounds Similar considerations are applicable in the chemistry of nucleic acids *and their specificity* *See* INERT GASES [F D C]

Bibliography F Cramer *Einschlussverbindun gen* 1954 W Schlenk Jr Organic occlusion com pounds *Fortsch chem Forsch* 2 92 145 1951

Clathrinida

An order of sponges in the subclass Calcinea of the class Calcarea These sponges have an asconoid structure and lack a true dermal membrane or cor tex The spongocoel is lined with choanocytes This order contains the family Clathrinidae *Clathrina Ascute* and *Dendya* are examples *See* CALCINEA *see also* CALCAREA [W D H]

Clavaxinellida

An order of sponges of the class Demospongiae subclass Tetractinomorpha with monaxonid mega scleres arranged in radial or plumose tracts In the suborder Epipolasina monactinal or diactinal megascleres are arranged in a radial pattern Microscleres include asters sigmas and small monactinal or diactinal spicules often prov ded with spines Spongin is rare

In the suborder Hadromerina the megascleres are always monactinal and usually have a terminal knob at one end Microscleres in the form of strep tasters asters sigmas or small spined d ac tinals may occur The megascleres tend to be ar ranged in tracts radiating from the center of the sponge spongin is rare I th e suborder Axinellina m acti scleres or both occur a dance of

spongin is usually present in the form of fibers in which the megascleres are embedded Micro scleres include rhaphides, sigmas, and asters A specialized dense axial skeleton is usually present The union of these groups to form the order Clavaxinellida is supported by the similarity of spicule types and their arrangement in radiating or plumose patterns and by the occurrence of oviparity in most of the species in which sexual processes are known

Clavaxinellidan sponges vary greatly in shape from radially symmetrical species which are spherical in shape to encrusting or massive species and upright branching types They occur in tidal and shallow waters of all seas and extend down to depths of at least 5500 meters Sponges comparable to existing clavaxinellidans occur scattered through the fossil record from Cambrian strata upward *See* DEMOSPONGIAE TETRACTINOMORPHA [W D H]

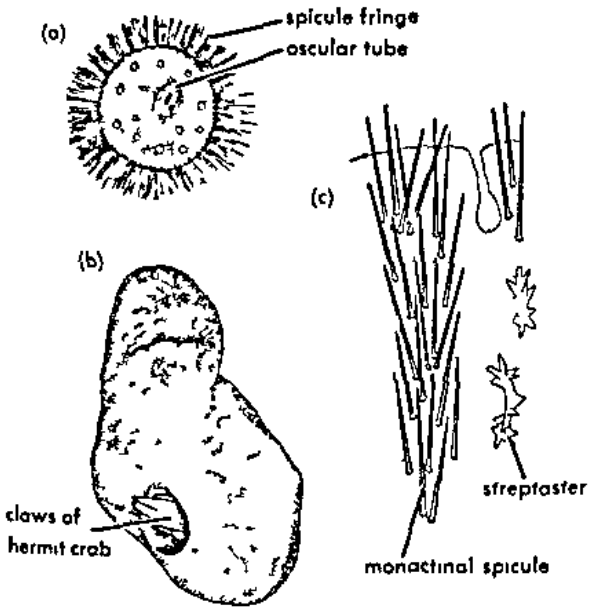


Fig 1 Representative hadromerine sponges (a) *Radiella sol* deep sea species with a peripheral fringe of spicules (*from Hyman 1940 after Ridley and Dendy 1887*) (b) *Suberites ficus* living on shell occupied by hermit crab (*from Hyman 1940 after Muller 1914*) (c) Spicule arrangement of *Spirastrella* (*after Hyman 1940*)

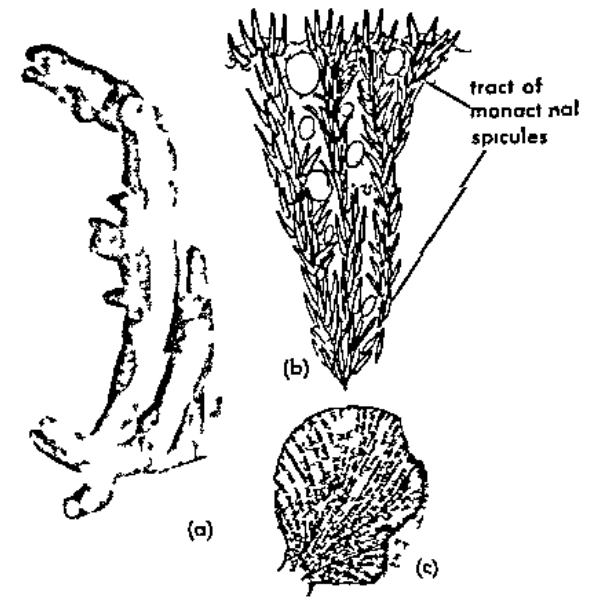


Fig 2 Representative axinellne sponges (a) *Axinella polycapella* (*after Hartman 1955*) (b) Section through *Axinella* showing plumose arrangement of spicule tracts (c) Enlarged portion of b showing spicule arrangement (*after Hyman 1940*)

Clay

The term clay has a dual meaning It is used both as a rock term and as a particle size term As a rock term clay has no genetic significance It is used for material that has been deposited as a sediment has formed by hydrothermal action or is the product of weathering Chemical analyses of clays show them to be composed primarily of silica alumina and water Iron alkalies and alkaline earths are also often present in appreciable quantities

As a rock term clay implies a natural earthy fine-grained material which develops plasticity when mixed with a limited amount of water Plasticity is that property of the moistened material which allows deformation of the material when pressure is applied In a plastic substance the deformed shape is maintained when the deforming force is removed

As a particle-size term clay refers to that fraction of an earthy material containing the smallest particles In the mechanical analysis of sedimentary rocks and soils material is normally divided into three size grades or fractions on the basis of particle size These are sand silt and clay fractions The maximum size of the particles comprising the clay size grade is defined differently by different observers In geology the tendency has been to define the clay grade as any material finer than about 4 microns (μ) in diameter In the investigation of soils there is a tendency to use 2 μ as the upper limit of the clay size grade There is a fundamental reason for choosing this value as the upper limit A large number of analyses have shown that the clay minerals tend to be concentrated in a size less than 2 μ It has also been observed that when naturally occurring larger flakes of clay mineral particles are slaked in water they break down more easily to this size *See* CLAY MINERALS

There is no sharp universal boundary between the particle size of the clay minerals and nonclay minerals in argillaceous sediments but numerous investigations have shown that nonclay minerals usually are not present in abundance in particles much smaller than 1–2 μ (For the best split of clay mineral and nonclay mineral components a separation at 2 μ is now frequently used) *See* ARGILLACEOUS ROCKS

Composition of clay materials The clay size grade materials which make up the rock clay are

always present in varying percentages Coarser grades composed generally of the nonclay minerals are thus also present in varying relative amounts In addition to clay minerals and nonclay minerals clays may also contain organic material and water soluble salts

The designation of a material as clay is often based solely on its bulk properties and appearance Unfortunately in many such materials the clay size grade and clay mineral fraction comprise less than 50% of the total rock A more complete study and analysis of the material often warrants reclassification of the rock as silt or even sand

Some material called clay does not meet all the above specifications So-called flint clay a refractory ceramic clay does not develop plasticity when mixed with water It does however have the other attributes of clay

Some types of sedimentary rocks are substantially of the same composition as clay but differ from clays in their textural characteristics The expression clay material is often used for any fine grained natural earthy argillaceous material when a more precise designation is not possible or desirable Clay material includes clays shales and argillites Soils would also be included if such materials contained an appreciable quantity of clay size grade material and were argillaceous *See* ARGILLITE SHALE

Properties of clay materials The properties of clay materials are controlled by at least five major factors The e attributes which characterize a clay material are clay mineral composition nonclay mineral composition organic material soluble salts and exchangeable ions and texture Generally the clay mineral composition is the most important factor and sometimes as little as 5% of a particular clay mineral may largely determine the properties of the whole clay

The economic use of a clay material is determined largely by its clay mineral composition In the ceramic industry only certain clays of a particular clay mineral composition will withstand high temperatures and can be used for making refractories The oil industry requires certain types of bentonite clay for the preparation of drilling muds Other types of bentonite clay are used for the preparation of catalysts in the refining of petroleum products *See* BENTONITE

The paper industry utilizes certain types of kaolinite clays for the coating and filling of paper In construction engineering a knowledge of the clay material on or through which a structure is to be built is essential The presence of even small amounts (5%) of montmorillonite warrants additional testing of the material to predict how the soil material will act when it is placed under different conditions *See* SOIL SOIL MECHANICS

In the field of agriculture the tilth of a soil its content of plant nutrients and its treatment possibilities with fertilizers are all to a large extent contingent on the clay mineral composition of the soil *See* CLAY COMMERCIAL CLAY PRODUCTS AR CHITECTURAL

[F M W R E G R]

Clay, commercial

Commercial clays or clays utilized as raw material in manufactures are among the most important nonmetallic mineral resources Their production in the United States is about 40 000 000 tons annually and reaches values over $100 000 000 The value of clay products chiefly brick tile and pottery is ordinarily more than $350 000 000 per year

The value of clays is closely related to their mineralogical and chemical composition particularly the clay mineral constituents (kaolinite montmorillonite illite chlorite and attapulgite) The presence of minor amounts of mineral or soluble salt impurities in clays restricts their use The more common mineral impurities are quartz, carbonates iron oxides and sulfides and feld par In addition many clays contain some organic material *See* CLAY MINERALS

Clay is an abundant raw material, however certain high grade types of clay deposits are limited in occurrence and supply Examples are the white kaolin clays found in abundance only in Georgia and South Carolina the high quality bentonites found in Wyoming South Dakota California Texas and Mississippi and the attapulgite clays found in Georgia and Florida

Kaolinitic clays *Clays containing a preponderance* of the clay mineral kaolinite are known as kaolinitic clays Several commercial clays are composed predominantly of kaolinite These are china clays paper clays kaolins ball clays fireclays and flint clays The terms china clay paper clay and kaolin are used interchangeably in industry *See* KAOLINITE

China clay China clays are high grade white kaolins found in the southeastern United States England Germany and many other countries In Georgia and South Carolina the largest producing states the deposits are composed almost wholly of the mineral kaolinite and occur as lenticular shaped bodies generally 6–15 ft in thickness Many grades of kaolin are used in the manufacture of ceramics (whitewares refractories and porcelain) paper rubber paint plastics insecticides adhesives catalysts and ink They are also used for many other industrial purposes

Kaolin or china clay has the desirable properties of being white in color very fine in particle size nonabrasive (hardness 2 2 5 on Mohs scale) and chemically inert in most uses The individual kaolin particle is a thin flat pseudohexagonal platelet so tiny that approximately 10 000 000 spread on a postage stamp would form a layer thinner than the thickness of a human hair This thin flat particle shape is a distinct advantage in many uses The grades of kaolin that are commercially available generally are based on particle size and on color or brightness

By far the largest consumer of white kaolins is the paper industry which uses them to make paper products smoother whiter and more printable The kaolin is used both as a filler in the sheet to enhance opacity and receptivity to ink and as a

thin coating (about 005 in) on the surface of the sheet to make it smoother and whiter for printing The clay coating makes possible sharp photo graphic illustrations and brilliant color printing Other important properties of kaolin for paper manufacture are softness of texture ease of dis persion in the coating process and ability to pro duce a high gloss finish

In ceramics the kaolin clays are used in white wares special refractories and porcelain insula tors In whitewares the kaolin provides a white body gives easy molding properties and adds strength dimensional stability and smooth sur faces to the finished product Refractoriness di mensional stability and chemical inertness make the kaolins uniquely suitable for special refrac tories In addition to the above properties the ex cellent dielectric properties of kaolin are very suitable for porcelain electric insulators *See* CE RAMIC TECHNOLOGY, PORCELAIN

In the manufacture of both natural and synthetic rubber kaolin clays are used as a functional filler The kaolin adds strength abrasion resistance ri gidity and whiteness It costs less than most other fillers used in rubber

In paint and ink kaolins are used as extenders because of their chemical inertness smooth flow properties ease of dispersion nonabrasiveness rel atively low cost and the high pigment volume concentrations that can be attained by their use

In plastics kaolin is used to provide smooth sur faces dimensional stability and better resistance to chemical attack and to improve physical and electrical properties to minimize water absorption to reduce brittleness and to lower costs

In insecticides the inertness low abrasiveness and good *adsorption and flow properties of kaolin* make it an effective carrying agent in both dust and spray forms

A relatively new field is the chemical modifica tion of kaolinite to make it an effective catalyst for use in petroleum refining The kaolin is treated with sulfuric acid and calcined to produce the catalyst

Calcined clay is another commercial product of the kaolins It is used in paint ceramics plastics paper and other materials The calcined kaolins have the advantage of increased whiteness The kaolinite is changed during the calcination to the minerals mullite and cristobalite Many industries are testing other possible uses of calcined kaolins

Ball clay Ball clays are composed mainly of the mineral kaolinite but usually are much darker in color than kaolin or china clay The term ball clay is used for a fine grained very plastic refractory bond clay Most ball clays contain minor amounts of organic material and the clay mineral mont morillonite Usually ball clays are finer grained than china clays This fineness together with the montmorillonite and organic material gives ball clays excellent plasticity and strength For these reasons and because they fire to a light cream color ball clays are commonly used in whitewares and sanitary ware The largest deposits of ball clays in the United States are in western Kentucky and western Tennessee

Fireclay This term is used for clays that will withstand temperatures of 1500°C or higher Such clays are composed primarily of the mineral kao linite The most common fireclays are the under clays or clays which occur directly under coal seams Not all underclays are fireclays because many contain materials that lower the fusion point to below 1500°C Fireclays are generally light to dark gray in color contain minor amounts of min eral impurities such as illite and quartz and fire to a cream or buff color Most fireclays are plastic but some are nonplastic and very hard these are known as flint clays

Fireclays are used primarily by the refractories industry The refractoriness of fireclays is propor tional to the amount of alumina present in the clay and is reduced by impurities such as calcium car bonate and iron compounds The foundry industry uses fireclay to bind sands into shapes in which metals can be cast From 10 to 15% fireclay is necessary to bind the sand grains together Fire clay bonded sands give the metal a smoother sur face than when other clays such as bentonite are used but equivalent or higher mold strengths can be attained with approximately one third as much bentonite In many cases even though the strength properties of bentonite bonded sands are higher fireclays are used if the cost of clay and transporta tion is lower Large quantities of fireclay are mined in Pennsylvania West Virginia Kentucky Ohio and Missouri

Flint clay This term is used for a special type of fireclay Flint clays are composed essentially of kaolinite and are also refractory but are nonplastic and very hard

Diaspore clay This is a special type of clay that is composed of the minerals diaspore and kaolinite Diaspore is a hydrated aluminum oxide with an Al_2O content of 85% and a water content of 15% This mineral is quite hard (6 5 7 on Mohs scale) and very refractory Diaspore clay is used almost exclusively by the refractories industry in making refractory brick However after calcination it is sometimes used as an abrasive material Diaspore clay is produced commercially in Missouri and Pennsylvania It is found in nature mixed with flint and plastic fireclays High grade diaspore clay con tains 65–70% Al_2O_3 When its Al_2O_3 content is 50–65% this material is called burley clay Because of extensive reserves of diaspore clay the United States Bureau of Mines has worked out a process for the production of metallic aluminum from diaspore clay Under present economic conditions however it cannot compete with bauxite in the pro duction of aluminum *See* BAUXITE

Mullite Mullite is a high temperature conversion product of many aluminum silicate minerals includ ing kaolinite pinite topaz dumortierite pyrophyl lite sericite andalusite kyanite and sillimanite Mullite is used in refractories to produce ma terials of high strength and great refractoriness Mullite does not spall withstands t shock

heating and cooling exceptionally well and is resistant to slag erosion It is used in making spark plugs laboratory crucibles kiln furniture saggars and other special refractories Mullite crystals occur as long needlelike or lathlike forms The intermeshing of these crystals produces high strength bodies The only natural occurrence of mullite is on the island of Mull in the Western Isles of Scotland and here it is found in such small quantities that it has no commercial significance

Bentonites Those clays that are composed mainly of the clay mineral montmorillonite and are formed by the alteration of volcanic ash are known as bentonites They are used in many industries the most important uses are as drilling muds and catalysts in the petroleum industry as bonding clays in foundries and as adsorbents in many industries there are other miscellaneous uses *See* MONTMORILLONITE

The largest producing areas of bentonite are in Wyoming in South Dakota in Texas and in Mississippi The Wyoming bentonite is composed predominantly of sodium montmorillonite whereas the Mississippi bentonite is composed largely of calcium montmorillonite Sodium montmorillonite and calcium montmorillonite have significantly different physical properties which regulate their use and acceptance by many industries

The term bentonite is a rock term but in industrial usage it has become almost synonymous with swelling clay Bentonite contains minor amounts of other clay minerals particularly illite and kaolinite and up to approximately 30% cristobalite the high temperature form of silicon dioxide The properties of the bentonite are almost wholly dependent on the type and amount of montmorillonite present

Drilling mud Drilling mud consists of bentonite water a weighting material such as barite and various electrolytes This mud is circulated in the hole at all times while the drilling is progressing The functions of the drilling mud are to remove the drill cuttings from the drill hole to form a filter cake on the wall of the drill hole to keep the drilling fluid in the hole and prevent water in the rock formations from entering the hole to cool and lubricate the bit and to prevent blowouts Bentonite especially the sodium variety imparts high viscosity and shear strength to the mud and also imparts a property called thixotropy A thixotropic body acts as a fluid when agitated and as a thick gel when standing Because the properties imparted by the bentonites to the drilling fluid are so important to the success of the oil industry these clays are an extremely important mineral commodity

Bonding clay Bentonites are used in the foundry industry to bind sands into desired shapes in which metals can be cast Only 3–5% bentonite is needed to bond the sand grains together Because of their fine particle size and the nature of their water adsorption, bentonites give the mold a higher green dry and hot strength than any other type of clay

Other uses Bentonites are also used as bleaching clays to remove coloring matter from oils and as adsorbents for oils insecticides alkaloids vitamins and many other materials Calcium montmorillonites generally have better decolorizing properties than the sodium variety Calcium bentonites are also used as catalysts and large quantities of sodium bentonite are used to line irrigation ditches and to seal leaks in dams because this material tends to form an impermeable cake by swelling and filling the pores Sodium montmorillonite will swell in water to many times its original size Calcium montmorillonite does not swell as much or as readily as the sodium variety and thus does not have the excellent thixotropic properties of sodium montmorillonite Bentonites are also used in such products as cosmetics deinking agents enamels, medicinal emulsions bodying agents and pastes

Attapulgite clays These are hydrated magnesium aluminum silicates which are commercially produced in a small area in southwestern Georgia and northwestern Florida They are commonly called fuller's earth the name used for any natural earthy material that will decolorize vegetable or mineral oils The attapulgite clays are used for the neutralization deodorization decolorization and refining of mineral and vegetable oils fats, and waxes as well as for rerefining and oil reclaiming Attapulgite clays are also used as adsorbents for removing water and oil from commercial and industrial floors and for adsorbing alkaloids vitamins carbohydrates and many other compound The attapulgite crystal has a long lathlike shape and makes a good suspending agent that is difficult to flocculate because of the physical settling hindrance of one crystal moving past another Therefore attapulgite finds extensive use in drilling muds for salt water formations because the suspensions are resistant to the flocculating action of electrolytes In addition to the above uses attapulgite clays are used as catalysts catalyst supports and fillers and in water clarifiers

Miscellaneous clays Most of these clays and shales contain mixtures of differing proportions of illite chlorite kaolinite and montmorillonite plus a variety of nonclay minerals By far the largest user of these miscellaneous clays is the structural clay products industry This industry manufactures brick drain tile sewer pipe conduit tile glazed tile terra cotta and other items

The clays that can be used for the different structural clay products necessarily have wide variations in properties For example a clay that can be used for conduit tile must be very plastic have high green and dry strength and uniform shrinkage for drain tile or common brick these properties do not have to be controlled so closely In general however the properties of clays that are important in the manufacture of structural clay products are plasticity green strength dry strength drying and firing shrinkage vitrification range and fired color These properties are largely dependent on the composition of the clay and the particle size of the constituents

Properties of clays Most clays become plastic when mixed with varying proportions of water Plasticity of a material can be defined as the ability of the material to undergo permanent deformation in any direction without rupture under a stress beyond that of elastic yielding Clays range from those which are very plastic called fat clay to those which are barely plastic called lean clay The type of clay mineral particle size particle shape organic matter soluble salts and adsorbed ions and the amount and type of nonclay minerals are all known to affect the plastic properties of a clay

Strength Green strength and dry strength properties are very important because most structural clay products are handled at least once and must be strong enough to maintain shape Green strength is the strength of the clay material in the wet plastic state Dry strength is the strength of the clay after it has been dried Plasticity and green strength are closely related and are affected largely by the same variables Dry strength is dependent on the proportion of fine particles present the shape of the individual particles the degree of hydration of the colloidal fraction the method of forming the ware and the extent of drying The presence of a small amount of montmorillonite which is of very fine particle size and highly hydrated generally increases the dry strength

Shrinkage Both drying and firing shrinkages are important properties of clay used for structural clay products Shrinkage is the loss in volume of a clay when it dries or when it is fired Drying shrinkage is dependent on the water content the character of the clay minerals and the particle size of the constituents Drying shrinkage is high in most very plastic clays and tends to produce cracking and warping It is low in sandy clays or clays of low plasticity and tends to produce a weak porous body Montmorillonite in relatively large amounts (10–25%) causes excessive shrinkage cracking and slow drying Firing shrinkage depends on the volatile materials present the types of crystalline phase changes that take place during firing and the dehydration characteristics of the clay minerals

Vitrification range The temperature range of vitrification or glass formation is a very important property in structural products Vitrification is due to a process of gradual fusion in which some of the more easily melted constituents begin to produce an increasing amount of liquid which makes up the glassy bonding material in the final fired product Some clays have a short vitrification range so that the temperature of the kiln must be very closely regulated Illites montmorillonites and chlorites all have lower vitrification temperatures than kaolinite Some nonclay minerals such as calcite and feldspar lower the vitrification temperature of the body by acting as fluxes The degree of vitrification developed depends on the duration of firing as well as on the temperature attained Usually the degree of vitrification is regulated by the amount of shrinkage and porosity that is needed in the final product There is however a practical limit as to the amount of shrinkage and reduction in porosity that can be attained at a given temperature

Color Color is important in most structural clay products particularly the maintenance of uniform color The color of a product is influenced by the state of oxidation of iron the state of division of the iron minerals the firing temperature and degree of vitrification the proportion of alumina lime and magnesia in the clay material and the composition of the fire gases during the burning operation The best white burning clays contain less than 1% Fe_2O_3 Buff burning clays contain 1 5% Fe O_3 and red burning clays contain 5% or more Fe_2O_3 Other constituents also affect the color but finely divided iron bearing minerals are considered to be the principal colorants

Uses All types of clay and shale are used in the structural products industry but in general the clays that are used are considered to be relatively low grade Clays that are used for conduit tile glazed tile and sewer pipe are underclays and shales that contain large proportions of kaolinite and illite The semirefractory plastic clays found directly beneath the coal seams make the best raw material for the above mentioned uses Brick and drain tile can be made from a wide variety of clays depending on their location and the quality of product desired Clays used for brick and drain tile must be plastic enough to be shaped In addition color and vitrification range are very important For common brick and drain tile shales and surface clays are usually suitable but for high quality face bricks shales and underclays are used Geographic location is a prime factor in the type of clay used for structural clay products because in general these products cannot be shipped great distances owing to excessive transportation costs Many raw materials of questionable quality are utilized in certain areas because no better raw material is available nearby

Lightweight aggregate is produced from many types of clays and shales In the past few years the production and consumption of manufactured lightweight aggregate from clay and shale have rapidly increased The raw material is heated very rapidly in rotary kilns or sintering machines to the temperature range between incipient and complete fusion After fusion has developed a molten jacket around the particle certain constituents if present release gas to produce bloating and vesiculation The molten jacket must be viscous enough to retain the expanding gas Shales containing illites montmorillonites or chlorites plus nonclay materials such as carbonates sulfates and organic matter are the best raw material for lightweight aggregate Adequate testing of a clay or shale is the only way to determine whether or not it will make a suitable lightweight aggregate Mineral and chemical composition particle size distribution fusion temperature and final strength of the aggregate particles are all important factors which control the production of lightweight aggregate from a clay or shale The presence of a high per

entage of kaolinite causes the material to be too refractory and the presence of excess fluxing agents causes the material to melt much too rapidly to control the vesiculation necessary to make the material lightweight

The cement industry uses large quantities of impure clays and shales Clays are used to provide alumina and silica to the charge for the cement kiln Practically any clay with an average alumina and silica content can be used and generally a clay can be found in the area in which the cement is being manufactured *See* CEMENT

See CLAY PRODUCTS ARCHITECTURAL POTTERY REFRACTORY [H H M]

Clay minerals

The clay minerals are the major components of clay materials They occur in extremely small particles which are essentially crystalline and are limited in number The clay minerals are essentially hydrous aluminum silicates Alkalies or alkaline earths are present as principal constituents in some of them Also in some clay minerals magnesium or iron or both substitute wholly or in part for the aluminum The ultimate chemical constituents of the clay minerals vary not only in amounts but also in the way in which they are combined or are present in various clay minerals *See* CLAY

Clay mineral concepts. The investigation of clay materials goes far back into antiquity because of their importance in industry agriculture geology and elsewhere A considerable number of concepts have been suggested to portray the essential components of all clay materials and to explain their variation in properties Most of these concepts are concerned with the way in which the chemical components are put together in clays that is to portray the fundamental building blocks of clay materials

Before the advent of adequate analytical techniques and tools for the study of materials as fine-grained as clays there was no general agreement as to the exact nature of these fundamental building blocks A very old idea is that all clay materials are composed of kaolinite frequently containing other materials considered to be impurities

Another concept particularly held by soil investigators was that a colloidal complex was the essential component This complex was thought to be amorphous and either inorganic or organic Some investigators regarded it as a loose mixture of the oxides of silicon aluminum and iron Another idea regarded this complex as a mixture of salts of weak ferroaluminosiliceous acids

Another concept considered clay to have two essential components One called clayite was thought to be the true clay substance in kaolins It was considered to be an amorphous substance with about the same chemical composition as the mineral kaolinite The other essential component called "pelinite" was suggested as the true clay substance in other clay materials The latter was thought to be an amorphous material with a higher silica content and more alkalies or alkaline earths or both than clayite

Still another concept was that fineness was the sole determining factor—thus clay materials could have any mineral composition

For many years some students have suggested that clays are composed of extremely small particles of a limited number of crystalline minerals This is the clay mineral concept which is now generally accepted It is not new but until the advent of x ray diffraction analysis the crystalline nature of the extremely small clay minerals could not be proved Recent work indicates that some clay materials contain extremely poorly crystalline components which are amorphous or very poorly crystalline Such material is not present in all clay materials or even most of them and thus cannot be considered a constituent generally responsible for clay properties

Classification of clay minerals No completely satisfactory classification of the clay minerals has yet been suggested Classification is difficult because clays are often composed of complex mixtures of clay minerals of such poor crystallinity that the individual components cannot be adequately characterized Also there seems to be a continuous gradation between some of the types The following classification has proved to be a workable one A major subdivision into amorphous and crystalline groups is made even though the amorphous components are relatively rare and of little importance

I Amorphous
  Allophane group
II Crystalline
  A Two layer type (sheet structures composed of units of one layer of silica tetrahedrons and one layer of alumina octahedrons)
    1 Equidimensional
      Kaolinite group Kaolinite nacrite dickite etc
    2 Elongate
      Halloysite group
  B Three layer types (sheet structures composed of two layers of silica tetrahedrons and one central dioctahedral or trioctahedral layer)
    1 Expanding structure
      a Equidimensional
        Montmorillonite group Montmorillonite sauconite and so forth
        Vermiculite
      b Elongate
        Montmorillonite group Nontronite saponite hectorite
    2 Nonexpanding structure
      Illite group
  C Regular mixed layer types (ordered stacking of alternate structural types)
    Chlorite group

D Chain structure types (similar to hornblende—chains of silica tetrahedrons linked together by octahedral groups of oxygens and hydroxyls containing Al and Mg atoms)
Attapulgite
Sepiolite
Palygorskite

The three layer minerals are divided into the expanding and nonexpanding types in this classification This subdivision is made even though there may be a continuous gradation between the two types The expanding attribute is a readily determinable diagnostic property since it imparts some unique physical properties to the clay materials composed of these minerals The expanding minerals are divided into equidimensional and elongate divisions because shape is a readily recognizable characteristic that probably reflects structural attributes

Nomenclature of clay minerals During the early work with clay minerals the name allophane came to be associated with amorphous constituents of clay The study of this material showed that some of it was actually crystalline although much of it was amorphous to x ray diffraction It has been suggested that the term allophane be used for all such amorphous clay mineral materials regardless of their composition

Kaolinite group Perhaps the best known clay minerals are those of the kaolinite group Three distinct mineral species are represented by this group They are kaolinite nacrite and dickite Anauxite has also been defined as a mineral with essentially the same attributes as kaolinite but with a higher silica alumina molecular ratio Early investigators believed anauxite to be an interlayer mixture of a double silica layer and a two layer sheet structure Recent x ray studies suggest that material called anauxite is simply a mixture of kaolinite and quartz *See* KAOLINITE

Halloysite group Minerals of the halloysite group are somewhat similar chemically to kaolinite but have different structural attributes There are two forms of the mineral halloysite One form has the *same chemical composition as kaolinite* the other is more hydrous with $4H_2O$ instead of $2H_2O$ in its composition Unfortunately there is no agreement among clay mineralogists regarding proper nomenclature for the halloysite minerals Thus the more hydrated form has been called endellite by some investigators and simply halloysite by others The lower hydration form has been called metahalloysite by some and halloysite by other students It has been suggested that halloysite be used as a general term for all naturally occurring specimens of the mineral regardless of their state of hydration When it is possible and necessary to describe the state of hydration additional self explanatory qualifications should be used *See* HALLOYSITE

Montmorillonite group Montmorillonite has as an essential characteristic its expanding structure that is the property of adsorbing variable amounts of water between individual unit layers Members of this group show considerable variation in the ratio of SiO_2 to R_2O_3 There can also be replacement of aluminum by iron and magnesium The iron rich montmorillonite is called nontronite and the magnesium rich variety is known as saponite *See* MONTMORILLONITE

Vermiculite Vermiculites also have an expanding structure They differ from montmorillonite in that only a limited degree of expansion can take place and their particle size is larger Vermiculites have been considered to be closely related to the micas and only recently have they been recognized as clay mineral constituents of clay materials *See* VERMICULITE

Illite The term illite was proposed not as a specific clay mineral name but as a general term for the micalike clay minerals It refers to any mica type clay mineral with a 10 angstrom c axis spacing which shows no expanding structure characteristics Illites include both trioctahedral and dioctahedral types of clay mineral micas *See* ILLITE

Chlorite group The chlorites are a group of green hydrous silicates which contain ferrous iron and are closely related to the micas Structurally they are regular interstratifications of single biotite mica layers and brucite layers Only recently have they been recognized as important constituents of clay materials The identification of chlorite is particularly difficult when kaolinite is present in the same clay material *See* CHLORITE

yet completely understood They are easily missed in clay mineral analyses and may be much more abundant than is now considered to be the case

Mixed layer combinations Many clay materials are composed of more than one clay mineral These clay mineral components are often random mixtures of discrete units so that there is no preferred geometric orientation In another type of mixing the layer type clay minerals are interstratified This is possible because of their structural similarity There are two different types of *such so called* mixed layer structures In one type there is a regular repetition of the different layers which are stacked along the *c* axis The other kind of mixed layer structure is a random irregular interstratification of layers without a uniform repetition of layers Mixed layers of illite and montmorillonite and of chlorite and vermiculite are particularly common in clay materials and can only be detected by careful x ray diffraction techniques *See* X RAY DIFFRACTION

Structure of clay minerals The atomic structures of the clay minerals consist of combinations of two basic structural units One unit consists of silica tetrahedrons in which each tetrahedron is made up of a silicon atom equidistant from four oxygen atoms or hydroxyl ions arranged in the form of a tetrahedron with the silicon atom at the

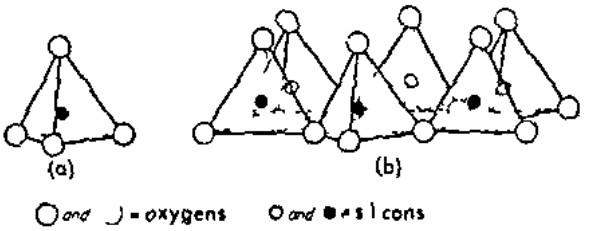


Fig 1 Diagrammatic sketch showing (a) single silica tetrahedron and (b) sheet structure of silica tetrahedrons arranged in a hexagonal network (From R E Grim Clay Mineralogy McGraw-Hill 1953)

center The silica tetrahedral groups are arranged to form a hexagonal network which is repeated in two directions to form a sheet (Fig 1) with the composition $Si_4O_6(OH)_4$ The tips of all tetrahedra point in the same direction and their bases are all in the same plane The composite structure of this unit may be viewed as a perforated basal plane of oxygen atoms a plane of silicon atoms forming a hexagonal network and a plane of hydroxyl atoms with each hydroxyl positioned at the tip of the tetrahedron directly above the silicon The thickness of this tetrahedrally coordinated unit is 4 93 angstrom units in clay mineral structures

The other structural unit consists of two sheets of closely packed oxygen atoms or hydroxyl ions in which aluminum iron or magnesium atoms are octahedrally coordinated (Fig 2) When aluminum is present only two thirds of all the possible positions are filled to balance the structure This is the dioctahedral gibbsite structure and has the formula $Al_2(OH)_6$ If all the positions are filled as when magnesium is present the trioctahedral brucite structure is formed with the formula $Mg_3(OH)_6$ The thickness of this sheet is 5 05 angstrom units in clay mineral structures

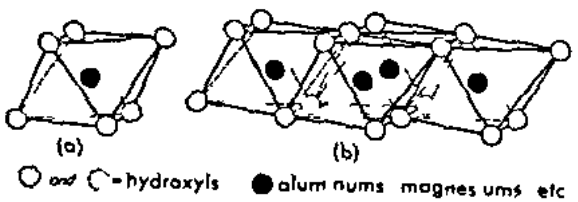


Fig 2 Diagrammatic sketch showing (a) single octahedral unit and (b) the sheet structure of the octahedral units. (From R E Grim Clay Mineralogy McGraw-Hill 1953)

Shape of clay minerals Because of the sheetlike nature of their structural units most of the clay minerals are flake shaped Some of the flakes have a distinct hexagonal outline A few of the clay minerals are tubular or elongate or both Some are fibrous and are composed of structural units different from those listed above The sepiolite palygorskite and attapulgite minerals have structural characteristics similar to the amphiboles Their basic structural unit is composed of silica tetrahedrons arranged in a double chain of composition Si_4O_{11} The chains are bound together by aluminum or magnesium atoms or both This structure is continuous in only one direction and it is restricted to a width of about 11 5 angstrom units

The precise determination of the shape and size of the various clay mineral particles has been made possible by the use of the electron microscope With this instrument the clay mineral particles can be magnified directly up to 15 000 times Subsequent photographic enlargement can then increase this magnification several times *See* MICROSCOPE ELECTRON

Properties of clay minerals The varied properties of the clay minerals are important in that they govern the economic use of clay materials

Ion exchange The ability of clay minerals to hold certain cations and anions which are readily exchangeable for other cations and anions is most significant The commonest exchangeable cations in clay materials are Ca^{++} Mg^{++}, H^+, K^+, NH_4^+ and Na^+ The more common exchangeable anions are SO_4 Cl PO_4^{3} and NO_3

There are two major causes for the exchange capacity of the clay minerals Broken bonds around the edges of silica alumina units give rise to unsatisfied charges which are balanced by adsorbed cations Substitutions within the structure result in unbalanced charges satisfied by exchangeable cations In addition some anions may be adsorbed by replacement of exposed hydroxyl ions and because of the structural fit of some of them with tetrahedral units

This property of ion exchange and the exchange reaction are of fundamental importance in all fields in which clay materials are used For example in soils the retention and availability of potash added in fertilizers depends on cation exchange between the potash salt and the clay mineral in the soil *See* ION EXCHANGE SOIL

Clay water system Another important property of clay materials is their ability to hold water This water is of two types low temperature water and OH structural water The low temperature water is driven off by heating to 100–150°C This is the water in pores on the surfaces and around the edges of the minerals composing the material It is also the interlayer water between the unit cell layers of minerals such as montmorillonite The water which occupies the tubular openings between the elongate structural units of the sepiolite attapulgite palygorskite minerals is also of this type

Abundant evidence shows that there is some sort of definite configuration of the water molecules initially adsorbed on the surfaces of clay materials however there is not agreement regarding the precise nature of the structure of this initially adsorbed water The configuration of this low temperature water and the factors controlling it largely determine the plastic bonding suspension compaction and other properties of clay materials which in turn govern their economic usage

Dehydration When clay materials are heated dehydration occurs Thus there is a loss of any water (adsorbed interlayer or structural OH water) held by the clay minerals The heating of clay ma

terials also causes changes in the clay mineral structures At relatively high temperatures these structural changes facilitate the formation of new mineral phases These structural modifications are particularly important in the firing of clay materials

Clay mineral organic reactions Another property of the clay minerals is their ability to react with organic materials Clays with a high adsorbing capacity are used in decolorizing oils while others provide catalysts in the cracking of organic compounds

Some analytical techniques for the analysis of clay materials are based on clay mineral organic reactions For example the identification of montmorillonite by x ray diffraction is greatly simplified by treating the material with glycerol or ethylene glycol which substitutes for water in the interlayer position and causes measurable expansion of the lattice along the c axis Some organic materials are also used in the identification of clay minerals by staining techniques

Optical properties The optical properties of the clay minerals are usually difficult to determine because of their extremely small size and because of inherent variations in the clay minerals themselves Replacements within the structure and variations in the amount of interlayer water are reflected by changes in the optical properties

Origin of clay minerals Many of the clay minerals have been synthesized in the laboratory under conditions varying from room temperature and atmospheric pressure to elevated temperatures and pressures From these experiments some general conclusions can be drawn regarding the environmental conditions favorable for the formation of the individual minerals At low temperatures acid conditions favor the formation of the kaolinite type of mineral whereas alkaline conditions favor the formation of montmorillonite if magnesium is present or mica if sufficient potassium is present

At elevated temperatures such generalities do not always hold and the minerals which form depend upon ionic concentration temperature and the Al_2O_3 SiO_2 ratio

Many of the clay minerals are of a hydrothermal origin With the possible exception of attapulgite palygorskite and vermiculite all have been reported in hydrothermal bodies frequently with metalliferous ore deposits Some hydrothermal clay deposits are monomineralic but most consist of a mixture of clay minerals *See* ORE AND MINERAL DEPOSITS

The weathering of soils and of different rock types also leads to the formation of clay minerals The type of clay mineral formed however depends upon a number of factors These are parent rock climate topography vegetation and time A complex interplay of these factors determines the weathering environment and its processes and thus the type of clay mineral which will form *See* WEATHERING PROCESSES

Clay minerals are abundant in sediments both recent and ancient In some cases at least the character of the clay minerals change in passing from one environment to another such as from fresh water to marine so that the clay mineral composition reflects the geologic history of the sediment *See* MARINE SEDIMENTS SEDIMENTARY ROCKS SEDIMENTATION (GEOLOGY) [F M W R E G R]

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Clay products, architectural

Materials such as brick structural tile drain tile pipe roofing tile terra cotta interior floor and wall tile and sanitary fixtures (toilets sinks) In some classifications the latter three (floor and wall tile and sanitary ware) are included in the field of whitewares (together with pottery and electrical ceramics) and the others called structural or heavy clay products *See* CLAY

Bricks may be solid or cored (that is with holes running through them) but in any case the area of solid in a plane parallel to the bearing faces (usually the horizontal plane) is at least 75% of the total area of these faces Brick ranges in color from a burned black through red and yellow buff to a nearly white cream Often a single brick has various colors Face brick has one or more specially finished faces and is intended for the outer surface of a wall it may be unglazed or glazed with either a clear (transparent) or an opaque glaze (*see* GLAZING) Brick without any special surface finish is called building or common brick Other types are paving and sewer brick which are hard and impervious

Structural tiles are hollow units the area of solid being less than 75% of the total area of the unit measured parallel to the bearing surface Tile is classified as load bearing or nonload bearing (partition tile) tile with a specially finished surface is face tile Again tile may be glazed or unglazed Structural tile used for load bearing in a floor may be called floor tile but it should not be confused with tile on the floor as a finish also referred to as floor tile The former might better be called structural or load bearing floor tile

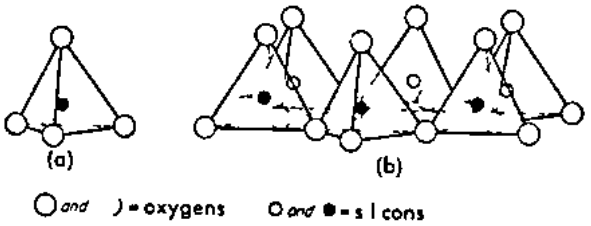
Drain tiles are cylindrical units usually unglazed with ends cut flush to give a butt joint

Clay pipe consists of cylindrical units with a flare or bell at one end to give a lap joint by fitting over the plain end of the next piece Pipe is usually glazed most commonly with a salt glaze

Roofing tile is made in various shapes and is of relatively low porosity it is not vitreous and generally is unglazed

The above five types are usually made of naturally occurring clay (some blending may be done) by an extrusion process except for some shapes of roofing tile which are more conveniently pressed For a discussion of these and other forming methods *see* CERAMIC TECHNOLOGY All architectural clay products are fired before use

Terra cotta is a decorative type of clay ware used for facing buildings Made by pressing plaster of paris molds it is c

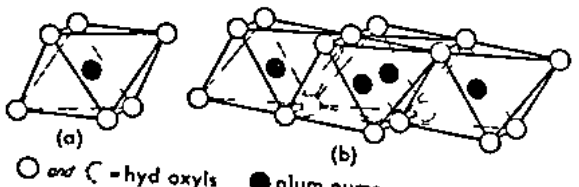


F g 1 D agrammat c sketch showing (a) s ngle s l ca tetrahedron and (b) sheet structure of s l ca tetrahe drons arranged n a hexagonal network (*From R E Gr m Clay M neralogy McGraw-H ll 1953*)

center The silica tetrahedral groups are arranged to form a hexagonal network which is repeated in two directions to form a sheet (Fig 1) with the composition $Si_2O_5(OH)_4$ The tips of all tetra hedra point in the same direction and their bases are all in the same plane The composite structure of this unit may be viewed as a perforated basal plane of oxygen atoms a plane of silicon atoms forming a hexagonal network and a plane of hy droxyl atoms with each hydroxyl positioned at the tip of the tetrahedron directly above the silicon The thickness of this tetrahedrally coordinated unit is 4 93 angstrom units in clay mineral structures

The other structural unit consists of two sheets of closely packed oxygen atoms or hydroxyl ions

u to balance the structure This is the dioctahedral gibbsite structure and has the formula $Al_2(OH)_6$ If all the positions are filled as when magnesium is present the trioctahedral brucite structure is formed with the formula $Mg_3(OH)_6$ The thickness of this sheet is 5 05 angstrom units in clay mineral structures



F g 2 D agrammat c sketch show ng (a) s ngle octa hedral un t and (b) the sheet structure of the octahe dral un ts (*From R E Gr m Clay M neralogy Mc Graw H ll 1953*)

Shape of clay minerals Because of the sheetlike nature of their structural units most of the clay minerals are flake shaped Some of the flakes have a distinct hexagonal outline A few of the clay minerals are tubular or elongate or both Some are fibrous and are composed of structural units differ ent from those listed above The sepiolite paly gorskite and attapulgite minerals have structural characteristics similar to the amphiboles Their basic structural unit is composed of silica tetrahe drons arranged in a double chain of composition Si_4O_{11} The chains are bound together by aluminum or magnesium atoms or both This structure is con tinuous in only one direction and it is restricted to a width of about 11 5 angstrom units

The precise determination of the shape and size of the various clay mineral particles has been made possible by the use of the electron microscope With this instrument the clay mineral particles can be magnified directly up to 15 000 times Subse quent photographic enlargement can then increase this magnification several times *See* MICROSCOPE ELECTRON

Properties of clay minerals The varied proper ties of the clay minerals are important in that they govern the economic use of clay materials

Ion exchange The ability of clay minerals to hold certain cations and anions which are read ly exchangeable for other cations and anions is most significant The commonest exchangeable cations in clay materials are Ca^{++} Mg^{++} H^+ K^+ NH_4^+ and Na The more common exchangeable anions are SO_4 Cl PO_4^{-3} and NO_3

There are two major causes for the exchange ca pacity of the clay minerals Broken bonds around the edges of silica alumina units give rise to unsat isfied charges which are balanced by adsorbed cat ions Substitutions within the structure result in unbalanced charges satisfied by exchangeable cat ions In addition some anions may be adsorbed by replacement of exposed hydroxyl ions and because of the structural fit of some of them with tetrahe dral units

This property of ion exchange and the exchange reaction are of fundamental importance in all fields in which clay materials are used For example in soils the retention and availability of potash added in fertilizers depends on cation exchange between the potash salt and the clay mineral in the so l. *See* ION EXCHANGE SOIL

Clay water system Another important property of clay materials is their ability to hold water Th s water is of two types low temperature water and OH structural water The low temperature water is driven off by heating to 100–150°C This is the wa ter in pores on the surfaces and around the edges of the minerals composing the material It is also the interlayer water between the unit cell layers of minerals such as montmorillonite The water which occupies the tubular openings between the elongate structural units of the sepiolite attapulgite paly gorskite minerals is also of this type

Abundant evidence shows that there is some sort of definite configuration of the water molecules ini tially adsorbed on the surfaces of clay materials however there is not agreement regarding the pre cise nature of the structure of this initially ad sorbed water The configuration of this low temper ature water and the factors controlling it largely determine the plastic bonding suspension com paction and other properties of clay materials which in turn govern their economic usage

Dehydration When clay materials are heated de hydration occurs Thus there is a loss of any water (adsorbed interlayer or structural OH water) held by the clay minerals The heating of clay ma

size that they can readily undergo the subsequent events of blastulation gastrulation and interaction that are involved in formation of tissues and organs Sooner or later cleavage segregates different cytoplasmic areas into different blastomeres thus subdividing the substance of the egg qualitatively These qualitative cytoplasmic differences among blastomeres are then sufficient to account for the initial establishment of different lines of differentiation in the progeny of different blastomeres even though the genetic content of all blastomeres is identical *See* CELL LINEAGE OVUM [R L W]

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Cleavage, rock

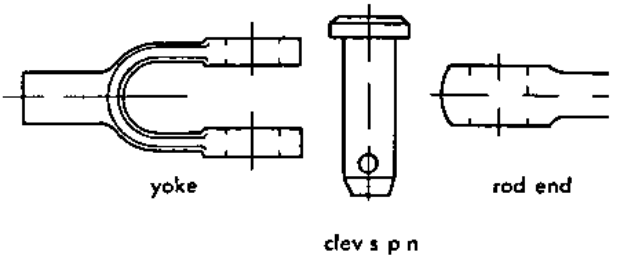
The capacity of a rock to split along certain parallel surfaces more easily than along others In the strict sense this definition includes primary structural surfaces such as surfaces of bedding planes in sedimentary rocks and flow laminations in igneous rocks As generally used however cleavage is restricted to secondary structures caused by mechanical processes that induce the rock to split or slide along surfaces that are related to the tensile and compressive forces generated in the earth s interior The nature and cause of these processes are still major problems to the geologist

A common example of a rock having a conspicuously well developed closely set cleavage is a roofing slate Such cleavage in fine grained rocks where the distances between smooth planar surfaces can be as close as ⅟₁₀ in is known as slaty cleavage In coarser grained rocks the capacity to part along approximately parallel surfaces is known as schistosity *See* SCHISTOSITY ROCK

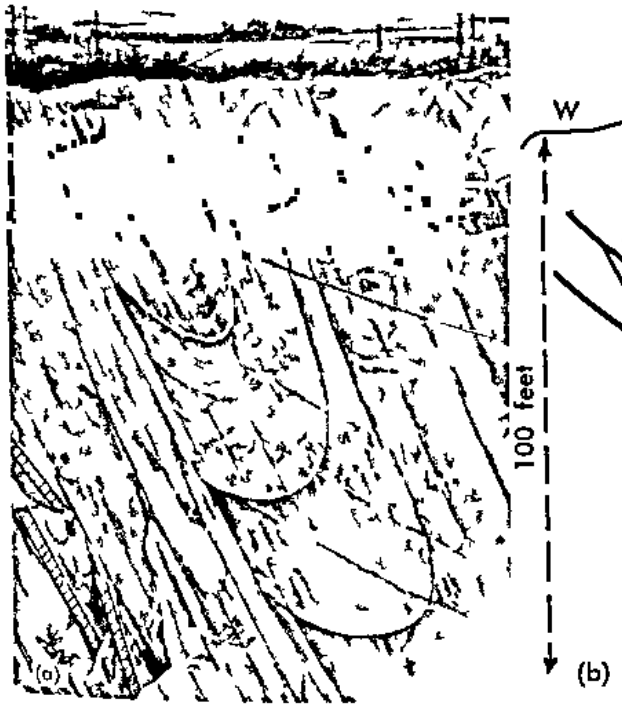
Rock cleavage is facilitated by a fixed arrangement of mineral particles in relation to the mechanically formed parallel surfaces of ready parting Micaceous minerals are most important in facilitating rock cleavage Mica possesses in itself a strong mineral cleavage that causes it to split readily into thin leaves consequently arrangement of micaceous minerals with their leaves parallel to mechanically developed planes of rock cleavage facilitates the capacity of the rock to split along these planes The presence of minerals in this arrangement is often cited as the whole cause of rock cleavage Cleavage in minerals however is caused by an ionic arrangement in the crystal lattice that is an inherent property of the mineral itself and is not related to forces that accompany the formation of rock cleavage in deformed rocks [E B K]

Clevis pin

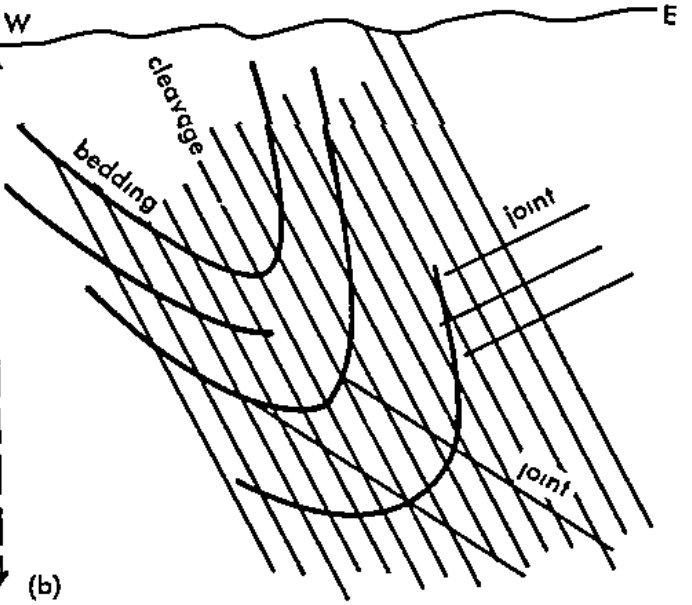
A fastener with a head at one end and a hole at the other used to join a clevis to a rod A clevis is a yoke with a hole formed or attached at one end of a rod (see sketch) When an eye or hole of a second rod is aligned with the hole in the yoke a



Clevis pin joins yoke to rod end



Slaty cleavage (a) North face of roofing slate quarry at West Pawlet Vermont (b) Diagram shows position of slaty cleavage in same quarry cutting across bedding of folded strata (*USGS Bull 586*)



clevis pin can be inserted to join the two A cotter pin can then be inserted in the hole of the clevis pin to hold it in yet the fastening is readily detachable This joint is used for rods in tension where some flexibility is required [1958]

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Climatic change

The long term fluctuation in rainfall temperature and other aspects of the earth's climate Today these are tentatively attributed to changes in the sun's output of energy the earth's atmosphere the character of the earth's surface and other factors Ample geological and paleontological evidence shows that climate has changed (or fluctuated) greatly during the history of the earth However the scope of the present article is limited to a discussion of meteorological evidence for climatic fluctuation within the recent historical period Climate through the ages is discussed extensively in other articles *See* DENDROCHRONOLOGY GEOLOGIC THERMOMETRY GLACIAL EPOCH PALEOCLIMATOLOGY PALEOECOLOGY PALLEOGEOGRAPHY PALYNOLOGY

It should be emphasized that most meteorological evidence for climatic change is meager in quantity and of controversial quality In the first place the time interval covered by even the most extended observational record is absurdly short when meas

meteorological record that varies with the practices of different countries and is of doubtful quality throughout also the large variations shown by the record may be the result of a variety of human and observational factors that are in no way related to natural causes

Nevertheless climatologists accept some of the meteorological evidence for climatic change during the historical period For example considerable evidence points toward a world wide warming during the last 50–65 years This warming has been particularly significant within the Arctic during

nland

nds in precipitation since 1885 but these appear to be regionally irregular and less conspicuous than is the case with temperature Below-average precipitation appears to have occurred over most of the United States the northern part of South America Africa Malaya and Australia Precipitation above the average appears to have occurred over the Arctic the North Temperate Zone in Mexico La Plata southern India and southeastern Asia The average wind patterns of the globe show similar fluctuations and these appear to agree with changes over time in the mean pressure distribution over the earth In fact the sea level pressure temperature and precipitation change patterns at middle and high latitudes are surprisingly consistent One observer has also noted a similar consistency when comparing the hemispherical distributions of these elements during periods of greatest and least development of sunspots

If it is assumed that no internal mechanism exists within the atmosphere to account for a progressive or cyclical change in climate the causes of climatic change must be related to extraterrestrial factors or to changes in other terrestrial influences The most plausible theories assign the causes of climatic change to one or more of the following (1) variations in the amount or character of solar radiation (2) variations in transmissivity of energy by the atmosphere due to changes in its composition for instance in its carbon dioxide or ozone content (3) variations in atmospheric transmissivity due to changes in turbidity through addition of such things as volcanic dust and meteoric debris (4) changes in the amount of heat transported by ocean currents due to fluctuations in the magnitude of the oceanic circulation (5) changes in the character of the earth's surface (distribution of land and sea orography extent of snow cover and others such as sea ice vegetative cover) changes in the inclination of the earth's axis of rotation changes in orbit or changes in planetary tidal forces

The last group of causes can be neglected so far as recent (historical) climatic change is concerned except perhaps in the local sense as described by J H Conover There is some evidence however that the first four groups of factors have had some bearing upon recent climatic fluctuations H Wexler indicates that rather significant climatic variations may have occurred in connection with variations in sunspot activity He substantiates this by comparing climatic data averaged for periods of greatest and least sunspot development In the longer term sense of course such climatic fluctuations will be cyclic in nature and will correspond in period to those observed for the sunspot cycle

With respect to causes (2) and (3) H Wexler has accumulated evidence tending to show that the world wide warming observed during the last half century can be attributed to two secular (nonperiodic) trends—increasing CO_2 content and decreasing atmospheric turbidity The first is probably brought about by increased industrial output of the products of combustion The second is considered by many as probably the result of a decrease in explosive type volcanic activity during the last 50 years These secular trends are of course superimposed upon the effects of the cyclic variation of solar radiation associated with the sunspot cycle

With respect to climatic changes resulting from fluctuations in the oceanic circulation some theoretical as well as recent empirical evidence indicates that the amount of heat advected into high latitudes by ocean currents may exhibit a periodic character (perhaps of the order of a decade) Such considerations are important if by such a mechanism we can account for relatively short term fluc

tuations in surface temperatures and particularly of the extent of surface ice of the polar seas M Ewing (1958) has considered the effects of the latter in attempting to account for the fluctuations of glacial with interglacial climate which apparently oc curred during the Pleistocene epoch [W C J]

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Climatic prediction

The estimation of the chances that specified cli matic conditions will obtain within a certain inter val in the future There are two basic contradictory postulates One assumes that there are no signifi cant secular trends or cyclic variations (beyond the annual cyclic period) This postulate underl es the estimation of climatic values required for the solu tion of many practical problems as in estimating expected rainfall intensities The problem is es sentially one of determining the distribution of the variable (Gaussian Poisson) and then of estimating the probability p after allowing for persistence *See* DISTRIBUTION (PROBABILITY) Where a secular trend or cyclic variation is postulated p must be modified through introduction of linear or curvi l near terms unless the form of the basic distribu tion is thought to change in which case entirely different expressions must be developed *See* CLI MATOLOGY [D I B]

Climatology

That branch of meteorology concerned with the physical state of the atmosphere during specified periods of time and within specified geographic areas In this definition specified geographic areas is the distinctive identifying phrase because it places primary emphasis upon physical conditions and processes in their geographic setting The climate of an area is the totality of the atmospheric cond tions of that area during a specified period of time with reference not only to the mean condi t ons but also to their variab lity

Climate on a global scale The entire earth is the primary geographic unit for consideration of cl matic processes and areal variations in climate because with areas of smaller size it is necessary to allow for the import (or export) of heat and moisture In contrast on a global scale the system is self contained because the net heat exchange be tween the atmosphere and outer space is essentially zero over a period of several years and there is no moisture exchange whatsoever

Two sets of factors determine the broad charac teristics of climatic regimes considered on a global scale (1) the size and shape of the earth coupled with the astronomic factors of earth rotation rela tive earth sun motions and the solar radiations and (2) the wholly terrestrial factors of atmospheric composition and extent the distribution of land and sea and the arrangement upon the lands of such gross physiographic features as major moun tain chains and plains areas

Solar illumination factors The size and shape of the earth together with the astronomic factors de termine the fundamental illumination and radia tion regimes—the regimes for an earth without atmosphere On an earth without atmosphere the illumination period and the incoming solar radia tion are wholly a function of the date and the latitude because there appear to be no significant variations in the output of total energy by the sun At the mean distance between earth and sun the incoming energy equals 1 94 g cal/(cm²) (min) for a surface normal to the incident rays This value is the solar constant which varies less than 1% from year to year As for the climatically rather negligible seasonal variations at perihelion (on about January 3 during the present century) 2 01 g cal are received at aphelion (about July 2) 1 88 *See* INSOLATION

Illumination periods are increased through the presence of an atmosphere A relatively small amount of the increase results from refraction which lengthens the period between sunrise and sunset By this means alone the daylight period is lengthened by a maximum amount of 7 min at the equator 23 min at 60° latitude and 8 days at the poles In addition and far more important the illumination period is lengthened by the scattering and diffuse reflection of light from the sun phe nomena that cause twilight Bright twilight suffi

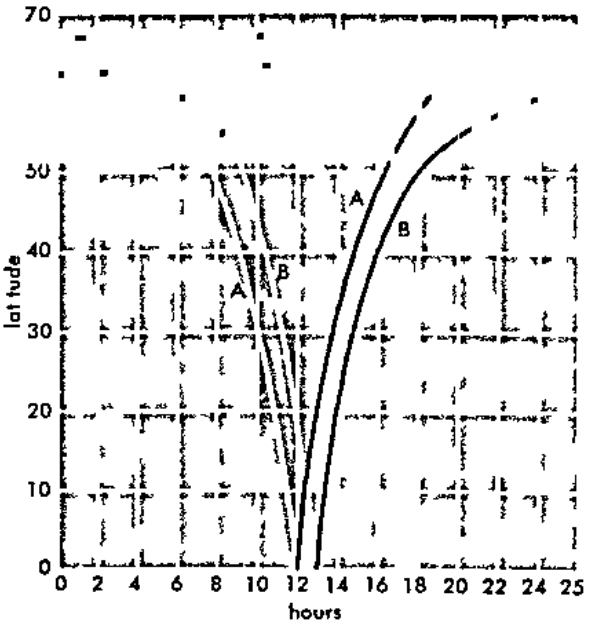


Fig 1 Illumination periods with and without an at mosphere A without an atmosphere B with an at mosphere and including periods of civil twilight

cient for normal outdoor activities corresponds with civil twilight At the poles civil twilight extends the longest daylight period by about 26 days beyond the 8 day extension caused solely by refraction Taking the two together because of the atmosphere the longest illumination period at the poles is not 6 months as it would be for an earth without atmosphere but 6 months and about 34 days Figure 1 shows corresponding relationships at latitudes 0–60° *See* GEOGRAPHY MATHEMATICAL METEOROLOGICAL OPTICS

Radiation and the earth's atmosphere The effects of the atmosphere on radiation relationships are even more pronounced Without the atmosphere incoming radiation would be distributed in an orderly manner, as a function of date and latitude (Fig 2) With the atmosphere, incoming radiation is reflected refracted scattered, and absorbed. Large atmospheric particles such as dust water droplets and ice crystals produce diffuse reflection Much smaller particles, such as molecules produce scattering that is inversely proportional to the fourth power of the wavelength of the radiation Ozone and water vapor are the chief absorbing substances with ozone absorption at wavelengths below 0 3 μ and water vapor absorption in several narrow bands between 0 7 and 1 9 and in two wide bands about 2 0 μ

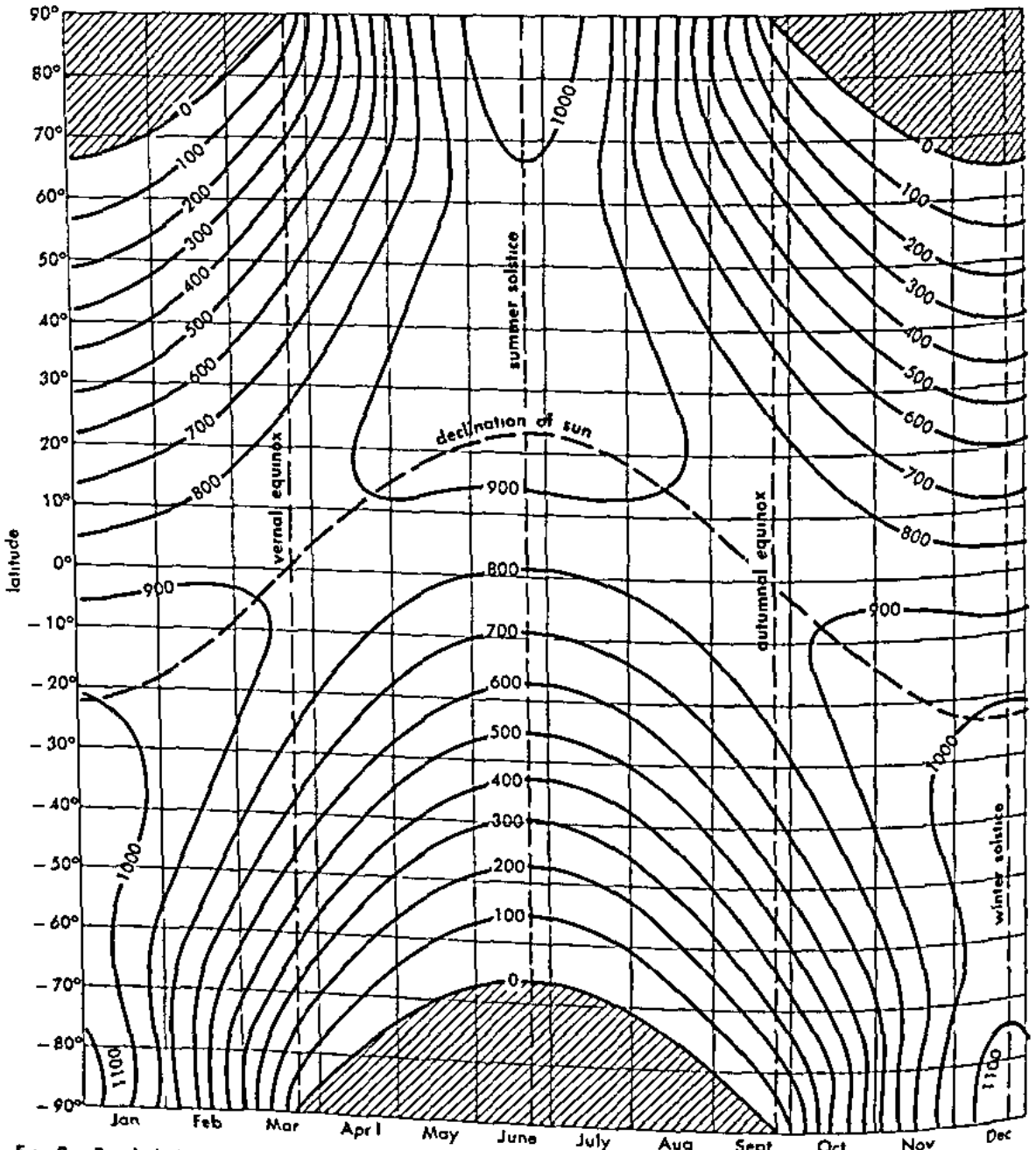


Fig 2 Total daily solar radiation for an earth without atmosphere The solid curves show total radiation per day, in g-cal/cm², on a horizontal surface (*After J B Leighly as given by R J List in Smithsonian Meteorological Tables*)

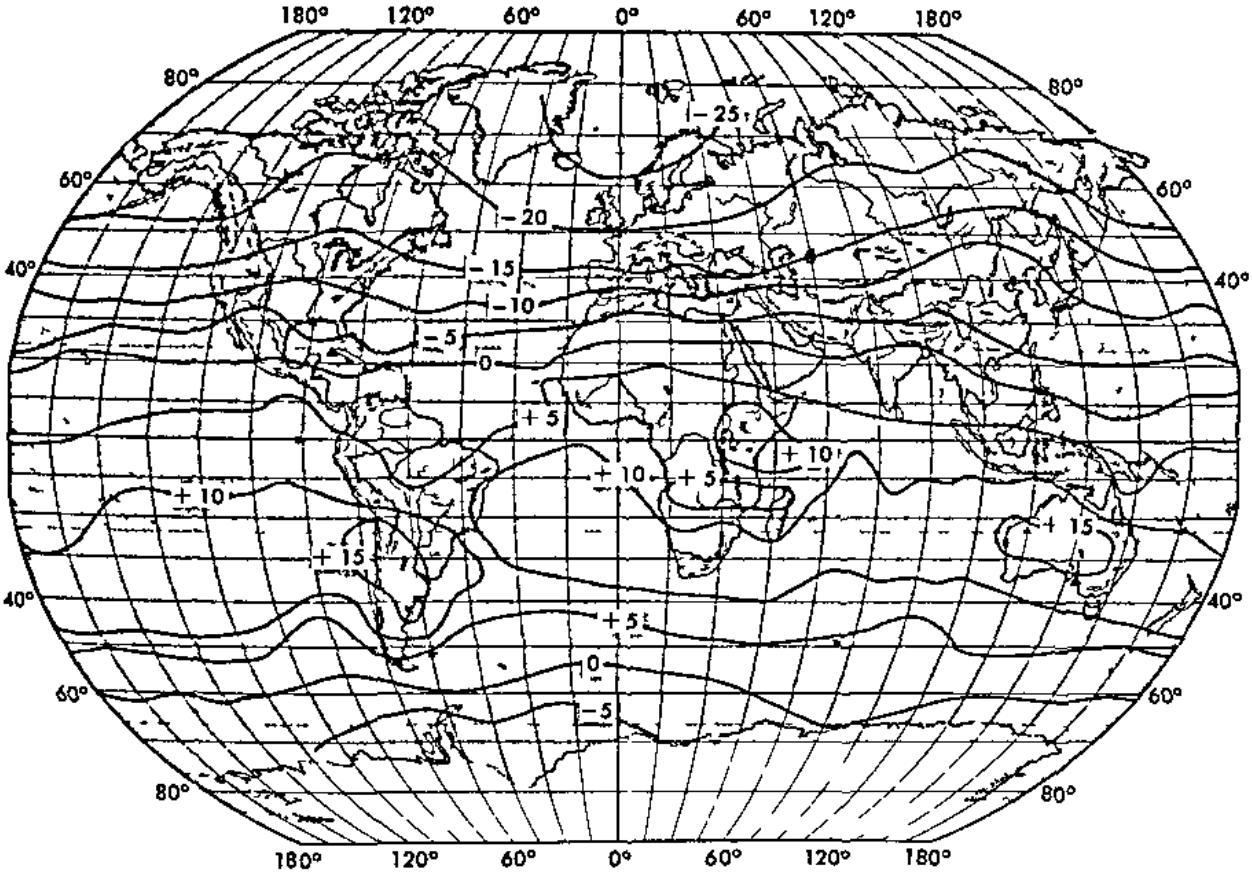


Fig 3 Net radiation over the earth, January Values in g cal/(cm²)(min) (*Modified after G C Simpson*)

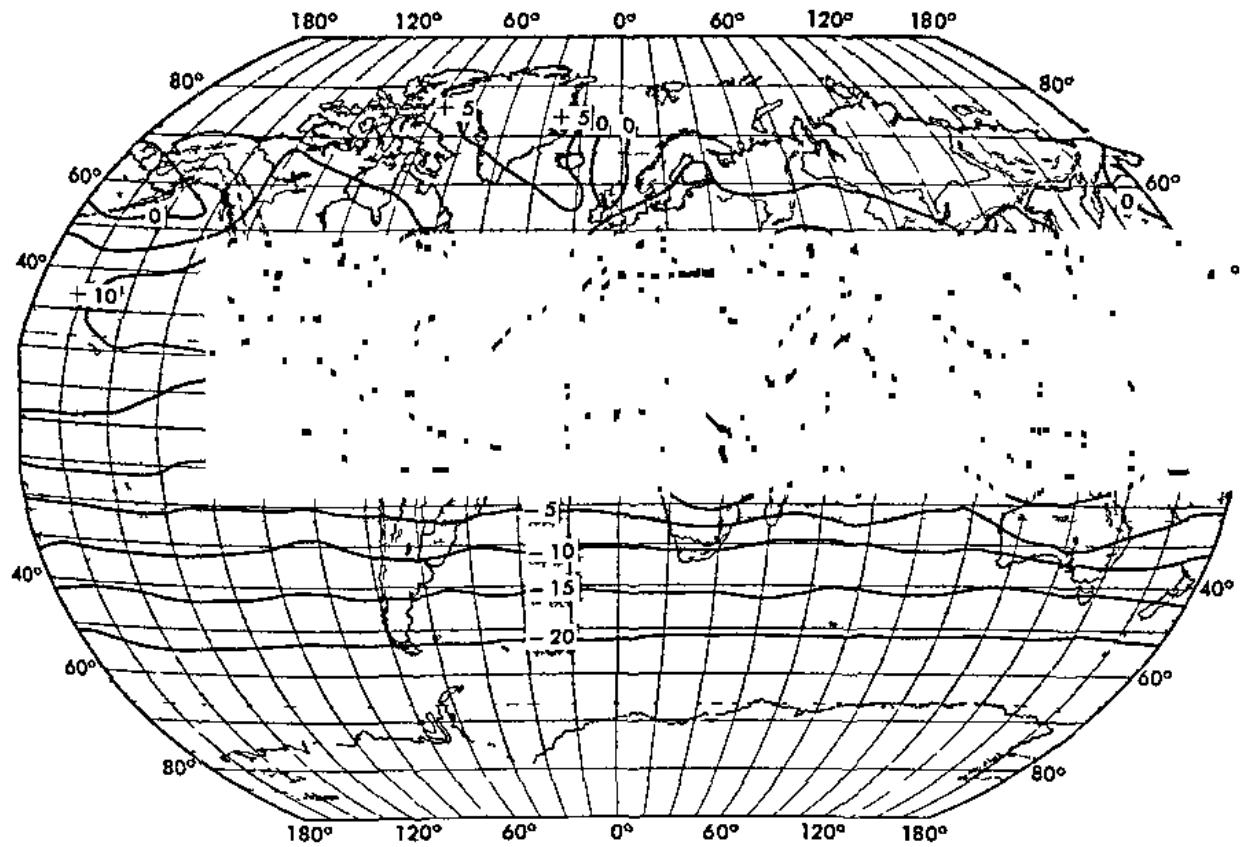


Fig 4 Net radiation over the earth, July Values in g cal/(cm²)(min) (*Modified after G C Simpson*)

On the average about 43% of the solar radiation that enters the atmosphere reaches the surface of the earth On clear days this value may exceed 80% on cloudy days it may be less than 30% In any instance the radiation reaching the earth's surface is partly reflected and partly absorbed Most land surfaces have an albedo (reflection coefficient) of 5–20% with the mean value about 12% Thus the land absorbs about 88% of the incident radiation A chief exception is a fresh snow surface with an albedo of about 80% (absorption 20%) Water has a mean albedo of 20% with values in excess of 80% when the sun is near the horizon and less than 2% when the sun's altitude is more than 50°

The earth itself radiates energy at long wavelengths in the infrared Atmospheric absorption of this terrestrial radiation is mainly by gaseous and liquid water (above 3 μ) and by carbon dioxide (13–18 μ) These substances themselves radiate transferring energy not only upward to space but also downward back to earth This is one of many complicating factors in the flux of radiation between earth and space *See* GREENHOUSE EFFECT TERRESTRIAL RADIATION TERRESTRIAL

Despite complexities G C Simpson was able to estimate how net radiation varies on a broad scale across the earth His maps for January and July are shown in Figs 3 and 4 The most significant features of these maps are that even in summer the areas of greatest net radiation gain lie equatorward of 40° (usually at less than 30°) that the areas of greatest gain are over the lands (in or adjacent to the dry air regions) and that the great net losses are in high latitudes over the oceans

Land and sea surface influences The climatic significance of the distribution of land and sea lies in the contrast between these two major kinds of surfaces regarding heating and cooling Except in regions of snow cover or inland water bodies the lands are heated to higher temperatures than are the seas both diurnally during the daytime and seasonally during the summer Oppositely during the nighttime and during the winter the lands are cooled to lower temperatures than are the seas As a direct result both diurnal and annual temperature ranges are greater over the land than over the sea *See* CONTINENTALITY WEATHER AND CLIMATE MARINE INFLUENCE ON WEATHER AND CLIMATE

The distribution of land and sea by 5° latitude zones is shown in Fig 5 The importance of this factor is evident from the companion curves showing mean temperatures by latitude circles between 70°N and 70°S for January and for July Note for example that the January temperature is 19°F at 50°N where land occupies more than half the latitude circle, and it is 38° in the corresponding month of July at 50°S where there is virtually no land

Land-sea distribution and the distribution of radiation are two of the three major factors that determine the broad features of the distribution of temperature The third factor is the circulation of the atmosphere and of the oceans In the mean both circulations transfer energy from lower to higher latitudes Of the transport, 85% is by the atmospheric circulation which carries energy both in the form of sensible heat and latent heat (as water vapor that will give up heat upon condensing) The high latitude regions of great net radiation loss (Figs 3 and 4) are in large part fed by energy derived from latent heat Of the transport, another 15% is accomplished through the circulation of ocean waters with warm water moving poleward along the western sides of the oceans and cool water moving equatorward along the eastern sides (*see* OCEAN CURRENTS, WIND) This circulation is reflected in the mean temperature maps for January and July (Figs 6 and 7), as in the northward bulge of the isotherms in the Iceland Spitsbergen Norway area Other notable features of these maps are the location of the cold poles in the interior of the great land masses and the displacement of the warmest zone northward from the equator a displacement associated with the great land mass of Africa in latitudes 10–30°N

Relations with air pressure and wind The global distribution of temperature is related to the distribution of surface air pressure and of wind (Figs 8 and 9) These relationships are neither simple nor direct but there tends to be an inverse relationship between mean temperature and mean surface pressure over the continents with the hot desert areas sustaining thermal lows and the cold polar areas sustaining thermal highs The mean low and high pressure areas over the oceans are quite different In the first instance they represent the summation of moving dynamic lows (extratropical cyclones) which are particularly common synoptic features in the Aleutian and Icelandic areas as well as in the waters north of Antarctica In the second instance they represent the summation of subtropical high cells which are persistent synoptic circulation features over the subtropical oceans, even though they vary continuously in size intensity, and location *See* AIR PRESSURE, ATMOSPHERIC HIGH ATMOSPHERIC LOW METEOROLOGY WIND

The mean pressure patterns are approximately matched by the patterns of dominant windflow The most constant winds are those of the trades which lie on the equatorward side of the subtropical oceanic highs and those of the monsoon circulation in the Asiatic Australian area In this great monsoon circulation winds blow outward from Asia and inward onto Australia during the Northern Hemisphere winter with a reversal of the circulation during the summer Other major wind flow regions are those of the westerlies to poleward of the oceanic highs and of the polar easterlies off Antarctica and Greenland Neither the westerlies nor the polar easterlies are as constant as the trades or the major monsoon winds because both

occur in areas that are frequently the scene of moving cyclones, which may bring winds from any direction

Marine atmospheric influences Air that moves long distances across the oceans acquires great quantities of moisture through evaporation from the ocean surface Because evaporation is greatest where cold dry air moves across much warmer ocean water, the most rapid flux of moisture from sea to air occurs on the western sides of the northern oceans in middle latitudes during the winter season, and over the waters off Antarctica during winter For example, at 35°N in the western Atlantic an average of about 600 g cal/(cm²) (day) of thermal energy is expended for evaporation of sea water In contrast at latitudes 0–20°N in the eastern Atlantic the value does not exceed 200 g cal during any season

Whatever the variations in detail the oceans everywhere make a large net contribution of water to the air (except when there is ice) Subsequently this moisture is carried onto the land by maritime

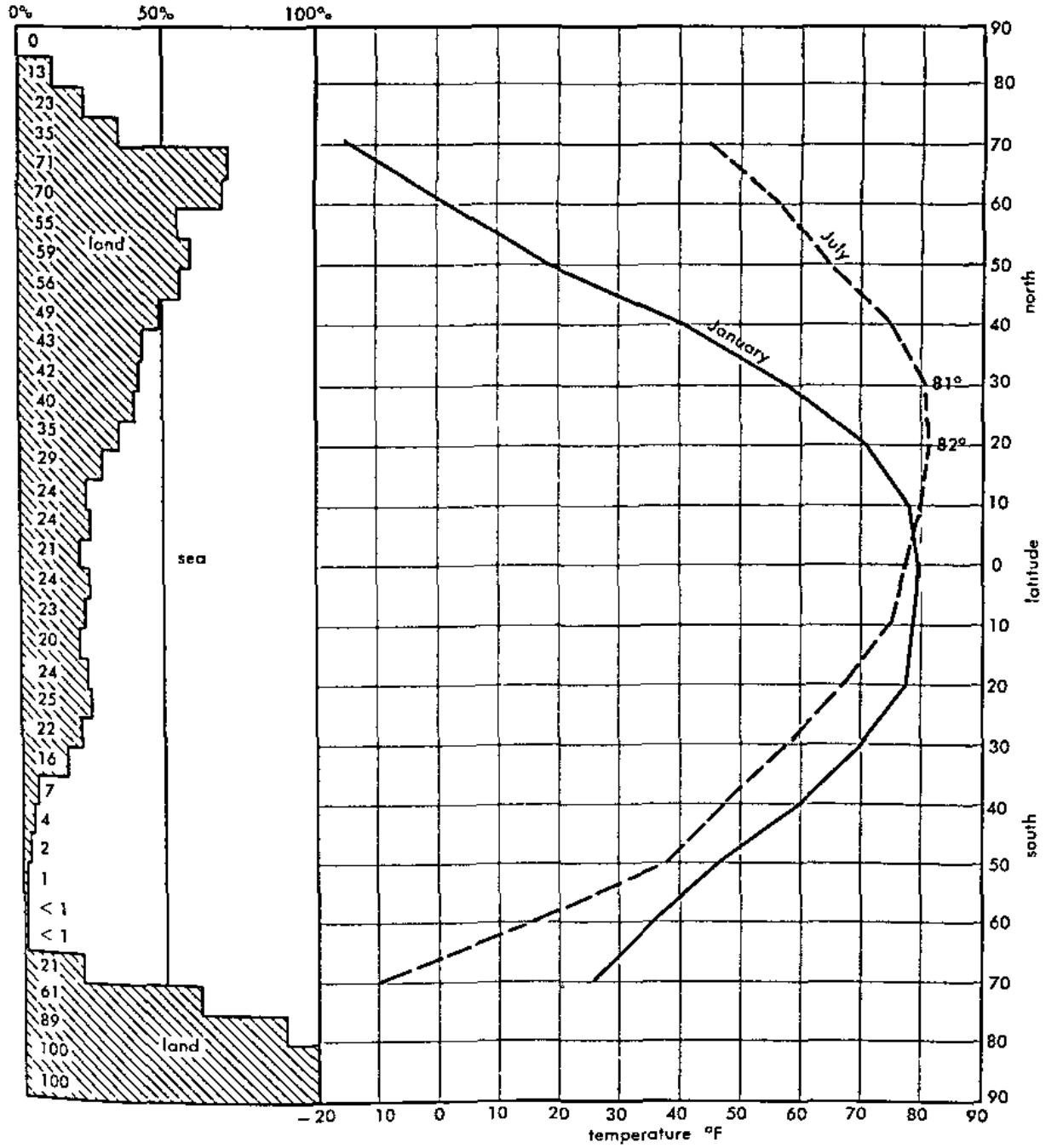


Fig 5 Land-sea distribution and mean January and July temperatures by latitudes (*Land sea percentages after E Kossinna temperatures after J Hann*)

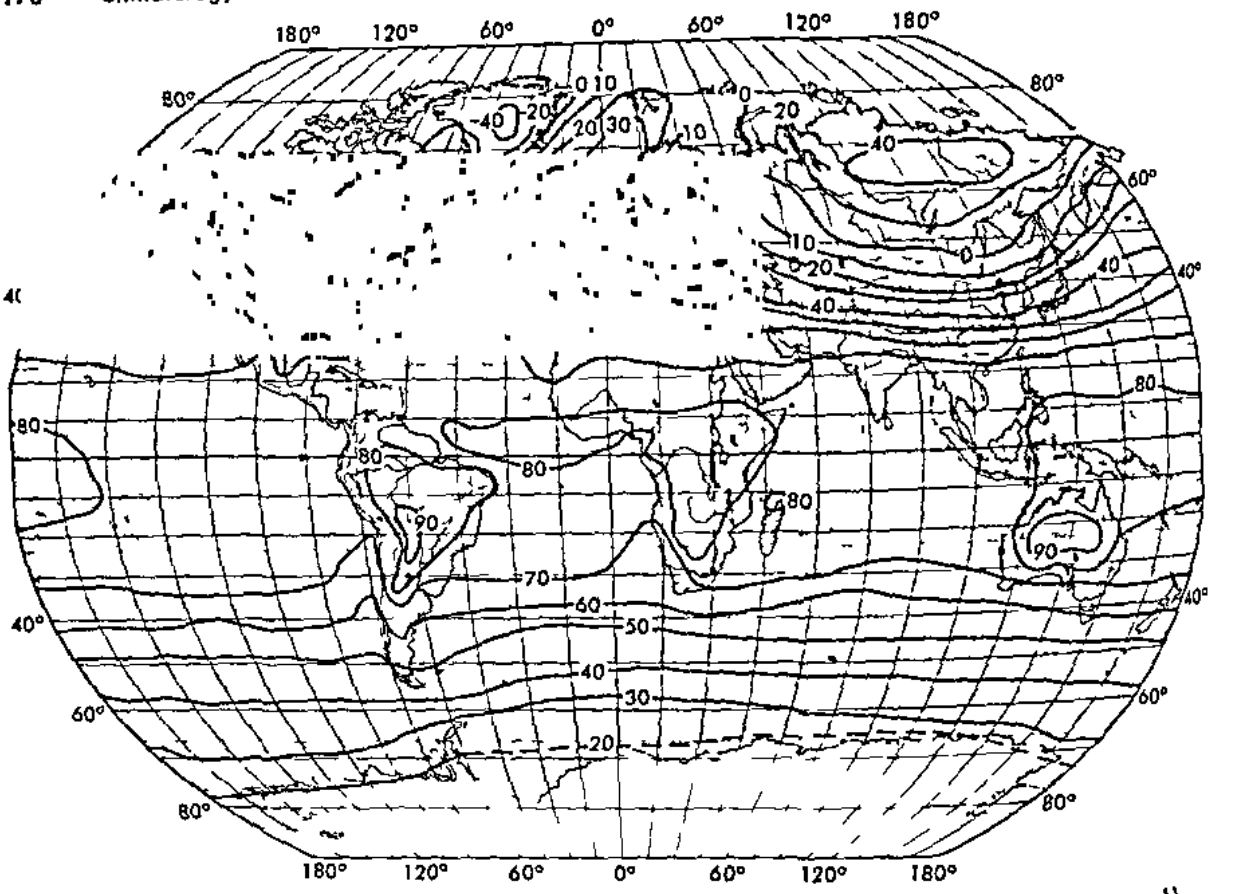


Fig 6 Mean sea level temperatures °F January (*Modified from Sir Napier Shaw, H E Landsberg, et al*)

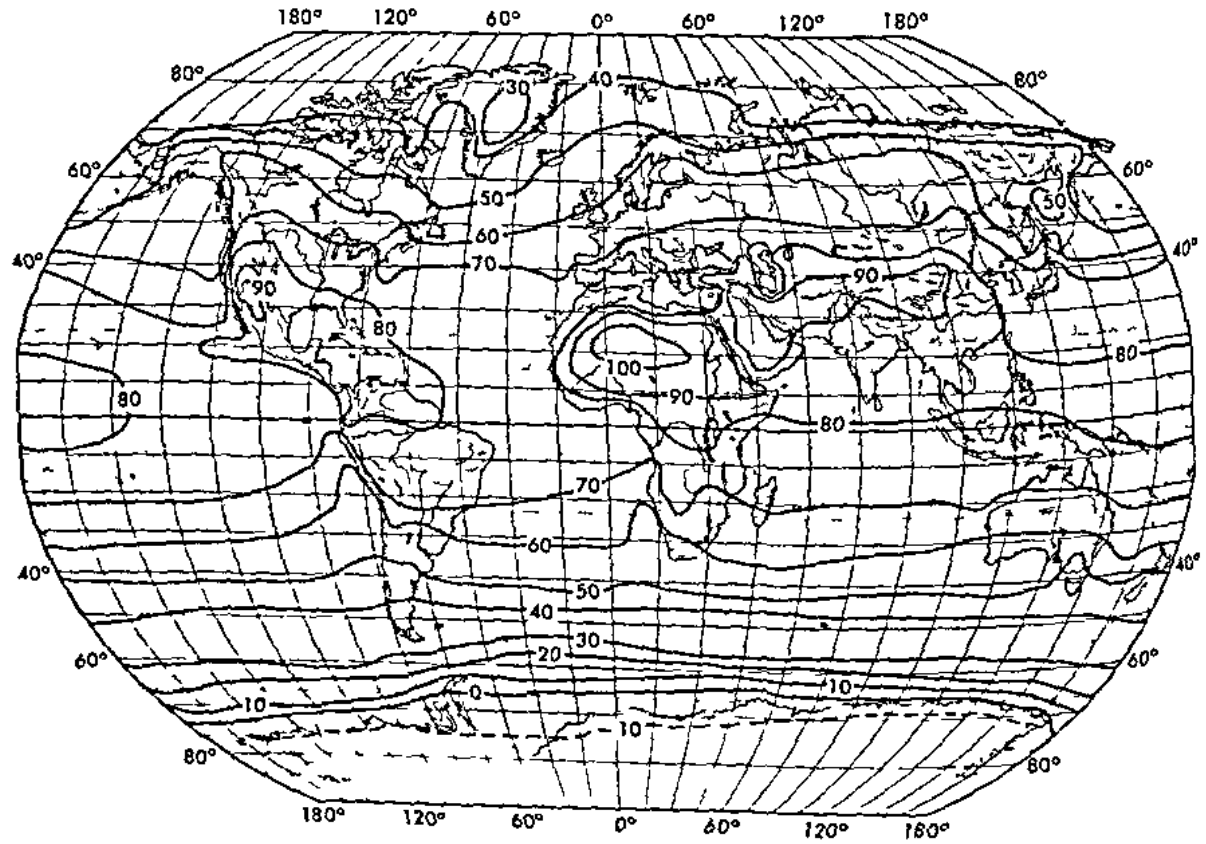


Fig 7 Mean sea level temperatures °F, July (*Modified from Sir Napier Shaw, H E Landsberg, et al*)

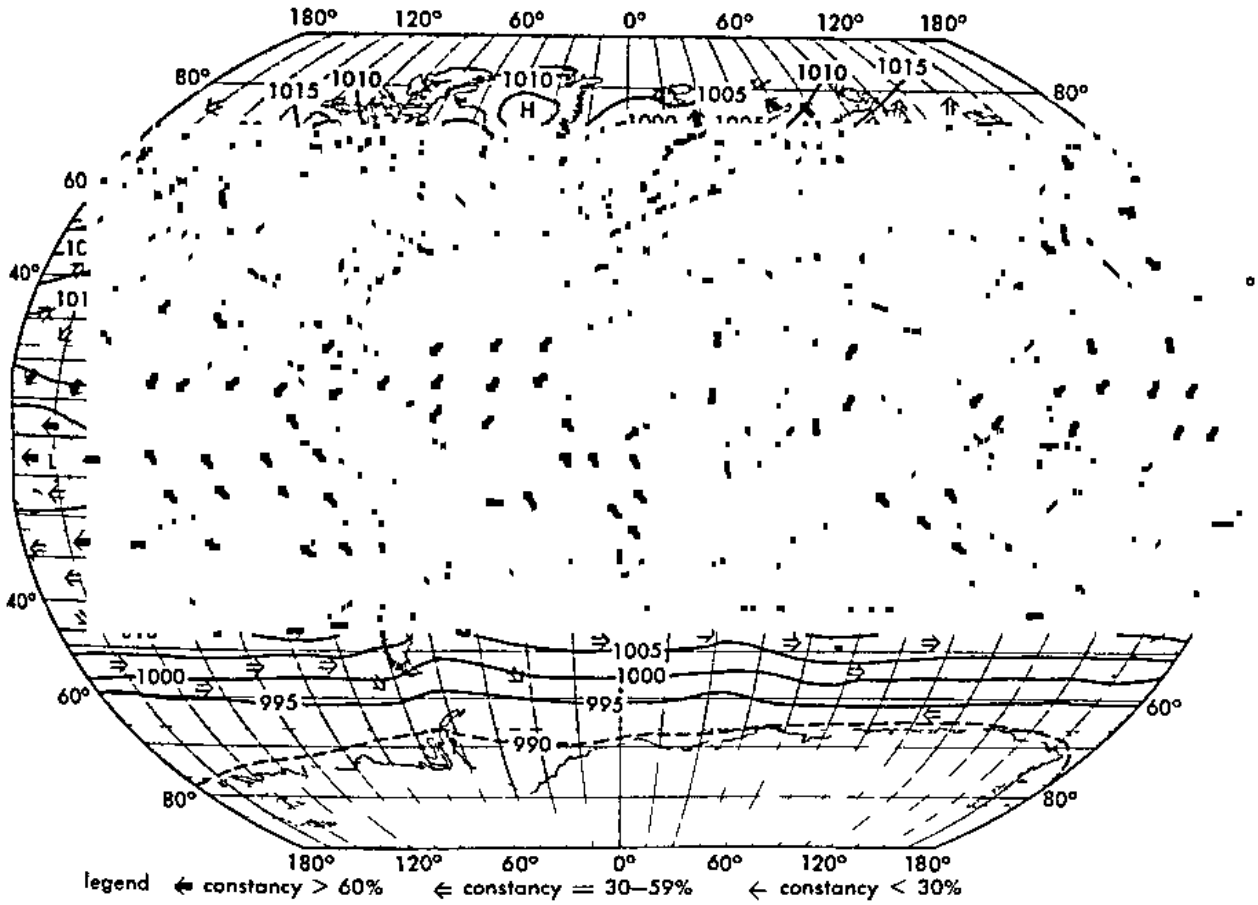


Fig 8 Mean surface air pressure and surface winds January Pressures are in millibars wind constancy indicated by type of arrow Wind directions are shown to nearest eight compass points E W directions true with reference to parallels and other directions true with reference to meridians (*Modified from McDonald Shaw, Landsberg, and others*)

air masses and there it is partly precipitated as rain snow, hail, dew, or frost Thereafter the water returns to the oceans in streams, as sheet wash along the margins of the lands as underground water or in moving air (chiefly dry continental air) that acquires water from the land through evaporation and transpiration This world wide water cycle is diagrammed in Fig 10 *See* HYDROLOGY

Continental precipitation patterns Figure 11 shows the mean annual precipitation over the continents Appreciable precipitation occurs only when moist air is forced to rise and this takes place largely through convection, through orographic lifting (the forced lifting of air upslope, as up the flanks of a mountain) or through convergence and the forced ascent of air within an eddy, particularly within an extratropical or tropical cyclone Hence the precipitation patterns of Fig 11 can be viewed in terms of the relative frequency with which moist maritime air is present and the frequency with which the air is forced to rise to appreciable heights The vertical structure of the air with reference to temperature and moisture is also important, because the structure may be stable and so resist vertical movement or it may be conditionally unstable, so that when forced lifting has produced condensation, the release of latent heat causes the air to rise to still greater heights

Annual precipitation is very high on the west coasts of the continents in high middle latitudes, in the major monsoon areas, and in equatorial areas On the west coasts of the continents the high totals are associated with frequent and prolonged cyclonic precipitation and with the orographic lifting of maritime air In these areas most of the precipitation is in the winter half year, when cyclonic storms are most common In contrast, the monsoon areas have their maximum rains during summer with an influx of very moist, conditionally unstable air Here as in the wet equatorial areas the rainfall mechanisms are convection orographic lifting and convergence in minor eddy systems However, in the equatorial areas the rainfall is fairly well distributed throughout the year

The extremely dry areas are characterized by infrequent invasions of moist unstable air and relatively little cyclonic activity These dry areas are the west coast deserts such as the Sahara, the desert basins that are shielded from fresh maritime air by high mountains such as the Tarim Basin, and the polar lands *See* BASIN

In absolute terms the widest swings in annual precipitation from year to year occur in the wettest areas of the monsoon and the equatorial

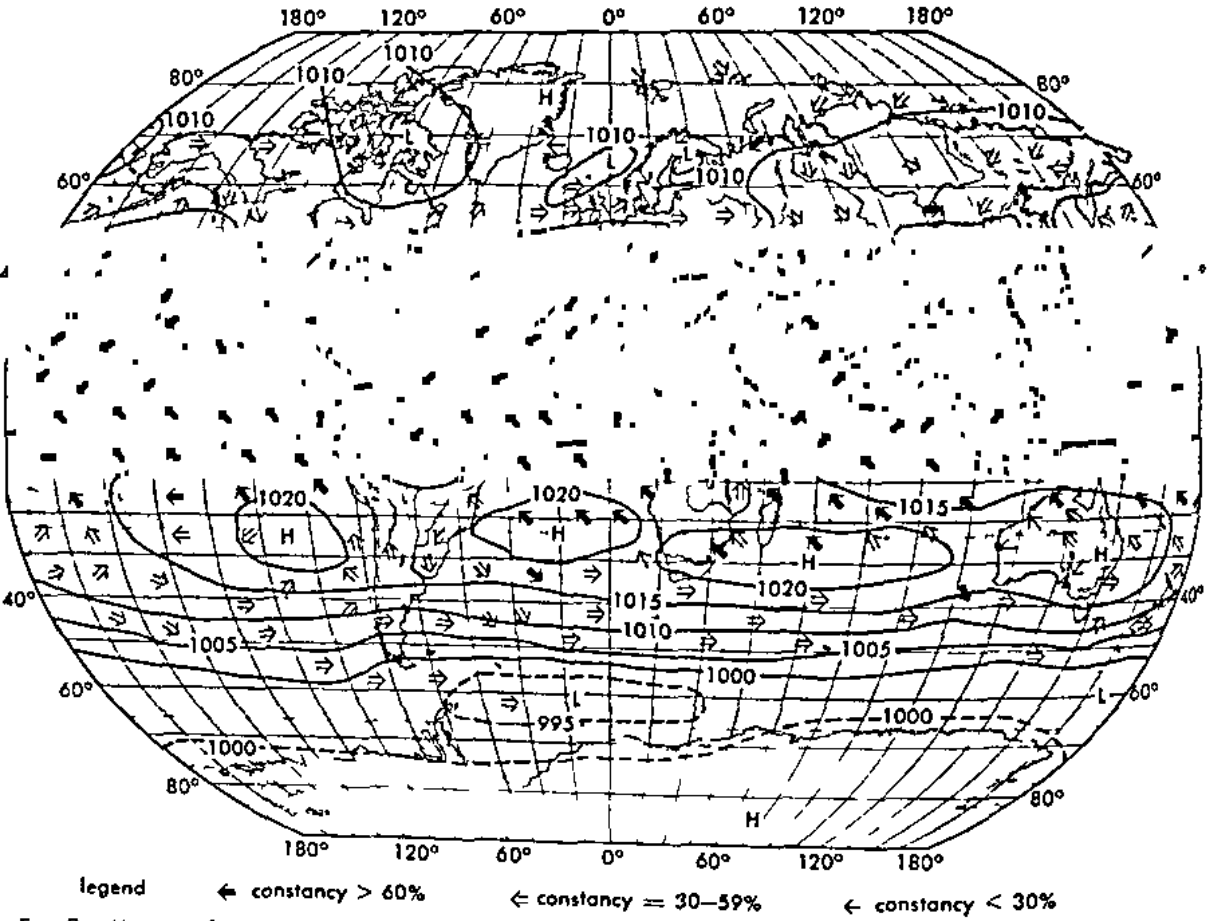


Fig 9 Mean surface air pressure and surface winds, July Pressures are in millibars wind constancy indicated by type of arrow Wind directions are shown to nearest eight compass points E W directions true with reference to parallels and other directions true with reference to meridians *(Modified from McDonald Shaw, Landsberg and others)*

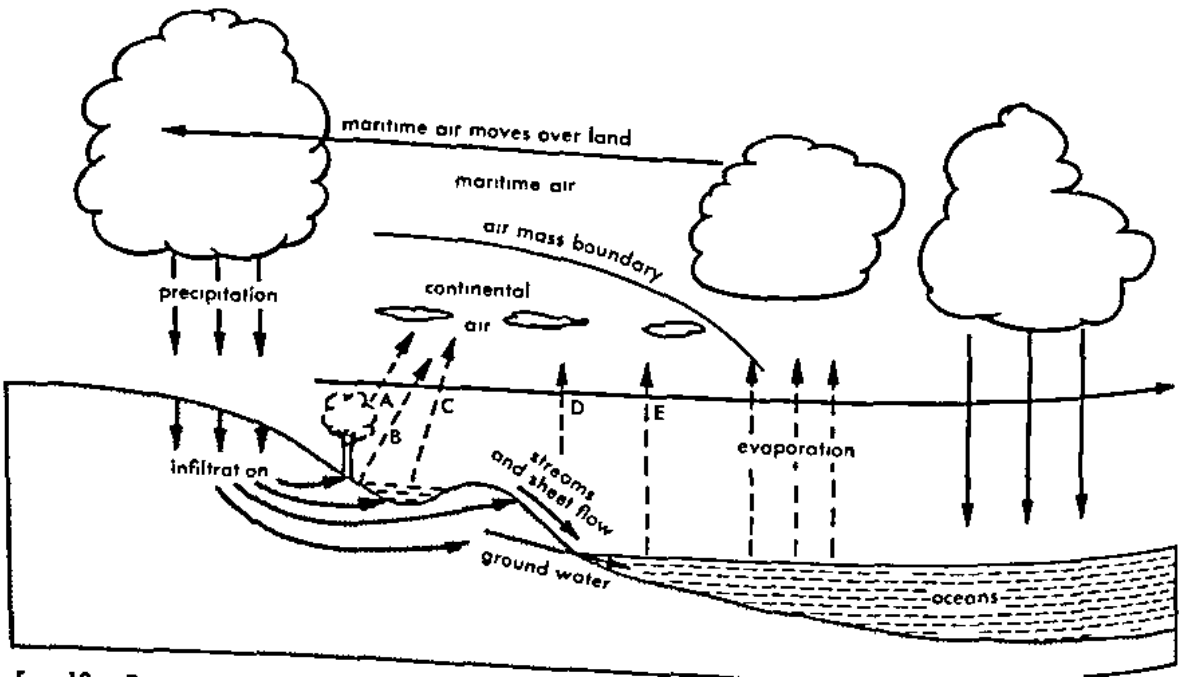


Fig 10 Diagrammatic portrayal of the hydrologic cycle Water returns chiefly to dry continental air through transpiration (A), evaporation from soil (B), lakes and ponds (C), and streams (D) Continental air moves over ocean to become more moist (E) with subsequent conversion to maritime air with precipitation over the oceans *(Adapted from B Holzman)*

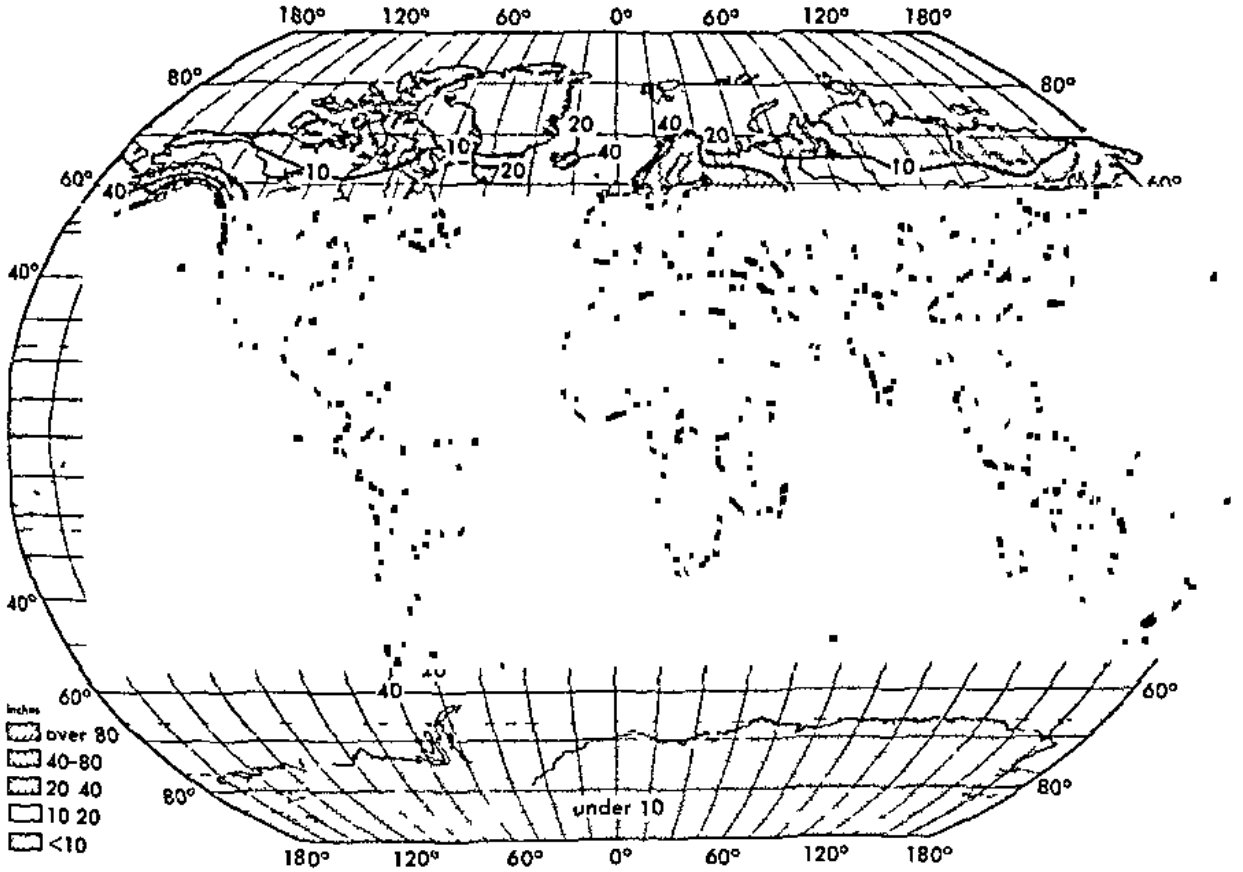


Fig 11 Mean annual precipitation on continents and major islands

Principal quantitative definitions of major climatic regions[a]

Symbol	Name of region	Mean temperature °F	Precipitation	
			Main season	Amount formula for inches[b]
Af	Tropical rainforest	>64 4[c]	All	Driest month >2 4 Annual >40
Aw	Tropical savanna	>64 4[c]	Summer	Driest month <2 4 Annual >40
BW	Desert		Winter	Annual <0 22t − 7
			Summer	Annual <0 22t − 1 5
			Even	Annual <0 22t − 4 25
BS	Steppe		Winter	Annual <0 44t − 14
			Summer	Annual <0 44t − 3
			Even	Annual <0 44t − 8 5
Cf	Humid mesothermal	<64 4 > 26 6[c]	Even	Annual >0 44t − 8 5
Cw	Humid mesothermal winter dry	<64 4 > 26 6[c]	Summer	Annual >0 44t − 3
Cs	Humid mesothermal summer dry	<64 4 > 26 6[c]	Winter	Annual >0 44t − 14
Df	Humid microthermal	<26 6[c] > 50[d]	Even	Annual >0 44t − 8 5
Dw	Humid microthermal, winter dry	26 6[c] > 50[d]	Summer	Annual >0 44t − 3
ET	Tundra	<50 > 32[d]		
EF	Perpetual frost	<32[d]		

[a] After W t artha, *An Introduction to Climate* McGraw-Hill 3d ed , 1954
A]erg

which is mean value) Precipitation values are in inches

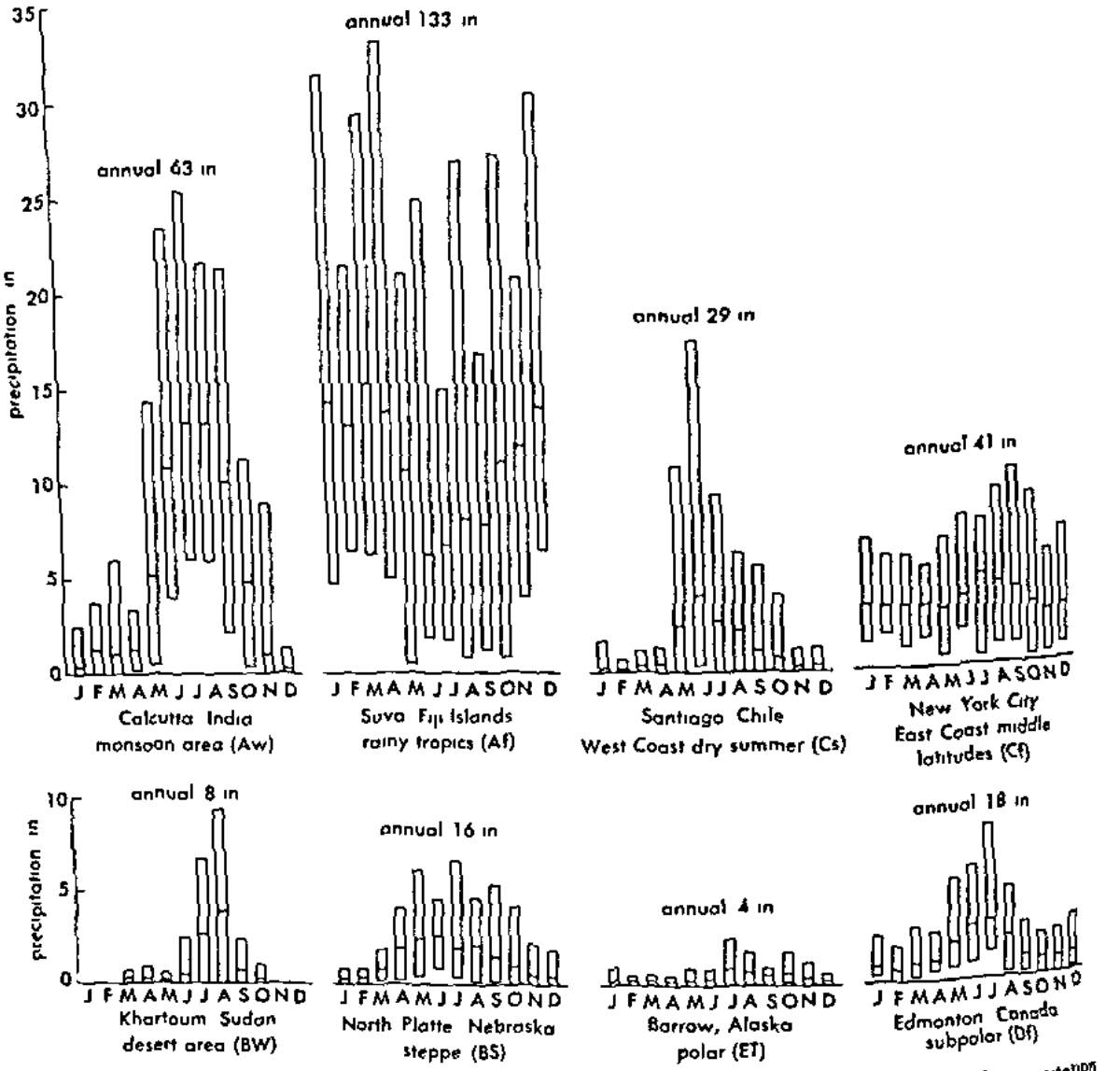


Fig 12 Mean annual precipitation, with mean and extreme monthly precipitation bar graphs, at selected stations Top of each bar shows extreme high value bottom of each bar extreme low value mean indicated by horizontal line within each bar A dash only at zero level indicates no recorded precipitation Letter symbols according to Koeppen type of climate (*Based on 19–20 yr data for 1921–1940, World Weather Records, Smithsonian Miscellaneous Collections*)

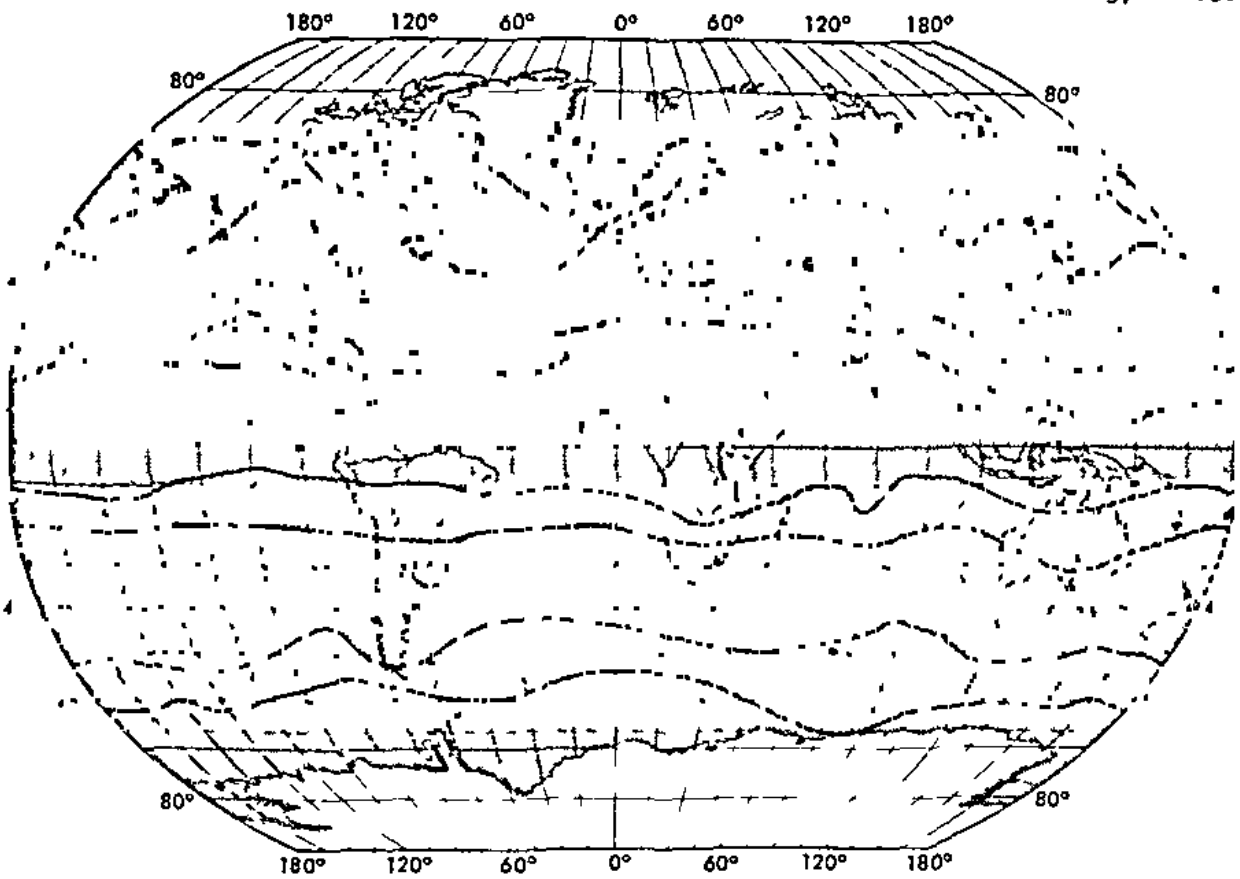
In these regions it is not uncommon during a 20-year period for the annual rainfall to range from a minimum of 60–80 in to a maximum of 200–300 in In percentage terms, the greatest variability is in the driest areas—the deserts and dry polar regions Here the minimum is less than 2 in in many localities with maximum annual amounts reaching 15 in or more in so-called wet years

The water circumstance of a locality is not only a function of the annual precipitation and its variability but even more of the distribution of precipitation throughout the year Figure 12 shows the seasonal precipitation regimes at eight selected localities Also shown are the extreme monthly precipitation amounts during the 20-year period covered by the graphs The general form of these graphs is in each instance broadly representative of the precipitation regime throughout the regions specified in the diagrams The variability as shown by the extreme values is typical

Climatic regions. An infinite number of schemes is available for the definition of climatic regions. These schemes fall into two classes, those intended to bring out one or another aspect of relationships [illegible] and those in- tween areal irresponding variations in phenomena related to climate

Fig 13 Major net radiation regions of the earth (*Modified from G C Simpson*)

Fig 14 Major climatic regions of the world according to Koeppen classification Except in Tibetan area high mountain effects (including ET or EF) are not shown For principal definitions of types, see table



net gain of total radiation in all months

net gain in most months net loss no greater than 5 g-cal (cm²)(min) in any month

wide variations, with net monthly gains and net monthly losses both exceeding 5 g-cal (cm²)(min)

net loss in most months net gain no greater than 5 g-cal (cm²)(min) in any month

net loss in all months

Fig 13

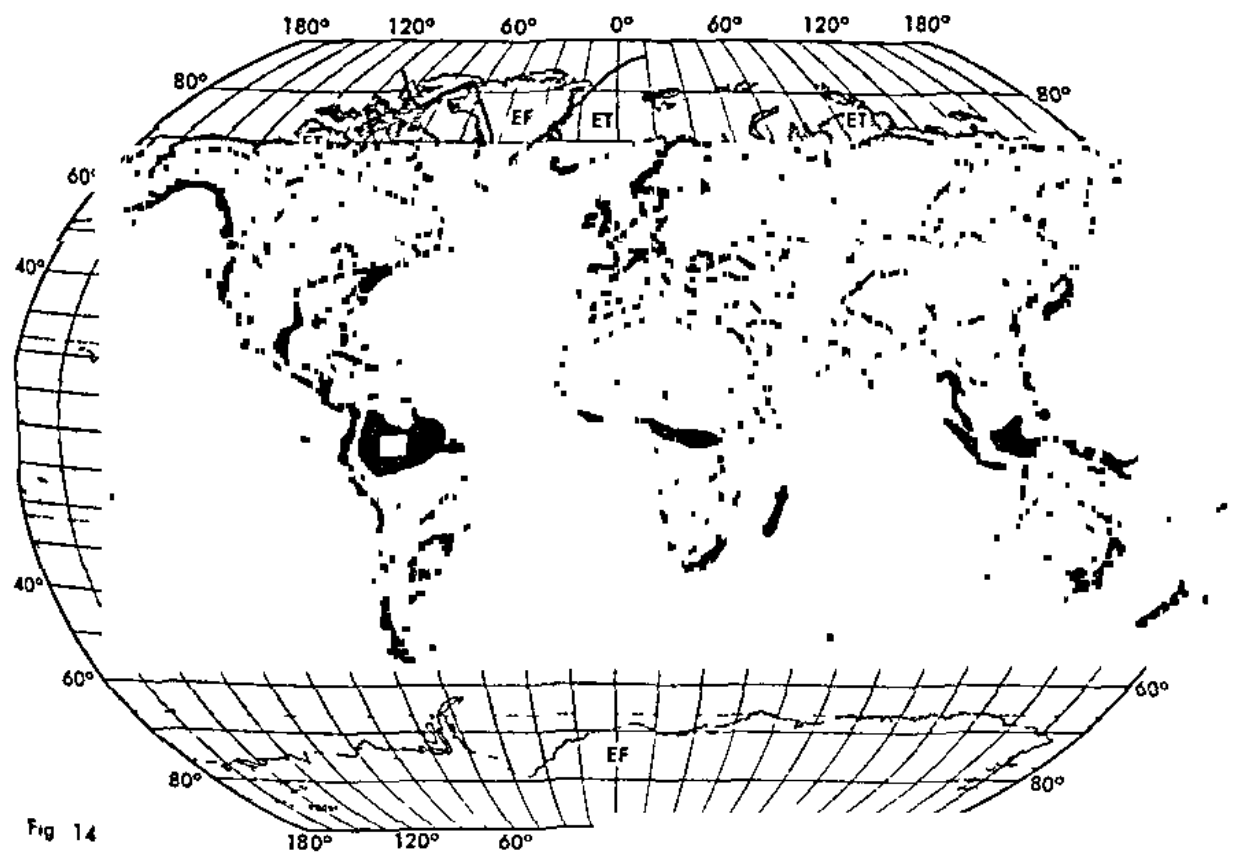


Fig 14

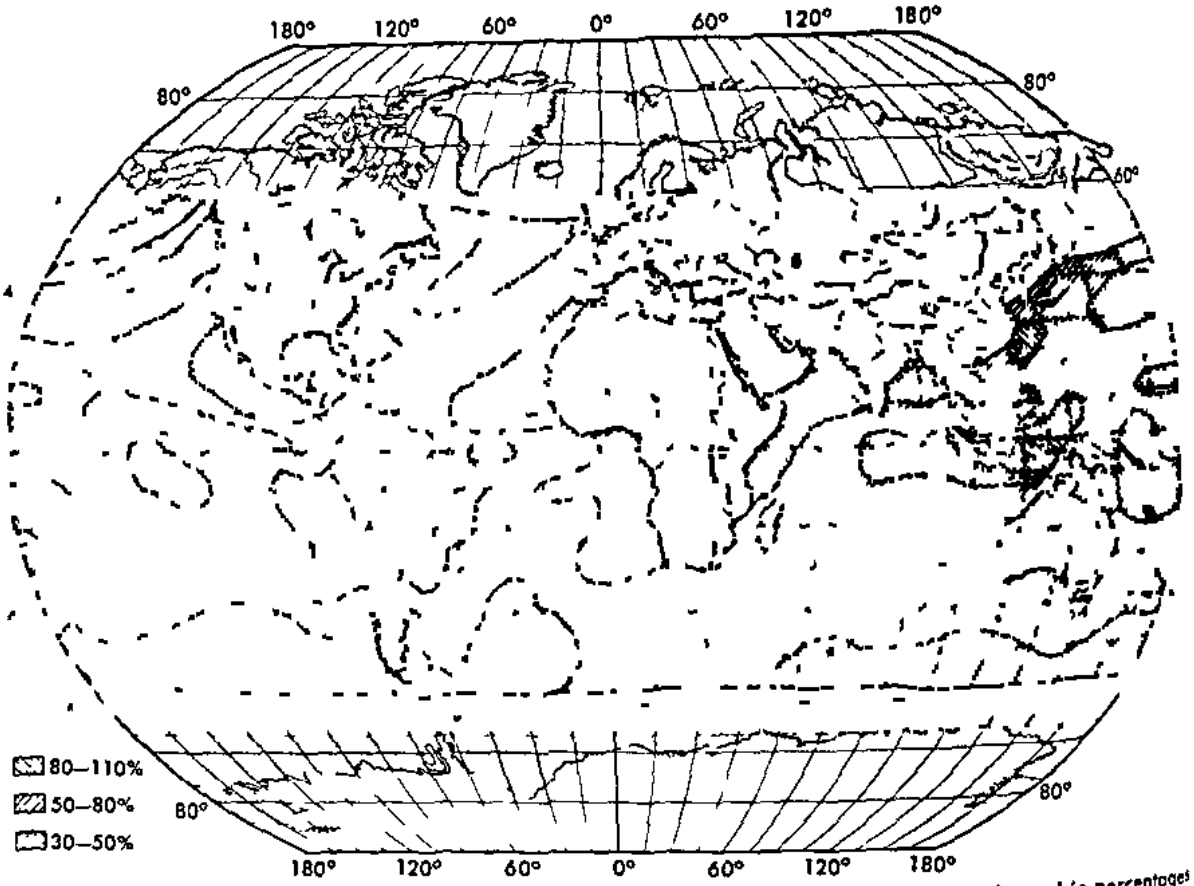


Fig 15 Climatic regions for fresh water supply on the oceans December–February How well climatic conditions meet requirements of rainfall and sunshine as related to use of solar stills is indicated in percentages (*After W C Jacobs*)

The first class of schemes is represented by Fig 13 which shows the major radiation regions of the earth The distinction is among regions in which the monthly radiation balance is always positive (in the mean) always negative never strongly positive never strongly negative or highly variable and ranging from strongly positive to strongly negative

The second class of schemes is represented by Figs 14 and 15 Figure 14 shows the major climatic regions of the earth according to W Koeppen's classification (contrast with Fig 13) This Koeppen classification was intended to bring out the general coincidence between the distribution of natural vegetative formations and climatic conditions It also serves however as a useful classification for purposes of general description in terms of quantitative definitions of precipitation and temperature conditions The major aspects of Koeppen's classification scheme are summarized in the table whose arrangement is taken from H E Landsberg Koeppen and his followers revised his classification twice and carried it beyond the broad scheme given here For example cold and hot deserts were distinguished isothermal regions (mean annual temperature range less than 9°F) were identified and subregions where fog was common were designated Clearly a climatic classification scheme such as this could be extended in any desired way to show areal variations in greater and greater detail

Quite different from Koeppen's scheme is that represented by Fig 15 This is a classification developed to solve a particular problem in applied climatology that of designing life rafts for use at sea The regions were defined primarily through consideration of the rainfall probabilities and the effective sunshine the latter being related to the efficiency of portable solar stills In applied climatology special classifications of these kinds are often useful

It is feasible and instructive to distinguish minor climatic regions not on a global scale but within much smaller areas Where such regions are defined upon the lands the topographic factor becomes very important This is especially true where the area is of the order of a few square miles or less. [D I B]

See MICROMETEOROLOGY

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Climax community

A particular grouping of natural populations of plants and animals In any local region the biota (group of living organisms) become sorted into a variety of combinations or communities according

to the local variations in environmental factors The relatively stable combination community which occurs on the most mesophytic sites is termed the climax community of the region (*see* COMMUNITY CLASSIFICATIONS) It commonly contains the most shade-tolerant plants of the area and those with the fewest adaptations to extreme conditions of moisture temperature, and nutrient supply From a dynamic standpoint the climax community is in a biological steady state such that time variations in its average composition occur about a mean The capture and utilization of energy is presumed to be at a higher level than in any other community of the region in the sense that more kinds of organisms both plant and animal participate in the gradual degradation of the original stored material The climax community is the end product or terminus of a series of successional or developmental changes that occurs on mesic sites (*see* SUCCESSION ECOLOGICAL) Its practical importance largely stems from this fact Land managers and others interested in natural landscapes can be guided in their management techniques by a knowledge of potential end points and the conditions that obtain within them

Kinds of climax The major controlling factor of the climax community just described is the climate since all other environmental factors are assumed to be medium for the region This climatic climax is the only one recognized by some investigators, who are thus adherents of the monoclimax hypothesis Other workers extend the term climax to any community of the region which is reasonably stable in apparent equilibrium with the environment, and which shows no evidence portending future changes in composition They are adherents of the polyclimax hypothesis which holds that soils topography fire animal interactions or other environmental factors in addition to climate may exert primary control over a biotic community and that the stable end products of such control are fully worthy of recognition as climaxes In most cases the climatic climax is an important factor in elucidating the active controlling agents of nonclimatically determined communities

Monoclimax (climatic climax) The greatest amount of information about the nature of the climax community has been gathered in the summer green temperate forests of the world The concept may have its greatest meaning in that region although it probably is important also in the forested tropics The attributes of climax are less apparent in the major grasslands savannas and subarctic conifer forests of the world and become hazy or nonexistent in deserts and arctic tundras where the idea of medium or mesic environment is difficult to apply

In the summergreen temperate forest a rather definite set of micro-environmental conditions exists within the climax stands for which the herbaceous plants and the seedlings of the trees possess distinct adaptations Perhaps the most important microclimatic factor is the low internal light intensity during the summer Light values near the forest floor are usually less than 1% of the intensity of full sunlight due to the dense leaf cover of the canopy of the dominant trees Few plants are able to endure such low light conditions but the few species with the ability (which include the seedlings of the climax trees) necessarily have a very low compensation point (*see* PHOTOSYNTHESIS) They have also a high chlorophyll content (8–10 micrograms per milligram of dry weight) relative to that in more open communities (2–4 micrograms per milligram of dry weight) and this chlorophyll is present in a chemical complex that makes it sensitive to photodestruction The environmental supply of moisture within the forest in the summer season is adequate for plant growth and above all is uniform due to reduced air turbulence reduced evapotranspirational loss and good internal soil drainage (*see* PLANT WATER RELATIONS OF) The plants tend to have a low osmotic pressure in their cell sap (usually less than 10 atm) They exist in a fully distended or turgid condition but the loss of as little as 3% of their original water content causes them to wilt

Many of the herbaceous species in the climatic climax community are unable to grow under the low light conditions prevailing during the summer They have developed adaptations which enable them to complete most or all of their life cycle in early spring before the leaves appear on the overhead trees They do this by very rapid growth supported by extensive food reserves in underground bulbs corms tubers or fleshy rhizomes, and by the simple rapid elongation and enlargement of flower buds which were formed during the preceding summer Their leaves commonly die down and disappear shortly after the tree canopy is complete and for this reason they are called spring ephemerals

Few of the plants of the climatic climax forest have seeds which are dispersed by mammals but many species have adaptations for transport of seeds by ants Plants with wind pollinated flowers are rare but insect pollinated flowers are common There are few burrowing mammals and hence little mass mechanical disturbance of the soil but the earthworm populations are high The latter plus many other types of soil fauna and large numbers of fleshy fungi lead to a rapid decay of leaf litter and an extensive incorporation of organic matter into the top layer of the mineral soil forming a rich mull humus This incorporation produces excellent water retaining capacities in the soil and also leads to a relatively high level of available nutrients

Polyclimax All of the plant communities of a region must be able to tolerate the full range of climate affecting that region but they may be influenced by many factors other than climate In some cases these other influences may be of a temporary nature subject to change by activities of the community itself as for example the improvement of soil through incorporation of organic matter the increase in atmospheric moisture and decrease in light through the development of a shield in forests or the decrease in depth of

and swamps through biotically influenced sedimentation or increased transpiration In such instances the communities present give internal evidence of the changes by obvious instability in species composition In other cases however the nonclimatic agents may be so extreme as to resist biotic change or at least to slow it to a nonsignificant rate The soil or the topography may be of such a nature that only geomorphological changes associated with base leveling or stream cutting are capable of inducing mesic or medium conditions These changes are so slow as to confer a high degree of permanence or stability on the communities which are in equilibrium with the extreme conditions Such communities then represent the polyclimax view and are best discussed under the major factors modifying the environment

Edaphic modifiers (edaphic climax) Soils may deviate markedly from those found under climatic climax communities Such deviations result from unusual parent materials as serpentine rocks from faulty drainage as in topographic depressions from nonloamy textures as in pure sands or clays or from a number of other causes Regardless of the reason for the unusual soils the plant communities found on them commonly differ greatly from the climatic normal usually by an increase in the dominance of species adapted to the special conditions Sometimes these changes may affect the entire gross appearance of the community as in the replacement of forest by savanna or grassland In tropical regions with a pronounced wet and dry season soils developed on geologically mature flatlands commonly exhibit impeded internal drainage due to a subsurface layer of impervious claylike materials or concretions (laterite) These sites are wet almost inundated during the rainy season but become depleted of nearly all water in the layer above the impervious pan during the dry season Such a severe seasonal alternation in moisture conditions is *unfavorable* for the growth of most trees but is tolerated well by a number of grasses and grassland *plants The community which develops there is a grassland with scattered trees* called a savanna which is an edaphic climax in a climate fully capable of supporting closed tropical *forest on* normal soils with good drainage

The reverse effect is more frequently seen in temperate zones where *excessively good* drainage resulting from high sand or gravel content in the soil leads to xeric or drought *modifications* in the climax community If the sands are *siliceous* the soils tend to have a reduced nutrient content as well as a reduced water supply *As a result* total production is low and little organic matter exists Hence the improvement of the *soil through* nutrient pumping and incorporation of water holding colloids is slow Given sufficient *time this* soil improvement can eventually make the *area* suitable for the climatic climax but in many regions the inherent dryness of the soil leads directly *to an* increase in severe fires The more or less permanent community which develops is in equilibrium *with both* the soil conditions and the fires and is made up of species of xerophytic tendencies which also are fire resistant The sand plains and pine barrens of New Jersey the Great Lakes states and other regions are typical examples of such edaphic communities They have a high stability in the presence of repeated fires but show rather quick changes in composition if artificially protected from fire

Topographic modifiers (topographic climax) The influence on vegetation of such major topographic features as mountains is usually difficult to detect because of accompanying differences in ma

drained depressions may exert controlling influence over the vegetation Large hills have a significantly different microclimate on their south slopes from that on their north slopes In the northern hemisphere the south slopes tend to be both hotter and drier than the north slopes In regions near the boundary of two major biocoenoses as along the prairie-forest border in central North America these directional differences often result in grassland communities just below the crest on the south slopes while the north slopes have forest communities of the prevailing climatic climax Near the center of the area of any one biocoenosis topography does not result in such a severe change in physiognomy but only in a change in composition of species The two slopes can develop to convergence only following the geological base levelling of the hill

Another major effect of topography is seen in lowland sites as along streams and lakes or other depressions Such sites have excessive moisture due to run off from adjacent uplands and the biotic communities developing there are composed of species with *special adaptations* to the higher water supply Ordinarily the community is able to do little to change the conditions toward mesic moisture levels such changes are dependent upon stream entrenchment alluviation or sedimentation all of which are very slow processes The communities that come into equilibrium with the high moisture conditions therefore are very stable *some* having persisted for 10 000 years or more as *in* the case of certain conifer swamps in northern glaciated regions Such stable communities are *topographic* climaxes which can develop to the climatic climax only if the controlling factor of excess moisture is removed by some external action

Disclimax The climatic climax and the edaphic and topographic modifications of it are presumed to represent natural conditions in which the biota have come into equilibrium with the physical environment unaffected by other outside agencies When disturbances are caused by man the communities may readjust their composition in response If a new stability is achieved as when the disturbance is uniformly and continually applied *the* community is called a disturbance climax or a dis climax Sometimes the same term is applied *to a*

plant community which is clearly influenced by one of its natural animal components such as the bison on the western short grass plains but such usage is often restricted to the effects of abnormal population levels of the animal particularly where these levels are themselves the result of man's activities

Overgrazing Populations of native herbivorous animals exert an effect on the plant composition of the world's grasslands but these effects are of a minor and nondisrupting nature When domesticated animals especially cattle sheep and goats are introduced to the same grasslands pronounced changes occur in the community both because the animals are confined within an enclosure and hence must use and reuse the same plants and because the populations per unit area are usually higher than those of the native animals The plant species change from those with erect stems and aerial growing points to recumbent prostrate or rosette plants with their leaves and buds close to the soil surface There is also an increase in species with spines and thorns or other devices which reduce their palatability Reductions in stature and growth form also occur in the understory of forests which are pastured When the size of the animal herd is carefully adjusted to the carrying capacity of the land as in some of the grazing regions of Europe a stable or pasture disclimax may result In many regions however the size of the herd is governed mostly by economic reasons such that animal plant interactions are varying and often on the side of continual degradation of the vegetation Under these conditions the requisite stability of a climax is not present Such combinations are called disturbance communities rather than disclimaxes

More or less similar changes in community composition sometimes occur when a native animal population is allowed to become excessively large as is the case of deer and rabbits in regions where natural predators have been eliminated

Lumbering Another man made disturbance which is prevalent in the forests of the world is that brought about by lumbering This varies from total destruction of the original community over large areas by clear cutting as in many commercial conifer forests to the long term removal of a few trees each year as by selective harvest of private woodlots While these activities may permanently change the nature of the community which can later develop on the lumbered areas they rarely result in a truly stable community and hence are considered to produce disturbance communities rather than disclimaxes

Fire Fires of natural origin especially those set by dry lightning are a common feature of many large regions of the world and as such are as much a part of the natural environment as rainfall sunlight or wind However such fires have the same effect as those deliberately or accidentally set by man and both are commonly considered disturbance factors In any case there have been fire using cultures in all major regions of the world for at least 30 000 years and hence many biotic communities have had time to come into equilibrium with fire whether natural or artificial

The effect of fire varies greatly with the type of vegetation and the general climate concerned Large areas of the tropical rain forests cannot burn unless they are first cut down In temperate zones, the climatic climax hardwood forests are similarly fire resistant and may burn only under unusual conditions of drought Northern conifer forests also burn primarily during drought but their greater inflammability permits wider destruction than in the hardwood region Most of the permanent pine forest areas of the world are fire disclimaxes in that they are perpetually maintained at the pine stage of succession through recurrent destruction and regeneration The chaparral of California is another major fire disclimax of similar behavior

Fire can create a differential competition, for instance it burns grass more readily than trees This is seen along the boundary between grassland and forest and in certain other places where fires are exceptionally effective as on the flatlands of the American Coastal Plain The forests are reduced to a scattered stand of the most fire-resistant tree species with an understory of grasses and other fire resistant herbaceous plants Nearly all of the temperate zone savannas and many tropical savannas as well are clear examples of fire disclimax

In the grasslands proper fire brings about no important change in biotic composition On the more humid edges of the grassland however fire is necessary to maintain the community in a healthy condition and to prevent it from smothering itself with undecomposed mulch and the same may be true of all grasslands Thus prairies may be thought of as climatic climaxes and fire a natural part of the environment Where there is artificial fire protection the resulting community is a disclimax

Fire is of infrequent occurrence on the major deserts and is similarly rare on the arctic tundra although there have been few detailed studies of the effects in these regions and little can be said of the nature of possible disclimaxes

Wind, salt spray, and fog Several other environmental factors usually associated with restricted geographical locations may cause deviations from a climatic climax In the high mountains of the world unidirectional winds of considerable strength may produce a gnarled and stunted forest at timberline which contains tree species not found elsewhere in the region These trees are well adapted to resist the shearing and twisting action of the strong winds and may remain alive for long periods with only a few green branches Along exposed sea coasts prevailing on shore winds create a similar effect aided by the salty droplets picked up from the waves This salt spray climax is widespread along the Atlantic and Gulf Coasts and is composed of specialized plants most able to tolerate the harmful effects of the salt

Persistent occurrence of a fog blanket along coastal areas or on abrupt mountain promont

may induce a fog climax The redwood forests along the Pacific Coast and the elfin woodland variant of the tropical cloud forests of the world are examples of such control *See* ECOLOGY ENVIRONMENT *see also* PLANT ANATOMY PLANT COMMUNITY PLANT PHYSIOLOGY [J T C]

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Climax plant formations

All the earth s surface is occupied to some extent by vegetation except for polar and alpine regions of permanent snow and ice and local physiographi cally active areas such as sand dune complexes (Sahara desert in part) Despite the hundreds of thousands of species of plants and the thousands of communities (associations) in which they occur there is a limited number of major world formation types Each formation occurs over wide areas most of them on all continents and each has a recogniz able structure because of the characteristic life forms (tree form grass form) of the dominant plants yet the floristic composition of a formation may be so different in its different areas of occur rence that no species is common to the major areas Each formation occupies a distinctive type of gen eral climate although variable local climates oc cur within its region

Plant geographers differ in their classifications of formations particularly the subdivisions of the world formations as they are intensively analyzed in local regions (*see* PLANT GEOGRAPHY) How ever the several formations fall into three major groups of terrestrial vegetation forests and wood lands grasslands and deserts These formations are listed in the following classification

Forest formations (including woodlands)
- Tropical rainforest (including subtropical types)
- Temperate rainforest (including mountain types)
- Tropical deciduous (monsoon) forest
- Summergreen deciduous forest
- Needle-leaved forest (circumboreal type espe cially)
- Evergreen hardwood (Mediterranean) forest
- Savanna (transitional to grassland)

Short (steppe) grassland

Desert formations
- Dry desert (including semidesert)
- Cold desert (tundra including alpine tundra)

Some minor types of stable vegetation are omit ted from this general classification such as the heather [illegible] rop anc [illegible] of the *cennia* and *Rhi ophora* of tropical ocean shores Likewise the vegetation of inland waters and of the sea is not considered and all animals are arbi trarily ignored although characteristic ones occur with each formation The major formations have typical climax dynamically stable communities However within each formation area most of the land usually is occupied by vegetation of d s turbed terrain by communities of plants under edaphic control (conditions of the substratum ter rain or associated microclimate that are extreme for the region), or by successional communities that have not had time to develop to climax status The formation when thought of in a regional areas but they have been in existence during mil lions of years and have migrated as their control ling climates have shifted on the face of the earth

Tropical rainforest This formation occurs ex tensively in broad lowland areas in the Amazon ba sin of South America in the Congo of West Africa in Malaya and in Indonesia with lesser areas else where that never have frost or a period of inade quate precipitation The tropical rainforest (Fig 1) is very rich in woody species (100 or more tree species per hectare) and is usually without domi nance by one or a few species which is in contrast with the monsoon forest and the temperate rainfor est in which dominance may occur It is structured in several layers the uppermost being a discontin uous layer of occasional emergent trees that extend far above the general canopy of the forest Inter nally there usually are one or two layers of lower trees and shrubs The ground cover often consists of reproduction of woody plants although openings in the generally dark forest permit a luxuriant growth of ferns and other herbs The tropical rain forest is famous for its climbing vines such as *Bauhinia* and *Carludovica* which vary from th n cords to massive stemmed lianas for the abundance of vascular epiphytes (many genera of Bromeli aceae Orchidaceae and Pteridophyta) and for cauliflory or the bearing of flowers and fruits on old stems and even on the trunks of trees as in



Fig 1 Tropical rainforest of upland type in the lower Amazon region Belém Pará Brazil Tall trees with crowns and plank shaped buttresses are typical Such forests may have 100 tree species on a hecta e

Theobroma and *Diospyros* Trees are commonly tall, with emergent ones very tall (250 ft or more in *Ceiba* and *Bertholletia*), and usually have columnar trunks which are unbranched up to the relatively small crowns Jungle is a term more appropriate for the forest edge, such as areas along streams where the light has full effect or where second growth has occurred The interior of old high, upland rainforest is comparatively open and easy to move through Many species of trees have planklike buttresses rising along the trunk from the main roots as seen in *Mora*, *Ceiba*, and *Terminalia*, and others such as *Tovomita*, *Clusia*, *Symphonia*, and *Ficus* stand on stilt roots Many lianas and some trees (*Ficus*) start as epiphytes and later make contact with the ground Tree leaves are medium to large, although many species such as the Leguminosae have compound leaves with medium to small leaflets Leaves are typically evergreen with entire margins and attenuated tips called drip points as in *Catostemma*, and are somewhat coriaceous in upper layers and thinner in lower ones Although the forest is luxurious in appearance, tree growth is slow because of the comparatively infertile, strongly leached soil and the intense competition for light and nutrients In contrast after clearings are abandoned secondary growth of trees like *Cecropia* is rapid, and many species have large leaves (Musaceae, Zingiberaceae, Marantaceae) The tropical rainforest is the home of aboriginal shifting cultivation, as cut and burned patches of the forest soon lose their fertility It produces many valuable and beautiful hardwoods such as ebony, mahogany, and rosewood, it is the region of industrial rubber and cacao plantations

Temperate rainforest. The trees in this formation are medium or tall in height and have medium or small hard evergreen leaves, although some associated trees have scalelike or needle shaped leaves Tree ferns and bamboos are abundant in certain areas of the temperate rainforest and moss and liverwort growth may cover the tree branches and the ground The formation occurs in many moist warm regions, but does not occupy extensive areas as it is impinged upon from all sides and seems to be in delicate balance With increasing heat and moisture, it grades into subtropical and tropical rainforest, with increased dryness or periodicity of precipitation, it grades into tropical deciduous forest, and with coolness, into summer green and needle leaved forest types It occurs on all continents and is variously composed floristically, but has some widely occurring "binding" genera such as *Podocarpus*, *Weinmannia*, *Drimys*, *Araucaria*, *Persea*, *Dacrydium*, *Laurelia*, *Cedrella*, and *Nothofagus* in the Southern Hemisphere Some examples of the temperate rainforest are the Kauri pine (*Agathis*) and southern beech (*Nothofagus*) forests of New Zealand the *Nothofagus* forest in Chile the sweetgum (*Liquidambar*) forests of Mexico the coastal redwood (*Sequoia*) forests of California, the Parana pine (*Araucaria*) forest of Brazil, and the laurel (*Laurus*) forest of the Canary Islands Other types occur on tropical and subtropical mountains where the climate is temperate and are called cloud forests when there is a high frequency of fogginess

Tropical deciduous (monsoon) forest. This is an intermediate type characteristically making transition to rainforest and savanna woodland It is usually referred to as the monsoon forest because its leaves are borne during the rainy season and many of the trees are deciduous during the dry season The leaves are small to medium and some evergreen elements are present It usually is a tall stratified forest with many life forms present Lianas and vascular epiphytes occur but are not as abundant as in the tropical rainforest which lacks a dry season With a more pronounced and usually drier season this formation grades into savanna woods which may be closed or in more extreme forms may be open and grassy Other transition may be with thorn woodland in Africa and South America Typical monsoon forests occur in southern Asia where teak (*Tectona grandis*) is important and there are related forests in Africa and

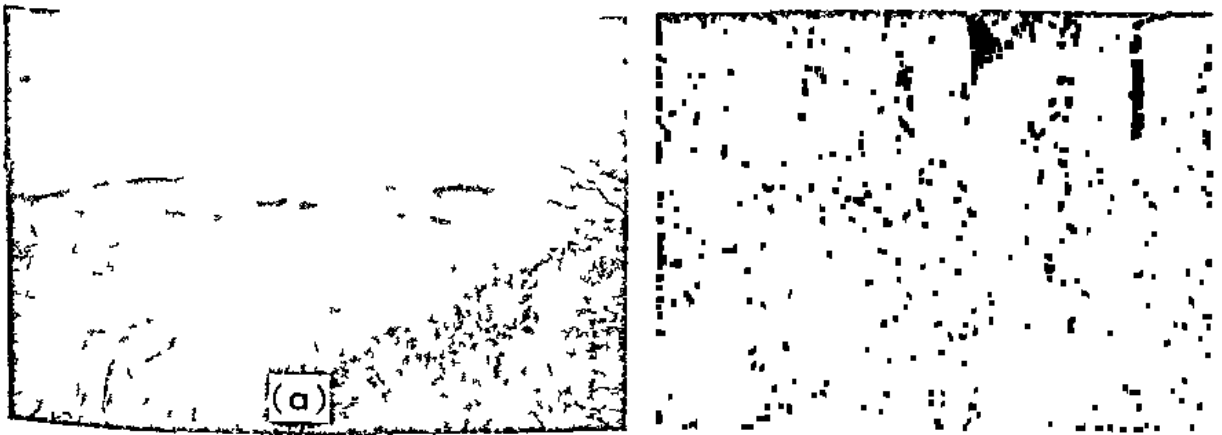


Fig 2 (a) Summergreen deciduous forest dominated by broad leaved hardwoods, including *Betula Aesculus Fagus, Acer, Quercus Carya, Ilex*, and others Southern state line region, Great Smoky Mountains Park Tennessee–North Carolina (b) Summergreen deciduous forest, interior view with *Quercus alba* numerous herbs, and the flowering shrub,

South America When monsoon forests occur with a less pronounced dry period and with more ever [illegible] the semideciduous

[illegible] This formation occurs in cool to cold temperate regions of the Northern Hemisphere where there is a long winter and a summer of several months without a pronounced dry period (Fig 2*a*) The rhythm of the forest is set by the contrast between the leafless profusely branched trees ending in a high even topped crown of fine twigs and the heavy summer canopy formed by broad membranaceous, mostly simple leaves This formation is comparatively rich in tree shrub and herbaceous species, and is typically structured in several layers by naturally tall and short trees shrubs and herbs (Fig 2*b*) Further rhythm is produced by a pronounced spring flora that comes quickly into bloom from subterranean bulbs rhizomes and corms Many of the plants of this spring flora are species of *Anemone, Erythronium Viola Geranium, Dicentra,* and *Claytonia* which complete their life cycles before the full shade of the forest canopy has developed in early summer Taller summer and autumnal layers of herbs replace the spring flora and greatly change the interior appearance of the forest except where the shade is most dense Climbing vines species of *Vitis* and *Psedera,* are infrequent and epiphytes are usually mosses, liverworts and lichens This forest formation is well represented in the eastern United States in Europe and contiguous Asia except for high latitudes the Mediterranean region and in southeastern Asia Some minor extensions into the warm temperate and subtropical zones occur at higher altitudes in Mexico It makes transition with grassland toward continental interiors with conifer forests northward and at higher altitudes and with various types of vegetation southward in warm temperate regions It is absent from the Southern Hemisphere in regions with a pronounced dry season and is poorly represented in western North America In the United States the northern hardwood forest is mostly characterized by maple (*Acer*) beech (*Fagus*) birch (*Betula*), and basswood (*Tilia*), with lesser amounts of other genera such as ash (*Fraxinus*), oak (*Quercus*), and hickory (*Carya*) Toward the drier continental interior the forest is dominated by oaks and hickories, finally forming a transition with the tall grass prairies The southern aspect of the forest has yellow poplar (*Liriodendron*), gum (*Nyssa*), walnut (*Juglans*), holly (*Ilex*), buckeye (*Aesculus*), sweetgum (*Liquidambar*), and magnolia (*Magnolia*) as well as species of genera of the other regions of the formation Chestnut (*Castanea*) was a prominent member of the eastern phase of the formation before it was eliminated by a blight. This forest produces many fine and commercially important hardwoods

Needle-leaved forest. This is best represented by the circumboreal forest dominated by spruce (*Picea*) and fir (*Abies*) (Fig 3*a*). It occurs south of the tundra and north of the summergreen deciduous forest or grassland (Fig 3*b*). The taiga is the northern part of the formation and lacks a closed tree canopy The tundra may be interpenetrated on higher and drier land The southern part is penetrated by broad leaved deciduous trees in the valleys and on warmer slopes or by grassland openings Upper elevations of mountain masses to the south of the Canadian spruce fir formation in the Northern Hemisphere have belts of needle-leaved forest with spruce and fir, or a variety of pines (*Pinus*) and other conifer genera such as *Juniperus, Cupressus, Cedrus, Linocedrus, Larix Tsuga,* and *Thuja* Some representatives of this formation occur on mountains in the tropical zone (*Pinus*) and in the Southern Hemisphere Some conifers belong to formations not dominated by needle-leaved species such as the hemlock (*Tsuga canadensis*) or are dominant in successional stages earlier than the climax such as the junipers (*Juniperus*) and pines (*Pinus*) The name of the forest comes from the needlelike or scalelike, hard evergreen leaves Mature trees, according to latitude or altitude and the nature of the species may be comparatively low or tall such as the Sitka spruce *Picea sitchensis,* and redwood, *Sequoia sempervirens* Typically the canopy is closed and the forest is dark although the central trunk is usually unforked Structure of the forest is simple, becau-

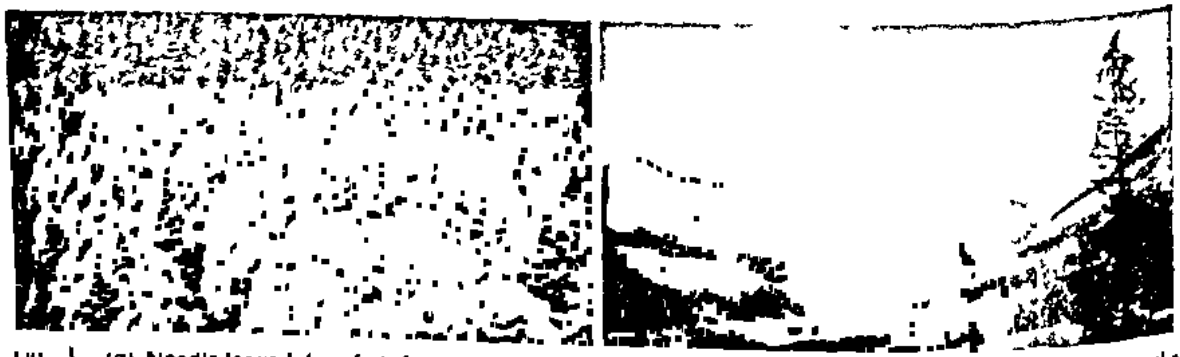


Fig 3 (*a*) Needle leaved (conifer) forest dominated by *Picea glauca, P mariana P rubens,* and *Abies balsamea,* Laurentides National Park, Quebec (*b*) Needle leaved (conifer) forest dominated by *Picea engelmani* and *Abies lasiocarpa,* central Colorado in the Silverton region Alpine tundra region above timber line

there are few layers in the vegetation and the dominant tree species are few in number but the ground cover although scanty in dry types often is a dense mat of mosses and lichens with associated ferns broad leaved herbs and low often evergreen shrubs (*Vaccinium Ledum Kalmia*) The formation is typically moist but conifer forests range into semiarid regions which have species of *Pinus* and *Juniperus* and into swamps where *Taxodium* is common In the tropical formation the climate is moist without a dry season and cool or cold Winters are long and snow cover may be deep Soils are acid and podsolized comparatively shallow and not fertile The boreal forest occupies vast areas in Asia Europe and America (principally in Canada) which are also the zones of abundant acid bogs and peat formation Other types of needle leaved forests occur in different climates and on different soils such as the juniper pinon woodlands of the southern Rocky Mountains This forest formation produces the world s most important commercial softwood lumber for building and pulp for paper manufacture

Evergreen hardwood forest Frequently this is called the Mediterranean forest after the area where it was first studied although it also occurs in the southwestern United States Chile southwest Africa and southwest Australia It occurs in regions where there is a Mediterranean type climate with cool to cold moist winters and long dry summers The result is that conditions are favorable for active growth in the spring with many herbs r sing from bulbs and again in the autumn when the dry summer is over In the Med terranean region the forest dominants are mostly oaks (*Quercus ilex* and *Q suber*) but centuries of abuse have reduced most of the reg on to scrubby vegetation called maquis or garigue In California the formation is represented by the oak madrone type (*Quercus Arbutus*) with fire and other disturbances producing a variety of types of chaparral (*Arctostaphylos Rhamnus*) in Chile by Rosaceae (*Quillaja*) and Lauraceae (*Persea Cryptocarya*) in Australia by gums (*Eucalyptus*) and many associated species and in the Cape region of South Africa by genera of Ericaceae Bruniaceae Rutaceae Rhamnaceae and Thymelaceae This forest formation is highly subject to fire and to degradation by grazing animals such as sheep and goats and by erosion so that it is seldom seen in mature form In the Mediterranean region it is the home of olive cultivation

Savanna This is a transitional formation between forest and grassland in which trees may occur generally but are widely spaced in islands of woodland or more or less as gallery woodland along drainage channels It can occur in temperate regions as a rather narrow ecotone with patches of grassland within the forest region and islands of trees within the grassland (Fig 4*a*) Minnesota to Illinois The formation may be extensive in tropical and subtropical regions as in the big game country of eastern Africa (*Acacia* savanna) and in the central plateau of Brazil the Campo cerrado The savanna of Brazil (Fig 4*b*) sharply abuts the rainforest in many places and varies from a closed or nearly closed woodland of short contorted th ck barked trees through more open structure with increasing density of grasses (Andropogoneae) and broad leaved herbs until there are no more trees present The soil is generally infertile and lateritic and sometimes there is a massive subterranean layer of stonelike laterite close to the surface Because of the strong seasonal distribution of rain the water table is fluctuating and sometimes very deep and vegetational activity is limited to the rainy season Common use of the savanna is for extensive animal husbandry because the forage value and carrying capacity of the vegetation are low and for subsistence agriculture along drainage channels Fire is frequent and some students of vegetation believe that all savanna has been produced from woodland by centuries or even millenniums of human interference especially set fires

Thorn forest This formation is dominated by small trees and shrubs many of which are armed with thorns and spines Leaves are absent succulent or deciduous during the long dry periods which may also be cool Succulent plants of many forms usually accompany the thorny bushes and



Fig 4 (a) *Juniperus Pinus* savanna southwestern Colorado with open spaced trees and xerophytic grasses (b) Tropical savanna near Barbacena Minas Geraes Brazil The low contorted largely evergreen broad leaved trees and a good cover of semixerophytic grasses are typical



Fig 5 Protected grassland in the Black Hills area east of Colorado Springs Colorado, showing tall and mid grasses in a generally short-grass (steppe) region

trees (Cactaceae in North America Euphorbiaceae in Africa) There is an ephemeral layer of herbs that appears after rains and sometimes a thin scattering of dry grasses The type is mostly tropical and subtropical and is represented by the caatinga of northeastern Brazil and the South African thorn bush This type is intermediate between desert and

to broad leaved summergreen forest (oak hickory type) on the more humid side and short grass plains (steppe) on the drier side Rainfall (20–40 in) is strongly seasonal with a dry summer and a cool or cold winter often with snow cover True dominants of the prairie include such grasses as *Andropogon scoparius, Sporobolus asper* and *S heterolepis Stipa spartea* and species of *Koeleria Agropyron, Muhlenbergia* and *Panicum* and the sedge genus *Carex* Numerous associated broad leaved herbs include many species of the families Leguminosae Rosaceae Scrophulariaceae and Umbelliferae Tall trees are sometimes present along the streams and some shrubs occur within the grassland such as species of *Salix* and *Symphoricarpus* Most vegetative activity stops after the effects of the spring snowmelt and early summer rains are over This is now a rich agricultural region concentrating on corn small grains and livestock The Hungarian puszta and moist grasslands of Eurasia belong to this subformation

Short grassland This is generally called the steppe In the United States it is the short grass plains (Fig 5) It makes contact with the tall grassland prairies on the moist side and with savanna thorn forest and desert on the dry side It is a continental formation with less precipitation (10–20 in) than the prairie The rainfall is less reliable and annual droughts are a hazard to agriculture Summers may be long and dry and winters long and cold at higher latitudes and cool to warm at lower ones Winds are strong and wind erosion occurs where the vegetation is disturbed The formation is typically dominated by short to medium high grasses Short grass dominants in the United States include *Bouteloua hirsuta* and *B gracilis Buchloë dactyloides*, and species of *Muhlenbergia* and *Carex* Mid grasses include *Agropyron smithi Hilaria jamesi Sporobolus cryptandrus*, and species of *Stipa, Oryzopsis, Festuca*, and *Elymus* Among the broad leaved herbs Compositae are especially abundant (*Aster, Solidago Grindelia Senecio Artemisia*) as are Leguminosae (*Oxytropis, Psoralea Petalostemon, Lupinus*) This formation was the main home of the American bison and now is largely devoted to the cattle industry and hazardous wheat raising in the less arid parts. It is the home of the man induced dust bowls In temperate regions the steppe plays a role corresponding to that of savanna in tropical regions In addition to the North American grasslands, extensive areas occur in Argentina and Uruguay, in Africa on both sides of the Sahara desert and in Asia mostly between latitudes 30 and 50°N from the Middle East to Mongolia and Manchuria

Dry desert The dry or true desert is both a climatic condition and the vegetation of dry regions Precipitation is low, from essentially nothing to a variable upper limit of about 10 in , and is erratic Atmospheric humidity is low in the day but dew is common at night Temperature varies from warm to hot for all months or may be cold in the winter at high latitudes and altitudes There is a strong daily change in temperature from hot bright days to clear cool nights In the southwestern United States the Chihuahua desert extends from southern New Mexico and western Texas southward into Mexico occupying the land between mountain ranges Organpipe and columnar tree cacti tree like yuccas and species of *Agave, Dasylirion* and *Hechtia* form a conspicuous part of the vegetation along with ocotillo (*Fouquieria*), mesquite (*Prosopis*), and creosote bush (*Larrea*) The low rainfall occurs largely in the summer The Sonoran desert occupies the lowlands around the Gulf of California in Sonora and Baja California and the adjacent United States It is characterized by the giant saguaro cactus (*Carnegiea gigantea*) and many species of prickly pear cactus (*Opuntia*), and the shrubby *Larrea* and *Franseria* (Fig 6) Ephemeral



Fig 6 Sonoran Desert vegetation west of Tucson Arizona with the saguaro *Carnegiea gigantea* mainly on south facing slopes

annuals are abundant after late winter rains Temperatures in the Mohave desert of California may exceed 100°F for long periods of time and precipitation around the Gulf is about 2 in annually Northward of these true severe desert areas in the Great Basin region the semideserts are less dry but colder and the northern part has severe winters Species of sagebrush especially *Artemisia tridentata* in the north and *A spinescens* in the south commonly are dominant, with shadscale (*Atriplex*) as an associate Many parts of this desert are salt encrusted with halophytes such as *Kochia Sarcobatus Allenrolfea* and *Salicornia* being important Desert vegetation is typically open with shrubs cacti and bushy herbs widely spaced but often there is root competition for the scanty water supplies and some species are deep-rooted The long severe dry periods are met variously by desert and semidesert plants Some are annual avoiding drought Others lose their leaves or are leafless all the time and many store water in succulent organs In addition to the American deserts described above there is the coastal Atacama desert in Pacific South America the Kalahari desert of southwest Africa the great Sahara desert of northern Africa which crosses the continent between 15 and 30°N latitude the great Arabian deserts of the Middle East and the deserts of Asia which extend from Kara Kum eastward to the Gobi Much of central Australia is occupied by the Simpson Victoria Gibson and other deserts Desert mountain ranges are covered at appropriate elevations by other plant formations often widely disjunct culminating even in boreal type needle-leaved forest and alpine tundra Oases where the water table is high or aquifers can be tapped by wells may support luxuriant gardens of melons vegetables and date palms With modern irrigation desert soils often prove to be exceedingly fertile Careful management is necessary to prevent the soil from becoming useless because of salt accumulation Deserts sustain some browsing and semideserts can be useful country for cattle horses and camels but overgrazing is easy and this can result in the spread of weedy shrubs such as the spread of sagebrush in the Great Basin desert and of mesquite around the Chihuahua desert

Tundra This formation comprises the vegetation of the treeless zone of high latitudes where winters are long and cold with temperatures falling to −60°F or lower Summers are short with no month averaging above 50°F Frost may occur in midsummer although daytime maxima may reach 80°F Precipitation usually is low snow cover thin and winds strong although fogs may be frequent and cloudiness high There are according to the latitude long winter nights when the sun rises a few hours low on the horizon or not at all and summer days when it never sets The ground is perennially frozen to great depths (permafrost) below a variable surface layer subject to summer thaw Although mountains hills and stream valleys occur much of the Arctic tundra landscape is of low relief However the microrelief is extremely important in controlling the patterns of occurrence of the plants and the communities which they form in the tundra formation Because all conditions of

changes of dominant species with slight changes in temperature and moisture The controlling forces in geomorphological processes and consequently in vegetational development and patterning are largely cryopedologic or caused by freezing thawing disruptions that result in polygons ice wedges surface ridges and various kinds of pools and ponds Although the general cast of the vegetation is low and monotonous there is intricate complexity and regional variation in community composition and patterning despite a relatively impoverished flora Frequent and often dominant plants are

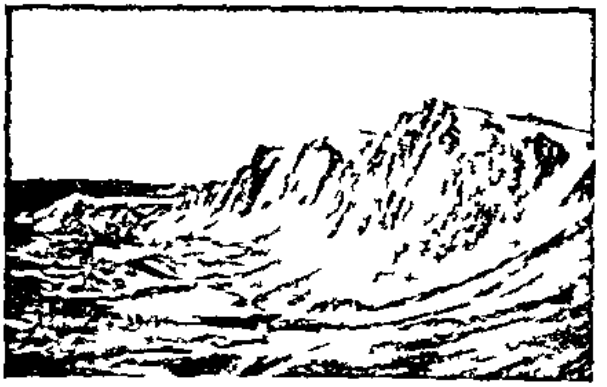


Fig 7 Alpine vegetation (tundra) Medicine Bow peak (12 005 ft altitude) Snowy Range Wyoming Dwarfed matted trees at timberline are mostly *Picea engelmanni* and *Abies lasiocarpa*

sedges grasses and grasslike herbs together with lichens mosses and liverworts In places there is an abundance of low creeping shrubs or densely compact ones and many herbs have cushionlike forms A few inches or feet of elevation produce dry situations with distinctive vegetation but there are many moist or wet sites and in places many ponds and lakes Tundra typically makes transition with coniferous forest by an ecotonal zone sometimes called the taiga Alpine tundra (Fig 7) occurs above the altitudinal tree line on mountain masses all over the world even near the Equator Its lower limit is higher in lower latitudes It is distinguished from Arctic tundra by greater precipitation and by the different light conditions which are the result of the latitude Some Arctic species extend far southward even in isolated alpine tundra [S A C]

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Clinical pathology

The diagnostic study of disease by means of laboratory tests on material from the living patient This service encompasses chemical microscopic hematologic microbiologic serologic metabolic and immunologic examination of blood urine sputum feces fluids and exudates The major disciplines of clinical pathology are included in urinalysis hematology blood chemistry bacteriology and parasitology (microbiology) fecal and sputum analysis serology blood banking and metabolic studies This article includes all of these aspects

In the diagnostic evaluation of a patient laboratory tests are considered as important as the clinical history or physical examination In some instances they may be the sole means of establishing a definitive diagnosis but normally they are used to corroborate clinical impressions Tests which prove the absence of abnormality are equally as valuable as those which indicate its presence

Clinical pathology did not emerge as an integrated entity from its origins in the clinical practice of medicine until the late nineteenth century Initially responsibility for the pursuit of laboratory procedures was entirely in the hands of the practicing physician With the increasing importance of such laboratory examinations and their growth in number and complexity a realization developed that such work must be delegated to specialists of laboratory medicine the clinical pathologists

URINALYSIS

A routine examination of the urine includes the following studies

Procedures	*Normal values*
Physical characteristics	
Volume	1000–1400 ml/day
Color	Straw amber
Transparency	Clear
Odor	Aromatic
Specific gravity	1 006–1 024
Routine chemical characteristics	
Reaction (pH)	4 0–8 0
Protein	0–80 mg/day
Sugar	None
Acetone	None
Bile	None
Microscopic examination	
Cells	
Erythrocytes	0–2/hpf*
Leukocytes	0–5/hpf
Epithelial	Variable/hpf
Casts	0 occasional/lpf†
Crystals	Variable/hpf

* High power field † low power field

Physical characteristics of urine considered during routine urinalysis are volume color transparency odor and specific gravity Urine which is formed by the kidneys is an excretory product of the body whereby wastes are removed and the water and acid base balance are regulated The following conditions are associated with increased volume of urinary output (polyuria) high fluid intake nervousness diabetes mellitus diabetes insipidus (up to 10 liters), and drugs (caffeine diuretics) With decreased output (oliguria) are associated such conditions as excessive sweating diarrhea vomiting chronic nephritis and heart failure

Complete absence of urine (anuria) which may occur in severe acute or chronic nephritis is incompatible with life

Physical characteristics such as color transparency and odor are usually of little clinical significance Red discoloration which can signify the presence of blood may also be caused by ingested foods or drugs A cloudy appearance can be due to the presence of blood pus or large numbers of bacteria or may result merely from the presence of many crystals Odor is usually of no significance At times such foods as asparagus may impart a characteristic odor Urines which are infected may have an ammoniacal odor A fruity odor is associated with diabetes mellitus The specific gravity of urine which is the ratio of the weight of a given volume of urine to an equal volume of water is greater than that of water because of the presence of dissolved substances such as salts nitrogenous material and other substances The normal range is 1 006 1 024 In a normal individual the specific gravity of daily urine specimens will vary at least 0 010 units A fixed specific gravity signifies the presence of severe kidney disease Higher values are found in diabetes mellitus fever and acute nephritis Lower values occur in association with excessive urinary output in such conditions as diabetes insipidus

Chemical characteristics Chemical characteristics of urine to be considered are the reaction and the amount of protein sugar acetone and bile present in a sample

The reaction is a measure of the acidity or alkalinity of the urine the normal pH (hydrogen ion concentration) varying from 4 0 to 8 0 In diabetes mellitus and prolonged fevers the urine tends to be acid (lower pH) After bicarbonate medication or an acid fruit diet it becomes somewhat alkaline (higher pH) Bacterial infection also may cause an alkaline reaction

Usually protein consists of albumin only of which the normal urine contains none or only a slight trace (less than 50 mg in a 24-hour period) An increased amount may be found after severe muscular exertion during pregnancy in cardiac failure and exposure to cold In disease of the kidney larger amounts of protein (up to 20 g day) may appear but under these conditions the larger molecular globulins are also present

The presence of sugar is known as glucosuria and generally reflects increased glucose levels of the blood It may be found in association with hyper thyroidism strenuous exercise emotional disturb ance and excessive ingestion of sugars but it is especially important when related to dial etes mel litus Sugar is often found during pregnancy but this is caused by the presence of lactose (milk sugar) rather than glucose

Acetone diacetic acid and β oxybutyric acid are the ketone bodies When these are present in urine the condition is known as ketonuria which is an expression of abnormal fat metal olism seen in un controlled diabetes mellitus starvation ether an esthesia fevers and gastrointestinal disorders

The presence of b ile indicates either damage to the liver or obstruction of the bile ducts of the liver Patients with these conditions are jaundiced The presence of jaundice without bile in the urine on the other hand is diagnostic of hemolytic disease of the blood

Microscopic examination The organized ele ments of the urine can be studied only with the aid of a microscope at a magnification of about 100X (low power) or 450X (high power) In prep aration 10 ml of urine is centrifuged for 5 min at 5000 revolutions per minute The sediment is re suspended in about 1 ml of the urine and a drop placed on a glass slide for microscopic examina tion It is then possible to estimate a number of cellular elements per high power field (hpf) or low power field (lpf) of the microscope The organ ized sediment of urine consists of leukocytes eryth rocytes epithelial cells casts and crystals

A small number of the cellular elements is a normal finding especially in the urine of women More than 3–5 leukocytes/hpf is usually indicative of inflammation in the kidney ureters bladder or prostate gland More than 1 2 erythrocytes/hpf may be indicative of bleeding from some portion of the urinary tract caused by inflammation tumor (neoplasm) stone or nephritis

Casts are cylindrical proteinaceous structures formed only in the kidney tubules There are sev eral types of cast—hyalin granular and cellular An occasional clear structureless hyalin cast may be seen in normal urine Granular casts differ from hyalin casts by the presence of fine or coarse granules and signify the presence of serious tubu lar damage in the kidney Blood and pus casts are seen in association with bleeding from the kidney or infection

There are numerous types of crystals the major ity not significant of organic disease Crystals of ingested drugs may signify impending renal dam age Amino acid crystals indicate severe liver dis ease

SPECIAL URINARY EXAMINATIONS

There are numerous additional urinary studies which are individually performed when certain spe cific diseases are suspected These are listed be low

Renal function tests	*Chemical determinations*	*Miscellaneous*
Addis count	Melanin	Pregnancy tests
Concentration dilution test	Occult blood Bence Jones pro tein	Hormone as-says
Phenolsulfon phthalein test	Calcium Amylase	Bacteriologic studies
Clearance tests	Calculus analysis Poisons	

Renal function tests These tests include the Addis count concentration and dilution tests phe-nolsulfonphthalein test and clearance tests

The Addis count estimates the number of eryth rocytes leukocytes and casts estimated from a 12 hour specimen of urine The values in normal patients are as follows erythrocytes 0–130 000 leukocytes 0–650 000 casts 0–2 000 (all hyalin) Increased numbers of these cells are significant of various forms of renal damage

A measure of the ability of the kidney to con centrate and dilute urine under stress is one of the more sensitive tests for early loss of function and is called the concentration dilution test The nor mal adult has a functional kidney reserve of four times the amount necessary to sustain life there fore a considerable degree of kidney damage may develop before loss of function is noted A specific gravity that fluctuates from a high of 1 030 on a restricted fluid intake to a low of 1 003 on a high water intake is indicative of a normally functioning kidney

The phenolsulfonphthalein test involves the ad ministration of 1 ml of this dye preferably given intravenously It is eliminated in the urine which is then collected at 15 min intervals for 2 hours Normally 40–50% of the dye is excreted in the first hour and 20–25% in the second hour Failure to excrete this amount of dye in the 2 hour time interval is indicative of depressed kidney function

In the clearance test a substance which is nor mally found in the blood such as urea or crea tinine is used as a basis for measuring renal ex cretory activity The ratio of the amount of either of these two substances excreted in two 1 hour pe riods contrasted with the level of these substances in the blood is calculated in terms of the amount of blood cleared of these substances in a given unit of time Values between 60 and 125% are consid ered normal Values below 60% signify an impair ment of kidney function

Chemical determinations Each of the chemical determinations mentioned in the previous table has special significance and is employed only under specific clinical indication The test for the pres-ence of melanin in the urine is utilized in patients with suspected melanotic cancer which is a tumor producing excessive quantities of melanin Tests for occult blood are employed when blood

mor or kidney stone is suspected and the red cells are too few or have been obscured by hemolysis (rupture) so that they are not visible under the microscope A small amount of calcium is normally present in the urine but when this is increased it is most often associated with hyperparathyroidism (overactivity of the parathyroid gland) In multiple myeloma a type of cancer involving the bone marrow an abnormal type of protein called the Bence Jones protein appears in the urine This is identified by the fact that a coagulum appears upon heating the urine but in contrast to other proteins disappears upon boiling Urinary amylase determinations are performed when acute inflammatory disease involves the pancreas Chemical analysis of renal calculi (stones) is performed to determine their chemical structure as an index of pathogenesis and as a guide to future management

At times it is important to know the types of drug a patient may be taking and whether or not poisons are present The urine is a convenient medium for making such determinations because it is secured easily and is available in sufficient amount for analysis with substances in relatively adequate concentration The substances most commonly detected are the salicylates barbiturates quinine morphine lead arsenic and mercury

Miscellaneous tests Included in this category are tests for pregnancy hormone assays and microorganisms Pregnant women elaborate increased concentrations of gonadotrophic (ovary affecting) hormones primarily in the placenta Such hormones also are present in even greater quantities in abnormal pregnancies (hydatidiform mole) as well as in certain cancers of the ovary and testicle When urine (or blood) from such patients is injected into test animals a characteristic change occurs in the animal In the rabbit (Friedman test) *for example* a hemorrhagic area develops which is a corpus luteum In the immature female rat test a red coloration of the ovary occurs in the male frog a discharge of spermatozoa develops and in the female frog ova are excreted all of which signify a positive test False positive or negative tests may result from biological variations in either the test animal or the patient in a small number of cases Usual accuracy ranges from 90 to 98%

A number of hormones have clinical significance and the urine is a convenient medium of assay Important among these are pituitary gonadotropins (a measure of normal pituitary function) 17 ketosteroids (a test of adrenal cortical function) and catecholamines (a test for the activity of the adrenal medulla usually for pheochromocytoma)

Normally urine is free of bacteria and parasites On occasion they may appear as contaminants when the technique of collection is not completely sterile Identification of such organisms either by microscopic examination of stained smears of the urine or by culture may reflect specific infections of the urinary tract. Occasionally organisms may be eliminated in the urine without producing local lesions in the kidney, as in typhoid fever

HEMATOLOGY

When disturbances of the normal hematologic pattern are associated with disease in other tissues of the body, such alteration is referred to as a secondary hematologic disease On the other hand when the disease directly involves the cells of the blood or the blood forming tissue (hematopoietic tissue) this is referred to as a primary disease of the blood See BLOOD

Composition Blood consists of two major fractions a fluid portion and a cellular portion The fluid portion (plasma) is made up of proteins carbohydrates, lipids (fats) nonprotein nitrogenous material and salts, the cellular portion contains erythrocytes (red blood cells), leukocytes (white blood ce
cellular
remainir
plasma only by the loss of fibrinogen (a protein) utilized in the process of clotting

Blood is a dynamic tissue, the measure of which at any given time represents a balance between the rate of formation and the rate of utilization storage or excretion of all of its elements The cellular elements are formed in the bone marrow and lymph nodes They are destroyed primarily in the spleen or elsewhere in the reticuloendothelial system of the body In the presence of disease these cellular elements may be destroyed at a rapid rate The dissolved substances of the plasma similarly represent a balance between the amount of materials ingested or formed in the various organs of the body especially the liver and the rate of disappearance

The following laboratory tests are utilized in the evaluation of hematological disorders blood volume complete blood counts including erythrocyte count hemoglobin determination leukocyte count and differential leukocyte count hematocrit determination, sedimentation rate, fragility test blood coagulation test for hemorrhagic diseases and tests for specific blood diseases such as anemia polycythemia leukemia and other diseases involving the leukocytes and diseases involving the blood platelets

Blood volume The normal adult body contains approximately 4500–5500 ml of blood which corresponds to about 7–8% of the total body weight It is decreased by severe hemorrhage dehydration or debilitating disease An increased volume is common in heart disease and in individuals living at high altitudes but the greatest increase is found in polycythemia vera (a condition characterized by the excessive production of erythrocytes)

Complete blood count The complete blood count
the physi

In the stained blood smear erythrocytes are non-nucleated biconcave disks measuring 5 5 9 5 μ in diameter When the cells contain excessive quantities of hemoglobin, they are distended and no longer biconcave Some of the cells are enlarged (macrocytes) others are small (microcytes) Still

Table 1 Normal values in a complete blood count

Procedure	Normal values
Erythrocyte count, males	4 500 000–5 500 000/mm³
females	4 000 000–5 000 000/mm³
Hemoglob n determ nation	
males	12 17 g/100 ml
females	11 15 g/100 ml
Leukocyte count	5000–10 000/mm³
D fferential leukocyte count	
Segmented neutrophilic leukocytes	55–65% (3000–6000/mm³)
Nonsegmented neutrophilic leukocytes	3 5% (150–500/mm³)
Eos nophils	1 4% (50–400/mm³)
Basophils	0 2ɔ–0 5% (15 50/mm³)
Lymphocytes	25 33% (1200–3000/mm³)
Monocytes	2–6% (100–600/mm³)

others show considerable variation in size (anisocytosis) and shape (poikilocytosis) often present in response to chronic blood destruction or blood loss from hemorrhage In the acute anemias distor tion in size and shape usually does not occur

Hemoglobin is a combination of iron and globu lin of which about eight different forms have been identified chiefly by electrophoretic separation The differences of molecular configuration are inherit able either as a dominant or recessive character Abnormal forms of hemoglobin often determine the shape of the erythrocyte such as in sickle cell disease hereditary spherocytosis and thalassemia

Leukocytes are considered in detail in the section on diseases involving leukocytes

Hematocrit determination After centrifugation the volume occupied by the packed cellular ele ments of the blood in relation to the total volume is referred to as the hematocrit The normal range for men is 42 52% for women 37–47% Variations from the normal usually parallel the hemoglobin and erythrocyte values but in pernicious anemia the hematocrit (and therefore the color index) is disproportionate In general anemias exhibit a low hematocrit value whereas polycythemias or de hydration reveal high values Calculation of cellu lar indices is made possible by relating the hema tocrit values to the number of erythrocytes and the hemoglobin concentration Normal values are shown below

Index	*Normal values*
Color index (CI)	0 9–1 1
Mean corpuscular hemoglobin (MCH)	27 32 $\mu\mu$g
Mean corpuscular volume (MCV)	80–90 μ^3
Mean corpuscular hemoglobin concentration (MCHC)	33–38%

This information is of value in the diagnosis of the many types of erythrocytic disorders particu larly pernicious anemia other macrocytic anemias congenital hemolytic anemia and the secondary anemias

Sedimentation rate When erythrocytes are per mitted to settle in their own plasma it has been observed that the rate of fall (sedimentation) is fairly constant within given limits For men by the Wintrobe technique the normal rate is 4–9 mm in 1 hour whereas for women it is 4–20 mm De creased sedimentation rates have been observed in polycythemia cardiac failure and sickle cell ane mia Increased rates have been associated with practically all infectious or inflammatory diseases myocardial infarction and malignant disease

Fragility test When erythrocytes are placed in an 0 85% (isotonic) salt solution the cells are not altered When the salt concentration is less than 0 85% (hypotonic) water enters the cells by osmo sis causing them to enlarge and eventually rupture (hemolyze) Normally in 0 45% saline less than 30% of the cells undergo hemolysis In the pres ence of increased erythrocyte fragility more than 70% of the cells hemolyze This procedure estab lishes or excludes the single disease process known as congenital hemolytic anemia

Blood coagulation tests The process of blood co agulation is extremely complicated as can be seen from the equations showing chemistry of blood co agulation For convenience the process has been di vided into three interdependent phases

Phase 1 $\left(\begin{matrix}\text{AHG}\\\text{PTC}\\\text{PTA}\end{matrix}\right)$ + $\left(\begin{matrix}\text{Platelet factor 3}\\+\\\text{Thromboplastin}\end{matrix}\right)$

Plasma factors

$+ Ca^{++} \rightarrow$ Thromboplastin

Phase 2 Thromboplastin + Proconvertin + $Ca^{++} \rightarrow$ Convertin

Convertin + Proaccelerin $\rightarrow$ Prothrombinase

Prothrombin + $\left(\begin{matrix}\text{Prothrombinase}\\+\\\text{?Platelet factor 1}\end{matrix}\right)$

$+ Ca^{++} \rightarrow$ Thrombin

Proaccelerin $\xrightarrow{\text{Thromb n}}$ Accelerin

Prothrombin + $\left(\begin{matrix}\text{Accelerin}\\\text{Prothrombinase}\\\text{Platelet factor 1}\end{matrix}\right)$

$+ Ca^{++} \rightarrow$ Thrombin

Phase 3 Fibrinogen + $\left(\begin{matrix}\text{Thrombin}\\+\\\text{?Platelet factor 2}\end{matrix}\right)$

$+ Ca^{++} \rightarrow$ Fibrin

Disturbances of blood coagulation may result from either congenital defects or acquired disease in this mechanism of blood clotting as follows

Congenital disease	*Acquired hemorrhagic diatheses*
Hemophilia	Complications of pregnancy
Hemophiloid dis eases	Production of anticoagulation factors
Afibrinogenemia	Stimulation of fibrinolytic sys tem
Deficiency of pro thrombin or ac cessory factors	Excessive blood transfusions
	Liver disease

The laboratory tests usually performed to elucidate the cause of the hemorrhagic diathesis are listed below

Test	*Normal values*
Bleeding time	1–3 *min*
Coagulation time (Lee and White)	6–13 *min*
Clot retraction time	Retraction starts in 1 hour complete in 24 *hours*
Prothrombin time	70–100%
Prothrombin conscription time	35–60 sec or more
Platelet count	150 000–300 000/mm³
Capillary resistance test	Less than 20 petechiae
Fibrinogen level	Over 125 mg 100 ml
Partial thromboplastin determination	50–100 *sec*

Specific blood diseases Most important of the specific blood diseases are the anemias and diseases involving the leukocytes

The anemias Anemia is characterized by a reduction in the number of erythrocytes in the amount of hemoglobin per unit volume of blood or in both Considerable confusion exists on the classification of the anemias but perhaps the most convenient is that based on etiology illustrated in the following outline

I Blood loss
  A Hemorrhage (due to trauma or disease)
  B Accelerated destruction of blood
    1 Toxic or infectious (pyogenic infections blood parasites or poisons)
    2 Acquired hemolytic factors (transfusion reactions erythroblastosis fetalis)
    3 Congenital structural abnormalities (sickle cell anemia congenital hemolytic anemia thalassemia)
    4 Accelerated reticuloendothelial function (hypersplenism)
II Decreased formation of blood
  A Depression of bone marrow activity
    1 Toxic or infectious (chronic infection renal disease or poisons)
    2 Mechanical displacement (tumor or osteosclerosis)
    3 Physical injury (radioactivity)
    4 Idiopathic atrophy
  B Deficiency of substances necessary for erythrocyte production
    1 Deficiency of essential vitamins (B_{12} B complex and C)
    2 Iron deficiency (due to inadequate absorption or chronic loss from hemorrhage)
    3 Diminished proteins (low intake or failure of absorption)
    4 Hormone deficiency (hypothyroidism)

Hemorrhage signifies the loss of blood from the vascular system either into the tissues or outside the body from the skin lungs or gastrointestinal tract In the acute hemorrhage there are no striking abnormalities of the erythrocytes other than reduction in total volume number and total hemoglobin of the blood This is reflected by decreased blood volume decreased erythrocyte count and hemoglobin and decreased hematocrit During recovery the reticulocyte count is increased *See* HEMORRHAGE

In chronic hemorrhage or other forms of chronic blood destruction there is reflected in addition to the foregoing considerable variation in the size and shape of the erythrocytes and cellular indices Examination of the bone marrow in such conditions reveals hyperplastic activity as evidence of the restorative process In those diseases which result from congenital hemoglobin abnormalities the characteristic cells can be identified in the peripheral blood and the abnormal hemoglobin detected by electrophoresis In hypersplenism usually all cellular elements of the blood are decreased

Those anemias due to disease of the bone marrow are easily identified in some instances by the histological and cytological examination of the bone marrow as for example in osteosclerosis and in the presence of cancer In the other conditions however the diagnosis is far more difficult requiring exhaustive ancillary laboratory investigations Those anemias which result from a deficiency of essential vitamins are referred to as the macrocytic anemias the most familiar example of which is pernicious anemia These are readily identified by macrocytosis elevated erythrocyte indices and characteristic bone marrow picture The other deficiency anemias are diagnosed by suitable biochemical tests of the blood

Polycythemia An increase in the number of erythrocytes per unit of blood as well as an increase in the total volume of blood is characteristic of polycythemia Polycythemia vera the primary form of the disease has no known cause Such patients are subject to death by thrombosis in a vital organ or the development of leukemia Secondary polycythemia is a compensatory response to a stimulus such as chronically reduced oxygen supply associated with living at high elevations chronic heart failure and pulmonary disease *See* THROMBOSIS *see also* EMBOLISM

Diseases involving the leukocytes Increases in the total leukocyte count above 10 000/mm³ are referred to as leukocytosis and leukopenia signifies a reduction below 5000/mm³ of blood

Leukopenia This is most commonly caused by viral infections but it may be encountered in some bacterial infections such as typhoid fever or in parasitic infestation such as malaria Occasionally it also reflects a noninfectious condition such as toxic depression of the bone marrow by poisons and some forms of leukemia *See* LEUKOPENIA

Leukocytosis This is most commonly caused by bacterial infection or inflammation of tissues from

any cause such as acute appendicitis The degree of leukocytosis found in most infections is in the range 10 000–25 000/mm³ although in rare conditions it may increase to 100 000/mm³ giving rise to the designation leukemoid reaction (resembling leukemia) In certain conditions such as strenuous exercise pregnancy or anesthesia a leukocytosis of 20 000/mm³ may be found and considered to be completely normal for that situation *See* CIRCULATION DISORDERS

Types of leukocytosis Most leukocytosis resulting from infection is characterized by an increase of neutrophilic leukocytes associated with an increase in the more immature forms the stab leukocytes A greater than average number of eosinophilic leukocytes (eosinophilia) is associated with allergy skin diseases Hodgkin s disease (a cancer of lymphoid tissue) and infestation with metazoan parasites Basophilic leukocytes however are not appreciably increased except in chronic myelogenous leukemia Lymphocytosis (increased number of lymphocytes) is found chiefly in viral infections such as whooping cough infectious mononucleosis mumps measles and sometimes in syphilis and tuberculosis Abnormal lymphocytes (immature forms with degenerative changes) are seen exclusive of leukemia in infectious mononucleosis Monocytosis (increase in monocytes) is uncommon and when present is usually slight It is seen with some degree of regularity in patients with active tuberculosis bacterial endocarditis brucellosis some bacillary dysenteries malaria rickettsial disease and Hodgkin s disease The basophils are rarely increased except in association with myelogenous leukemia *See* BACILLARY DYSENTERY BRUCELLOSIS ENDOCARDITIS MALARIA RICKETTSIOSES TUBERCULOSIS

Leukemia This is a disease of unknown cause which is essentially a cancer involving the leukocytes of the blood characterized by a marked increase in the production of these cells and a fatal termination The classification of leukemia is based upon the course of the disease and the predominating type of cell Therefore there may be either acute or chronic lymphocytic granulocytic or monocytic leukemia rarely eosinophilic

The bone marrow in leukemia consistently reflects the disease by the marked proliferation of the abnormal cell type which invades and replaces the normal tissue of the bone marrow The peripheral blood on occasion exhibits a low total count referred to as aleukemic leukemia but usually the predominating leukemic cell type is present in increased numbers 100 000 or more with a marked shift to the immature cell type The normal cells of the peripheral blood are either reduced in number or absent The erythrocytes usually are greatly reduced in number exhibiting considerable variation in size and shape and loss of hemoglobin content The blood platelets may be increased early in the disease but usually are decreased so that hemorrhagic phenomena supervene in the patient *See* LEUKEMIA

Diseases involving blood platelets Platelets (thrombocytes) are nonnucleated fragments derived from the cytoplasm of the megakaryocytes in the bone marrow measuring 2–4 μ in diameter Normally there are 150 000–300 000 platelets/mm³ of blood They are intimately associated with the process of blood coagulation A reduction in their number is referred to as thrombocytopenia of which there are two types One is referred to as a primary idiopathic thrombocytopenia for which there is no known cause A secondary form is associated with a depression of the bone marrow due to drugs or other causes On rare occasions a marked increase in the number of platelets in the blood is found (thrombocythemia) due either to splenectomy (operative removal of the spleen) or to unknown causes *See* SPLEEN DISORDERS

BLOOD CHEMISTRY

The biochemical composition of the blood plasma is often characteristically altered in disease The major chemical constituents of importance to the physician and subject to frequent analysis in the routine laboratory are listed below

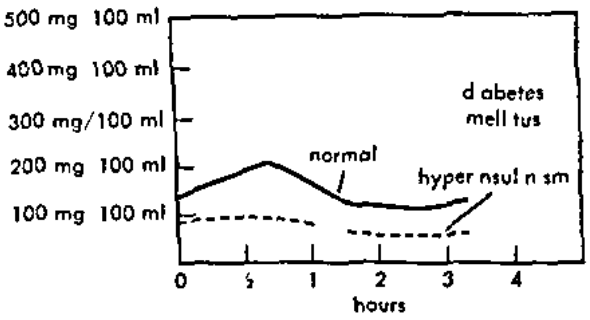
Glucose	Electrolytes
Nonprotein nitrogen	Calcium
Creatinine	Chloride
Uric acid	Phosphorus
Urea	Sodium
Total NPN	Potassium
Proteins	CO_2 combining power
Albumin	*pH*
Globulin	Lipids
Bilirubin	Cholesterol
Enzymes	Cholesterol esters
Amylase	Neutral fat
Lipase	Phospholipids
Alkaline phosphatase	Fatty acids
Acid phosphatase	
Transaminase	

Glucose The most important sugar of the blood is glucose the normal value for which is 90–120 mg/100 ml When the glucose level is elevated the patient has hyperglycemia and conversely hypoglycemia when it is low Hyperglycemia may be associated with diabetes mellitus hyperthyroidism hyperpituitarism coronary thrombosis and pregnancy whereas hypoglycemia occurs in cases of hyperinsulinism hypothyroidism hypopituitarism liver disease destruction of the adrenal glands and starvation

Diabetes mellitus a disease of the pancreas whereby insufficient insulin is secreted is characterized by hyperglycemia When the blood glucose level reaches 160 mg/100 ml or more the glucose spills into the urine In severe diabetes values of 600–1000 mg/100 ml of blood have been reported *See* PANCREAS DISORDERS

To assist further in the diagnosis of diabetes mellitus a glucose tolerance test has been devi given amount of glucose is ingested by the lowing which it is absorbed from t

into the blood In the normal individual the blood glucose level rises to less than 200 mg within 30–60 m n and a normal level is restored within 2 hours In true diabetes blood glucose concentrations of 300–500 mg 100 ml of blood are found and remain elevated for several hours (see illustration)



Compar son of normal blood glucose level w th those n d abetes mell tus and hyper nsul n sm

Hyperinsulinism is the result of an excess of in sulin in the blood caused by hypersecretion from the islets of Langerhans or by a tumor of the pan creas In this condition fasting blood glucose values of 40–60 mg/100 ml have been found associated with emotional disturbances or even coma Glucose tolerance tests of such patients reveal values which rarely exceed the normal fasting level (100 mg/100 ml) and may drop to levels of 40–50 mg 100 ml

Nonprotein nitrogen Chemical substances con taining nitrogen are divided into proteins and non protein nitrogen The latter substances are the waste products of metabolism which are to be ulti mately removed from the blood by the kidneys When these substances accumulate in the blood they usually indicate an abnormality in the excre tory function of the kidneys The following list gives the substances which belong to the general category of nonprotein nitrogens

Substance	*Normal values*
Creatinine	1 2 mg/100 ml
Uric acid	2–4 mg/100 ml
Urea nitrogen	10–15 mg/100 ml
Total NPN	25–35 mg/100 ml

Increased concentrations of creatinine are found in kidney disease urinary obstruction some forms of liver disease and intestinal obstruction Uric acid is increased chiefly in gout some forms of kid ney disease arthritis leukemia polycythemia ec lampsia and dia betes It is decreased primarily in severe degenerative disease of the liver Urea the principal waste product of the metabolism of pro teins is increased primarily in kidney disease and in urinary obstruction but sometimes in intestinal obstruction some forms of poisoning heart fail ure dehydration and infections It is decreased in acute liver destruction *See* COLIC KIDNEY DISOR DERS LIVER DISORDERS TOPICS URINARY BLADDER DISORDERS

Table 2 Significant diseases and protein values

Disease	Albumin	Globulin	Total protein
Nephritis	Decreased	Normal	Decreased
Multiple myeloma	Normal	Increased	Increased
Hepatitis	Decrease l	Increased	Decreased
Cirrhosis of the liver	Decreased	Normal	Decreased

Proteins The blood proteins comprise ch efly albumin several types of globulins antibodies en zymes and hormones In the routine protein deter mination albumin and the globulins only are of significance Their normal serum values are

Albumin	3 5–5 5 g/100 ml serum
Globulin	1 3–3 3 g/100 ml serum
Total protein	6–8 g/100 ml serum

The major function of the blood protein is to fur nish metabolic energy and nitrogen for tissue growth and to maintain the water balance between blood and tissues When blood proteins are de creased the capacity of the blood to hold water i diminished whereupon it diffuses into tissues caus ing edema The most significant diseases in which abnormal protein values may be expected are pre sented in the accompanying table *See* EDEMA

Amylase is increased primarily in acute pancre atitis mumps hyperthyroidism peritonitis and gall stones Usually elevated values in the blood are evanescent lasting only one or several days and are diagnostic of pancreatitis

The chief diagnostic value of lipase is in acute or chronic pancreatitis where elevated values gen erally last a week or more

Alkaline phosphatase is derived primarily from the bone It is increased in rickets hyperparathy roidism carcinoma of the bone Paget s disease and a few other related diseases It is decreased in scurvy hyperparathyroidism and chronic nephriti

Acid phosphatase is normally derived from the prostate gland and other tissues Increased values are found in carcinoma of the prostate gland hy perparathyroidism and acute granulocytic leuke mia

Transaminase is derived chiefly from muscle pri marily skeletal muscle but also from cardiac mus cle and the liver Elevated values are seen prima rily in destructive lesions involving these organs It has its most important application in patients with coronary occlusion with myocardial infarction and in acute hepatitis *See* INFARCTION

Electrolytes These elements have a complex role in maintaining the physiological balance of the body They maintain the normal neutral pH (7.3–7 5) of the blood by neutralizing the acidity of waste materials control the water balance and par ticipate in metabolic functions and blood coagu lation Slight deviations in pH may cause illnes and marked deviations may cause death The im portant electrolytes commonly assayed in the blood are included in the following table together with their normal values

Table 3 Important electrolytes in blood

Electrolyte	Normal value	
	meq/liter	mg/100 ml
Calcium	4 5 5 5	9–11 5
Chloride (as NaCl)	96–10ɔ	4ɔ0–500 (whole blood) 5ˀ0–620 (serum)
Phosphorus		2 5–4
Sod um	13ɔ 152	300–330
Potassium	4 1 5 6	16–22
CO_2 combining power	23 34 (adults)	5ɔ 75 vol %
pH		7 3 7 5

Increased calcium values are associated with hyperparathyroidism and hypervitaminosis D Decreased values occur in hypoparathyroidism vitamin D deficiency and sprue Addison's disease (degeneration of the adrenal cortex) is also associated with disturbance of electrolyte values especially sodium potassium and chloride Increased *sodium concentration usually results in water retention* (edema) Excessive or decreased potassium may be fatal primarily because of its effect on the heart

Blood lipids The lipids or fats of the blood are derived from ingested food They are broken down in the intestine by enzymatic action saponified by bile and salts and absorbed into the intestinal epithelium where they are resynthesized to fats Following this they are deposited in the intestinal lymphatics and carried by way of the thoracic duct into the blood Because lipids are insoluble in watery solution in order to solubilize the larger neutral fat particles in blood they are broken up into an emulsion partly by the churning action of blood into small particles (chylomicrons) which are coated with a protein layer to keep them in *suspension Other lipids* such as cholesterol and fatty acids are made soluble by combination with fatty acids and proteins to form lipoproteins *See* LYMPHATIC SYSTEM

Lipids	*Normal values*
Total lipid	<900
Neutral fat	<400
Cholesterol	150–250
Cholesterol esters	60–75%
Phospholipids	175–275
Cholesterol phosphorus ratio	<1 00

The blood lipids are important for the normal nutrition of the human body the production of hormones and *participation in cellular structures The* lipids of the blood appear to be one of the major factors in the production of coronary artery disease which leads ultimately to death by coronary artery occlusion and myocardial infarction

Miscellaneous biochemical tests There are numerous additional chemical tests that are performed upon the blood when indicated Some of the more important follow

Liver function test The liver is one of the largest organs in the body weighing about 1500 g (approximately 3 lb) It has numerous functions of which some major ones are (1) manufacture and distribution of many of the essential substances for the proper nutrition of the body, (2) storing of certain food substances and (3) detoxification of poisons A large number of blood chemical determinations are designed for the study of the functional capacity of the liver Because it functions in so many different ways it is possible for some portions to be operating normally while other portions may be abnormal For this reason an evaluation of liver function must always be made with a multiplicity of tests designed to measure the different functions The most useful laboratory procedures in part to evaluate the functional capacity of the liver are bromsulfalein determination thymol turbidity cephalincholesterol flocculation total cholesterol and cholesterol esters albumin and globulins of the blood with A/G ratio transaminase of the blood prothrombin time and bilirubin determination Some of these such as the bromsulfalein the cephalin cholesterol flocculation and the protein determinations are primarily useful for parenchymatous liver disease For the more acute disease the blood transaminase vitamin K thymol turbidity cholesterol and cholesterol esters are extremely useful

Disorders of the liver may be associated with jaundice an excess concentration of bile in the tissues Jaundice may result from one of several disease processes (1) obstructive jaundice which results from a block of the bile ducts (2) hepatic jaundice which results from severe disease of the liver parenchyma and (3) hemolytic jaundice in which there is an excessive destruction of the erythrocytes of the body with a release of excess hemoglobin which is converted into a bile pigment (*see* JAUNDICE) To evaluate the basis for the jaundice the following chemical determinations may be performed the icterus index serum bilirubin Van den Bergh reaction urinary bile urinary urobilinogen and fecal urobilinogen

Either the total bilirubin or the icterus index may be used to determine the extent of the accumulation of bile in the blood Daily repetition of *the test is often required to determine the* progress of the disease The Van den Bergh test which separates the bile pigment into two components the direct and the indirect bilirubin diagnostically differentiates the obstructive and hemolytic types of jaundice

Iron Practically all of the iron in the blood is *in the form of* hemoglobin *that substance used for* the transport of oxygen and carbon dioxide in the blood The normal concentration of iron in blood is 60–120 mg/100 ml In iron deficiency anemias this is diminished in polycythemia and hemochromatosis it is increased

Vitamins Only vitamins A C K and F are susceptible to quantitation Deficiency of vitamin A is associated with some forms of skin disease night blindness vitamin C deficiency with vitamin K with blood clotting deficiency

MIN

Protein bound iodine This substance presumably represents the thyroid hormone thyroxin and its concentration in the blood parallels thyroid secretory activity Normal values are 4–8 μg/100 ml of blood Increased values are associated with hyperthyroidism decreased values with hypothyroidism *See* METABOLIC DISORDERS

BACTERIOLOGY AND PARASITOLOGY

The microbiological examination of material from human patients requires special techniques for the detection and identification of infecting organisms These include direct examination of suspected material either as wet mounts or stained smears cultural techniques on numerous artificial media inoculation of laboratory test animals such as the guinea pig white mice rats and pigeons and reaction with specific immune sera

The subject of microbiology has been dealt with in detail under the various disease entities As applied to clinical pathology assistance for the detection of the offending organism is required from the attending physician because the many techniques that may be used differ greatly in their application depending on the nature of the infection The dictates of good medical practice require that no antibiotic be administered prior to bacterial examination lest the microorganisms be inhibited from growth on artificial culture media Techniques for detecting tubercle bacilli are different from those for pyogenic organisms fungi and viruses In acquiring the specimen for testing proper technique must be used to secure the infected material without contamination from the contiguous skin or from other tissues When such precautions are taken it may be assumed that the cultured microorganisms are the infecting agents of the patient Some tests exist to help differentiate pathogenic from non patho en

[illegible] microbiology to ascertain which of the available drugs are most effective in dealing with the infecting microorganism This information is secured usually by placing small quantities of each antibiotic impregnated paper disk in contact with solid culture media on which the organisms are growing Where sensitivity is present the m[illegible] fail to grow i[illegible] absent no su[illegible] technique th[illegible] proper drug to cure a specific infection

FECAL AND SPUTUM ANALYSIS

Feces This represents the undigested or partially digested residue of ingested food together with bacteria secretions and excretions of the gastrointestinal tissues and ancillary organs In the normal adult the daily excretion of feces is rarely in excess of 250 g *See* GASTROINTESTINAL TRACT DISORDERS

Examination of the feces is of value in diseases of the gastrointestinal tract as well as those of the pancreas and liver Tests which reveal the presence of blood signify an ulcerative lesion somewhere in the gastrointestinal tract either inflammatory or as a result of cancer If the blood is black (met hemoglobin) the bleeding is usually from a point high in the intestinal tract such as the esophagus stomach or small intestine If it is red and the erythrocytes are still preserved it usually signifies bleeding from a point in the large intestine

Under normal conditions the nitrogen carbohydrate and fat of the stool rarely exceed 25% of the total dry weight In pancreatic disease or primary disease of the small and large intestine as in sprue and in obstruction of the bile ducts the weight of the stool is far greater and the total fat may be increased to as much as 70% In such conditions the stool is pale may contain gas bubbles appear greasy and have a foul odor

One of the most important examinations of the stool is that which uncovers the presence of metazoan parasites such as *Entamoeba histolytica* and various types of tapeworm (*Taenia saginata*) pinworms (*Oxyuris vermicularis*) and others

Bacillary infections which cause dysentery such as the typhoid group (*Salmonella*) are frequently detected by culture of the stool This is done with the aid of specialized media which inhibit the growth of normal bacterial flora and permit the growth and identification of pathogenic organisms *See* TYPHOID FEVER

Sputum Sputum represents the secretory material from the lower respiratory tract (lungs and bronchi) Saliva and nasopharyngeal secretions are not part of the sputum and should not be examined as such Of importance in any examination of sputum is the volume odor color and cellular and bacterial content Normally the sputum is clear to slightly opaque somewhat frothy and contains a small amount of mucoid material and some epithelial cells In bronchiectasis (dilation of the bronchi of the lungs) the volume of sputum may exceed 100 ml/day When an infection is present the sputum may be opaque and contain many pus cells as well as blood At this time it becomes sticky and tenacious as a result of increased quantities of fibrin and mucus In chronic heart failure the sputum becomes rust colored as a result of the presence of many large phagocytic cells containing hemosiderin (heart failure cells) A bloody sputum may be seen also in association with heart failure and hemorrhagic degenerations in the lung The odor of the sputum may become foul depending upon the type of bacterial infection present and the existence of necrotic tissue *See* RESPIRATORY SYSTEM DISORDERS

Cellular examination of the sputum is important particularly for the identification of heart failure cells pus cells elastic fibers (significant of lung destruction) presence of eosinophils (usually associated with bronchial asthma), and the presence of bacteria and fungi An important recent development in the examination of sputum is a new preparative and staining technique for the micro-

scopical detection of cancer cells in smears of the sputum (the Papanicolaou technique)

SEROLOGY

Serologic tests are based upon antigen antibody reactions which are a reflection of the humoral response of the body to disease In clinical medicine the antigen antibody reaction implies the introduction into the body of an antigenic substance which may be a disease producing organism a foreign tissue or even foods with the production of antibodies against these substances chiefly by the reticuloendothelial system Basically antigens are protein substances but they may be complexed with lipids and carbohydrates The antibodies are usually specific in their capacity to neutralize or destroy the antigen but occasionally nonspecific antibody systems are developed The concentration of such antibodies is a function of the dose and type of antigen time chemical composition and the variable capacity of the host to produce them (*see* SEROLOGY) The types of antibodies produced and their reactions are listed as follows

Antibody	*Reaction*
Agglutinins	Agglutination or clumping of cells
Precipitins	Clumping of molecular aggregates forming a precipitate
Antitoxins	Neutralization of toxic substances
Lysins	Rupture or dissolution of cells
Opsonins	Sensitization of antigens to facilitate their destruction by phagocytic cells

Based on the antigen antibody reaction are the following clinical laboratory tests

Test	*Laboratory application for identification of*
Agglutination reactions	Brucellosis Tularemia Typhoid fever Paratyphoid fever Bacillary dysentery Rickettsial diseases Leptospiral infection
Heterophil agglutination tests (nonspecific)	Infectious mononucleosis
Cold hemagglutination	Viral infections
Precipitin tests	Syphilis Proteins Blood stains (medicolegal)
Toxin antitoxin reactions	Diphtheria (Schick test) Scarlet fever (Dick test) Viral disease (protective tests)
Complement fixation tests (nonspecific)	Syphilis Gonorrhea Antibody titration

BLOOD BANKING

The discovery by K Landsteiner in 1900 of the specific genetically determined antigenic character of the erythrocytes of the blood opened new frontiers in the field of hematology This led to the classification of human erythrocytes into four major groups A B O or AB (international classification) These antigens (agglutinogens) are present on the surface of the erythrocyte and in the serum of blood containing these cell types there are naturally occurring complementary antibodies referred to as agglutinins *See* BLOOD GROUPS.

Table 4 Agglutinogens and agglutinins of the major blood groups

Blood group (agglutinogens)	Agglutinins (serum)	Incidence in population %
AB	o	5
A	b	10
B	a	40
O	ab	50

Cross matching A technique has been developed with the above information for the pretesting of blood to determine its compatibility for blood

cipient are mixed with the donor serum this represents the minor cross-match technique If recipient serum contains agglutinins identical to the donor cell then upon mixing the erythrocytes will agglutinate or hemolyze Such bloods are incompatible and therefore dangerous to transfuse Only when the cross match techniques reveal no agglu

1926 by K Landsteiner A Wiener [illegible] R Stetsen These newer blood factors were designated agglutinogens M N and P They differ from the major blood groups in that no agglutinins of similar identity are found occurring naturally in the serum and therefore they lack importance in blood transfusion testing

Rh factor In 1937 Landsteiner and Wiener initiated the discovery of a new set of blood factors referred to as the Rh system These factors were so designated because they were discovered in connection with experiments using the blood of rhesus monkeys Since then numerous additional agglu [illegible] been discovered and named after the

positive fetus. Such antigens may be responsi for serious transfusion reactions if previous zation of the recipient has taken place

Not only for detection of prior sensitization by any of these antigenic agglutinogens but also as additional safeguard against incompatibility of blood in transfusions an elaborate system of testing and cross matching has been evolved in the clinical laboratory based on systems of immunological testing This includes blood typing for each of the major blood and Rh factors major and minor cross matching for major compatibility of blood direct and indirect testing with Coombs serum (specific human protein antisera) for Rh and other sensitization and titering techniques for degree of sensitization

In addition information derived from the inheritance of blood grouping has evolved a system of medicolegal importance namely the technique of paternity testing which supplies information which can be used in disputed parenthood although for paternity exclusion only It is probable that blood groups exist which have yet to be discovered

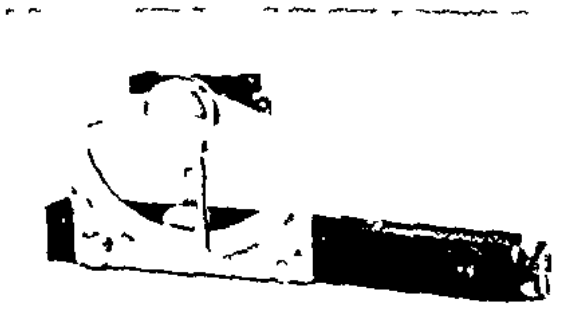
METABOLIC STUDIES

The basal metabolic rate (BMR) is a measure of heat production based on oxygen consumption in the fasting individual at complete rest As such it is an indirect measure of thyroid activity and is largely replaced by more direct methods such as the determination of the concentration of protein bound iodine (thyroxin) or the uptake of radioactive iodine (I^{131}) by the thyroid gland

The BMR is usually expressed in per cent variation above or below the normal for the age and sex of the patient Values above +10% are usually associated with hyperthyroidism and those below −10% with hypothyroidism It must be borne in mind that physiological variations in the human body such as menstruation nervousness or physical activity or diseases such as fever hypertension leukemia and heart failure all can produce an increase in metabolism thereby masking hypothyroidism or supporting a false positive diagnosis of hyperthyroidism *See* SPECIALIZED TISSUE [R S S]

Clinometer

A hand held surveying device for measuring vertical angles It consists of a sighting tube surmounted by a graduated vertical arc with an attached level bubble A 45° mirror inside the tube permits the observer to see the bubble at the same time he sights a point with a horizontal wire Manipulation of the vertical arc brings the bubble to center in coincidence with the sighted point, the vertical angle is indicated on the arc The clinometer is used mainly to determine slope angles for reduction of measured slope distance to horizontal distance With the arc set at 0° the clinometer also can be used as a hand level *See* SURVEYING [R H D O]



Clinometer (*Keuffel and Esser Co*)

Clipping circuit

An electronic circuit that prevents the transmission of any portion of an electrical signal that exceeds a prescribed amplitude, by effectively opening the transmission path

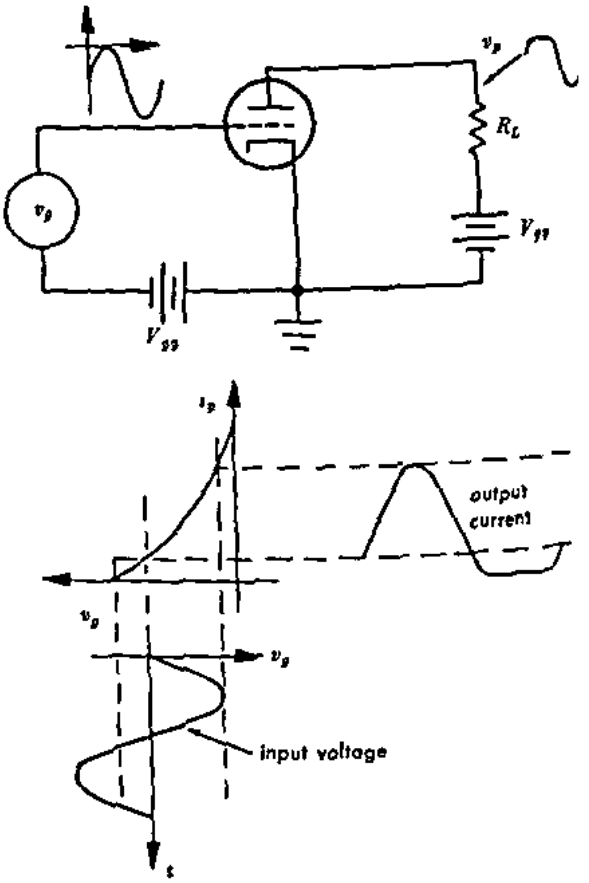


Fig 1 Triode vacuum tube clipper

A transistor or multielectrode vacuum tube may be used as a clipper by biasing its input so that the device is out of its operating range for a portion of the amplitude of the input signal as shown in Fig 1 for a triode vacuum tube The graphical construction using the dynamic transfer characteristic for a particular value of R_L shows the input output relationship The bias voltage V_{gg} makes a portion of the input signal sufficiently negative so that plate current will not flow This results in a clipping of the output current waveform and consequently of the output voltage waveform *See* BIAS (ELECTRON TUBE)

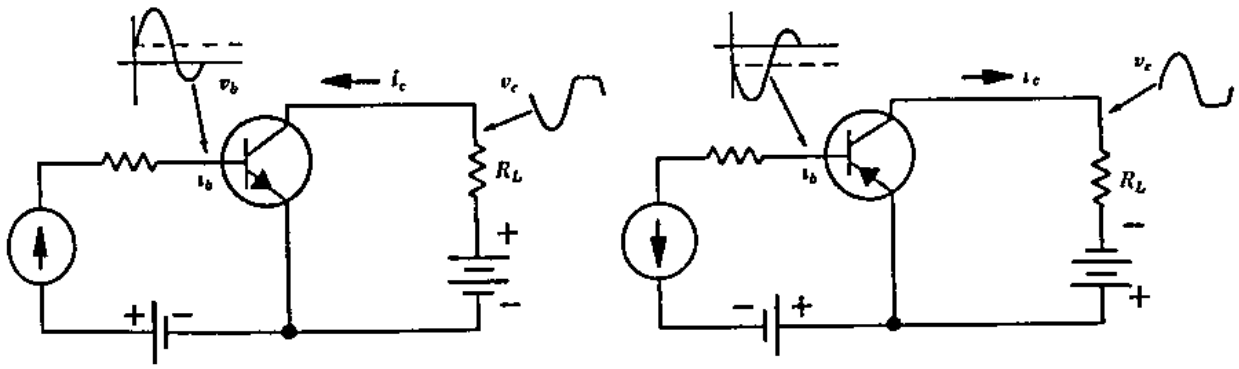


Fig 2 Transistor clippers

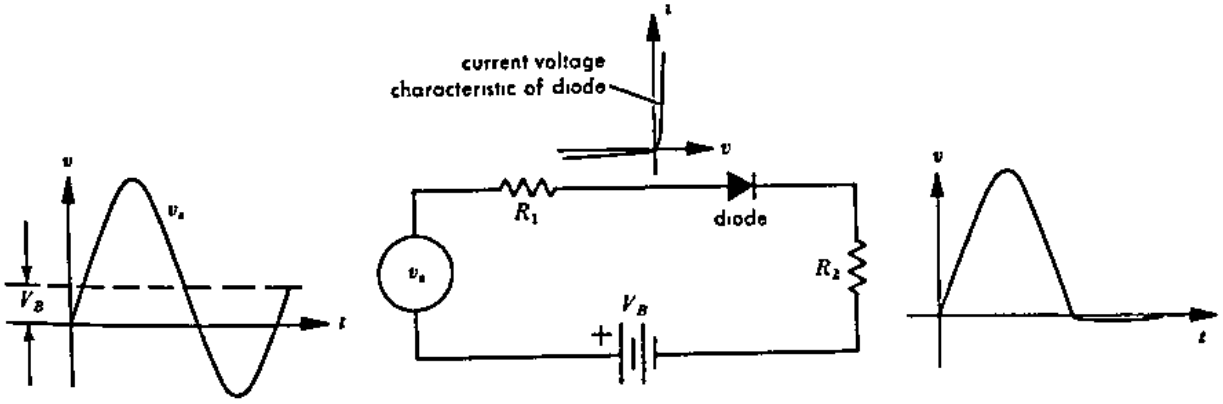


Fig 3 Series diode clipping

The use of transistors in a similar arrangement provides an additional versatility because of the availability of both *p n p* and *n p n* types The one chosen depends on the desired clipping polarity Figure 2 illustrates the two common emitter clippers *See* TRANSISTOR CONNECTION

Semiconductor or vacuum diodes function as clippers when inserted in the signal path in such a manner that they are forward biased (a low resistance) for the portion of the signal to be transmitted and reverse biased (a high resistance) for the portion of the signal above the desired clipping amplitude Such diode clipping is illustrated in Fig 3 If the resistance of the diode in its forward biased mode is made low compared to the source and load resistances R_1 and R_2 the output will be a replica of the input as determined by the voltage divider action of R_2 and R_1 When the potential on the input side of the diode becomes negative, the diode enters its reverse-bias state and becomes essentially an open circuit in the transmission path This condition is approximated if the reverse resistance of the diode is several orders of magnitude greater than R_1 and R_2 Clipping of the positive portion of the waveform may be achieved by reversing the polarity of the bias voltage and of the diode

The term clipper is sometimes used more broadly to include the function of limiting (*see* LIMITER CIRCUIT) Limiting and clipping circuits are often used together or separately to achieve essentially the same result For other wave shaping circuits *see* WAVE SHAPING CIRCUITS [C M C]

Clock

A device for indicating the passage of time Most clocks contain a means for producing a regularly recurring action, such as the swing of a pendulum the oscillation of a spiral spring and balance wheel, the oscillation of a piezoelectric crystal, or the comparison of a high frequency signal with the radiation from the hyperfine structure of the ground state of atoms (*see* ATOMIC CLOCK, QUARTZ CLOCK WATCH) The present article describes the refinements of mechanical clocks

Basic movement. The recurring action of a mechanical clock depends on the swing of a pendulum or the oscillation of a balance wheel and balance spring or hair spring mechanisms capable of repeating their cyclic movements with great regularity A counting mechanism, consisting of a gear train with calibrated dial and indicating hands, sometimes with a striking mechanism, marks the number of oscillations that have occurred although the graduations are in seconds minutes, and hours A weight or spring ordinarily supplies power to operate the oscillating and the counting mechanisms However, temperature changes, accelerations, automatic windings, or electric power may provide the power (The conventional electric clock is not an independent timepiece but is a repeater whose accuracy depends on a remote primary clock) Usually an escapement transmits power from the counting mechanism to the oscillating mechanism The accuracy of a clock c primarily on the escapement

Escapements Figure 1 depicts an anchor or recoil escapement Anchor A is connected loosely

pallet P_1 or P_2 [illegible] tain oscillation The other pallet then checks an other tooth the curve of the pallet forcing the wheel slightly backward The reaction helps to reverse the pendulum swing and to correct for circular error

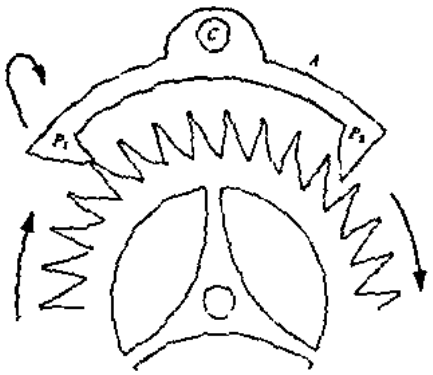


Fig 1 Anchor escapement common in domestic pendulum clocks tends to compensate for changes in amplitude of swing because of irregularly cut gears and varying lubrication

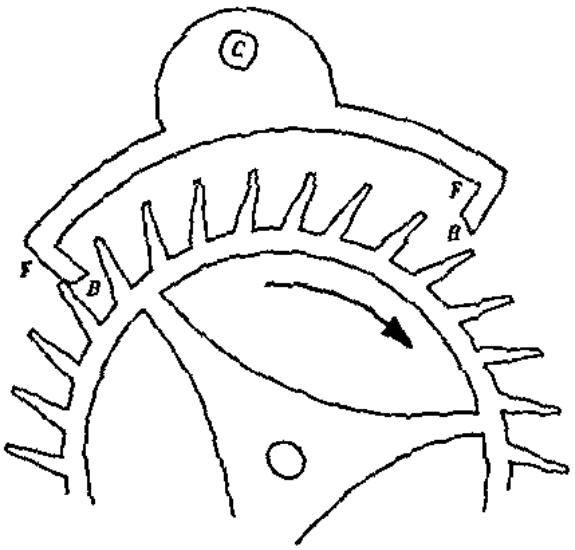


Fig 2 Dead beat escapement although lacking the corrective feature of the recoil type gives better performance if well made

Figure 2 shows a dead beat escapement Faces F are circles about C so that the wheel is stationary except near midswing when a thrust on B allows a tooth to escape Figure 3 shows a lever escapement in which a balance wheel swings through a much larger angle than does a pendulum Balance wheel and escapement are connected only while impulse pallet I is in a notch of lever L As I enters a notch it pushes the lever and then receives an impulse from it Disk D and safety pallet S prevent the lever from moving accidentally be

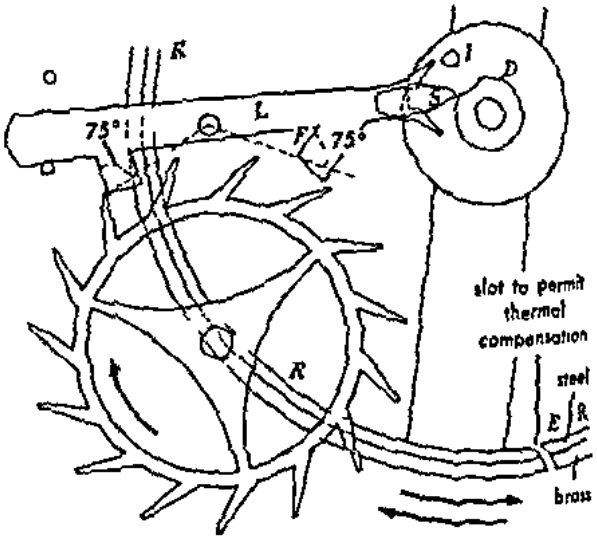


Fig 3 Lever escapement used in good spring clocks and watches is detached from the balance wheel during most of a cycle, thus promoting accurate time keeping

fore I returns, thus the mechanism tolerates appreciable vibration The escapement pallets are similar to those of Fig 2, but faces F are drawn or inclined so that the escape wheel moves slightly forward after each tooth locks, this motion pulls S clear of D, leaving the balance wheel completely detached *See* ESCAPEMENT

In the escapement of Fig 4, the balance wheel is completely detached except for three brief action periods (1) when pallet P presses detent D to unlock catch L, (2) when an impulse is being given to pallet I, and (3) when P lifts gold spring G on its return half swing *See* CHRONOMETER

Power supply. A weight gives uniform power but a spring develops less force as it runs down A fuzee by which a cord or chain is unwrapped from

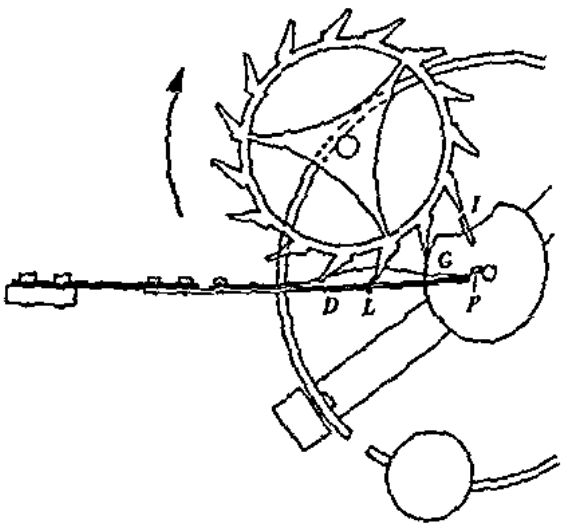


Fig 4 Escapement used in ships chronometers is sensitive to sudden movements but otherwise can keep within 1 sec/day pallets need no oil

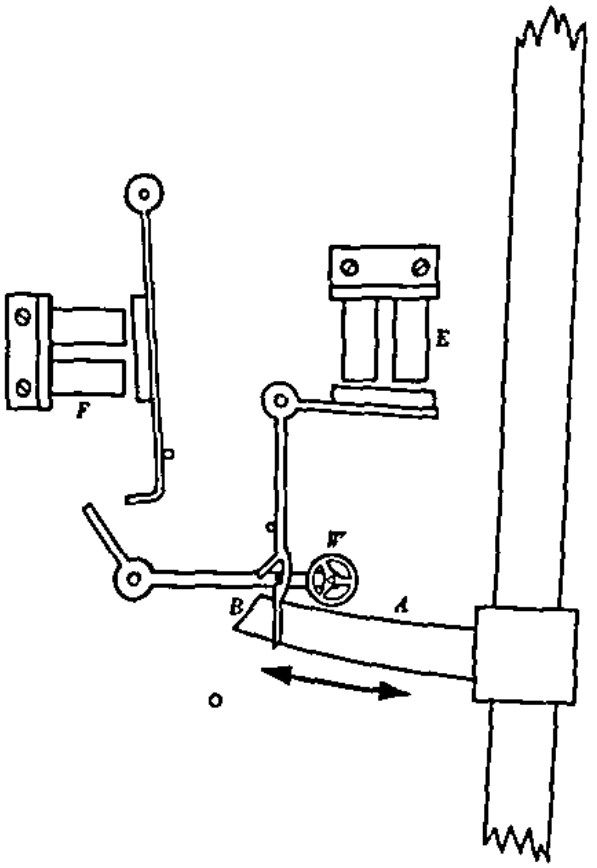


Fig 5 In Shortt free pendulum clock the master has only a pendulum and impulse giver escapement and counting gears are in a separate slave clock (not shown)

an increasing spiral on the first gear provides uniform force from a spring Alternatively there may be a remontoir with a small secondary spring driving the clock and being rewound frequently by the mainspring or by an electric motor

Wind and snow apply large force to the hands of outdoor turret clocks A gravity escapement isolates the pendulum from such forces In this design first used on the Great Westminster Clock (Big Ben) which has run since the mid 1800s with nearly chronometric accuracy the escape wheel alternately lifts two weighted arms away from the pendulum as it swings out and releases them alternately against the pendulum as it swings back The maintaining pushes come from the weighted arms rather than directly from the driving power

Temperature compensation The rate of a pendulum or balance wheel decreases if it expands with rising temperature Expansion is counteracted by using two metals of different expansion coefficients In a compensated balance wheel rim R is of brass and steel fused together and cut (Fig 3) Small screw weights added near free end E increase the effect near the spoke they counteract it Alternatively the hair spring can be of an alloy that changes in stiffness with temperature

Shortt clock For still greater accuracy in the Shortt or free pendulum clock a master pendulum is enclosed in an airtight and nearly evacuated case in a constant temperature cellar This pendulum swings freely for about 30 sec until wheel W is released by electromagnet E and rolls along arm A attached to the pendulum rod (Fig 5) Near the end of the swing wheel W rides down slope B giving the pendulum the slight impulse needed to maintain oscillation for another 30 sec In falling off wheel W triggers the circuit and is reset by electromagnet F The trigger pulse also serves as a synchronizing signal to a slave clock which is a complete clock with pendulum and indicating mechanism If the slave is slow the pulse accelerates one swing of its pendulum *See* HOROLOGY *see also* TIME [R DE A]

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Clock control systems

Systems in which a timing device is used to generate the control function also known as time-controlled systems A common example of a clock control system is the household alarm clock In this device the instant of time at which a buzzer sounds an alarm is controlled by a clock

A clock control system contains two essential components a timing device and a controlled process or controlled device The areas of application of such control systems range from the commonplace sounding of an alarm clock to the control of complex sequences of events in guided missiles and satellite launchers Clock control systems are usually open loop control systems since the control action is dependent only on the system input elapsed time in this case *See* OPEN LOOP CONTROL SYSTEM

There are many different types of timing devices These devices may be divided into five functional classes

1 Time switch A time switch runs continuously and opens and closes electrical contacts at preset instants of time They are used in industrial plants for turning on lights and the heating system and to preheat solder pots ovens and other equipment before the start of the working day For another example of the use of a time switch *see* TRAFFIC CONTROL SYSTEMS

2 Time delay relay This device has a preset time delay or time lag between the energizing or deenergizing of the time delay device and the subsequent operation of the contacts which actuate the load For example time-delay relays are used to delay the application of plate voltage in electronic systems until after the heater voltage has been applied in order to prolong vacuum tube life

3 Interval timer An interval timer operates a set of contacts during a preset time interval and at the end of the interval returns the contacts to

their normal positions This device is similar in function to a time delay relay except that the time interval is controlled much more accurately and the time interval may be many times longer than achievable with time-delay relays Examples of the use of interval timers are the control of exposure time in photographic reproduction processes and the control of the duration of a spot welding operation

4 Time-cycle controller This device operates a set of contacts during a preset time interval in such a way that a prescribed set of related events will occur in the desired sequence during the preset interval An example of the application of a time cycle controller is in the control of the start up of an electric motor

5 Time schedule controller This device is used to adjust the value of a process variable (temperature pressure and so on) in accordance with a predetermined time schedule An example of the application of a time-schedule controller is an annealing furnace where the furnace temperature must follow a carefully laid out program of variation with time [J C TR]

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Clock paradox

The [illegible] ple of [illegible] dif- [illegible] rt of the theory of relativity that the clock of an observer who passes back and forth will be slower than the clock of an observer at rest Actually the clock paradox al o commonly referred to as the twin paradox is no paradox at all but is based on a misinterpretation of the principles of relativity

In his original paper expounding the special theory of relativity On the Electrodynamics of Moving Bodies (1905) Albert Einstein described the behavior of clocks in motion thus *If at the points A and B there are two stationary clocks which viewed by a stationary observer are synchronous and if the clock at A is moved with the velocity v along the line AB to B then on its arrival at B the two clocks no longer synchronize but the clock moved from A to B lags behind the other which has remained at B by* $\frac{1}{2}tv^2/c^2$ (up to magnitudes of fourth and higher orders) *t* being the time required for the journey from *A* to *B*

"It is at once apparent that this result still holds if the clock moves from *A* to *B* in any polygonal line and also when the points *A* and *B* coincide

This original description of the effect and its analysis hold good today Though the clock paradox flares up in the scientific literature every now and then nothing fundamental has been added since 1905 This article explains the clock effect reports briefly on its experimental confirmation and comments on its supposed paradoxical aspects For related discussion of the physical principles of the clock paradox *see* RELATIVITY SPACE TIME

Theory According to the theory of relativity light signals in empty space propagate at a uniform speed c about 3.0×10^{10} cm/sec for all observers Consider now two observers of whom the second travels at a uniform velocity v relative to the first Let the first observer set up a source of light and at a distance *L* from the source a mirror so that light may travel from the source *S* to the mirror *M* and back again its path of travel arranged at right angles to the direction of velocity v of the second observer

Whereas for the first observer the light travels a distance 2*L* for each complete circuit *SMS* the second observer will see the same light signal travel the larger distance 2*L'* In the illustration *Q* represents the distance that both source and mirror have traveled in the time that it takes the light signal to get from *S* to *M* If the second observer were to set up an experiment of his own resembling in every detail that of the first observer but moving along with himself he would find that his own light signal completes a circuit in less time than that of the first observer But the first observer would find just the reverse to be true each observer would find his own light signal to be the first to complete a given number of circuits

This result is explained by the fact that the two observers do not agree as to which of two distant events takes place first the two events being the completion of the *n*th circuit by either light signal. The outcome also does not single out one observer as being better than the other in accordance with the principle of relativity

Now let the second observer suddenly reverse the direction of his motion relative to the first observer Because he has undergone a sudden acceleration whereas the first observer has not the second observer is now in a different Lorentz frame of reference (a frame which has its own system of time) than he was originally his notions as to the simultaneity of given events have undergone a change (*see* FRAME OF REFERENCE) For instance whereas before his acceleration the second observer must have concluded that his light signal was ahead of the other in completing the *n*th circuit he now finds that the reverse is true Nothing of this sort has happened to the first observer He

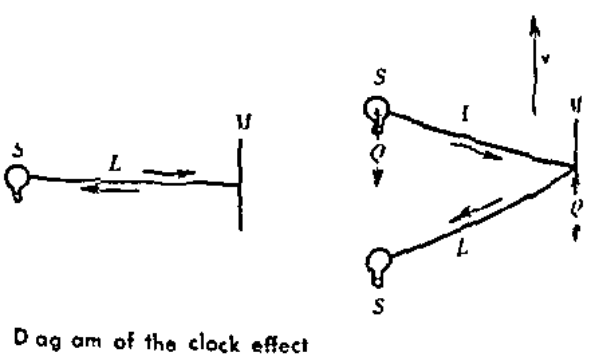


Diagram of the clock effect

remains in his original Lorentz frame throughout the experiment He sees the second observer coming back toward him the second observer's light signal still arriving slower than his own When the two observers meet again the first observer s light signal has actually completed a larger number of circuits $S M S$ than that of the second observer

The light signal traveling back and forth between source and mirror is an example of a "clock The result of this experiment is that a clock taken on a round trip goes slower than one which remains at rest

Experimental verification A number of experiments have been performed to verify the change in the rate of rapidly traveling clocks The predicted relative change is $(1 - v^2/c^2)^{1/2}$, v being the speed of the clock and c the speed of light If v equals 3×10^4 *cm/sec (about 1000 ft/sec) for instance* this change amounts to $\frac{1}{2} \times 10^{-12}$ of the original rate or a little over 10 μsec/year Hence for a significant verification one requires either very high relative speeds approaching the speed of light or extremely sensitive and stable frequency measuring instruments

Spectral lines of moving hydrogen H Ives and G Stilwell in 1938 observed the radiation of hydrogen atoms in a gaseous discharge tube in which the atoms had been ionized and brought to an accurately known speed by means of an accelerating voltage They compared the wavelengths of their spectral lines with those of hydrogen ions at rest Because the apparent frequency of radiation is affected by the Doppler effect (the change in apparent frequency due to relative motion of source and observer) much more than by the relativistic shift to be observed they also looked at the traveling hydrogen ions through a mirror in which the ions would appear going in the opposite direction In the absence of any relativistic effect the lines of the ions at rest would have appeared exactly in the center between the Doppler displaced lines Actually Ives and Stilwell observed a slight asymmetry exactly the one predicted by the relativistic clock effect For additional information on the Ives Stilwell experiment *see* DOPPLER EFFECT

Lifetime of mesons The so called penetrating fraction of cosmic rays observed on the surface of the earth consists mostly of μ mesons which decay spontaneously into electrons (or positrons) and neutrino antineutrino pairs which have a mean lifetime of about 2×10^{-6} sec By comparing the relative abundance of these mesons at various elevations and also in deep mine shafts and by determining the distribution of energies one can determine the apparent lifetime and its dependence on the meson speeds This lifetime has been found to depend on speed roughly in the manner predicted by relativity A more precise confirmation would require the performance of the experiment with man made mesons having precisely known speeds

So called paradox It has been claimed that the theory of relativity is self contradictory because on the one hand it asserts the equivalence of all observers whereas on the other hand the clock effect provides a possibility to distinguish between a clock at rest and a clock making a round trip Actually the principle of relativity asserts only the equivalence of *inertial* observers that is observers not undergoing a change in motion relative to one another Obviously if two observers meet on two distinct occasions at least one of them must have undergone an acceleration at one time and hence does not qualify as an inertial observer Therefore the paradox is based on a misinterpretation of the principle of relativity

Implications for space travel The slowing down of clocks moving at speeds less than one one hundredth of the speed of light (less than 1000 miles/sec) is so small as to be negligible for practical purposes *Hence the clock effect is unlikely to* have any implications on space travel within our own solar system

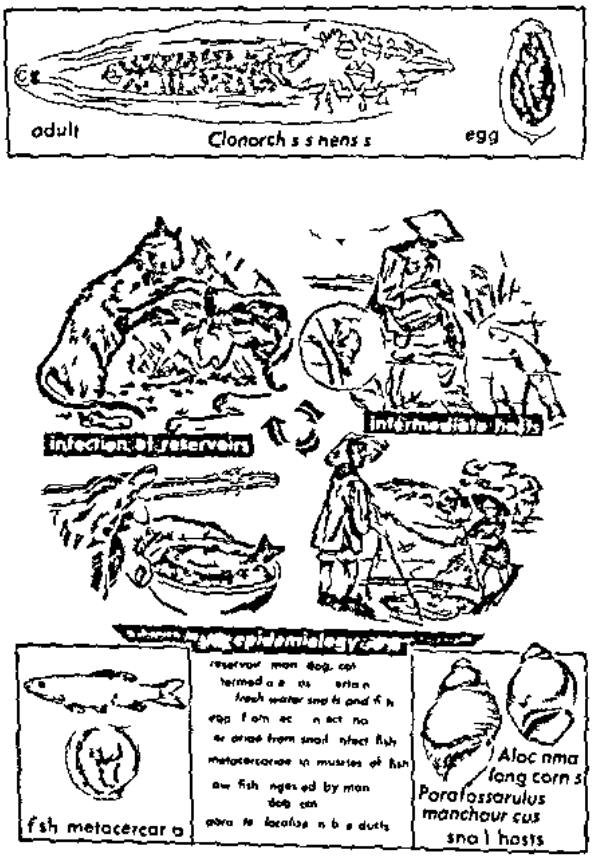
If in the distant future mankind should attempt travel to distant stars then there would be so much time to accelerate and to decelerate near the end of the trip that the retardation of all processes including the rate of aging of the passengers might play a role But the lifetime of human passengers is by no means the only problem that must be faced before interstellar travel becomes a reality It seems likely that advances in the biological sciences will be made in the meantime as well so that the passengers may be assured a long life span simply by medical measures For the foreseeable future the relativistic retardation of life processes appears to belong to the realm of science fiction rather than to form part of the serious planning for space travel [PGB]

Clonorchiasis

An infection of man and other fish eating mammals caused by the trematode *Opisthorchis (Clonorchis) sinensis which is usually found in the bile ducts* The condition is also called Chinese liver fluke disease Southern China is the classic hyperendemic focus because of the habit there of eating raw fresh water fish Endemicity is also associated with the use of night soil as fertilizer Cats and dogs act as reservoirs

The diagnosis of an infection by *Opisthorchis sinensis* depends on the recovery of the characteristic operculate eggs from the feces Aspirated bile or duodenal fluids also may contain these eggs Differential diagnosis is necessary to distinguish *Opisthorchis* infections from those of *Heterophyes heterophyes* and *Metagonimus yokagawai* Prognosis is good in light infections Gentian violet is the drug of choice for treatment *See* HETEROPHYIASIS

The minute (30 μ) eggs pass in feces and are ingested by aquatic snails (*Parafossarulus Bulinus*) within which the larval cycle sporocyst—rediae—cercariae ensues The cercariae emerge and encyst in fish *Ctenopharyngodon idellus* in particular When the fish is eaten uncooked the larvae



Epidemiology of clonorchiasis (*From T T Mackie G W Hunter and C B Worth A Manual of Tropical Medicine* 2d ed Saunders 1954)

excyst and arrive in the bile ducts causing their progressive hypertrophy with resultant cholecystitis and hepatitis Infection is cumulative Treatment is satisfactory with medicinal gentian violet only in early or light infections *See* DIGENEA PARASITOLOGY MEDICAL

[J F MA]

Closed circuit television

A type of television in which the signal is transmitted from the point of origin only to receivers that have been permitted to have access to it by previous arrangement It follows that the purpose of closed circuit TV is to enable visual information to be transmitted to a selected audience These characteristics are in contrast with those of broadcast TV in which all receivers in a given area have access to the broadcast signals effectively covering that area *See* TELEVISION

Technical considerations Closed circuit TV has been accomplished with a great many signal forms and transmission means The signal forms extend from closed circuit theater TV signals requiring bandwidths of 5–15 megacycles (Mc) down to slow scan TV signals usually used for still picture transmission in which the narrowest frequency band required is about 3000 cycles The means of transmission extend from broadband microwave radio circuits down to standard telephone message channels In a few instances a standard 4 Mc type of signal has been broadcast in a coded form This could be received only on those receivers having proper decoding equipment Because this method uses broadcast channels a part of the public domain it has not been permitted by the Federal Communications Commission except for experimental periods of short duration The remainder of this article will deal only with the nonbroadcast type of closed circuit transmission

The types of visual information for which closed circuit transmission is desired vary greatly from moving pictures for entertainment to essentially still pictures conveying business information such as bank balances and signatures When transmitting still pictures a narrow bandwidth circuit may be used with relatively long times of transmission such as 5 10 sec or more according to the customer's requirements

A good quality picture may be transmitted over a narrow band circuit providing the required transmission time can be taken An equation relating frame time T, lines per picture height N and bandwidth B in cps for a picture with a 4×3 aspect ratio (width to height) is

$$T = \frac{0.508\,N^2}{B} \text{ sec}$$

For a 525 line picture and a bandwidth of 4.2 Mc $T = 1/10$ sec which is the frame period of standard broadcast TV For the same number of lines per picture and a bandwidth of 2.5 kc, $T = 56$ sec For $N \approx 200$ and $B = 2.5$ kc $T = 8.1$ sec

Applications A variety of closed circuit systems is in use or in development These differ according to their purpose and function the information to be transmitted and the type and distance of transmission

The common theater television system such as that used for heavyweight championship boxing matches employs a 4-Mc video bandwidth on a 6 Mc channel (same as standard broadcast television) and uses the facilities of a common carrier (usually the Bell Telephone System) for either local or intercity transmission Long distance transmission is either by beamed microwaves or coaxial cable The experimental Eidophor theater system employs a wider than normal video bandwidth (up to 15 Mc) and therefore requires a special transmission system Sound for both these theater systems is by separate circuit

In addition to the coded broadcast home entertainment systems experimental systems using radio frequency transmission over coaxial cables have been tested These use standard 4 Mc video bandwidth and usually employ carrier frequencies in the vhf television range Sometimes sub-vhf frequencies (8–50 Mc) are used These must be translated to the vhf range before reaching the receiver because standard vhf receivers are used

Educational television systems employ either coaxial cable transmission (for short and medium distances) or a combination of microwave and coaxial cable transmission The latter is often used in state wide educational networks connecting state-

operated secondary schools and colleges Both systems employ standard 4-Mc video bandwidth

Industrial uses of closed-circuit television are many and varied One system, frequently used for business conferences and demonstrations, employs the same 4-Mc system as in theater television Many industrial uses are for transmitting static displays or other information that does not require movement or rapid change of scene These are sometimes served by the same 4-Mc common carrier system, but can also be served by audio program circuits of 5- to 15 kc bandwidth over common carriers These systems include those used by ticket agents and routing supervisors who must have access to display board information and those used by bank tellers to check balances and signatures

Industry and government also use closed circuit television for visual checks on operating conditions of a variety of operations Typical applications are to monitor hazardous or unusual locations such as close-ups of steel rolling mill operations and furnace interiors, to observe congested traffic areas from high vantage points, and to examine underwater operations These systems use the transmission method described for the home entertainment system

Experimental work on a telephone television attachment, which would enable each party to see a succession of still pictures of the party at the other end, has received some attention in communication laboratories This would employ only a 3 kc bandwidth and would be transmitted over telephone circuits [J M B]

Closed-loop control system

A system in which the value of some output quantity of the system is continuously or periodically measured and used to manipulate another quantity an input to the system, in such a way as to make the first quantity or some other dependent output follow a desired pattern of values At each instant the measured value is compared to the desired value of the measured quantity The difference is used to change the value of an input to the system Such systems are also called feedback control systems because the measured value is fed back to be used to manipulate an input quantity For a complete discussion of closed loop systems *see* CONTROL SYSTEMS

Examples of uses of closed loop control systems are to control the temperature of homes and other environments, to control the temperature pressure flow rates, and other quantities in industrial processes, to control the direction of heavy guns, and to guide airplanes and missiles [J A H]

Cloud

Suspensions of minute droplets or ice crystals produced by the condensation of water vapor (the ordinary atmospheric cloud) Other clouds less commonly seen are composed of smokes or dusts (*see* ATMOSPHERIC POLLUTION, DUST STORM) This article presents an introductory outline of cloud formation upon which to base an understanding of cloud classifications For a more technical consideration of the physical character of atmospheric clouds, including the condensation and precipitation of water vapor, *see* CLOUD PHYSICS

Rudiments of cloud formation. A grasp of a few physical and meteorological relationships aids in an understanding of clouds and skies First, if water vapor is cooled sufficiently it becomes saturated that is in equilibrium with a plane surface of liquid water (or ice) at the same temperature Further cooling in the presence of such a surface causes condensation upon it, in the absence of any surfaces no condensation occurs until a substantial further cooling provokes condensation upon random large aggregates of water molecules In the atmosphere even in the apparent absence of any surfaces they are in fact always provided by invisible motes upon which the condensation proceeds at barely appreciable cooling beyond the state of saturation Consequently, when atmospheric water vapor is chilled sufficiently, such motes, or condensation nuclei swell into minute water droplets and form a visible cloud The total concentration of liquid in the cloud is controlled by its temperature and the degree of chilling beyond the state in which saturation occurred, and in most clouds approximates to 1 g in 1 m^3 of air The concentration of droplets is controlled by the concentrations and properties of the motes and the speed of the chilling at the beginning of the condensation In the atmosphere these are such that there are usually about 100,000 000 droplets/m^3 Because the cloud water is at first fairly evenly shared among them, these droplets are necessarily of microscopic size, and an important part of the study of clouds is concerned with the ways in which they often become aggregated into drops large enough to fall to the ground as rain

The chilling which produces clouds is almost always associated with the upward movements of air which carry heat from the earth's surface and restore to the atmosphere that heat lost by radiation into space These movements are most pronounced in storms which are accompanied by thick dense clouds, but also take place on a smaller scale in fair weather, producing scattered clouds or dappled skies (*see* STORM) Rising air cools by several degrees Centigrade for each kilometer of ascent, so that even over equatorial regions temperatures below 0°C are encountered a few kilometers above the ground and clouds of frozen particles prevail at higher levels Of the abundant motes which facilitate droplet condensation very few cause direct condensation into ice crystals or stimulate the freezing of droplets and especially at temperatures near 0°C their numbers may be vanishingly small Consequently, at these temperatures, clouds of unfrozen droplets are not infrequently encountered (supercooled clouds) In general, however ice crystals occur in very much smaller concentrations than the droplets of liquid clouds and



Fig 1 Cirrus a thin tufted variant of this type of cloud and sky pattern (*F Ellerman Mount Wilson California U S Weather Bureau*)



Fig 2 Cumulus showing signs of broken or fracto cumulus patterns (*A A Lothman U S Weather Bureau*)



Fig 3 Stratus low with an altostratus overcast during the passage of a slow moving cold front Most of this stratus formation is below the tops of the hills (*U S Weather Bureau*)

by condensation alone become large enough to fall from their parent cloud Even small high clouds may produce or become trails of snow crystals whereas droplet clouds are characteristically compact in appearance with well defined edges, and produce rain only when dense and well developed vertically (2 km or more thick)

Classification of clouds The contrast in cloud forms mentioned above was recognized in the first widely accepted classification as well as in several succeeding classifications The first was that of L. Howard (*London 1803*) recognizing three fundamental types (1) the stratiform (layer) (2) cumuliform (heap) and (3) cirriform (fibrous) The first two are indeed fundamental representing clouds formed respectively in stable and in convectively unstable atmospheres whereas the clouds of the third type are the ice clouds which are in general higher and more tenuous and less clearly reveal the kind of air motion which led to



Fig 4 View of cirrostratus sky above the top of fog as seen from Mount Wilson California The top of the fog (foreground of view) presents a pattern resembling stratocumulus sky (*F Ellerman U S Weather Bureau*)

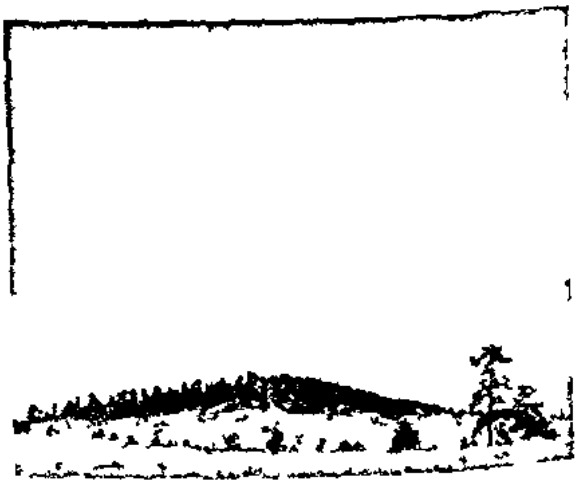


Fig 5 Cirrocumulus patterns predominating with cirrus of cirrostratus sky in background (*A A Lothman U S Weather Bureau*)



Fig 6 Altocumulus cloud and sky pattern (*G A Loft U S Weather Bureau*)



Fig 7 *Altostratus* Except that altostratus is developed at a higher level this might be a representative view of nimbostratus the low hanging gray skies from which prolonged rain or snow falls (C F Brooks U S Weather Bureau)

their formation Succeeding classifications continued to be based upon the visual appearance or form of the clouds differentiating relatively minor features but later in the nineteenth century increasing importance was attached to cloud height because direct measurements of winds above the ground were then very difficult and it was hoped to obtain wind data on a great scale by combining observations of apparent cloud motion with reasonably accurate estimates of cloud height based solely on their form

WMO cloud classification The World Meteorological Organization (WMO) uses a classification which with minor modifications dates from 1894 and represents a choice made at that time from a number of competing classifications It divides clouds into low level (base below about 2 km) middle level (about 2 to 7 km) and high level (between roughly 7 and 14 km) forms within the middle latitudes The names of the three basic forms of clouds are used in combination to define altogether ten main characteristic forms or genera

1 Cirrus are high white clouds with a silken or fibrous appearance

2 Cumulus are detached dense clouds which rise in domes or towers from a level low base

3 Stratus are extensive layers or flat patches of low clouds without detail

4 Cirrostratus is cirrus so abundant as to fuse into a layer

5 Cirrocumulus is formed of high clouds broken into a delicate wavy or dappled pattern

6 Stratocumulus is a low level layer cloud having a dappled lumpy or wavy structure See the foreground of Fig 4

7 Altocumulus is similar to stratocumulus but lies at intermediate levels



Fig 8 Cumulonimbus clouds over the upland adjoining the upper Colorado River valley Note the rain showers under some of the clouds (*Lt B H USN U S Weather Bureau*)

Cloud classification based on air motion and associated physical characteristics

Kind of motion	Typical vertical speeds cm/sec	Kind of cloud	Name	Characteristic dimensions km: Horizontal	Characteristic dimensions km: Vertical	Characteristic precipitation
Widespread slow ascent associated with cyclones (stable atmosphere)	10	Thick layers	Cirrus, cirrostratus, altostratus, altocumulus	10^3	1–2	Snow trails
			nimbostratus	10^3	10	Prolonged moderate rain or snow
Convection due to passage over warm surface (unstable atmosphere)	10^2	Small heap cloud	Cumulus	1	1	None
	10^3	Shower and thunder cloud	Cumulonimbus	10	10	Intense showers of rain or hail
Irregular stirring causing chilling during passage over cold surface (stable atmosphere)	10	Shallow low layer clouds fogs	Stratus, Stratocumulus	10^2 – 10^3	<1	None or slight drizzle or snow

8 *Altostratus* is a thick extensive layer cloud at intermediate levels

9 Nimbostratus is a dark widespread cloud with a low base from which prolonged rain or snow falls

10 Cumulonimbus is a large *cumulus* which produces a shower

Classification by air motion Modern detailed studies of clouds were stimulated by the discovery of cheap methods of seeding supercooled clouds with artificial motes promoting ice-crystal formation aimed at stimulating or increasing snowfall These studies show that the external form of clouds gives only indirect and incomplete clues to the physical properties which determine their evolution Throughout this evolution the most important properties appear to be the air motion and the size distribution spectrum of all the cloud particles including the condensation nuclei These properties vary significantly with time and position within the cloud so that cloud studies demand the intensive examination of individual clouds with expensive facilities such as aircraft and radar The interplay of physical processes in atmospheric clouds is very complicated and until it is better understood no satisfactory physical classification will be possible From a general meteorological point of view a classification can be based upon the kind of air motion associated with the cloud as shown in the table [F H L]

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Cloud chamber

A particle detector in which the path of a fast charged particle is made visible by the formation of liquid droplets on the ions left by the particle as it passes through the gas of the chamber (see PARTICLE DETECTOR) Cloud chambers are used in research in nuclear physics and can give detailed information on the particle in addition to the simple fact that the particle passed through They can be operated at pressures below atmospheric near atmospheric or up to 50 atmospheres depending on the application In size they vary from a few inches in diameter up to large walk in chambers containing many metal plates

Supersaturated vapor is vapor whose pressure exceeds the saturation vapor pressure at the temperature prevailing It is unstable and condensation occurs in the presence of suitable nuclei The interior of a cloud chamber contains a mixture of a gas such as air argon or helium and a vapor such as water or alcohol When such a mixture is made supersaturated in the vapor component by cooling of the gas the vapor tends to condense preferentially on charged atoms in the gas Since a fast moving charged particle produces many such ions in its passage through the gas condensation of the vapor leaves a trail of droplets to indicate the path of the particle When properly illuminated these droplets are visible and may be photographed A permanent record of the path of the particle may thus be obtained for examination at a later time

Supersaturation methods The supersaturation necessary for drop formation may be obtained in two ways (1) In the Wilson cloud chamber the saturated vapor gas mixture is suddenly expanded causing supersaturation of the vapor at the resulting lower temperature Usually the expansion is produced by motion of a rubber diaphragm or a piston The amount of expansion must be carefully controlled too little expansion will result in insufficient supersaturation to cause drop condensation while overexpansion will give a dense fog in

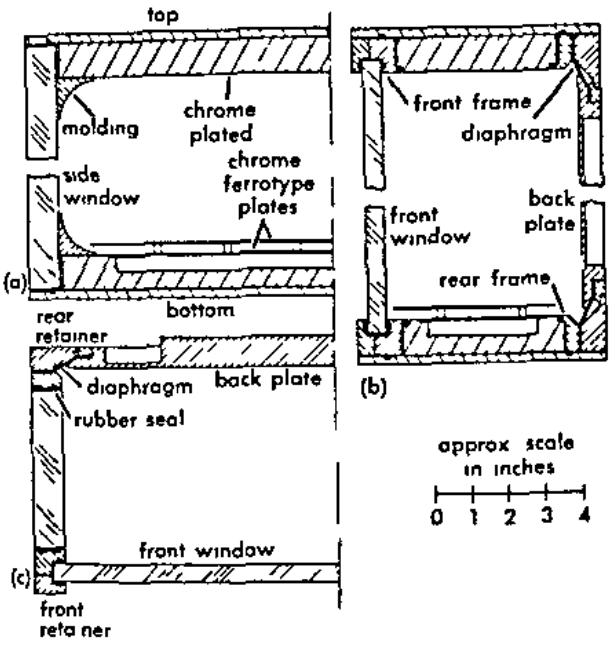


Fig 1 Cloud chamber designed for use in a magnetic field (a) Vertical section parallel to front (b) Vertical section parallel to side (c) Horizontal section The back plate moves to produce the expansion The mechanism for compressing the chamber and producing the expansion is not shown The photograph in Fig 2 was taken using this cloud chamber

respective of the presence of ions in the gas (2) The second method for obtaining supersaturation is used in the diffusion cloud chamber A temperature gradient is maintained in the gas by cooling the bottom of the chamber and warming the top Vapor introduced at the top diffuses toward the bottom and cools as it goes A certain region in the chamber becomes supersaturated and the vapor will condense on ions if they are present The diffusion chamber is thus continuously sensitive, as contrasted to the Wilson chamber which is sensitive only for a fraction of a second after an expansion is made

To overcome the short sensitive time, Wilson cloud chambers are often counter controlled Auxiliary particle detectors are used to signal the presence of a fast charged particle, and to cause the expansion of the chamber within a few milliseconds after the passage of the particle Wilson cloud chambers used in cosmic ray research are usually counter controlled because of the random time of arrival of cosmic ray particles

Information obtained. A cloud chamber can give information on the momentum of the particle if the chamber is placed in a magnetic field (Figs 1 and 2) The curvature of the track can be measured on the photograph and the value of the curvature together with the magnitude of the field gives the momentum The sign of the charge can usually be determined also, if the direction of motion of the particle is known since positive and negative particles curve in opposite directions Another physical quantity that may be determined in a cloud chamber is the velocity of the particle since the ionization produced by the charged particle depends on its velocity in a known way With good photographic technique, individual droplets along the track are visible, and the number of these droplets is closely related to the number of ions along the track A combination of the measurements, velocity and momentum, yields a value for the mass of the particle thus identifying it

Cloud chambers may be used to determine the range of a particle, the distance required to bring it to rest For low energy particles the energy lost to the gas may be sufficient to bring a particle to rest in the chamber To stop a high energy particle, metal plates are inserted in the chamber with spaces between where the tracks may be seen (see Fig 3) A particle brought to rest in a given plate will have passed through a certain amount of ma

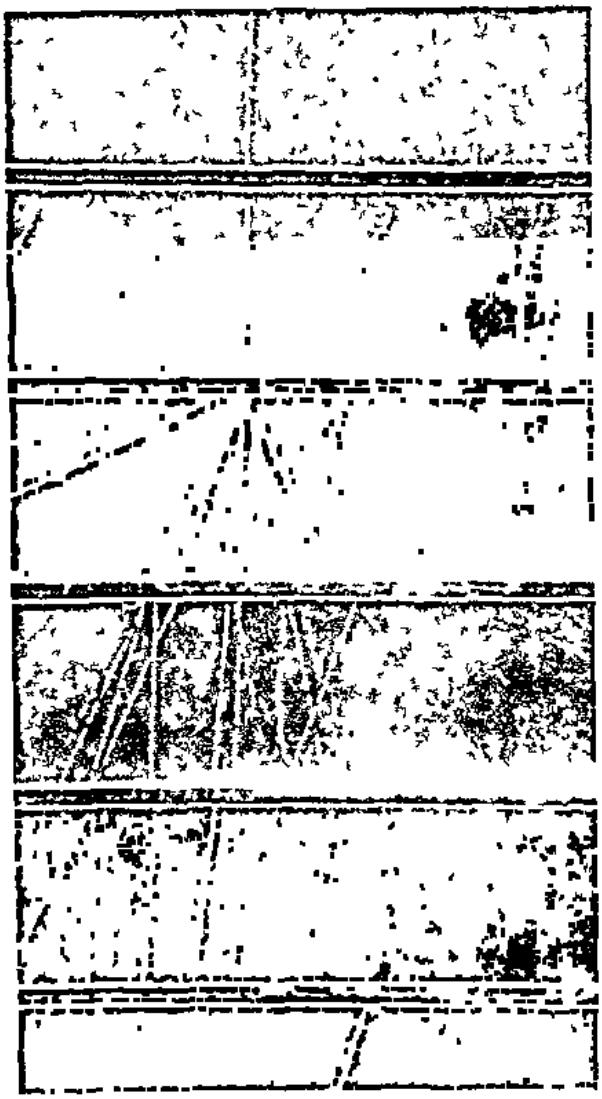


Fig 2 A nuclear interaction produced by a cosmic ray particle above the chamber is analyzed in a cloud chamber placed in a magnetic field The circles at the top of the picture are tracks of electrons spiralling in the magnetic field The heavy track is a proton The light track which becomes three tracks just above the center of the chamber is a K meson, which disintegrates in flight into three π-mesons $K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$ The tracks are all curved because of the magnetic field



Fig 3 A nuclear interaction produced by a cosmic ray particle occurs in one of the lead plates of a cloud chamber The particles produced in the interaction are mesons nucleons and a hyperon which traverse the other lead plates in the cloud chamber

terial which can be determined to give the range of the particle

Dead time Wilson cloud chambers have the disadvantage of a long dead time it takes at least a minute for an expansion type chamber to come to equilibrium and be ready for the next expansion Diffusion chambers have no such dead time and are therefore much more suitable for use near a high energy particle accelerator where the particles come out in pulses only a few seconds apart *See* BUBBLE CHAMBER [W B F]

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Cloud physics

The study of the physical processes governing the formation and the release (collectively known as precipitation)

The factors of prime importance are the motion of the air its water vapor content and the numbers and properties of the particles in the air which act as centers of condensation and freezing Because of the complexity of atmospheric motions and the enormous variability in vapor and particle content of the air it seems impossible to construct a detailed general theory of the manner in which clouds and precipitation develop However calculations based on the present conception of laws governing the growth and aggregation of cloud particles and on simple models of air motion provide reasonable explanations for the observed formation of precipitation in different kinds of clouds

Cloud formation Clouds are formed by the lifting of damp air which cools by expansion under continuously falling pressure The relative humidity increases until the air approaches saturation Then condensation occurs on some of the wide variety of aerosol particles present these exist in concentrations ranging from less than 100 particles per cubic centimeter (cm^3) in clean maritime air to perhaps 10^6 per cm^3 in the highly polluted air of an industrial city A portion of these particles are hygroscopic and promote condensation at relative humidities below 100% but for continued condensation leading to the formation of cloud droplets, the air must be slightly supersaturated Among the highly efficient condensation nuclei are the salt particles produced by the evaporation of sea spray but it now appears that particles produced by man made fires and by natural combustion (for example forest fires) also make a major contribution Condensation onto the nuclei continues as rapidly as the water vapor is made available by cooling of the air and gives rise to droplets of the order of 0 01 millimeter (mm) in diameter These droplet

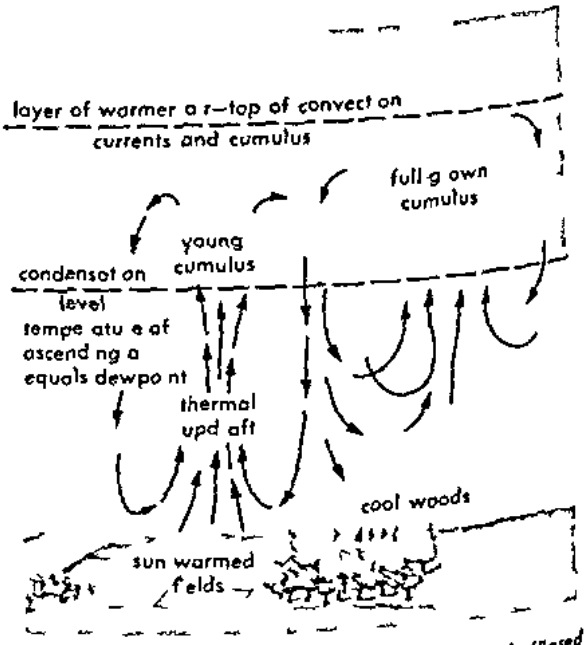


Fig 1 Diagram of birth of a cumulus cloud (*Based on photodisplay in Willetts Memorial Weather Exhibit Hayden Planetarium New York City*)

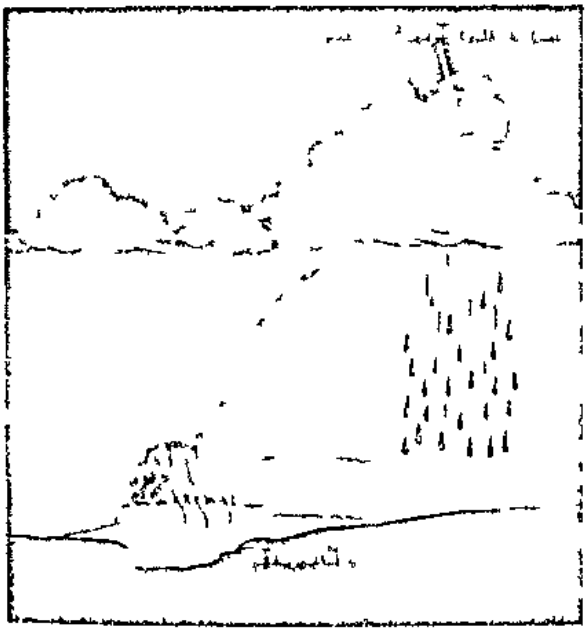


Fig 2 Diagram of formation of rain (*Based on photodisplay in Willetts Memorial Weather Exhibit, Hayden Planetarium, New York City*)

usually present in concentrations of a few hundreds per cm³, constitute a nonprecipitating water cloud

Mechanisms of precipitation release. Growing clouds are sustained by upward air currents which may vary in strength from a few centimeters per second (cm/sec) to several meters (m) per second Considerable growth of the cloud droplets (with falling speeds of only about 1 cm/sec) is therefore necessary if they are to fall through the cloud, survive evaporation in the unsaturated air beneath and reach the ground as drizzle or rain Drizzle drops have radii exceeding 0 1 mm while the largest raindrops are about 6 mm across and fall at nearly 10 m/sec The production of a relatively few large particles from a large population of much smaller ones may be achieved in one of two ways

The coalescence process Cloud droplets are seldom of uniform size for several reasons Droplets arise on nuclei of various sizes and grow under slightly different conditions of temperature and supersaturation in different parts of the cloud Some small drops may remain inside the cloud for longer than others before being carried into the drier air outside

A droplet appreciably larger than average will fall faster than the smaller ones, and so will collide and fuse (coalesce) with some of those which it overtakes Calculations show that in a deep cloud containing strong upward air currents and high concentr[illegible]

in tropical and subtropical regions from clouds whose tops do not reach the 0°C level and therefore cannot contain ice crystals which are responsible for most precipitation Radar evidence also suggests that showers in temperate latitudes may sometimes be initiated by the coalescence of waterdrops, although the clouds may later reach to heights at which ice crystals may form in their upper parts

Initiation of the coalescence mechanism requires the presence of some droplets exceeding 20 microns (μ) in diameter (1 μ = 0 0001 cm) Over the oceans and in adjacent land areas they may well be supplied as droplets of sea spray, but in the interiors of continents where so called giant salt particles of marine origin are probably scarce, it may be harder for the coalescence mechanism to begin

The ice crystal process The second method of releasing precipitation can operate only if the cloud top reaches elevations where temperatures are below 0°C and the droplets in the upper cloud regions become supercooled At temperatures below −40°C the droplets freeze automatically or spontaneously, at higher temperatures they can freeze only if they are infected with special, minute particles called ice nuclei As the temperature falls below 0°C, more and more ice nuclei become active, and ice crystals appear in increasing numbers *among the supercooled droplets But such a mixture* of supercooled droplets and ice crystals is unstable The cloudy air being usually only slightly supersaturated with water vapor as far as the droplets are concerned is strongly oversaturated for the ice crystals, which therefore grow more rapidly than the droplets After several minutes the growing crystals will acquire definite falling speeds, and several of them may become joined together to form a snowflake In falling into the warmer regions of the cloud however, this may melt and reach the ground as a raindrop

Precipitation from layer cloud systems. The deep, extensive multilayer cloud systems, from which fall precipitation of a usually widespread, persistent character, are generally formed in cyclonic depressions (lows) and near fronts Such cloud systems are associated with feeble upcurrents of only a few cm/sec, which last for at least several hours Although the structure of these great rain cloud systems, which are being explored by aircraft and radar, is not yet well understood, it appears that they rarely produce rain as distinct from drizzle, unless their tops are colder than about −12°C. This suggests that ice crystals may be responsible Such a view is supported by the fact that the radar signals from these clouds usually take a characteristic form which has been clearly identified with the melting of snowflakes

The production of showers Precipitation from shower clouds and thunderstorms whether in the form of raindrops, pellets of soft hail, or true hailstones is generally of greater intensity and shorter duration than that from layer clouds and is usually composed of larger particles The clouds themselves are characterized by their large vertical depth strong vertical air currents, and high concentrations of liquid water, all these factors favoring the rapid growth of precipitation elements by coalescence

In a cloud composed wholly of liquid water rain drops may grow by coalescence with smaller drop lets For example a droplet being carried up from the cloud base would grow as it ascends by sweep ing up smaller droplets When it becomes too heavy to be supported by the vertical upcurrents the droplet will then fall continuing to grow by the same process on its downward journey Finally if the cloud is sufficiently deep the droplet will emerge from its base as a raindrop

In a dense vigorous cloud several kilometers deep the drop may attain its limiting stable diam eter (about 5 mm) before reaching the cloud base and thus will break up into several large fragments Each of these may continue to grow and attain breakup size The number of raindrops may in crease so rapidly in this manner that after a few minutes the accumulated mass of water can no longer be supported by the upcurrents and falls out as a heavy shower The conditions which favor this rapid multiplication of raindrops occur more read ily in tropical regions

In temperate regions where the 0°C level is much lower in elevation conditions are more favorable for the ice crystal mechanism However many showers may be initiated by coalescence of water drops

The ice crystals will grow initially by sublimation of vapor in much the same way as in layer clouds but when their diameters exceed about 0 1 mm growth by collision with supercooled droplets will predominate Droplets freeze on impact to form pellets of soft hail The average density of the par ticle may be as low as 0 3 or even 0 1 gram/cm³ because air spaces are formed between the frozen droplets so that in a dense cloud drops will increase rapidly in size However the growth of the particle is restricted by the fact that it may collect super cooled water more rapidly than it can be frozen and so acquire a liquid coat which on subsequent freez ing produces a layer of clear ice Alternate layers of opaque and clear ice are characteristic of large hailstones Their formation m[illegible]

[illegible] water content and were exposed to stronger and weaker updrafts within the cloud

The development of precipitation in thunder clouds is closely associated with lightning The mechanism by which the electric charge dissipated in lightning flashes is generated and separated in the cloud has been debated for more than 200 years, but there is still no satisfactory theory How ever a majority opinion holds that lightning is closely associated with the appearance of the ice phase and the most promising theory suggests that the charge is produced by the momentary collision between ice crystals and pellets of [illegible]

[illegible] cooling and freezing of water the nature origin and mode of action of the ice nuclei and the mech anism of ice crystal growth which produces the vari ous snow crystal forms

It has now been established how the maximum degree to which a sample of water may be super cooled depends on its purity volume and rate of cooling The freezing temperatures of waterdrops containing foreign particles vary linearly as the logarithm of the droplet volumes for a constant rate of cooling This relationship which has been estab lished for drops varying between 10 μ and 1 cm in diameter characterizes the heterogeneous nuclea tion of water drops and is probably a consequence of the fact that the ice nucleating ability of atmos pheric aerosol increases logarithmically with de creasing temperature

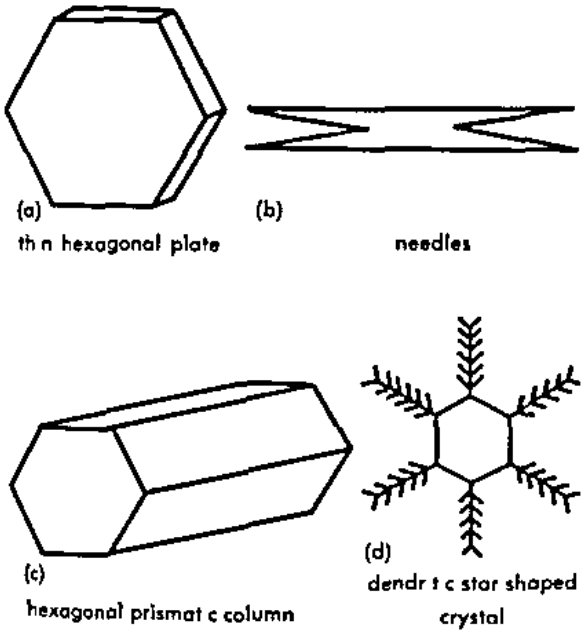
When extreme precautions are taken to purify the water and to exclude all solid particles small droplets about 1 μ in diameter may be super cooled to −40°C and drops of 1 mm diameter to −33°C Under these conditions freezing occurs spontaneously without the aid of foreign nuclei

The nature and origin of the ice nuclei which are necessary to induce freezing of cloud droplets at temperatures above −40°C are still not clear Measurements made with large cloud chambers on aircraft indicate that the most efficient nuclei, active at temperatures above −10°C are present in concentrations of only about 10 in a cubic meter of air but as the temperature is lowered the numbers of ice crystals increase logarithmically to reach concentrations of about 1 per liter at −20°C and 100 per liter at −30°C Since these measured concentrations of nuclei are less than one one-hundredth of the numbers that apparently are consumed in the production of snow, it seems that there must exist processes by which the original numbers of ice crystals are rapidly multiplied Laboratory experiments suggest the fragmentation of the delicate snow crystals and the ejection of ice splinters from freezing droplets as probable mechanisms

The most likely source of atmospheric ice nuclei is provided by the soil and mineral dust particles carried aloft by the wind Laboratory tests have shown that although most common minerals are relatively inactive a number of silicate minerals of the clay family produce ice crystals in a super cooled cloud at temperatures above −18°C A major constituent of some clays kaolinite which is active below −9°C is probably the main source of highly efficient nuclei

The fact that there may often be a deficiency of efficient ice nuclei in the atmosphere has led to a search for artificial nuclei which might be intro duced into supercooled clouds in large numbers Silver iodide is a most effective substance being active at −4°C, while lead iodide and cupric sulfide have threshold temperatures of −6°C for freezing nuclei

In general the most effective ice-nucleating sub stances both natural and artificial are hexagonal crystals in which spacings between adjacent rows



Fg 3 D agram of ice crystal types formed in var ous temperature ranges (°C) (a) 0 to −3° −8 to 12° −16 to −25° (b) −3 to −5° (c) −5 to −8° below −25° (d) −12 to −16°

of atoms differ from those of ice by less than 16% This similarity of crystal geometry is not the only factor which determines the nucleating efficiency Among other things it is important that the sub stances be almost insoluble in water

The collection of snow crystals from clouds at d fferent temperatures has revealed their great vari ety of shape and form By growing ice crystals on a fine fiber suspended in a cloud chamber B J Mason has been able to reproduce all the naturally occur ring forms along a fiber extending through air tem peratures 0 to −40°C and has observed clear cut changes of crystal habit These range from

Hexagonal plates → needles → hollow prisms → plates → stellar dendrites → plates → prisms

occurring along the length of the fiber in a varied temperature environment (Fig 3) This fivefold change of habit over such a small temperature range is puzzling but careful measurements have shown that the temperature and not the supersatu ration of the environment is primarily responsible The supersaturat on is however important in de term ning the growth rates of the crystals and the development of their dendritic forms

Artificial stimulation of rain The presence of either ice crystals or some comparatively large waterdroplets (to initiate the coalescence mech anism) appears essential to the natural release of precipitation Rain making experiments are con ducted on the assumption that some clouds pre cipitate inefficiently or not at all because they are deficient in natural nuclei and that this deficiency can be remedied by seeding the clouds artif cially with dry ice or silver iodide to produce ice crystals or by introducing waterdroplets or large hygro scopic nuclei In the dry ice method pellets of about 1 cm diameter are dropped from an aircraft into the top of a supercooled cloud Each pellet chills a thin sheath of air near its surface to well below −40°C and produces perhaps 10^6 minute ice crystals which subsequently spread through the cloud grow and aggregate into snowflakes Only a few pounds of dry ice are required to seed a large cumulus cloud Some hundreds of experiments car ried out mainly in Australia Canada South Africa and the United States have shown that cumulus clouds in a suitable state of development may be induced to rain by seeding them with dry ice on occasions when neighboring clouds untreated do not precipitate However the amounts of rain pro duced have usually been rather small

For large scale trials designed to modify the rain fall from widespread cloud systems over large areas the cost of aircraft is usually prohibitive The technique in this case is to release a silver iodide smoke from the ground and rely on the air currents to carry it up into the supercooled regions of the cloud In this method with no control over the subsequent transport of the smoke it is not pos sible to make a reliable estimate of the concentra tions of ice nuclei reaching cloud level nor is it

the natural rainfall in the absence of seeding activi ties make the design and evaluation of a large-scale operation so difficult

In the data so far published no convincing evi dence can be found that large increases in rainfall have been produced consistently over large areas Indeed in temperate latitudes most rain falls from deep layer cloud systems whose tops usually reach to levels at which there are abundant natural ice nuclei and in which the natural precipitation proc

some redistribution might be effected

Perhaps more promising as additional sources of rain or snow are the persistent supercooled clouds produced by the ascent of damp air over large mountain barriers The continuous generation of an appropriate concentration of ice crystals near the windward edge might well produce a persistent light snowfall to the leeward since water vapor is continually being made available for crystal growth by lifting of the air The condensed water once converted into snow crystals has a much greater opportunity of reach ng the mountain surface with out evaporating and might accumulate in appreci able amount if seeding were maintained for many hours

Preliminary results of trials now being carried out in favorable locations in the Un ted States and Australia indicate seasonal precipitation increases of al out 20% The experiments will have to l tinued for several more years before these i

can confidently be ascribed to the effects of cloud seeding

Attempts to stimulate the coalescence process by spraying waterdroplets or dispersing salt crystals into the bases of incipient showe clouds have been made in places as far apart as Australia the Carib bean East Africa and Paki tan The results of tl ese experiments though enco iraging are not yet suff cient to allow definite conclusions

The science of cloud modification is however still in its infancy It may well be that further knowledge of cloud behavior and of natural precipi tation mechanisms will suggest new possibilities and improved techniques which will lead to devel opments far beyond those which seem likely at the present time *See* WEATHER MODIFICATION

[B J MA]

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Clove

The unopened flower bud of a small conical sym metrical evergreen tree *Eugenia carvophyllata* of the myrtle family (Myrtaceae) The cloves are picked by hand and dried in the sun or by artificial



Cloves (*Eugen a caryophyllata*) (*Amer can Sp ce Trade Assoc*)

means The crop is uncertain and *diff cult* to grow Cloves one of the most important and *useful* spices are strongly aromatic and have a pungent flavor They are used as a culinary spice for flavoring pickles ketch ip and sauces in *medicine* and for perfuming the breath and the air in rooms The es sential oil distilled from cloves by water or steam has even more uses The chief clove producing countries are Zanzibar with 90% of the total out put Indonesia Mauritius and the West Indies *See* MYRTALES SPICE AND FLAVORING

[P D S]

Clover

A common name used loosely to designate the true clovers sweet clovers and other members of the plant family Leguminosa This article discus es true clovers sweet clover and clover diseases

TRUE CLOVERS

The true clovers are plants of the genus *Trifo lium* order Rosales There are approximately 250 species in the world Collectively they represent the most important genus of forage legumes in agriculture Different species constitute one or more crops on every continent As indicated by the number of species and their ecotypes (subspecies) that have been collected and described the center of origin appears to be southeastern Europe and southwestern Asia Minor Many species are found in countries that border the Mediterranean sea About 80 species are native to the United States most of them occurring in the general regions of the Rocky and Cascade mountains and the Sierra Nevada Although these native clovers are not used as crop plants they contribute to the range for grazing and wild hay and also supply nitrogen to associated grasses Of those that are now named it is possible that many are variants of other species Only a few are native to the humid eastern states Most clovers are highly palatable and nutritious to livestock The name clover is often applied to mem bers of legume genera other than *Trifolium*

The true clovers are herbaceous annual or peren nial plants However many perennial species be have as biennials or annuals under attacks of disease or insects unfavorable climatic or soil cond tions or improper management In general clovers thrive under cool moist conditions although one native species desert clover (*T gymnocarpum*) tolerates semiarid conditions Usually annual spe cies behave as winter annuals where winter cond tions are not severe and as summer annuals at northern latitudes and high altitudes Clovers grow best where adequate supplies of calcium pho phorus and potassium are naturally present in the soil or where these elements are applied in lime stone and fertilizers They grow from a few inches to several feet tall depending on the species and the environmental conditions The leaves have 3-5 roundish to spearlike leaflets The florets rang ng from 5 to 200 in number are borne in heads Colors include white pink red purple and yellow and various mixtures The basic haploid chromosome numbers of the species are 6 7 and 8 Somatic chromosomes range from 12 to about 130 form ng diploids tetraploids and polyploids The flowers of some species are self sterile and must be cro s pollinated before seed will form the flowers of other species may be self fertile and capable of self pollination others are self fertile l ut do not set seed unless the flowers are tripped and the pollen scattered onto the stigma Cross pollination and tripping of flowers are effected principally b

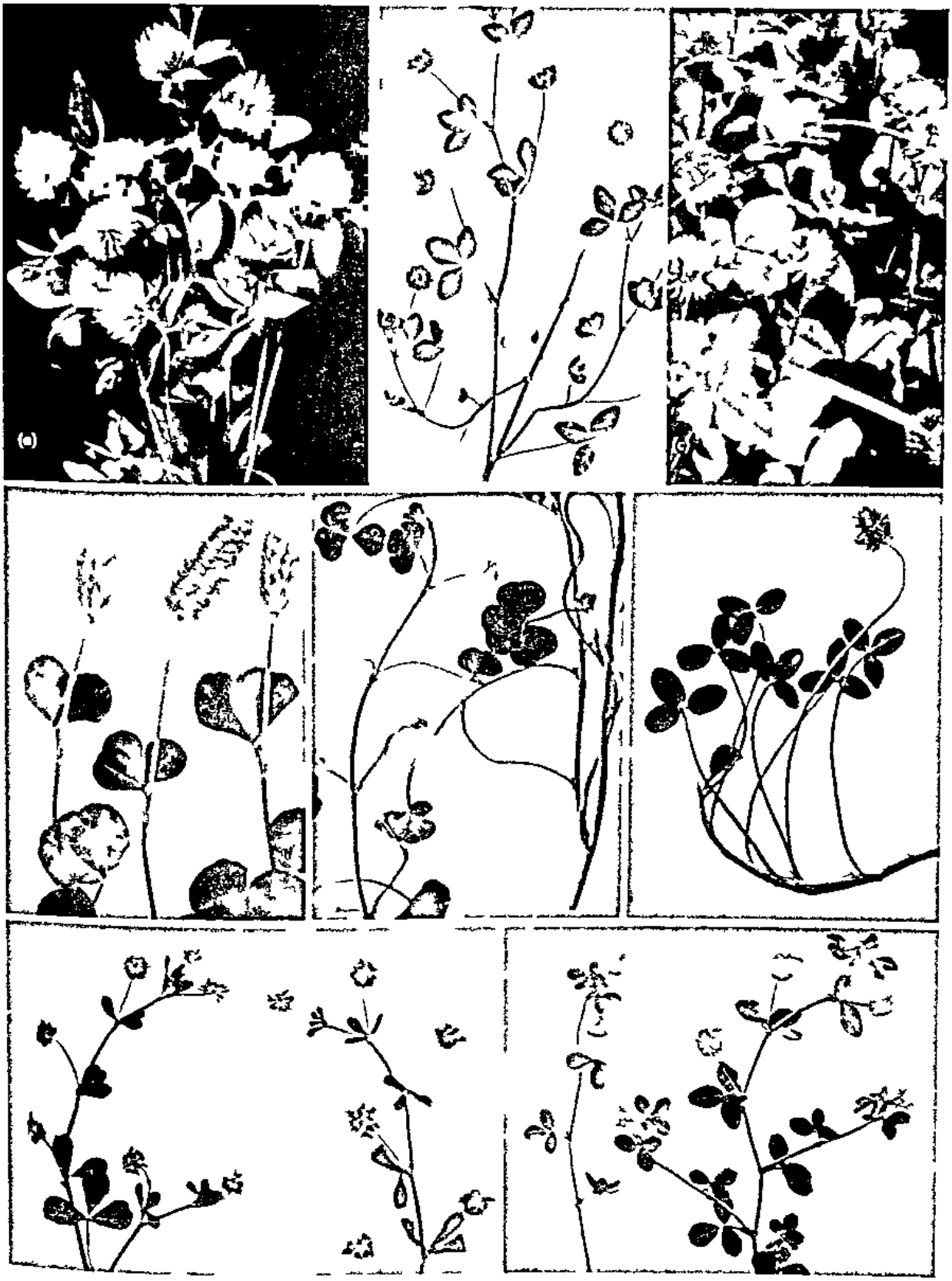


Fig 1 Important clover species (a) Red clover *Trifolium pratense* (b) Alsike clover *T hybridum* (c) White clover *T repens* (d) Crimson clover *T incarnatum* (e) Subclover *T subterraneum* (f) Strawberry clover *T fragiferum* (g) Persian clover *T resupinatum* (h) Large hop clover *T campestre* (*procumbens*) (USDA)

bees that visit the flowers for nectar and pollen Seed color ranges from yellow to deep purple some being bicolored There are approximately 60 000–70 000 seeds per lb

Important species All the clover species of agricultural importance in the United States are introduced (exotic) plants Figure 1 shows some of the species most widely used red clover (*T pratense*) alsike clover (*T hybridum*) white clover (*T repens*) crimson clover (*T incarnatum*) subclover (*T subterraneum*) strawberry clover (*T fragiferum*) persian clover (*T resupinatum*) large hop clover (*T campestre* or *procumbens*) and small hop clover (*T dubium*) Others of regional importance mostly adapted to specific environmental conditions are rose clover (*T hirtum*) barseem clover (*T alexandrinum*) ball clover (*T nigrescens*) lappa clover (*T lappaceum*) and big flower clover (*T michelianum*)

Uses Clovers are used for hay pasture silage and soil improvement Certain kinds may be used for all purposes whereas others because of their low growth are best suited for grazing All kinds when well grown in thick stands are good for soil improvement. Thoroughly inoculated plants add 50–200 lb of nitrogen per acre when plowed under for soil improvement the amount added depending on growth thickness of stand and length of growing season Clovers may be grown alone in combination with grasses and other legumes or with small grains In the humid states, or where irrigated clovers are sown most frequently with small grain companion crops In the Corn Belt they are generally spring seeded whereas in the southern states and in the West Coast region they should be seeded in the fall for best results

Species characteristics The following sections discuss the characteristics of the most important species

Red clover Red clover is composed of two forms medium and mammoth producing two and one hay cuts respectively The large purplish red flower heads are round An upright growing perennial red clover generally persists for 2 years in northern United States but behaves as a winter annual in the South When planted alone or with small grain seeding rates are 10–15 lb per acre When seeded with grass and other mixtures 4–8 lb are sufficient Under favorable growth conditions seed yields average 70 lb per acre but in the West under irrigation may reach 600–800 lb There are several varieties and strains of red clover such as Kenland Pennscott Dollard and Chesapeake Where adapted these produce higher yields of forage and are more persistent than common red clover

Alsike clover Alsike clover widely used in the northern States is an upright growing species that behaves like a biennial The growth pattern seeding methods mixtures and uses are similar to those of red clover The flower heads are much like those of white clover in shape and size but are slightly more pinkish Alsike clover is more tolerant of wet, poorly drained soils than red clover

White clover White clover a perennial inhabitant of lawns and closely grazed pastures is the most important pasture legume in the humid states As the name implies the flowers are generally white but sometimes they are tinged with pink The stems grow on the soil surface and root at the joints (nodes) as the plant spreads There are three main types large intermediate and small with all gradations between Ladino is the best known and most widely seeded variety of the large type whereas Louisiana S1 represents the intermediate type The small type is found principally in pastures that are continuously and closely grazed All types are nutritious and are relished by all classes of livestock and poultry The protein content ranges from 15 to 30% depending on plant age and the succulency of growth Ladino white clover is sometimes used for silage and hay White clover is mainly grown with low growing grasses not being tolerant of the tall growing kinds Seeding rates vary from ½ to 2 lb per acre depending on the seed mixture For successful growth it is important to use the variety or strain best adapted to the particular climatic and soil conditions Limestone and fertilizer must usually be used to get a thick stand and good growth Spring seeding is recommended for the northern states and fall seeding for regions having mild winters For best growth of the clover grass clover mixtures should be grazed or cut frequently

Crimson clover Crimson clover is used principally as a winter annual for pasture and as a soil improving crop from the latitude of the Ohio River southward and along the West Coast The yellow seed approximately 120 000 per lb are planted at the rate of 15–20 lb per acre during the late summer and fall months in a prepared seedbed of or grass which is closely grazed or cut The seedlings make a rosette of leafy growth during the winter months With the advent of spring growth is rapid the plant reaches 1½–3 ft in height and the flower stems elongate terminating with pointed crimson flower heads in late spring or early summer The plant dies when the seed mature Seed yields average about 250 lb per acre even though large quantities are lost by shattering Crimson clover is seeded alone with small grains and grasses or on grass turf During the winter it may be grazed when growth reaches 4 in although if it is too heavily grazed regrowth is slow The greatest return for soil improvement is obtained when the largest growth is plowed under There are several varieties of crimson clover including Dixie Auburn Autauga Chief Talladega and many local strains When conditions are favorable all of these will reseed forming volunteer stands in the fall from seed shattered the previous spring Common crimson clover does not reseed When used with Bermuda or other perennial summer growing grasses the fall growth of the grass must be closely grazed or clipped

Subclover Subclover a winter annual now extensively used for grazing in the coastal sections

of the western states, is the basic pasture crop of the sheep and cattle industry of Australia The seed are blue-black and the largest of any clover species (about 60 000 per lb) The flower heads on decumbent stems are inconspicuous As the seed develop fishhook shaped appendages are produced which by their twisting action, pull them into the soil hence the name subclover Seed production is large but the seed are difficult to harvest When once established fall stands develop from seed produced the preceding months The Australian varieties Mt Barker, Tallatook, and Nangeela have proved to be best adapted to most conditions in the United States Subclover appears to have considerable promise as a pasture legume under many conditions in the southern United States, but better adapted varieties are needed

Other clovers Strawberry clover a perennial is a nutritious pasture plant similar in growth habit to *white clover* for which it is frequently mistaken The pinkish flower head looks like a strawberry hence the common name It is highly tolerant of the wet salty soil common to the western states

Persian clover is a winter annual used mostly for pasture and soil improvement but is also an excellent silage plant It is particularly adapted to the wet, heavy soils of the lower southern part of the United States The flowers are light purple and the mature seed are enclosed in balloonlike capsules that shatter easily, float on water, and are readily blown about by the wind Persian clover is relished by all classes of livestock

Large hop clover and small hop clover, widely distributed as winter annuals in the southern states are used in pastures They are more tolerant of low soil fertility than the other species are less productive, but are highly palatable to livestock The flower heads are bright yellow and when mature, look like the flowers of the hop plant The two species are similar

Rose clover is a relatively new winter annual and appears to be best adapted to the foothill rangelands of California

Berseem is the least tolerant of the clovers to winter freezing and is grown only in limited amounts in southern California and Arizona

Other recently introduced species are ball clover, lappa clover, and big flower clover, all winter annuals *Lappa clover grows best in the heavy dark* marl soils of the South whereas ball and big flower clovers appear to be more widely adapted All are used for pasture, although big flower clover may also be used for hay, as it grows taller than the other two

Seaside clover (*T willdenowii*), white-tipped clover (*T variegatum*), and long stalked clover (*T longipes*) are the most widely distributed of the native western species All produce thick stands and good growth under varying conditions *See* GENETICS LEGUME FORAGES, REPRODUCTION, PLANT



Fig 2 White sweetclover *Melilotus alba* (USDA)

SWEETCLOVER

Sweetclover is the common name for all but one species of legumes of the genus *Melilotus*, order Rosales The exception is sour clover, *M indica*

Origin and distribution. There are approximately 20 species of sweetclover Some of the biennial species have an annual form The roots of the biennials develop crown buds from which the second year growth arises, the roots of annuals do not develop crown buds Sweetclovers are native to the Mediterranean region and adjacent countries but several are widely scattered throughout the world generally by chance introduction None is indigenous to the United States White sweetclover, *M alba*, and yellow sweetclover, *M officinalis* are important forage and soil improvement plants in the United States and Canada and are found growing along roadsides and in waste places in every State (Fig 2) Sour clover, a yellow flowered winter annual, is of some value for soil improvement only along the Gulf Coast and in southern New Mexico, Arizona, and California Improved varieties of white and yellow sweetclovers with many desired characteristics are available for farm use

Uses. Sweetclover is used as a field crop in regions of the United States and Canada where the rainfall is 17 in or more during the growing season, where the soil is neutral or where limestone and other needed minerals are applied It is most ex



Fig 3 Injury inside roots of red clover caused by crown and root rot organisms such as species of *Pythium Fusarium* and *Sclerotinia*



Fig 4 Northern anthracnose lesions on stems and leaf petiole of red clover

tensively grown in the Great Plains and Corn Belt regions either alone or in rotations with small grains and corn and is used for grazing soil improvement and hay Except for those of certain improved varieties the plants are somewhat bitter because of the presence of coumarin External and internal bleeding of animals may result from feeding spoiled sweetclover hay or improperly preserved silage containing sweetclover a decomposition product of coumarin (4 hydroxycoumarin commonly called dicumarol) which develops during spoilage being the toxic principle Research has led to its use in medicine and for making warfarin a rodenticide [E A H]

CLOVER DISEASES

Clovers may be attacked separately or simultaneously by bacteria fungi nematodes and viruses Clover diseases are best controlled by growing adapted varieties that tolerate some of the important pathogens

Fungus diseases Fungi such as species of *Pythium Fusarium* and *Sclerotinia* produce root and crown rots They are important in the establishment and persistence of clovers These fungi can attack plants at any stage of their development and either kill or weaken the plants so that they die during periods of drought or low winter temperatures (Fig 3)

Leaf and stem pathogens usually do not kill plants but produce lesions that reduce the functional leaf surface or girdle stems When abundant

destructive virus diseases that produce leaf mottling and distortion stunt the plants and reduce vigor Some viruses infect not only clovers but also other legumes and nonlegumes The viruses are initially spread by insects but some may also be spread by mowing [K W K]

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Clupeiformes

An order of the subclass Actinopterygii also known as the Isospondyli Three grades or levels of organization may be recognized among fishes of the subclass Actinopterygii Of these the chondrostean and holostean levels are antecedent to the teleostean grade In the Recent fauna these older groups are represented by four orders the chondrosteans which include the Polypteriformes and Acipenseriformes and the holosteans or Semionotiformes and Amiiformes with more or less archaic characters including a heterocercal tail and fulcral scales Only about 42 species are included The teleostean level includes 24 orders with many thousands of species The Clupeiformes is the oldest and most centralized of these orders and from it the other soft rayed fishes as well as the spiny rayed types have evolved

The characters of the order are basic to the soft rayed fishes other groups of which represent chiefly modifications innovations or loss from the fundamental clupeiform plan These generalized features of the Clupeiformes include a caudal fin which is homocercal no fin spines a pelvic fin which, if present is usually abdominal in position and usually has numerous rays a pelvic girdle which is not attached to the cleithra a pectoral fin base which is usually more or less horizontal and placed low on the side an upper jaw which is bordered by the premaxillae and maxillae an orbitosphenoid which is usually present as well as the mesocoracoid absence of Weberian apparatus a swim bladder which usually has a duct a post temporal which is usually forked and articulates with the skull scales which are cycloid or absent and branchiostegal rays which are variable in number and arrangement



Fig 1 Tarpon *Megalops atlantica* (After G B Goode Geat Internat onal Fisheries Exhibition London 1883 U S Natl Museum Bull 27 1884)

Clupeiform fishes are definitely known from the Lower Jurassic and may have appeared in the Upper Triassic They became increasingly numerous and by the Upper Cretaceous had differentiated into a considerable variety of types Among Recent forms the tarpon and its relatives are the most primitive They commonly retain a vascular swim bladder that is lost in higher types the terminal four or more vertebrae are turned upward in support of the caudal fin and gular plates are retained

The Clupeiformes ranks third in size among the orders of fishes It may be classified in about 9 suborders 33 Recent families 210 genera and about 900 species Most of these are marine fishes that are abundant in all seas Some are adapted to warm shore waters others to pelagic or deep bathypelagic existence a few live in Arctic seas and many inhabit warm or cold fresh waters or are anadromous that is they enter fresh water to reproduce

The suborder Clupeoidei comprises 8 families of which the Clupeidae is the largest and most important The Clupeidae includes the sardines and herrings and the anchovies are placed here or as a closely related family These are valuable food fishes taken chiefly in northern seas and bays

The Stomiatoidei make up a suborder of several families that inhabit the middle depths of the oceans are of small size and often grotesque form and are equipped with photophores They adorn the pages of accounts about deep sea animal life See PHOTOPHORE GLAND

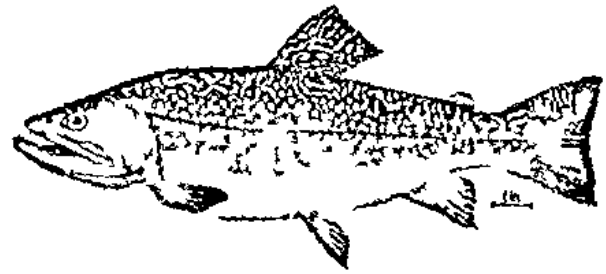


Fig 2 Brook trout *Salvelinus fontinalis* (After G B Goode Great Internat onal Fisheries Exhibition London 1883 U S Natl Museum Bull 27 1884)

Included in the suborder Salmonoidei are many of the most important of all fishes especially the family Salmonidae or trout whitefishes and graylings The several species of Pacific salmon constitute an unparalleled economic resource of the north Pacific and the trout char and salmon provide an enormously valuable recreational resource in all northern lands and through introduction in cold southern waters as well

Other suborders include the mormyrids or elephant fishes of African rivers the Esocidae or pikes of northern fresh waters the large osteoglossids of southern continents and the specialized gigantiurids of oceanic depths *See* ACTINOPTERYGII [B M B]

Clutch

A machine element for the connection and disconnection of shafts in equipment drives If both shafts to be connected can be stopped or made to move relatively slowly a positive type mechanical clutch may be used If an initially stationary shaft is to be driven by a moving shaft friction surfaces must be interposed to absorb the relative slippage until the speeds are the same Likewise friction slippage allows one shaft to stop after the clutch is released

There are many limitations on the applications of clutches for transmitting power through shafts These limitations are created by the rotational speed of the shafts the quantity of torque delivered the space required for the mechanical parts the availability of materials having the proper characteristics for absorbing frictional energy and the heat dissipation qualities of assemblies for heavy duty applications Clutches may be created by the individual designer or they may be purchased from manufacturers who have developed many specialized units

Positive clutch When positive connection of one shaft with another in a given position is needed a positive clutch is used This clutch is the simplest of all shaft connectors sliding on a keyed shaft section or a splined portion and operating with a shift lever on a collar element (Fig 1) Because it does not slip no heat is generated in this clutch Interference of the interlocking portions prevents engagement at high speeds at low speeds if connection occurs shock loads are transmitted

shafting

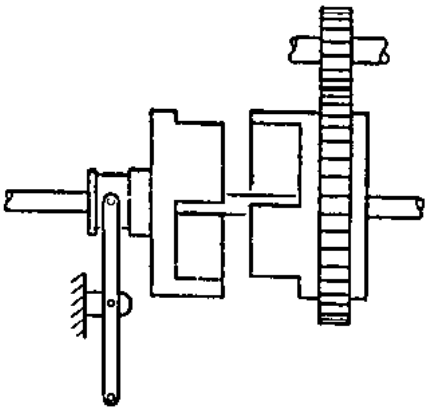


Fig 1 Square jaw type positive clutch

Square jaw Positive clutches may consist of two or more jaws of square section which mesh together in the opposing clutches Because the faces sides and bottoms are rectangular meshing does not result on contact unless the jaws are aligned Thus although square jaw clutches are the strongest and most elementary to construct the difficulty of engagement limits their use

Spiral jaw A modification of the square jaw clutch Although the most common positive clutch is the spiral jaw type ratchet and gear teeth elements may be used in the clutch faces Most power presses use these positive clutches to drive the punch press parts for exact positioning and for automatically releasing the drive after completion of the working stroke The starting impact on such equipment is not considered harmful although wear and fatigue stresses from shock loads must be considered in the design

Friction clutch When the axial pressure of the clutch faces on each other serves to transmit torque instead of the mating shape of their parts the

speed of the driven load gradually approaches that of the engine until the two speeds are the same The rate at which the load can be applied to the engine depends upon the coefficient of friction of the materials in contact the normal pressure on these materials the mean radius of the tangential force and the ability of the clutch elements and the housing to dissipate the heat generated during the slipping period If this rate of application is too rapid the rotational inertia resistance becomes high

A friction clutch is necessary for connecting a rotating shaft of a machine to a stationary shaft so that it may be brought up to speed without shock and transmit torque for the development of useful work The three common designs for friction clutches combining axial and radial types are cone clutches disk clutches and rim clutches All these types require a common activation mechanism one that has a stationary lever engaging a collar which by its displacement loads and unloads the friction surfaces to operate the clutch

Cone clutch In one form of friction clutch the surfaces are sections of a pair of cones (Fig 2) This shape uses the wedging action of the mating surfaces under relatively small axial forces to transmit the friction torque These forces may be established by the compression of axial springs or by the outward displacement of bell crank levers to apply axial thrust to the conical surfaces To operate the clutch a cylindrical spool mounted on the main shaft activates thrust levers and self locking toggles when displaced by the shifting lever and yokes The cone clutch is an elementary device and is limited in its versatility and power range

Industrial applications of the cone clutch include uses as a power take-off on couplings for driving pulleys sheaves and hoisting drums which are run intermittently from a continuously rotating shaft

Machine tool applications of the cone clutch arose from the requirements for reversing the spindle on high speed machines With double clutches in opposition and a plastic impregnated woven material for the inner cone the lower inertia of the cone clutch elements permits rapid reversal with low energy loss

Disk clutch With the advent of improved friction materials disk clutches have become more common than cone clutches They are capable of wide application in the industrial and automotive fields (Fig 3) Disk clutches are not subject to centrifugal effects present a large friction area in a small space establish uniform pressure distributions for effective torque transmission and are capable of effectively dissipating the heat generated to the external housing

The disk clutch consists essentially of one or more friction disks connected to a driven shaft by splines These friction disks have specially prepared friction material riveted to both sides Contact plates keyed to the inner surface of an external hub separate the friction disks The axial force necessary to establish tangential friction between the friction disks and the contact plates for the

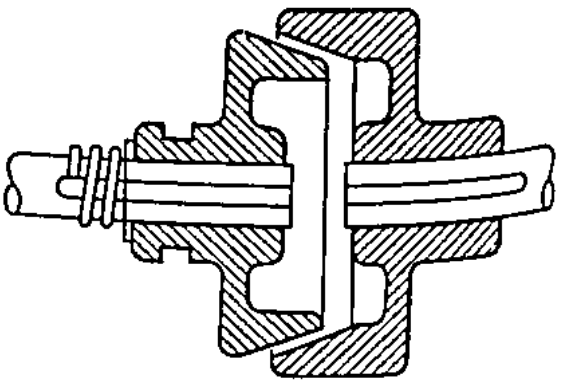


Fig 2 Cone type friction clutch

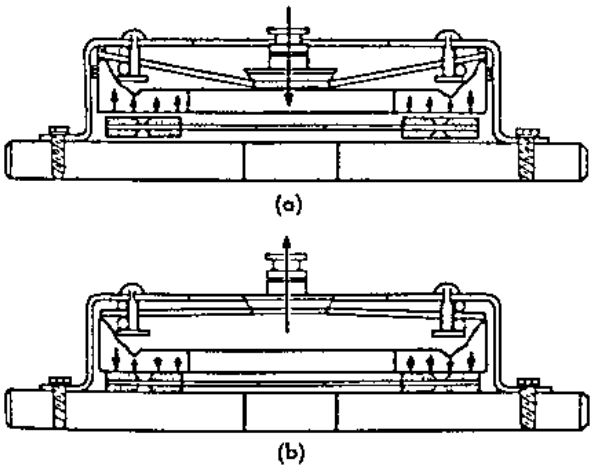


Fig 3 Disk type friction clutch (a) In disengaged position (b) In engaged position

transmission of the torque, is applied through an end pressure plate by springs or toggles in the assembly

The disk clutch may be operated dry as in most automobile drives or wet by flooding it with a liquid as in heavier automotive power equipment and in industrial engines The advantage of wet operation is the ability to remove heat by circulating the liquid enclosed in the clutch housing

Of particular importance are the friction materials used on the clutch disks, many special mechanical designs have been developed for large power drives and machine tools

Rim clutch Another form of frictional contact clutch has surface elements that apply pressure to the rim either externally or internally Clutches of this nature may have hinged shoes connected together by an expanding or contracting kinematic mechanism on a hub fixed to one shaft and riding on a drum or rim attached to a hub on a second shaft They have clutch expansion rings or external bands which when displaced are capable of transmitting torque to the clutch rim The rims may be grooved to increase the surface the clutch may have a double grip internal and external or pneumatically expanding flexible tubes may set the friction surfaces against the rim (*see* BRAKE) Because the clutch rotates with the shaft when it is engaged its balancing must be considered

Overrunning clutch The driven shaft can run faster than the driving shaft with an overrunning clutch This action permits freewheeling as the driving shaft slows down or another source of power is applied Effectively this is a friction pawl and ratchet drive wherein balls or rollers become wedged between the sleeve and recessed pockets machined in the hub (*see* RATCHET) The clutch does not slip when the second shaft is driven and is released automatically when the second shaft runs faster than the driver Specially shaped struts or sprags may replace the balls, springs may be employed to hold the pawl elements in position (Fig 4) Mechanisms have been devised for reversing the direction of operation In the design the effective wedging angle must be slightly greater than the coefficient of friction of the wedging elements

Centrifugal clutch Centrifugal force from the speed of rotation can operate the clutching mechanism Heavy expanding friction shoes may act by centrifugal force on the internal surface of a rim clutch Flyball type mechanisms are used to activate clutching surfaces on cones and disks This type of clutch is not normally used because it becomes unwieldy and unsafe with increasing size

Hydraulic clutch. Clutch action is also produced by hydraulic couplings with a smoothness not possible with a mechanical clutch (*see* FLUID COUPLING) Automatic transmissions in automobiles represent a fundamental use of hydraulic clutches (*see* TORQUE CONVERTER) [J J R]

Electromagnetic clutch Magnetic coupling between conductors provides a basis for several types of clutches The magnetic attraction between a current carrying coil and a ferromagnetic clutch plate serves to actuate a disk type clutch Slippage in such a clutch produces heat that must be dissipated and wear that reduces the life of the clutch plate Thus the electromagnetically controlled disk clutch is used to engage a load to its driving source A typical unit 24 in in diameter and weighing about 600 lb develops 2400 lb ft of torque when excited at 2 amp and 115 dc volts at a maximum safe speed of 1200 rpm it transmits 540 hp Multiple interleaved disks alternately splined to the driving and driven shafts provide a compact structure (Fig 5) [J E G]

Magnetic fluid and powder clutches Finely divided magnetic particles in an oil carrier or dry can fill the space between what in effect is a disk clutch Upon the application of a magnetic field the particles tend to coalesce thereby creating viscous or friction forces between the clutch members The wet type provides the smoother operation, the dry type is freer from loss of particles Torque at a fixed moderate excitation is independent of slip

Eddy current clutch The current induced by a magnetic field can serve as the torque transmitting means In the eddy current clutch a coil carrying direct current in one rotating member establishes poles that generate currents in the adjacent smooth conductive ring of the mating member Torque increases as the slip increases and as the excitation

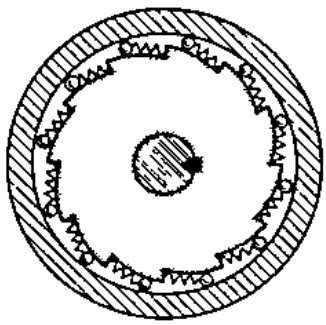


Fig 4 Overrunning clutch with spring constrained rollers or balls

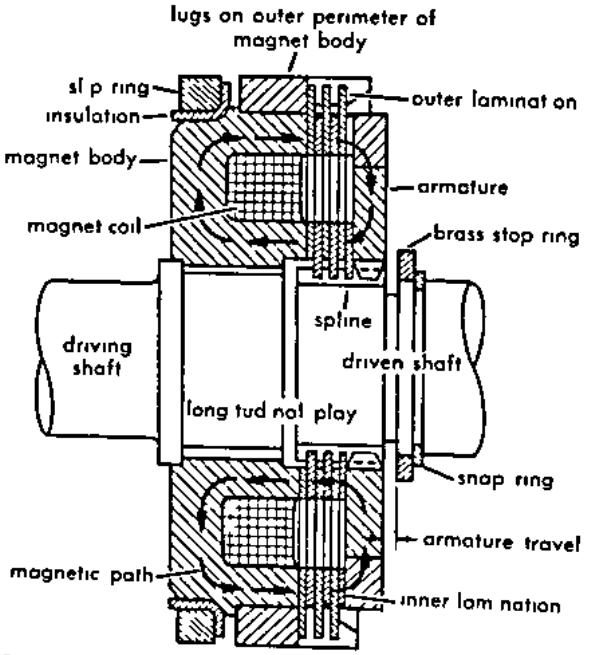


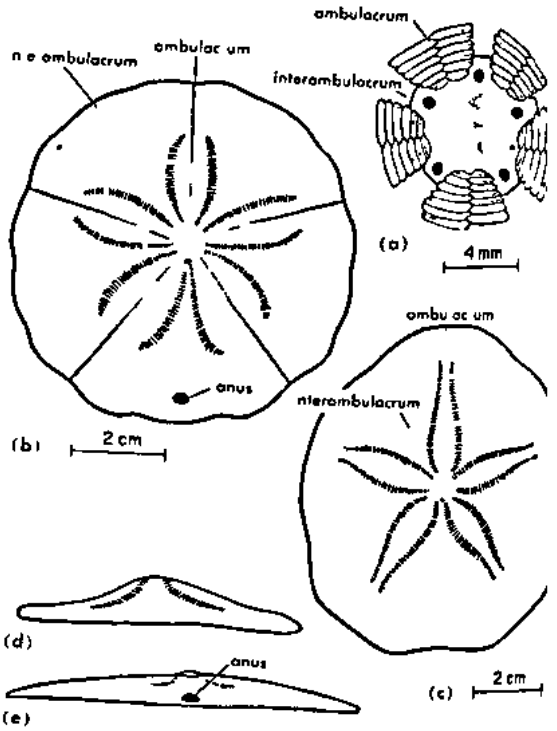
Fig 5 Electromagnetically activated multiple disk clutch (*I T E Circuit Breaker Company*)

increases Efficiency is high better than 96% at full load Excitation depends on size and is typically 2% of the total power handled The coupling acts as an untuned damper and therefore does not transmit torsional vibration This characteristic and the rising torque slip characteristic are desirable in such applications as power shovels drag lines industrial trucks punch presses and wind tunnels Such a clutch consists of a separately excited motor and generator combined into a single machine Clutch action can be obtained by electrically connecting a generator on the driving shaft to a motor on the driver or by various intermediate designs *See* DYNAMOMETER, ELECTRIC ROTATING MACHINERY

Hysteresis clutch For low power applications, where continuous control without slip is needed, as in instrument servos a hysteresis clutch may be used Direct current excitation of a coil in one part generates a steady flux field that magnetizes an iron ring on the other part the ring having high magnetic retentivity The action induces poles in the iron ring Attraction between the induced poles in the ring and the control field produces a torque that opposes rotation between the two parts of the clutch Within its load limit the hysteresis clutch transmits rotation without slip Like the eddy current clutch there is no contact surface to wear so that the characteristics are stable and the life is long *See* BRAKE, COUPLING [JEG JJR]

Clypeasteroida

An order of exocyclic Euechinoidea which have a monobasal apical system in which all the genital plates fuse together The ambulacra are petaloid on the aboral side and wider than the interambulacra on the adoral side The adult has keeled teeth without lateral flanges (see illustration) The order probably arose in the Late Cretaceous from Holectypoida Tertiary fossils are very common and extant species range the coastlines of tropical and temperate seas Relatively short time span some fossil species make them valuable as index forms in stratigraphy Many species are gregarious and occur in closely packed colonies of perhaps millions of individuals There are 16 fami



(a) *Laganum*, monobasal apical system (b) Arachnoides, a sand dollar, aboral aspect (c) *Laganum* aboral aspect (d) *Laganum*, posterior aspect (e) *Arachnoides* posterior aspect

arranged in 4 suborders *See* ECHINOIDEA, EUECHINOIDEA, HOLECTYPOIDA [HBF]

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Cnidosporidia

A subclass of the Sporozoa or spore-producing Protozoa These animals are parasites of cells and tissues of invertebrates, fishes, a few amphibians, and turtles There are four recognized orders Myxosporidia Actinomyxidia Microsporidia and Helicosporidia

A distinctive structure of this group of parasites is the spore containing one or more protoplasmic masses called sporoplasms The spore also contains one or more filaments which lie coiled within the spore proper or within one or more polar capsules The spore membrane may consist of a single chitinous piece or two or more parts called valves

When the spore is ingested by a new host, the filaments are extruded and at the same time the sporoplasm is released The sporoplasm now called an amebula, reaches the specific site of infection

directly through the intestinal wall or by way of the blood stream The amebula becomes a trophozoite a stage in the life cycle which feeds and grows at the expense of the host Asexual reproduction by repeated binary fission multiple fission internal and external budding or plasmotomy results in cells which develop into sporonts or sporoblasts producing one or more spores *See* SPOROZOA

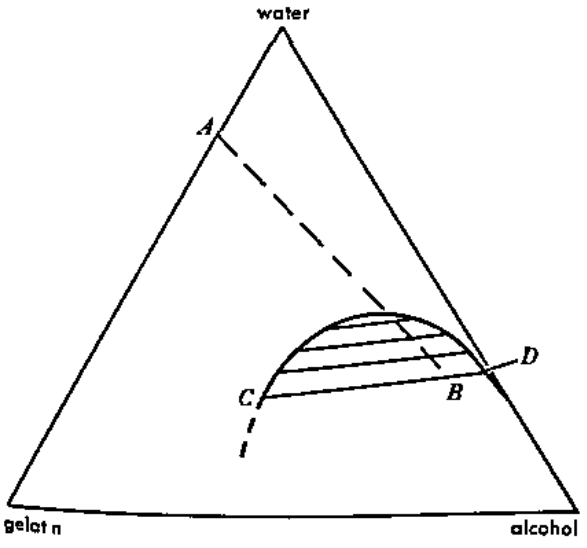
The fact that the spore may be formed from several cells has led to the suggestion that the Actinomyxidia may be metazoans possibly related to the class Dicyemidae of the phylum Mesozoa *See* DICYEMIDA REPRODUCTION ANIMAL [R F N]

Coacervation

The separation by addition of a third component of an aqueous solution of a macromolecular colloid (polymer) into two liquid phases one of which is colloid rich (the coacervate) and the other an aqueous solution of the coacervating agent (the equilibrium liquid)

Coacervation is held to have a widespread biological significance The mutual precipitation of proteins the mechanism of antibody formation and the protoplasmic membrane of the biological cell have been cited as examples of coacervation phenomena or coacervate morphology

The diagram represents the three-component system gelatin + water + alcohol it is a simplification of the actual facts to describe gelatin as a single component and for this reason the diagram is merely schematic The dotted line *AB* represents the addition of alcohol to a dilute aqueous solution of gelatin represented by point *A* until the final total composition (point *B*) is reached This latter point lies in a two phase region of the phase diagram the composition corresponding to it would therefore appear as two separate liquid phases one of them having the composition represented by point *C* (the coacervate) and the other represented by point *D* (the equilibrium liquid) A characteristic feature of the phenomenon of coacervation is that nearly all the colloid (gelatin in this case) is present in the coacervate and the composition of the equilibrium liquid is therefore a nearly pure alcohol water mixture The diagram shows the coacervate to have a lower alcohol water ratio than the equilibrium liquid



Coacervation (schematic) in the system isoelectric gelatin + water + alcohol

Properties of coacervates Coacervation has been described above as no more than a special case of phase separation in a multicomponent system In this respect the phenomenon differs not at all from that of more familiar ternary systems containing no colloidal or macromolecular constituent such as is formed for example by adding water to a dilute solution of vinyl acetate in acetic acid At a sufficiently high concentration of water a separation of two liquid phases takes place one liquid contains nearly all the vinyl acetate corresponding to the coacervate and the other liquid is essentially a dilute aqueous solution of acetic acid When the coacervate contains a macromolecular constituent however its physical behavior presents obvious differences in character The enormous size of the molecule introduces surface effects such as the possibility of independent interactions at different sites on the surface thereby affecting the structure of the coacervate Also because of its content of macromolecular component a coacervate typically has a viscosity that is several orders of magnitude greater than that of its equilibrium liquid This physical characteristic more than any other distinguishes coacervate separation from the analogous phase separation shown in ternary systems of micromolecular components

The rheological behavior of a coacervate is that of a Newtonian liquid of very great viscosity furthermore on addition of more water the coacervate passes again into the sol state These observations indicate that in the coacervate the micromolecular constituents are present as occluded liquid largely held between the primary macromolecules The surface interactions that are responsible for this structure may be between nonionized groups or between ions the former mechanism is styled simple coacervation the latter complex coacervation No clear cut distinction exists because in certain cases (for example in the mixture gum arabic + electrolyte + alcohol) both mechanisms act simultaneously

Mechanism of formation An aqueous isoelectric gelatin sol can be coacervated not only by addition of alcohol but also by addition of sodium sulfate or simple phenols (phenol the three dihydric phenols and the three trihydric phenols) chebulic acid digalloyl glucose or tannin In none of these cases is there any mechanism of ionic neutralization The coacervating agent may operate by reducing the activity of water electrolytes take up water of ionic hydration and substances such as alcohol or phenolics form hydrogen bonds with water Alternatively the coacervating agent more particularly the phenols also may act by specific inter-

action with amine or amide groups of the gelatin The coacervating agent need not be a micromolecular substance that can form hydrogen bonds The addition of another macromolecule with its own demands for water to satisfy the hydrogen bonding propensities of its groups can also create competition for the solvent and cause a phase separation Thus two coacervates may separate from the system when two concentrated colloidal sols for example gelatin and starch or gelatin and gum arabic are mixed together The latter process is still classified as simple coacervation because it occurs at a pH greater than the isoelectric point of the gelatin at which both colloids are negatively charged Nevertheless the possibility of some direct interaction between the two colloids must not be ruled out even in these examples of simple coacervation

Complex coacervation is exhibited also by the same system (gelatin and gum arabic sols) if the pH is less than the isoelectric point of the gelatin where the two colloids have opposite electric charges In this case a single coacervate phase that contains both colloids is produced and the equilibrium liquid is pure water This so called complex coacervation does not differ greatly from the mutual coagulation of positively and negatively charged hydrophilic sols *See* COLLOID CYTOLOGY EQUILIBRIUM PHASE RHEOLOGY [S RO]

Bibliography P K Koets Phase separation in aqueous colloidal systems *Reports on Progress in Physics* 10 129–140 1946 H R Kruyt s (ed) *Colloid Science* vol 2 1949

Coagulation

A separation or precipitation from a dispersed state of suspensoid particles resulting from their growth In many cases a suspension of a colloidal crystalline solid may be precipitated by a prolonged heating during which the larger particles grow at the expense of the smaller

Certain colloidal suspensions may be precipitated or coagulated by the addition of an electrolyte to the suspending medium

Solidification of an entire phase may result from a condensation reaction between a solute and solvent or from a condensation of solute molecules in which the liquid phase is trapped in its meshes This process is also described by the term coagulation "setting of a gel and clotting of blood are examples *See* COLLOID GEL ISOELECTRIC POINT [F J J]

Coal

The general name for the natural rocklike brown to black derivative of forest type plant material usually accumulated in peat beds By burial and subsequent geological processes coal is progressively compressed and indurated finally altering into graphite or graphitelike material In American terminology the rank varieties of coal comprising this carbonification series consist of lignitic coal represented by brown coal and lignite bituminous coal represented by subbituminous coals and anthracite coals consisting of semianthracite and anthracite and metaanthracite *See* LIGNITE PEAT

Formation of coal Coal may originate from isolated fragments of vegetation but most coal represents the carbonification of woody plants accumulated in peat beds These are mainly of two kinds autochthonous deposits representing accumulations at the place of plant growth such as those found in the Great Dismal Swamp of Virginia and allochthonous deposits accumulated elsewhere than at the place of growth by the drifting action of stream lake or sea currents such as the Red River rafts Generally autochthonous coal deposits overlie seat rock or underclay containing traces of plant roots called Stigmaria in the case of coals of Paleozoic age *See* COAL PALEOBOTANY SEDIMENTATION (GEOLOGY)

Biochemical activity modifies the character of the unsubmerged lightly submerged or lightly buried peat This process consists in part of general oxidation but mainly of attack by aerobic bacteria and fungi that can live only where oxygen is available and of anaerobic bacteria where water or thin sediments cover the peat Fires set by lightning or other causes may consume part of the peat from time to time leaving in places a residue of char coal which may eventually be incorporated into the coal bed in the form of fusain known to miners as mineral charcoal mother of coal and mother coal *See* DIAGENESIS

The forest fire origin of fusain is disputed by many botanists who believe the presence of certain combustible components in fusain such as resins indicates that chemical causes operating under special conditions bring about the formation of fusain No completely satisfactory explanation of the origin of fusain has been stated It is found in all ranks of coal with relatively little difference in composition There is also transitional material between normally coalified wood or bark and fusain called semifusain Because of its porosity fusain is commonly mineralized into a hard or heavy substance unmineralized fusain is soft and light Fusain occurs in all sizes from particles of microscopic dimension to aggregates forming fairly continuous thin sheets or lenses several feet across and several inches thick

The material composing the peat which is finally transformed into coal varies with differences in source material in conditions of accumulation and diagenesis and in the length of time involved prior to burial Figure 1 shows the relative resistance of the principal peat forming plant substances to microbic decomposition Based upon the peat forming components which are more or less segregated into bands several common types or varieties of coal can be recognized

Unbanded coal is represented by cannel or sapropelic coal and includes common cannel and algal cannel variously designated boghead cannel

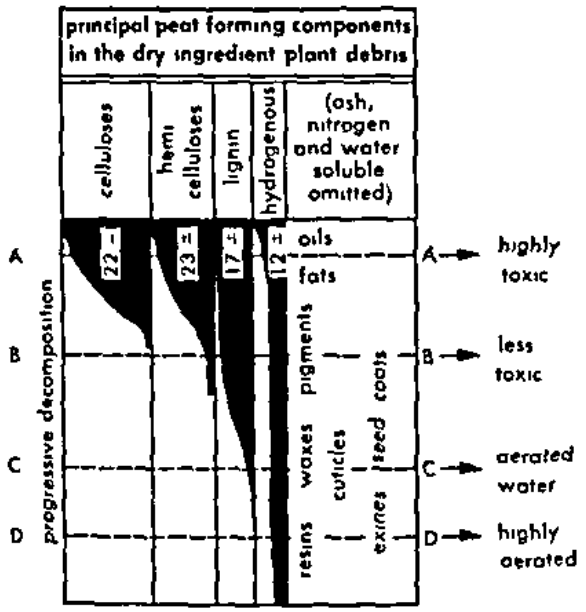


Fig 1 Approximate proportions of principal peat forming plant substances plotted according to the relative resistance to microbic decomposition and order of disappearance (*After D White*)

and torbanite The microscope is used to determine the presence of algae in the latter type Cannel coals are also distinguished by their greasy luster and blocky, conchoidal fracture *See* SAPROPEL, TORBANITE

Banded coal may be either bright or dull Banded bituminous coal is produced by thin lenses of highly lustrous coalified wood or bark called vitrain if of megascopically distinguishable thickness (½ mm or 1/50 in) Intervening between such black, lustrous bands are layers of more or less striated bright or dull coal (clarain or durain respectively) The clarain contains a predominance of fine vitrainlike laminae or lenses (microvitrain), microvitrain is of minor importance in durain and this material has a dull luster Dullness may also result from a predominance of mineral matter or from a relatively high content of bituminous matter, such as spores, cuticles, resins and waxes Likewise the presence of opaque matter or fine fusain contributes to dullness

Carbonification. This term refers to the process of coal metamorphism brought about by increasing weight of overriding sediments by tectonic movements, by an increase in temperature resulting from depth of burial, or from close approach to or contact with igneous intrusions or extrusions Increase in pressure affects principally the physical properties of the coal, that is hardness, strength optical anisotropy, and porosity Increase in temperature acts chiefly to modify the chemical composition by increasing the carbon content and decreasing the content of oxygen and hydrogen decreasing the volatile matter and increasing the amount of fixed carbon, and increasing the calorific value to a maximum with about 20% volatile matter Rapid metamorphism or carbonification of coal, effected by close approach to or contact with igneous intrusions or extrusions, may result in the formation of natural coke Natural coke is found in some coal fields but is relatively rare *See* METAMORPHISM

Coal classification. The classification and description of coal depends largely upon information supplied by chemical analysis and the results of a number of empirical tests Chemical analyses are of two kinds the elementary or ultimate analysis, and the proximate or commercial type of analysis The ultimate analysis is usually limited to the per cent of hydrogen carbon oxygen nitrogen, and sulfur exclusive of the mineral matter or ash Phosphorus may be determined for those coals which are used for metallurgical purposes The proximate analysis, which is empirical in character, is the prevailing form of analysis in North America In this analysis systematically standardized procedures are used to provide values for volatile matter fixed carbon, moisture, and ash, all of which add up to 100% Calorific and sulfur values are also determined the latter sometimes in terms of forms of sulfur such as pyritic, organic, and sulfate sulfur

It is common practice to use qualifying terms, such as 'moisture free" (mf), "moisture-and ash free" (maf) "pure coal " and "as received," in presenting the findings of proximate and ultimate analyses Usually values are determined initially on a "moisture free" or "dry" basis, the other forms of analysis being calculated with the use of determined moisture and ash values The maf value is much used on the mistaken assumption that it represents the heat value or composition of the pure coal material, as though the formation of ash from the original mineral matter were without calorific or other effects To make a rapid and convenient allowance for the errors inherent in the maf values various procedures have been devised to arrive at a mineral matter free (mmf) basis of comparison and classification The best known of these devices is that proposed by S W Parr whereby so called unit coal or the correction to be applied to obtain approximately correct values for mmf coal is obtained

$$\text{Unit coal} = 1.00 - (1.08\ \text{ash}\ \% + 0.55\ \text{sulfur}\ \%)$$

Using this formula

$$\text{Moist mmf Btu} = \frac{\text{As rec'd Btu} - 5000\ \text{sulfur}\ \%}{1.00 - (1.08\ \text{ash}\ \% + 0.55\ \text{sulfur}\ \%)}$$

and

$$\text{Dry mmf fixed carbon} = \frac{\text{Fixed carbon} - 0.15\ \text{sulfur}\ \%}{1.00 - (\text{moisture}\ \% + 1.08\ \text{ash}\ \% + 0.55\ \text{sulfur}\ \%)}$$

The calculations are all based upon the "as received" values, and both moist and dry mmf values are used in the standard classification of coal rank (see Table 1)

Mineral matter The determination of mineral matter composition on an elementary basis requires a much more elaborate procedure than is necessary for the coal material itself since the mineral substances found in coal show important local and regional variations The following detrital minerals other than clay minerals and quartz are reported from an Illinois coal bed feldspar garnet common hornblende apatite zircon muscovite epidote biotite augite kyanite rutile staurolite topaz tourmaline and chloritic material Secondary minerals consist of kaolinite calcite and pyrite Other secondary minerals such as siderite and ankerite are commonly present in coal In specially mineralized areas the range of secondary minerals is almost unlimited *See* MINERAL

The character of the nonorganic matter in the coal has a considerable effect upon the fusion temperature of the ash the determination of which is one of the common subsidiary tests in coal analysis procedure In general ash that fuses at high temperature is preferred to low fusion ash the temperature being below 2000°F for low fusion ash and above 2400°F for high fusion ash the range is about 1600–2800°F

Rank The term rank refers to the stage of carbonification reached in the course of metamorphism (In international usage the term type is sometimes given the meaning commonly given to rank in North America and in much of the world No equivalent of the American term type is given) Classification of coal by rank is fundamental in coal description and generally is based upon the chemical composition as stated in the previous section on Carbonification and upon proximate values based upon mmf coal obtained from standard face samples In the case of low rank bituminous and subbituminous coals rank also is based upon weathering and agglutinating characteristics and in the case of brown coal and lignite upon state of consolidation In Europe coking properties are a more common basis of classification than in North America The American Society of Testing Materials standards of rank classification of coals of North America are shown in Table 1 The higher rank coals are classified with respect to fixed carbon on the dry basis (mmf) and the lower rank coals according to Btu on the moist basis (mmf)

The difference between common banded and the sapropelic or cannelloid types of coal of the same rank which occur in the same general region is mainly in the higher hydrogen and slightly higher calorific value of the latter type

Calorific values The calorific values of coal are expressed in British thermal units (Btu) per pound in English speaking countries in calories per gram where the decimal system prevails Heat values determined by a calorimeter vary for coal material from about 6400 Btu for California lignite to about 16 000 Btu for some maf cannel coal Proximate and ultimate analyses of representative United States coals by rank are given in Table 2

Table 1 Classification of coals by rank[a]

Class and group	Limits of fixed carbon or Btu mineral matter free basis	Requisite physical properties
I Anthracitic		
1 Meta anthracite	Dry fixed carbon (FC) 98% or more dry volatile matter (VM) 2% or less	
2 Anthracite	Dry FC 92% or more and less than 98% dry VM 8% or less and more than 2%	
3 Semi anthracite	Dry FC 86% or more and less than 92% dry VM 14% or less and more than 8%	Nonagglomerating[b]
II Bituminous[c]		
1 Low volatile bituminous coal	Dry FC 78% or more and less than 86% dry VM 22% or less and more than 14%	
2 Medium volatile bituminous coal	Dry FC, 69% or more and less than 78% dry VM 31% or less and more than 22%	
3 High volatile A bituminous coal	Dry FC less than 69% dry VM more than 31% and moist[d] Btu 14 000[e] or more	
4 High volatile B bituminous coal	Moist[d] Btu 13 000 or more and less than 14 000[e]	
5 High volatile C bituminous coal	Moist Btu 11 000 or more and less than 13 000[e]	Agglomerating or nonweathering[f]
III Subbituminous		
1 Subbituminous A coal	Moist Btu 11 000 or more and less than 13 000[e]	Weathering and nonagglomerating
2 Subbituminous B coal	Moist Btu 9500 or more and less than 11 000[e]	
3 Subbituminous C coal	Moist Btu 8300 or more and less than 9500[e]	
IV Lignitic		
1 Lignite	Moist Btu less than 8300	Consolidated
2 Brown coal	Moist Btu less than 8300	Unconsolidated

[a] From A C Fieldner and W A Selvig *Methods of Analyzing Coal and Coke* U S Bur Mines Bull 492 19 1 This classification does not include a few coals that have

fixed carbon or have more than 15 500 moist, mineral matter free Btu

[b] If agglomerating the coal is classified in low volatile group of bituminous class

[c] It is recognized that there may be noncaking varieties in each group of the bituminous class

[d] Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal

[e] Coals ... con ... tion on the dry ... to ... C

bituminous-coal group namely (1) agglomerating and nonweathering (2) agglomerating and weathering (3) nonagglomerating and nonweathering

Table 2 Proximate and ultimate analyses of samples of each rank of common banded coal in the United States

Rank	State	Proximate analysis %				Ultimate analysis %					Heating value Btu/lb
		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	
Anthracite	Pennsylvania	4 1	4 8	81 8	9 0	0 6	3 4	79 8	1 0	6 2	13 130
Semianthracite	Arkansas	2 8	11 9	75 2	10 1	2 2	3 7	78 3	1 7	4 0	13 360
Bituminous coal											
Low volatile	Maryland	2 3	19 6	65 8	12 3	3 1	4 5	74 5	1 4	4 2	13 220
Medium volatile	Alabama	3 1	23 4	63 6	9 9	0 8	4 9	76 7	1 5	6 2	13 530
High volatile A	Kentucky	3 2	36 8	56 1	3 6	0 6	5 6	79 1	1 6	9 2	14 090
High volatile B	Ohio	5 9	43 8	46 5	3 8	3 0	5 7	72 2	1 3	11 0	13 150
High volatile C	Illinois	11 8	33 3	39 9	12 0	2 5	5 8	58 8	1 0	19 9	10 550
Subbituminous coal											
Rank A	Washington	13 9	34 2	41 0	10 9	0 6	6 2	57 5	1 1	23 4	10 330
Rank B	Wyoming	22 2	32 2	40 3	4 3	0 5	6 9	53 9	1 0	33 4	9 620
Rank C	Colorado	25 8	31 1	38 1	4 7	0 3	6 3	50 0	0 6	38 1	8 580
Lignite	North Dakota	36 8	27 8	30 2	5 2	0 1	6 9	41 2	0 7	45 6	6 960

SOURCE *Technology of Lignitic Coals* U S Bur Mines Inf Circ 769 1954 Counties and sources of information omitted

the analyses being on the 'as received basis *See* BRITISH THERMAL UNIT (BTU) CALORIE CALORIMETRY

Physical characteristics The physical characteristics of coal concern the structural aspects of the coal bed and texture as determined by the megascopic and microscopic physical constitution of the coal itself Structurally the coal bed (also called seam and less appropriately vein) is a geological stratum characterized by the same irregularities in thickness uniformity and continuity as other strata of sedimentary origin Thickness varies greatly German brown coals occasionally approach 300 ft A drill hole in the Lake De Smet area in Wyoming penetrated 223 ft of lignitic or subbituminous coal essentially in one bed In 1955 65% of the coal produced in the United States came from beds 3–6 ft thick the average thickness that year being 62 in with mining in some cases being carried on in beds less than 24 in thick

Coal beds may consist of essentially uniform continuous strata or like other sedimentary deposits may be made up of distinctly different bands or benches of varying thickness The benches may be separated by thin layers of clay shale fusain pyrite or other mineral matter commonly called partings by the miner Clay or shale bands may be called blue bands as is the persistent clay parting in the Herrin (no 6) coal bed of Illinois Like other sedimentary strata coal beds may be structurally disturbed by folding and faulting so that the originally approximate horizontality of position is lost to the extent that beds may become vertically oriented or even overturned as in the anthracite fields of eastern United States and in other places in the world where similar high rank coals are found

Texture The texture of the coal itself is determined by the character grain and distribution of its megascopic and microscopic components In general banded coals composed of relatively coarse highly lustrous vitrain lenses (¼ in or more in thickness) are considered coarsely textured As the thickness of the vitrain bands progressively lessens *the texture becomes finebanded* and then microbanded with bright laminae composed of microvitrain Coals with less than 5% vitrain or microvitrain are regarded as nonbanded or cannelloid

In general the same textural units are observed in bituminous and anthracite coals The names employed for the lithotypes that is vitrain clarain and durain are somewhat less suitable for lignitic coals for in these ranks of coal the bands of material that appear as vitrain in bituminous coals and anthracite commonly have the unmistakable appearance of tree trunks and pieces of wood or bark

Microscopic texture is determined by the physical composition of the lithotypes as noted above or of the anthraxylon and attritus in terms of the microscopic constituents The microscopy and petrology of coal are concerned very largely with these constituents This textural aspect of coal is of importance in accurate coal description and classification and for an understanding of the behavior of coal in its preparation and utilization

Botanical and petrologic entities The fundamen

by microscopic means This approach has commonly been referred to as coal microscopy although the use of the phrase coal petrography has become more frequent in recent years The other point of view that assumed by Marie C Stopes of England and accepted in much of the world is based upon the concept of the four megascopic ingredients now called lithotypes vitrain clarain durain and fusain Since these concern coal materials as rock substances the concept provides a basis for the petrologic study of coal

Coal microscopy The microscopic study of coal as developed in North America is primarily concerned with the botanical entities or phyterals of coal, with fusain regarded as a coal substance of unique character and with appropriate consideration being given to mineral matter By 1930 Thiessen had established three categories of microscopic components anthraxylon attritus and fusain and had recognized and described most of the botanical constituents of coal This established a system of nomenclature description and classification which has been followed essentially in publications of the U S Bureau of Mines concerned with coal microscopy since that date Anthraxylon consists of coal occurring in bands in which wood or bark structure is microscopically evident All vitrain of the European classification if more than 14 microns thick is regarded as anthraxylon below this threshold it is classified as attritus The attritus consists of finely textured coalified plant entities or phyterals not classified as anthraxylon (less than 14 microns) or fusain (less than 40 microns) Attritus therefore may contain very fine shreds of anthraxylonlike material fine particles of fusain disintegrated or macerated humic material or humic degradation matter (HDM) in addition to the following constituents resins waxes cuticles spore and pollen exines algae opaque matter fungal bodies such as sclerotia and fine mineral matter of various kinds with clay minerals usually predominating The subdivision of attritus into translucent and opaque attritus on the basis of its content of opaque matter is the only subdivision made of the attritus with respect to variations

Amer
ore of
those

with 20–30% opaque matter are classified as semi splint coals Generally no equivalent classification is recognized in other parts of the world

Analysis and classification of coals on the microscopic basis have usually been made in terms of the major components anthraxylon attritus and fusain with consideration given to the quantity of opaque attritus and mineral matter These distinctions in regard to opaque attritus have been applied because splint coals are generally not amenable to hydrogenation and commonly not to carbonization Coal microscopy technique depends almost entirely on the use of thin translucent sections of coal a technique which is not adapted for use with high rank low volatile and anthracitic coals Maceration has also been used as a means of breaking down the coal and isolating the more resistant constituents thus incidentally providing the fossil spores that are the basis of the science of palynology *See* PALYNOLOGY

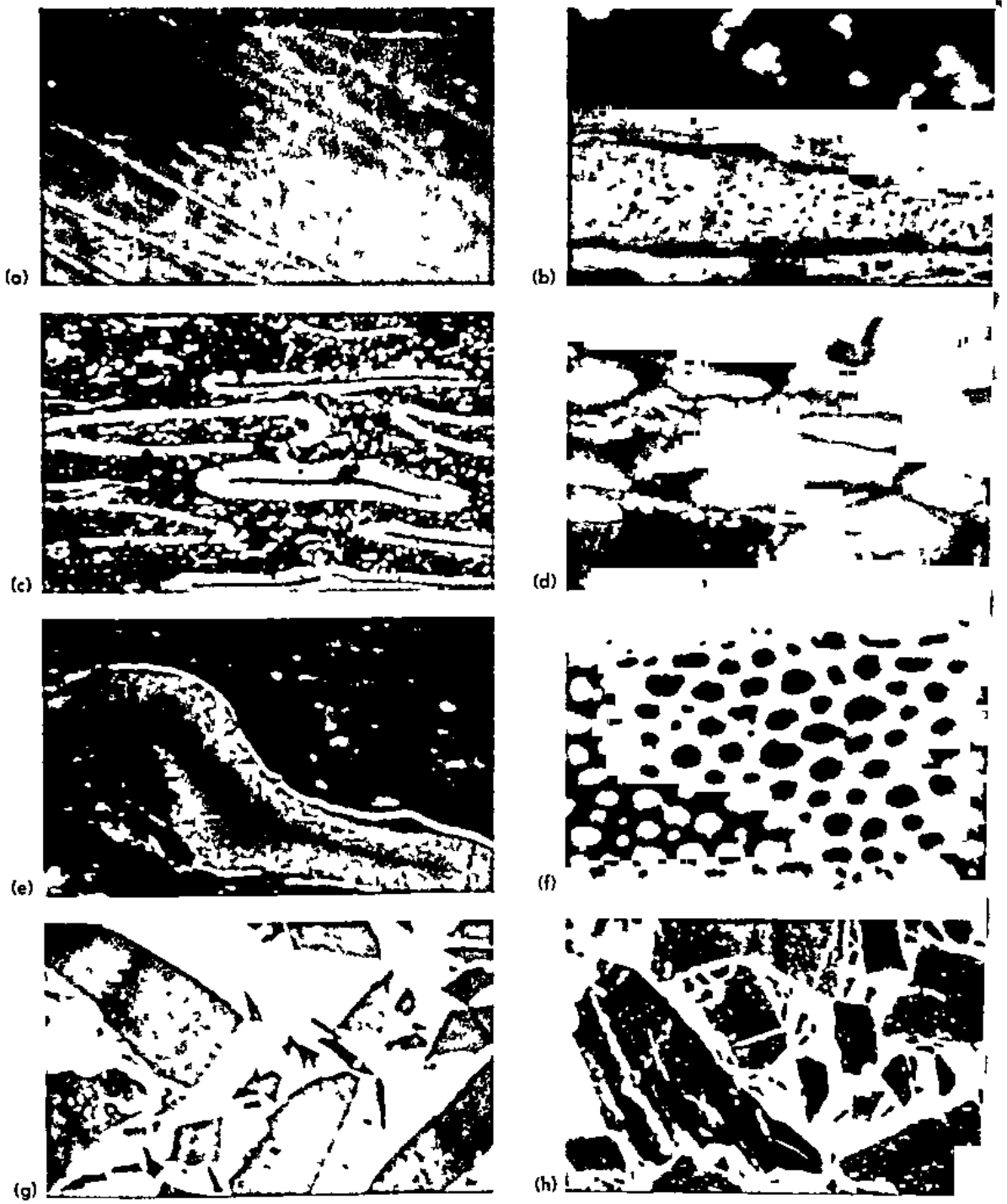
Coal petrology The petrologic study of coal requires a procedure of description and classification based upon the nature of coal as rock material The primary rock varieties or lithotypes are vitrain clarain durain and fusain These names with the exception of fusain are less suitably applicable to lignite and brown coal In this respect the American system which can use the same terms for all ranks of coal differs importantly from the European system The idea of the composite nature of rocks as composed of minerals is applied to the lithotypes of coal Thus macerals are the equivalent mineral like constituents of the lithotypes Each is regarded as a particular coal substance derived from a particular variety of organic material such as wood bark resins spore exines cuticles and others They have each been given a special name with a distinctive ending which indicates their derivation Those most commonly listed are collinite (possibly equivalent of humic degradation matter or structureless vitrain) telinite (vitrain with structure about equivalent of anthraxylon) sporinite cutinite resinite alginite micrinite (opaque matter) fusinite semifusinite (transitional between telinite and fusinite) and sclerotinite (fungal bodies) As a means of simplification three varieties or maceral groups have been set up vitrinite representing the first two macerals listed resinite the following four and inertinite

[illegible] fic

in coal petrography is applicable to all coals above lignitic rank and is used by some investigators even for these low rank coals Identification of the macerals is based partly on form and partly on difference in reflectivity the degree of reflectivity increasing with increase in carbon content In medium rank coals contrast between the different constituents is marked (Fig 3) but becomes less obvious as rank increases

Evaluation and uses Although the utilization of coal varies widely with rank three general fields may be distinguished They are combustion (domestic industrial railroads and public utilities) gasification and carbonization (high temperature coke for metallurgical uses and low temperature coke for production of smokeless fuel) Anthracite is used mainly for domestic and related types of heating some fine sizes are blended with bituminous coal to make metallurgical coke Besides the main use of lignitic coal for combustion either in the raw state or in dehydrated and briqueted form it is a source of industrial carbon industrial gases and montan wax *See* COKE LIGNITE

The evaluation of coal for particular uses is usually based upon the information provided by the ultimate and proximate analyses the values for



Organic substances common in bituminous coals as shown in photomicrographs of thin sections (*Coal Research Section College of Mineral Industries Pennsylvania State University*)

(a) Three varieties of vitrinitic material distinguished by colors of the three bands ×75

(b) Yellowish, mottled, vitrinitic substance below a deep red brown vitrinite material Vitrinitic substances of types illustrated in (a) and (b) comprise bulk of most high volatile bituminous coals ×75

(c) Exinite (yellow) and micrinite (black) materials often encountered in durain layers of coal seams ×60

(d) Resinite (light yellow oval areas) embedded in vitrinitic matrix ×60

(e) Large megaspore of exinitic material differing from that shown in (c) line in center of coalified megaspore and bulk of associated material ×103

(f) Black areas show fusinite forming remnants of plant cell walls White areas represent cell cavities now filled with mineral matter ×75

(g) Coal particles composed of vitrinitic material Such concentrations can be produced in coal preparation plants by proper beneficiation procedures ×20

(h) Concentration of coal particles of varied composition Controlling relative concentrations of each particle type in a coke-oven feed mits production of high-quality metal

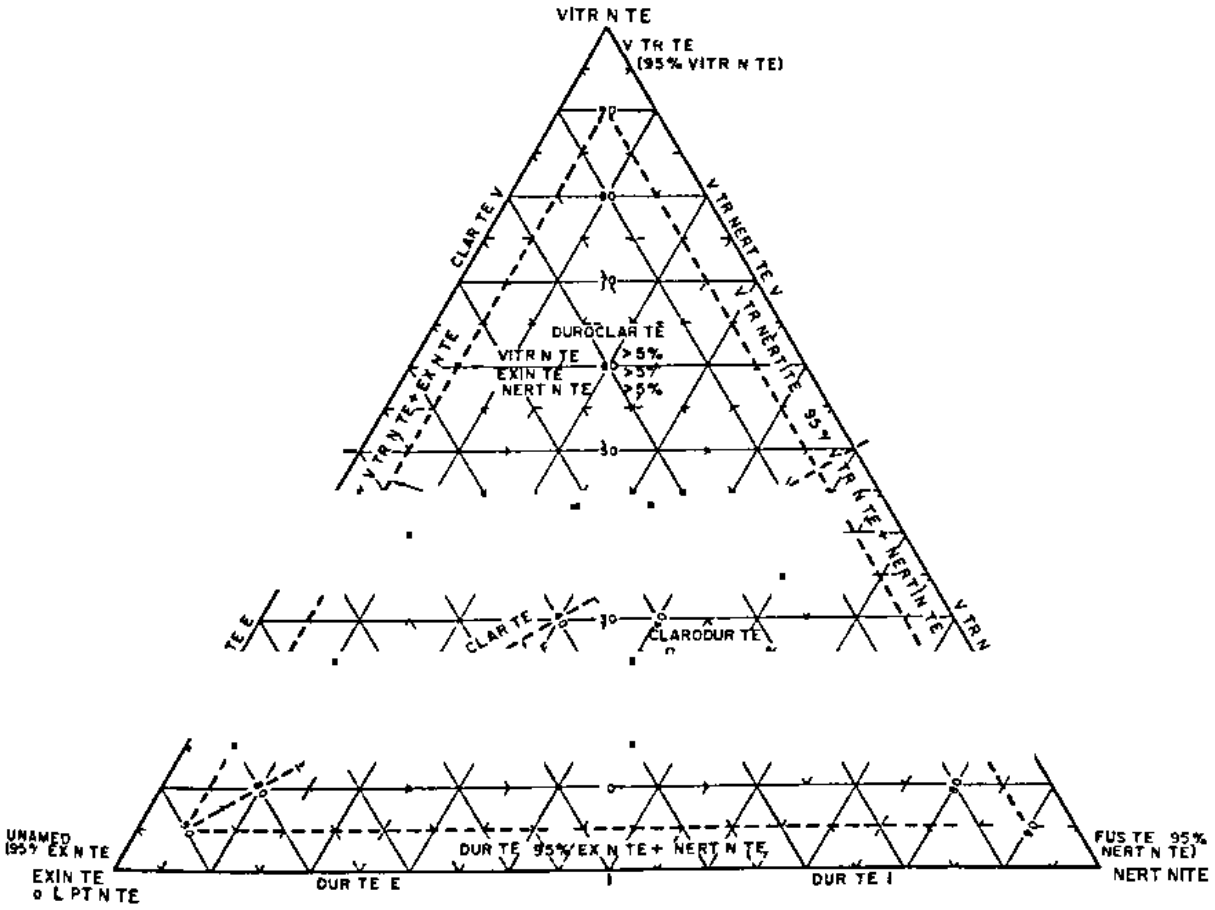


Fig 2 Triangular diagram showing the petrographic classification of coal by microlithotypes on the basis of group maceral composition (vitrain te + nertain te and exain te) Except for group macerals all terms refer to microlith

sulfur and the heat value The proximate analysis is preferred in the United States These criteria provide the means of classifying the coal by rank and with the cost per ton known the value of the coal in terms of 1 000 000 Btu Ash fusion values are co[illegible]

required These tests consist of (1) plasticity tests (2) swelling and swelling pressure tests (3) agglutinating tests and (4) agglomerating tests

Occurrence Coal is found on every continent in the islands of Oceania and in the West Indies The amount of coal in the various countries varies greatly The six countries with the greatest reserve (in millions of tons) were as follows in 1948 United States 2 028 000 China 1 011 000 U S S R restricted 998 000 Germany 279 516 Union of South Africa 205 305 and United Kingdom 172 200 The six countries with the greatest reserve (in millions of tons) of lignitic coal were United States 852 000 U S S R restricted 202 000 Alaska 62 963 Germany 56 758 Australia 39 200 and Canada 33 024

The distribution of coal by rank geologic age and district is indicated in Fig 4 The index numbers which refer to coal districts are grouped by continent and country in the accompany

Africa Belgian Congo 144 Natal 147 *Asia* China 163 132 167 135 India 19 Siberia (U S S R) 118 172 119 129 128 131 133 183 171 Turkestan 125 *Australia* 8 134 New Zea



Fig 3 Photograph of polished surface of coal representing a portion of clarain from a high volatile Ohio coal bed The white particles represent opaque matter some of which is fusain the small black elongated particles are mainly microspores the matrix is mainly vitrain te The coal shown here would be classified as duro-clarite (*Photo by G E Smith Ohio Div*

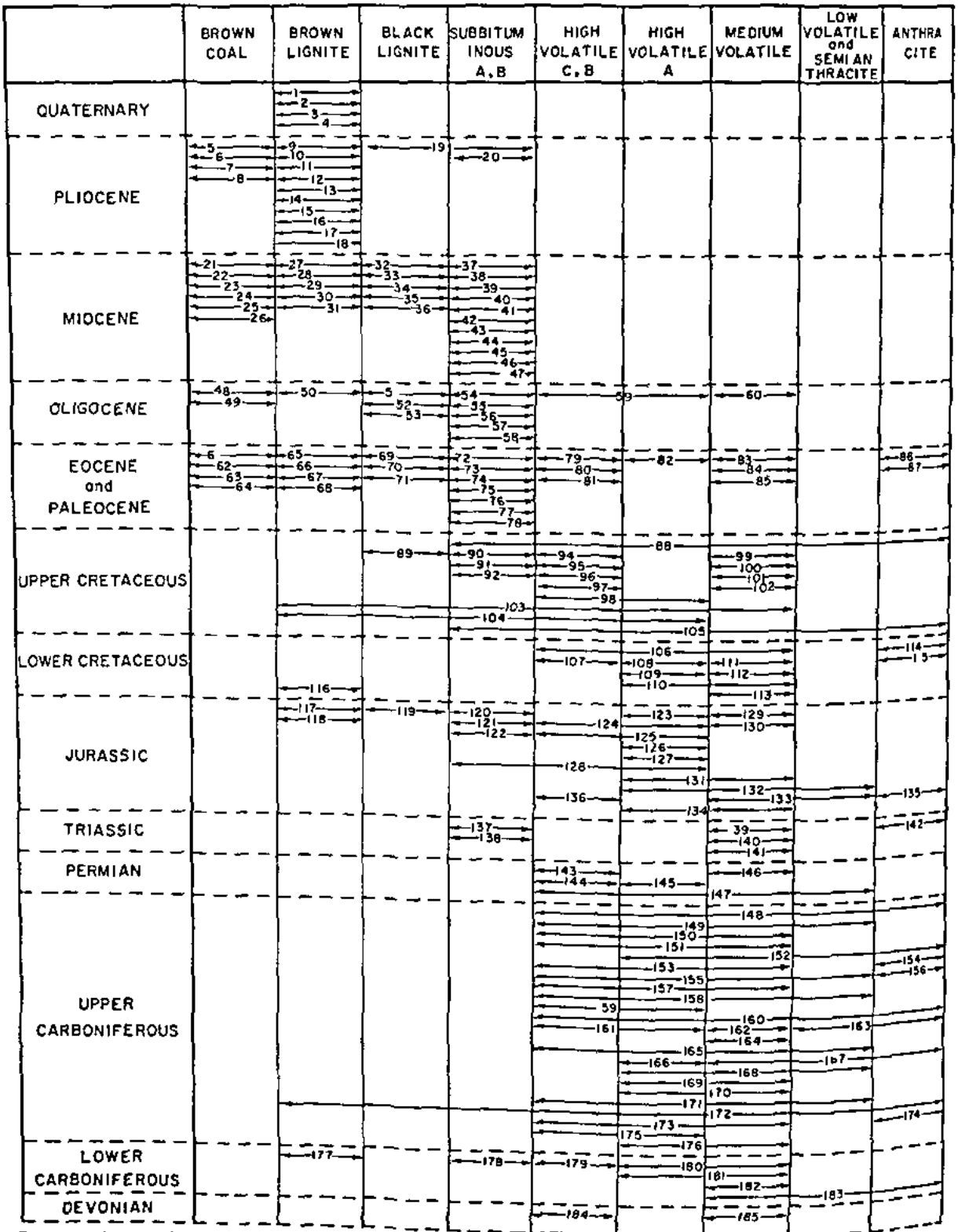


Fig 4 Age and rank of coal in the better known coal fields of the world The index numbers are identified in the last paragraph of the article (*After W Petrascheck and W E Petrascheck, Lagerstattenlehre* Springer, 1950)

land 31, 36 89, 98 *Oceania* Borneo, 81, Sumatra, 78 *Europe* Austria, 1, 3 14 29, 33, 38, 72, 123, 139, Bavaria, 2, 24, Bulgaria, 7 20 100, Czechoslovakia, 16, 28 32, 37, 55, 91, 161, *164*, England, 48 153, 155, 158, 157, 180, 182, France, 53, 165, 166, 168, East Germany, 5, 21, 22, 23 90, 121, 137, 106, 143, West Germany, 24, 49, 61, 63 62, 64 2, 27, 57, 59, 127, 150, Greece, 75, 86, Hungary, 30 35, 42 44 74, 95, 130, Italy, 18, 45, 83, Poland 6, 138, 149, 151, Ruhr district, 148, Romania 17 129, 162, Russia (U S S R), 117, 177, 124 126 179, 184, 185, Scotland, 120, 181; Spain, 160,

Spitzbergen 76, 178, 79, 82, 84, 107, 108, Switzerland 4, 87, 154, Turkey, 58, Yugoslavia, 10, 11, 12, 13 15, 50, 34, 51, 52, 39, 40, 41, 47, 54, 56, 60, 85, 99, 142, 156 *North America* Canada, 68, 116 101 110 176, 112, 113, 115, Mexico, 141, United States 43, 77, 92, 65, 66, 67, 69, 70, 71, 80, 96, 97, 103 101, 102, 88, 105, 140, 173 174, 175 *South America* Brazil, 145, Peru, 46, 111, 109, 114

[C H C]

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Coal balls

Subspherical masses containing mineral matter and embedded plant material, found in coal seams and overlying beds of the late Paleozoic The mineral content of the balls usually consists of calcium or magnesium carbonate, or sometimes iron pyrites



Photomicrograph of peel made from coal ball containing the branch of a fern

In some areas coal balls are found only in coal seams overlain by marine limestones Although some coal balls are barren of recognizable plant remains, others contain fragments showing excellent preservation of internal plant structures

All known deposits of coal balls in North America Europe, and the British Isles are associated with Pennsylvanian and Permian beds of bituminous coal They usually are present as rounded nodules or irregular masses at the surface of the bed or in the upper part of the coal seam They vary from small pea sized nodules to irregularly formed masses weighing tons

Coal balls are a hinderance to operations when encountered in coal mines After being sorted from the coal they may be used as ballast for road beds, otherwise they are discarded Some of the best specimens occur in stream beds in which coal seams have been exposed by erosion

To study the embedded plant material a coal ball is cut with a diamond saw, and serial sections 30–40 microns thick are made from the cut surface by the "peel technique" Slides are then prepared from the sections of fossilized material When observed under the microscope, they may show the arrangement of plant tissues, the cell wall structure and the cytological detail including nuclei and plastids This information aids in the reconstruction of ancient plants and the understanding of plant evolution *See* PALEOBOTANY, *see also* CONCRETION [W N S]

Coal chemicals

For about 100 years chemicals obtained as by products in the primary processing of coal to metallurgical coke have been the main source of aromatic compounds used as intermediates in the synthesis of dyes drugs antiseptics and solvents Although some aromatic hydrocarbons such as toluene and xylene are now obtained largely from petroleum refineries the main source of others such as benzene, naphthalene, anthracene, and phenanthrene is still the by product coke oven Heterocyclic nitrogen compounds such as pyridines and quinolines are also obtained largely from coal tar Although much phenol is produced by hydrolysis of monochlorobenzene and by decomposition of cumene hydroperoxide the bulk of the phenol, cresols, and xylenols is still obtained from coal tar

Table 1 Analysis of a typical coke-oven crude light oil

Component	% by vol
Forerunnings	
Cyclopentadiene	0 5
Carbon disulfide	0 5
Amylenes unidentified substances	1 0
Crude benzol	
Benzene	57 0
Thiophene	0 2
Saturated nonaromatic hydrocarbons	3 0
Unsaturates unidentified substances	3 0
Crude toluol	
Toluene	13 0
Saturated nonaromatic hydrocarbons	0 1
Unsaturates unidentified substances	1 0
Crude light solvent	
Xylenes	5 0
Ethylbenzene	0 4
Styrene	0 8
Saturated nonaromatic hydrocarbons	0 3
Unsaturates unidentified substances	1 0
Crude heavy solvent	
Coumarone indene dicyclopentadiene	5 0
Polyalkylbenzenes hydrindene, etc	4 0
Naphthalene	1 0
Unidentified heavy oils	1 0
Wash oil	
(Used to separate light oil from coke oven gas)	5 0

Table 2 Utilization of coal tar in the United States*

Use	%
Directly for fuel	17
Pitch for fuel	20
Pitch for roofing	3
Pitch coke	2
Pitch-oil	0 7
Creosote oil and other distillates	31 2
Naphthalene	2 5
Tar acids	1 1
Tar bases	0 5
Road tars	22

* Total production 833 000 000 gal (in 1956)

Coke-oven by products in percentage of the coal used are gas 18 5 light oil 1 0 and tar 3 5 Coke oven gas is a mixture of methane carbon monoxide hydrogen small amounts of higher hydrocarbons ammonia and hydrogen sulfide Most of the ammonia is recovered as about 20 lb of ammonium sulfate per ton of coal but only about 10% of the hydrogen sulfide is recovered as elemental sulfur Most of the coke oven gas is used as fuel The composition of a typical coke oven crude light oil is shown in Table 1 The unidentified fractions contain very small amounts of a large number of hydrocarbons and organic compounds containing oxygen and nitrogen In 1956 in the United States 297 500 000 gal of crude light oil was produced Refining yielded 235 500 000 gal of salable products The uses of coal tar are outlined in Table 2

Although several hundred chemical compounds have been isolated from coal tar a relatively small number are present in appreciable amounts These may be grouped as in Table 3

All the compounds in Table 3 except the monomethylnaphthalenes are of some commercial importance The amounts recovered and sold however are only 5–25% of the totals present in the coal tar

The direct utilization of coal as a source of bulk organic chemicals has been the objective of much research and development Oxidation of aqueous alkaline slurries of coal with oxygen under pressure yields a mixture of aromatic carboxylic acids Because of the presence of nitrogen compounds and hydroxy acids this mixture is difficult to refine Milder oxidation to humic acids and use of these or their ammonium salts as soil conditioners have been suggested The reactions of coal with chlorine and fluorine have not yet been adequately explored. Hydrogenation of coal at elevated temperatures and pressures yields much larger amounts of tar acids and aromatic hydrocarbons of commercial importance than are obtained by carbonization However this operation is too costly to compete with other sources of these chemicals *See* BERGIUS PROCESS COKE DESTRUCTIVE DISTILLATION PYROLYSIS

[H H ST]

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Table 3 Coal tar chemicals

Compound	Fraction of whole tar %	Use
Naphthalene	10 9	Phthalic acid
Monomethylnaphthalenes	2 5	
Acenaphthenes	1 4	Dye intermediates
Fluorene	1 6	Organic syntheses
Phenanthrene	4 0	Dyes explosives
Anthracene	1 0	Dye intermediates
Carbazole (and other similar compounds)	2 3	Dye intermediates
Phenol	0 7	Plastics
Cresols and xylenols	1 5	Antiseptics Organic syntheses
Pyridine picolines, lutidines, quinolines, acridine and other tar bases	0 3	Drugs, dyes, antioxidants

Coal gasification

The partial combustion of coal or coke to produce a gaseous fuel is an industrial operation whose technology is of great scientific and commercial interest The gaseous fuel usually is a mixture containing hydrogen and carbon monoxide in the ratio 0 7 to 1 3 volumes of hydrogen per volume of carbon monoxide When steam and oxygen react with a granular bed of coal or coke at about atmospheric pressure and 1000°C (1832°F) the oxygen is rapidly and completely consumed in the early stages and the temperature of the solid fuel increases to a level where the endothermic reactions of carbon with steam and with carbon dioxide occur at a rate large enough to maintain continuous production of the gaseous fuel In the so called blue water gas intermittent producer a granular bed of coal or coke is first blasted with air until the temperature is about 1200°C (2192°F) Then the blast is shifted to steam until the temperature drops below about 900°C (1652°F) The gaseous products of the air blast are discarded Those of the steam blast are cooled and collected for distribution as fuel or as synthesis gas and used for synthesis of hydrocarbons and oxygen containing organic compounds by way of the catalytic hydrogenation of carbon monoxide The thermal efficiency (the percentage of the heating value of the coal or coke present in the gaseous products) of this type of gasification is about 60% Some of the continuously operating producers using oxygen steam blast discharge the ash of the coal or coke as a molten slag Another type of continuous producer operates under a pressure of about 25 atmospheres (atm) and the gaseous fuel so produced contains 15–20 volume % of methane and has about 50% higher heating value than gas produced at atmospheric pressure The thermal efficiency of continuously operating oxygen fed gas producers is about 80%

All the gas producers mentioned above require carefully sized lumps of noncaking coal or coke Metallurgical coke made by carbonization of bituminous coal at 900°C (1652°F) or anthracite

coal is used in most of the producers operating at atmospheric pressure in the United States and Canada In Europe, fixed bed gas producers using noncaking subbituminous coals are widely used Many of these European plants are designed to produce a mixture of water gas and carbonization gases, and in some of them the tar is recycled to the gas generator so as to achieve complete gasification The thermal efficiency of total gasification plants using noncaking coals is about 90% Active development of gasifiers using powdered coal oxygen, and steam for both atmospheric and elevated pressures is now in progress in the United States and in Europe

The highest heating value of the gaseous fuels produced by the plants described above is about 450 Btu/ft³ Mixing water gas with the gaseous products of the thermal decomposition of heavy fuel oil (2 7 gal of oil per 1000 ft³ of water gas) raises the heating value of the gas to about 525 Btu/ft³ A very large saving in costs of fuel gas storage and transmission systems is possible if gas of about 1000 Btu/ft³ is available This saving already has been effected in most of the rapidly growing urban sections of the United States by the introduction of pipelines for transportation of natural gas The cost of natural gas in these urban areas is increasing steadily, and within the next decade a competitive source of high Btu gas made from coal may be developed A possible process can be based on the catalytic hydrogenation of coal at pressures above 70 atm and temperatures above 600°C (1112°F) to produce chiefly a mixture of C_2 to C_4 hydrocarbons and enough heavy oil, or char, to supply a water gas plant for the manufacture of the hydrogen needed for the initial reaction with coal *See* FUEL GAS [H H ST]

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Coal mining

The technical and mechanical job of removing coal from the earth and preparing it for market Coal occurring in flat or pitching (sloping) seams, is taken out of open pits removed by strip mining or obtained by underground mining The bulk of coal production in the United States is from flat seams, in Europe a higher proportion occurs in pitching seams Over the last 25 years coal mining has progressed from an industry of manual workmen to one of skilled operators of modern machinery Deep or underground mining is emphasized in this article for other techniques, *see* MINING, OPEN CUT OR PIT, MINING, STRIP.

Prospecting and planning. When a coal property is prospected, development is commonly planned for the life of the property This involves projecting and estimating the working sequence of the various parts of the area, the type of mining equipment to be used, the type of power, roof control ... ition irop

A first step in coal property development is to obtain seam information from drilling and outcrop openings or adjoining properties Correlation of drilling and other data helps the developer understand such things as seam thickness, roof conditions, gas liberation, and grades and quality of the coal

After preliminary analysis and correlations, the engineering details (system of mining, types of machinery to be used productive capacity) are planned and costs of opening, developing, and operating the mine are estimated A reasonable evaluation can then be based on the projected costs and markets available

Types of coal mining. The systems of underground coal mining generally in use are room and pillar, longwall and, in a few places in Europe, hydraulic In the room and pillar system, tunnels are carved into the seam leaving pillars of coal for support In some mines pillars are removed in subsequent mining allowing the overlying strata to collapse, in others the pillars are not recovered In longwall mining, widely spaced tunnels are driven leaving large blocks of coal These blocks are completely extracted allowing the roof material to collapse behind the coal face as it is removed In hydraulic mining, as now practiced, a stream of water is directed against the coal face with sufficient pressure to dislodge the coal The water also acts as a transporting medium

Equipment The type of equipment used at the mining face is governed by a complex of factors Outstanding are the relative difficulty of supporting the immediate roof the height of the seam, grades of coal, maintenance required on machinery, and productivity expected of manpower using different types of machines Today mechanical equipment falls into two classes, the so called conventional and the continuous miner machine With the former, several machines are used in a cycle of operation, undercutting or top cutting the seam with cutting machines, blasting down the face, loading coal with a mechanical loader, and transporting it from the face by shuttle car or conveyor The continuous miner has been used in many seams It bores or rips to dislodge the coal from the face without blasting, then loads the coal and puts it into the transportation system

The power source for operating mining machinery can be liquid fuels seldom used in coal mining, or electricity, either dc or ac Power distribution for a mining property has to be planned for a whole mine in the same manner as is the actual mining operation

Based on prospecting information and actual experience, the amount and type of roof control for the protection of workmen is determined The old type of roof support is so called timber, this may be simply wooden posts or may consist of beams of steel or wood supported by posts or fastened to the walls In the last 10 years, the use of roof bolts has replaced a great amount of timber support Holes are drilled into the roof and steel rods, held by ex

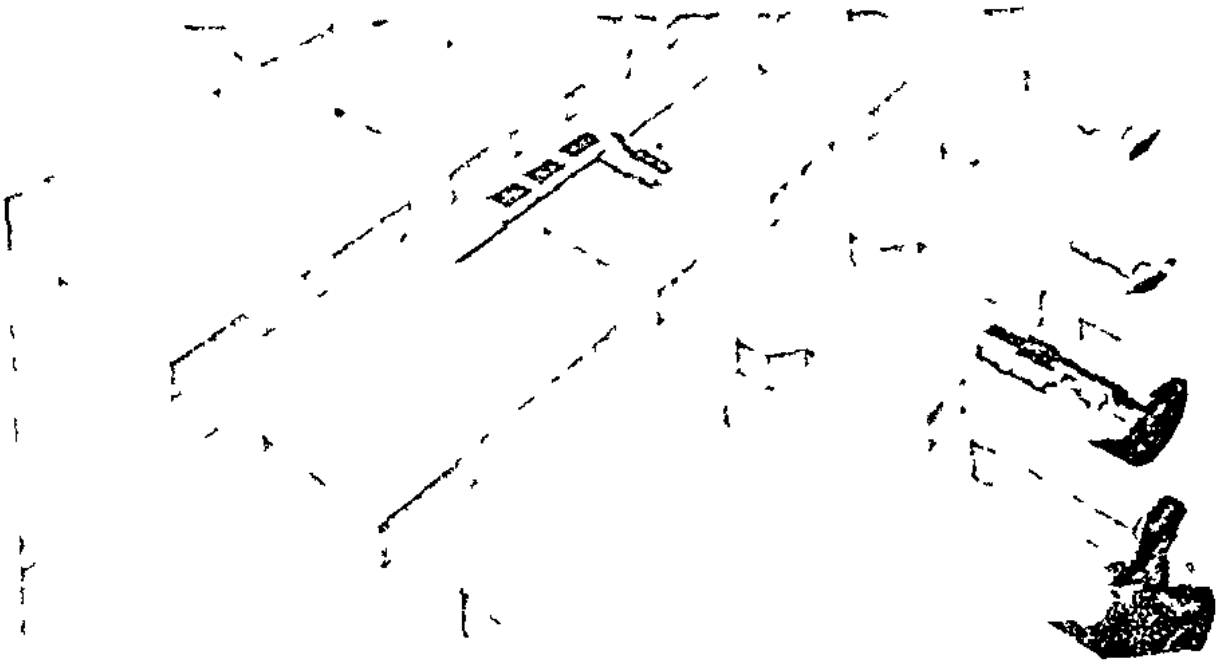


Fig 1 Conventional coal mining system underground using shuttle car and train haulage (*Joy Manufacturing Company*)

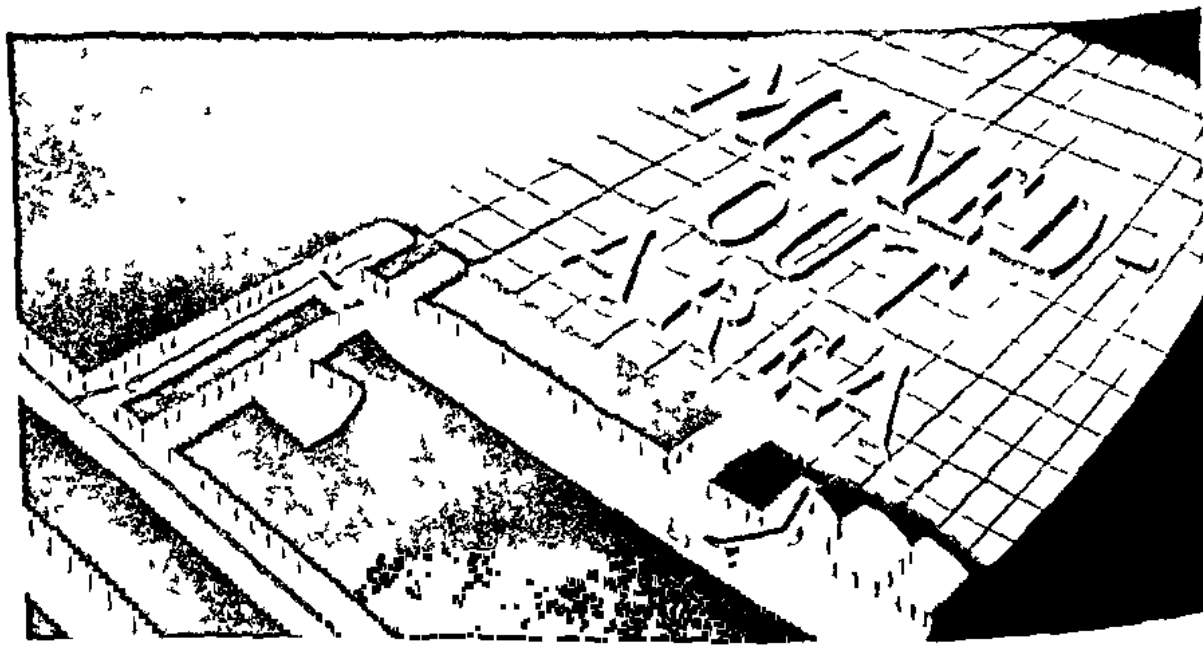


Fig 2 Mining system with continuous miner using shuttle car and belt haulage (*Joy Manufacturing Company*)

tions to be controlled. Roof bolting ties many roof materials together as one large beam instead of letting the various strata act as separate beams. For permanent support at some mines the roof is Gunited particularly where the roof material is subject to deterioration by weathering if exposed to the air currents.

The transportation of mined coal from the working face to the main transportation system is commonly accomplished by shuttle cars (underground trucks) or by some type of conveyor. Shuttle cars are used predominantly, although many properties with steep grades or thin coal find it more economical to do this part of the transportation by conveyors. In cases of hydraulic mining on the European continent the water used to break down the coal also conveys the coal away from the face.



Fig 3 Continuous miner loading into shuttle car Note roof supported with bolts and planks. (Lee-Norse Company)

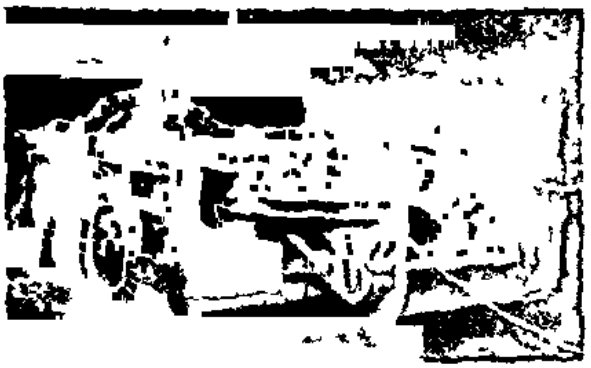


Fig 4 Shuttle car hauling from face area (National Mine Service Company)

The main transportation from the vicinity of the face areas to the surface or to shafts or slopes is generally by a track system using locomotives to pull mine cars Although not as common there are many instances where coal is transported on conveyor belts Main line belt transportation eliminates a great deal of the grading required for track haulage but requires essentially the same amount of maintenance and roof protection

In track systems the largest cars that seam height and width of working areas will permit are used Modern mine cars hold from 6 to 20 tons of material Most have solid bodies that are emptied by tipping or rotary dumping Motive power is generally electric locomotives of 20–50 tons weight

Coal without surface outcrop must be elevated by a slope or shaft Almost all slopes are on inclinations that permit the use of belts to transport the coal dumped at the bottom of the slope to the surface These belts are installed to carry the maximum production of the mine on a daily or shift basis When the coal is brought to a shaft it is dumped into skip buckets and hoisted to a dump at the surface Modern installations of these shafts are completely automatic as to loading and dumping

An underground coal mine consists of a great number of spaces and openings in which people must work safely In many cases however explosive gas is emitted Hence artificial ventilation over the entire mine is required to maintain a normal atmosphere and to dilute and carry away such gases Numerous shafts and fans provide the necessary volume of air *See* MINING OPERATING FACILITIES

Drainage To prevent water entering and to eliminate water from the mine is the aim of mine drainage Removing excess water from mine properties may be difficult and expensive in extreme cases over 30 tons of water have to be removed for each ton of coal mined

Cleaning, grading and shipping After the coal is brought to the surface if the foreign material in it is not excessive in quantity or type it may be loaded directly into transportation facilities for the market However coal from most seams requires preparation to provide a desired and uniform quality A number of washing devices are used for cleaning coal all of which operate on the basic principle of the difference of specific gravity between coal and foreign material The coal is floated in a vessel and the foreign material being heavier, drops to the bottom Washed coal in sizes less than ¾ in carries sufficient water from the washing circuit that it must be dewatered to be acceptable on the market Where a market can accept a moisture content of 7–8% mechanical devices can meet the requirements If a lower moisture is required the product after being mechanically dewatered is thermally dried of surface moisture to the required extent Once the coal is ready for market it is loaded for shipment to the customer by railroad water transportation or in some cases belt conveyor systems and even pipeline

Future trends In view of improvements in the past the following developments can be expected at some future time

1 Remote control of face machinery to improve productivity and to lessen both the roof control required and the exposure of workmen to face hazards

2 Transportation systems that require no manpower except minimum routine maintenance

3 Automatic gas detection systems that will not only make gas problems known by alarm but will also cut off all electric power in the areas involved

4 Increased safety through greater use of diesel power equipment which will reduce the need for electricity in the coal mine and wider use of ac power in working face areas lessening the hazard of electricity

5 Further automation in preparations plants at

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Coal paleobotany

A special branch of the paleobotanical sciences concerned with the origin composition mode of occurrence, and significance of the fossil plant m

terials that occur in or are associated with coal seams Information developed in this field of science (1) provides knowledge useful to the biologist in his efforts to describe the development of the plant world (2) aids the geologist in unraveling the complexities of coal measure stratigraphy in order to reconstruct the geography of past ages and to describe ancient climates and (3) has practical application in the coal coke and coal chemical industries

Nature of coal seams All coal seams consist of countless fragments of fossilized plant material admixed with varying percentages of mineral matter The organic and inorganic materials initially accumulate in some type of swamp environment Any chemical or physical alteration experienced by the organic fragments during the course of transportation and deposition is followed by another series of changes effected by the chemical physical and microbiological agents characterizing the environment in which the particle comes to rest Subsequent burial beneath a thick cover of sediment induces further physical and chemical alteration of the particles comprising the coal seam Usually a consolidated layer of well bonded fragments results In some instances crustal deformation and even volcanism add their modifying effects Thus the chemical composition size shape and orientation of the fossilized plant remains are influenced both before and after death by biological processes and by the chemical and physical processes attending their postdepositional history Even in coal seams that have been metamorphosed to anthracitic rank certain of the constituents remain recognizable as portions of particular plant organs tissues or cells Such entities are classed as phyterals and in paleobotanical descriptions of coal seams these are identified as specifically as possible as megaspores cuticles periderm and so on In seams of peat lignite and high volatile bituminous coal entities are more readily recognized as particular phyterals than they are in higher rank deposits This is partly the result of fewer being destroyed by the metamorphic processes and partly because of the distinctiveness of the substances composing the entity in question

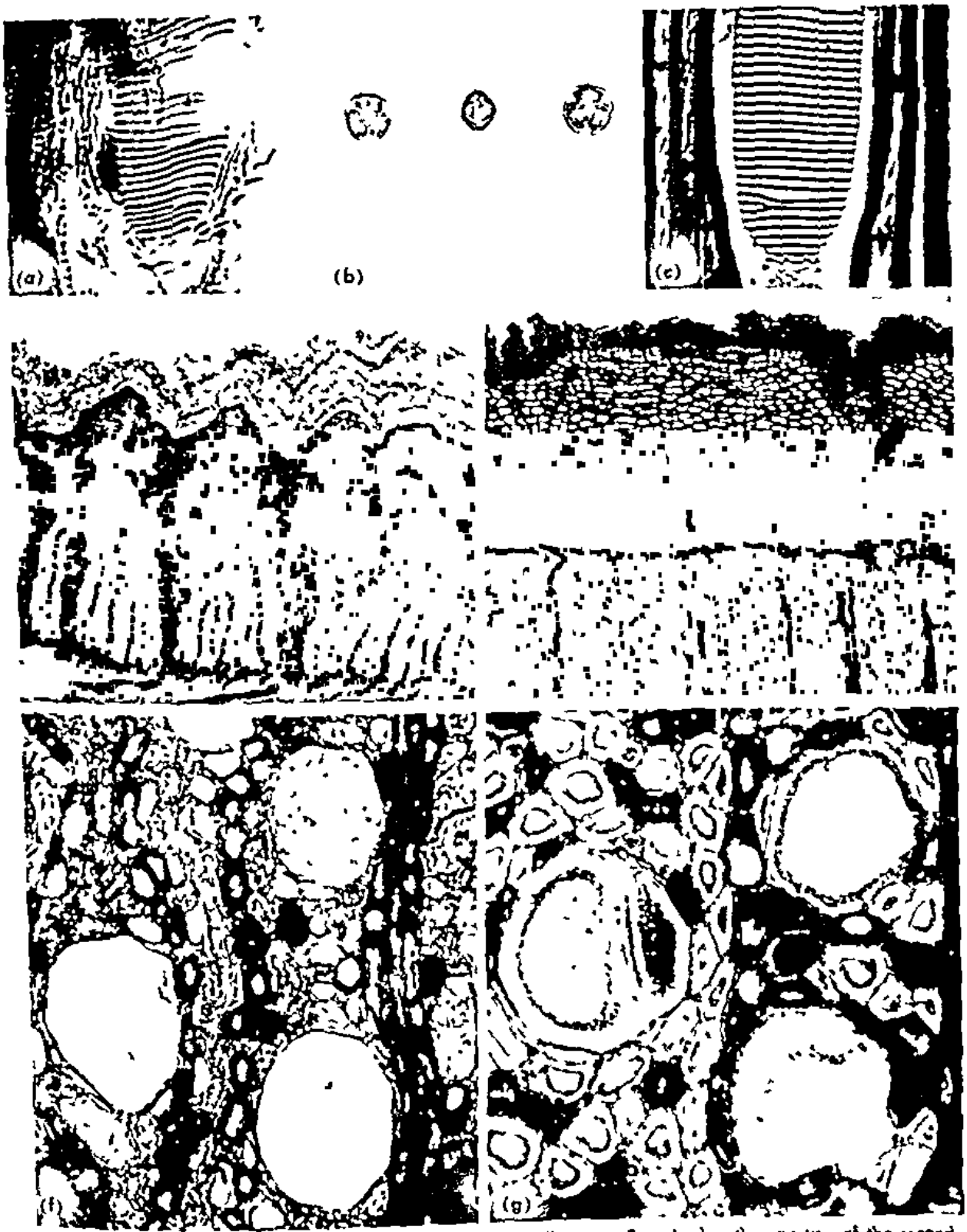
In some instances the fossilized plant fragments can be recognized as remnants of a plant of some particular family genus or species When this is possible information can be obtained on the vegetation extant at the time the source peat was formed and such data aid greatly in reconstructing paleogeographies and paleoclimatic patterns Perhaps the most extensive studies of this type are those conducted on the Tertiary brown coals of the Rhine Valley in Germany From these detailed reconstructions have been prepared describing and illustrating the three major swamp environments that gave rise to the sedimentary layers comprising these spectacular coal seams

Plant fossils in coal seams Pollen grains and spores are more adequately preserved in coals than are most other plant parts Recognition of this fact coupled with an appreciation of the high degree to which these fossils are diagnostic of floral composition has led to the rapid development of the paleobotanical subscience of palynology Fruits seeds and identifiable woods also occur as coalified fossils and are deserving of more attention than has been accorded them in the past Often minute structural details are preserved (see illustration) Identifiable leaf fossils are comparatively uncommon although the coalified cuticles of leaves are frequently encountered and their botanical affinities determined Occasionally coal seams contain fossil rich coal balls Essentially all types of plant fossil including entire leaves cones and seeds are encountered in these discrete nodular masses Within the coal ball the altered but undistorted plant tissues are thoroughly impregnated with mineral matter usually with calcite or dolomite Comparatively few coal seams have been encountered with large concentrations of coal balls but these have provided a wealth of detailed information on the nature of the plants which gave rise to the coals concerned *See* COAL BALLS, FOSSIL SEEDS AND FRUITS, PALYNOLOGY

Sedimentary units comprising coal seams As implied previously coal seams generally are composed of several superposed sedimentary layers each having formed under somewhat different environmental conditions The coal petrologist and paleobotanist recognizes these layers because of their distinctive textural appearance and because each consists of a particular association of organic and inorganic materials Accordingly each coal seam usually contains several types of coal These coal types or lithotypes possess characteristic suites of physical properties and knowledge of these properties is very profitably employed in manipulating coal composition in coal preparation and beneficiation plants

A given lithotype may form several of the constituent layers of lithobodies of a coal seam Each lithobody often possesses a characteristic assemblage of botanically identifiable fossil plant fragments rendering the unit recognizable to the coal paleobotanist without reference to its textural or compositional features Paleobotanical descriptions of coal beds may relate to the entire thickness of the seam without regard for the seam's composite nature or the fossils may be described in relation to the particular lithobody sequence The more detailed type of description is required if paleoecological interpretations are to be made or if detailed stratigraphic work is involved

Interrelations with coal petrology Another facet of coal paleobotany concerns the nature of the substances which compose the coalified plant fragments When his attention is focused upon such matters the coal paleobotanist is indistinguishable from the coal petrologist and both begin to encroach on the province of the coal chemist It is noteworthy however that the paleobotanist tends to concentrate his attention on the genetic relationships of the various coal substances and hence



(a) Coalified remnants of a scalariform perforation plate in the vessel element of a piece of lignitized *Cyrilla* wood from an Oligocene lignite deposit near Brandon, Vermont (b) Coalified *Cyrilla* pollen grains extracted from the Brandon, Vermont, lignite (c) Scalariform perforation plate of a vessel in the wood of the modern *Cyrilla racemiflora* (d) Transverse section of lignitized bark of *Cyrilla* from the Brandon, Vermont lignite (e) Transverse section of the extant *Cyrilla racemiflora* bark with a portion of the secondary xylem shown in lower half of the photograph (f) Transverse section of the coalified secondary xylem of *Cyrilla* wood from the Brandon, Vermont, lignite showing the preservation of considerable structural detail (g) Transverse section of the secondary xylem of *Cyrilla racemiflora* showing the structure of the vessels, fiber tracheids, wood parenchyma and rays Note the effects of coalification by comparing with (f)

upon the steps in the derivation and subsequent evolution of maceral materials The initial stages of coalification tend to be ignored by the coal chemist and petrologist and the study of these have quite properly been thought of as an integral part of coal paleobotany Thus through the study of the botanical character of coalified fossils and by means of investigating the substances produced by the coalification process coal paleobotanists extend man s knowledge of the organically derived sediments of the earth's crust [W SP]

Coal Sack

An area in one of the brighter regions of the Southern Milky Way which to the naked eye appears entirely devoid of stars and hence dark with respect to the surrounding Milky Way region Telescopic and spectroscopic observations reveal that the Coal Sack is a cloud of small solid particles approximately 120 parsecs (400 light years) from Earth and 10 15 parsecs in diameter The cloud not only absorbs about two thirds of the visible light passing through it but also strongly reddens the transmitted light The Coal Sack is located just to the southeast of the Southern Cross *See* INTERSTELLAR MATTER [W LI]

Coastal engineering

A branch of civil engineering pertaining to the study of the action of the seas on shore lines and to the design of structures to protect against this action Design theory is essentially empirical based on lengthy observations and measurements made on existing structures and on large and small scale model tests The two basic problems are the destructive power of waves and their ability to transport material As to the types of protective construction groins seawalls bulkheads and revetments are primarily for beach and shore protection breakwaters and jetties protect maritime properties and activities *See* BREAKWATER BULKHEAD, JETTY SEA WALL

Beach erosion When subjected to wave action shore lines continuously change their configuration through the processes of erosion and accretion the latter being the gradual build up of land Material transported from erosion zones to accretion zones is referred to as littoral drift and its movement under the influence of the waves and currents as littoral transport A beach is stabilized when no further erosion or accretion takes place Groins are used to help stabilize a beach *See* GROIN (ENGINEERING) SHORE PROCESSES

Waves and wave forces The height length and period of waves are functions of the intensity and duration of the generating winds and of the fetch (the continuous area of water over which the winds blow in a constant direction) Waves change their physical characteristics as they travel toward shore from deep water through a transitional zone into shallow water where the depth becomes less than one twenty fifth the wave length It is the shallow water and transitional wave that is of primary concern to designers of protective structures

In analyzing wave forces exerted on structures, three distinct wave types should be considered nonbreaking waves breaking waves, and broken waves Nonbreaking waves striking vertical surfaces produce a standing wave, or clapotis whose effect is that of essentially hydrostatic pressure. In addition breaking waves and broken waves produce dynamic effects due to turbulent water and compression of entrapped air pockets These dynamic effects may far exceed the hydrostatic forces [EJQ]

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Coastal landforms

The characteristic features and patterns of land in a coastal zone subject to marine and subaerial processes of erosion and deposition Coastland lies between the shoreline, or mean low water line and the hinterland and includes many minor features of coastal relief as well as major features of shoreline topography As treated here emphasis is placed upon regional aspects of coastal morphology For a discussion of beach and nearshore processes *see* SHORE PROCESSES

Vigorous wave action a variety of currents water of high saline content and steady winds produce both constructional and destructional landforms as they act on land with whatever rock composition and structure topographic characteristics and vegetational cover it may possess In addition to the agents working upon landforms the changing position of shorelines with respect to sea level is an important factor in coastal evolution

The attack of the sea has been concentrated at or near its present level only for some 5000–6000 years During the preceding 130 centuries or so, sea level rose some 400 ft as a result of the increase in ocean volume by meltwaters from the waning continental ice in late Pleistocene time Coastal landforms which originated during low stands of the sea now lie submerged offshore *See* SEA LEVEL FLUCTUATIONS

Constructional landforms Included among these forms are deltas deltaic coastal plains beaches bars, spits reefs dunes and many minor features Also included in this group are structures of organic origin Along the coasts of warm seas algae coral and other organisms may cement beach materials into firm beach rock or they may accumulate in huge quantities to form reefs which sometimes extend considerable distances offshore These are constructional landforms as are the low flats of sediment trapped around the roots of mangroves and other plants on some shores The position and development of these features are related to the stand of the sea during their formation *See* CORAL REEF, MANGROVE SWAMP, ORGANIC REEF

Deltas grow seaward in estuaries and at river mouths They may even extend outward into seas where rivers deposit their loads more rapidly than

land subsides or currents carry sediment away The location of a delta depends on the topography of the mainland which determines the location of the river mouth Where the land is flat as in the case of a broad flood plain leading to the sea the river mouth occurs at the lower end of a meander belt the position of which depends on diversions that commonly occur as far as several hundred miles in land If diversions of river courses into new meander belts occur frequently delta growth may take place vigorously first at one site then at another which may be many miles away Eventually the coastal flat becomes a deltaic coastal plain Beaches fringe its front Grassy marshes lakes and embayments of various kinds commonly form a low zone behind the beaches across which the natural levees of branching distributary streams form relatively firm and dry strips of land leading to the sea *See* DELTA, FLOOD PLAINS, MARINE MARSH PLAINS

Destructional landforms Erosional landforms include sea cliffs wave cut beaches arches and caves near sea level detached masses of rock which form islands and sea stacks and many other forms whose characteristic features have developed under the dominant influence of local topography rock type and rock structure (Figs 1 and 2)

Erosional forms depend to a large extent upon the *type of coast under attack Thus resistant rock* may have changed but little during 50–60 centuries of exposure to wave attack as in the case of massive crystalline bedrock along coasts in the vicinity of Rio de Janeiro and many rugged coasts elsewhere Unconsolidated rock such as most Tertiary and Quaternary *sediments commonly* has been driven back to form smooth coasts with long straight beaches which may border the mainland or lie some distance offshore In these cases wave action and chemical weathering processes have proved capable of disintegrating the rock into fine debris of sizes small enough for currents to transport and deposit as beach Contrasts in coastal types which are related to the kind of rock at the shoreline may be noted on opposite sides of the Baltic Sea to the east and west of the Rhone Delta or between the smooth coast of Texas and



Fig 1 Quaternary wave-cut terrace Unreduced masses rise above terrace level North of Point Hartford California (USGS)

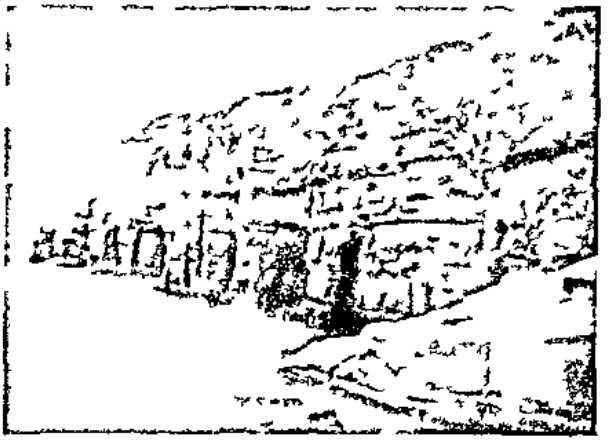


Fig 2 Caverns in Eocene sandstone near La Jolla California (USGS)

the irregular coast of Newfoundland *See* WEATHERING PROCESSES

Fiord coasts A bedrock region that is deeply scoured by glaciers may become a fiord coast Along such coasts deep estuaries may extend far inland often between sheer cliffs over which high waterfalls plunge as along the coasts of Norway southern Alaska and southern Chile *See* FIORD

Ria coasts Ria coasts are characterized by irregular coastal indentations similar to fiorded coasts but with a more subdued relief they are produced by drowning of nonglacial topography (Fig 3)

Karst coasts Karstic features are produced in strata of relatively soluble limestone along some coasts such as the Dalmation Coast of the Adriatic Sea *See* KARST TOPOGRAPHY

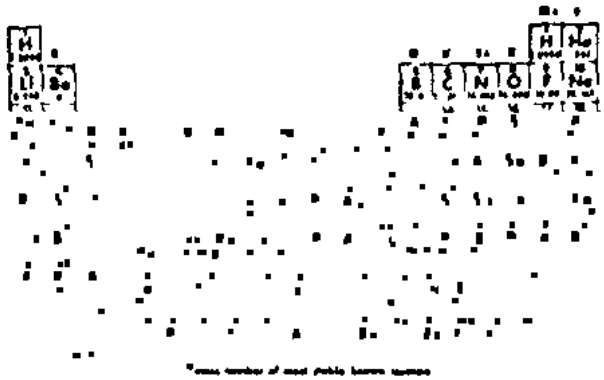
Emergent and submergent shorelines Smooth coasts were regarded by many geomorphologists as exhibiting shorelines of emergence based on the hypothesis that sea bottoms are flat so that

that land had lowered to some extent permitting seas to drown complicated topography which had *been produced by weathering and erosion of surfaces* exposed to the atmosphere However with the realization that the Recent rise of sea level is *of much greater magnitude than formerly supposed* there has come greater acceptance of the idea that oceanic shorelines are universally drowned Contrasts between smooth and irregular coasts have largely developed during the brief latest stillstand of sea level The classic examples of shorelines of emergence in fact exhibit abundant evidence of drowning Smooth coasts from New Jersey southward demonstrate the ability of the Atlantic to smooth coastal outlines and produce long beaches in unconsolidated rock whereas the irregular outlines of Chesapeake and other bays inland are products of flooding valleys which were cut during the earlier low stand of the sea

New shorelines Uplift of land occurs rapidly along many coasts particularly those with moun

Cobalt

Chemical symbol Co a gray metallic element similar to iron and nickel in both its free and combined states It is widely distributed in nature making up about 0 001% of the igneous rocks of the earth s crust compared with 0 02% for nickel It occurs in meteors stars sea and fresh



waters soils plants and animals Cobalt and its alloys are wear and corrosion resistant even at high temperatures The most important commercial applications are in making alloys for use at high temperatures magnetic alloys and alloys for use in machine tools Cobalt is required in small amounts by plants and animals The artificially produced radioactive isotope of cobalt cobalt 60 is widely used in industry research and medicine

Natural occurrence Traces of cobalt are found in many ores of iron nickel copper silver manganese and zinc but the commercially important cobalt minerals are arsenides oxides and sulfides

Cobalt is mixed with nickel in many of the minerals found near Sudbury Canada and in similar copper nickel sulfide orebodies Belgian Congo has been the predominant cobalt producer for many years other important sources being Rhodesia Canada United States and Morocco World output in 1958 was about 14 600 tons of

Table 1 Cobalt minerals

Name	Formula	Occurrence
Arsenides		
Smaltite and safflorite	$CoAs_2$	Canada Morocco United States
Skutterudite	$CoAs_3$	Canada Morocco U S
Cobaltite	$CoAsS$	Canada Morocco U S
Oxidized minerals		
Asbolite	$CoO\ 2MnO_2\ 4H_2O$	New Caledonia
Heterogenite	$CoO\ 2Co_2O_3\ 6H_2O$	Belgian Congo
Sphaerocobaltite	$CoCO_3$	East Germany Italy Belgian Congo
Erythrite	$3CoO\ As_2O_5\ 8H_2O$	East Germany Canada U S
Sulfides		
Carrollite	$CuCo_2S_4$	Belgian Congo Rhodesia
Linnaeite	Co_3S_4	Mississippi

Table 2 Properties of cobalt

Atomic weight	58 94
Atomic number	27
Melting point	1495°C
Specific gravity	8 9
Electronic configuration	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^2$
Oxidation states	2+ 3+

metal The United States is world s largest consumer of cobalt

Physical and chemical properties Cobalt is ferromagnetic and resembles iron and nickel in hardness tensile strength machinability thermal properties and electrochemical behavior

At ordinary temperature the stable crystal form of cobalt is close-packed hexagonal, whereas above 400°C. face centered cubic is the stable structure. The metal is unaffected by air or water under normal conditions is rapidly attacked by sulfuric acid hydrochloric acid and nitric acid but only slowly by hydrofluoric acid ammonium hydroxide and sodium hydroxide

Cobalt exhibits variable valence forms complex ions and colored compounds as do all of the transition elements

Metallurgical extraction The processes used in extracting cobalt from its ores vary according to the type of ore and geographical location of the ore deposit

Arsenical ores are concentrated by hand sorting gravity separation or froth flotation and are smelted in a blast furnace with coke and limestone to a speiss (an impure mixture of iron cobalt and nickel arsenides) The speiss is ground roasted with salt and leached with water Insoluble chlorides remaining after the leaching process are ground with sulfuric acid washed and filtered and the washings are added to the liquid from the leaching step The combined solution is treated with an oxidizing agent and then neutralized with lime

Basic ferric arsenate precipitates and is removed leaving a solution containing cobalt and nickel The addition of successive portions of sodium hydroxide and sodium hypochlorite precipitates cobalt as the hydroxide initially pure and finally admixed with nickel hydroxide The cobalt precipitate is dried ground and formed into pellets which are reduced by heating with charcoal to cobalt metal

In the Rhodesia Congo copper belt cobalt production is an important ancillary operation Various cobaltiferous materials such as high grade ores concentrates and slags, are smelted in electric furnaces with coke and a suitable flux to yield a crude alloy of copper cobalt and iron containing about 40% cobalt This alloy is sent to overseas refineries Treatment with hot 20% sulfuric acid dissolves cobalt and iron Iron is removed from the solution by treatment with sodium chlorate and carbonate Cobalt is precipitated as the hydroxide by treatment with sodium hypochlorite and purified in the manner described for arsenical ores

Most of the production from Africa is in the form of electrolytic cobalt In Belgian Congo the residual slimes from the copper leaching process are dissolved, most of the copper is removed from the solution electrolytically, and the last traces by cementation on cobalt granules Cobalt in this solution is precipitated as the hydroxide by treatment with lime removed by filtration, dissolved in sulfuric acid and electrolytically deposited on steel cathodes, using lead anodes In Rhodesia a cobalt concentrate is obtained by ore flotation after prior removal of most of the copper minerals in a high grade copper concentrate It then is roasted to transform cobalt sulfide to cobalt sulfate and at the same time to leave most of the copper and iron in a water insoluble state The roasted concentrate is leached with hot water, and the pH of the solution is adjusted with lime to precipitate all the iron and most of the copper Residual copper is cemented out on cobalt granules Cobalt in the solution is then precipitated with lime dissolved in sulfuric acid, and separated electrolytically

Recovery of cobalt as a by product of the nickel industry may take several forms (1) In electrolytic refining of nickel, cobalt is removed from the anolyte, the solution in the anode compartment of the electrolysis cell, by chlorine and basic nickel carbonate, in the form of an impure slime containing nickel, copper, and iron, as well as cobalt This slime is dissolved in sulfuric acid and sulfur dioxide, and more fresh slime is added to reoxidize the iron and to precipitate it as ferric hydroxide Copper is removed by cementation on nickel powder and cobalt is separated from nickel with sodium hypochlorite The crude cobaltic hydroxide is redissolved in sulfuric acid and sulfur dioxide and the hypochlorite separation repeated to reduce the nickel contamination (2) Where the carbonyl process is employed to refine nickel cobalt is not volatilized with the nickel at atmospheric pressure and remains in the residue The residue is roasted and leached, and the copper and iron are removed by precipitation as hydroxide from slightly acid solution Cobalt is precipitated from the solution as crude cobaltic hydroxide which is purified to high grade oxide (3) In the recovery of nickel by leaching reduced lateritic ores or nickeliferous pyrrhotite with ammonium carbonate, any cobalt present is largely precipitated with the final basic nickel carbonate (4) Cobalt is also obtained in the pressure leaching of nickel sulfide concentrates in acid or ammonia solution Metallic nickel and cobalt are precipitated from the solution with hydrogen under elevated pressure and temperature

Uses of cobalt. About 80% of the world's cobalt output is used in the metallic state Alloys that retain their strength and other desirable properties at high temperatures are widely used in jet aircraft, gas turbines, and other equipment that operates at high temperatures Most of these alloys contain from 20 to 65% cobalt, together with nickel chromium, molybdenum, tungsten and other elements Large quantities of cobalt are used in the production of magnets The best commercial magnet steel contains 35% cobalt, together with some tungsten and chromium The valuable Alnico magnet alloys usually contain 6–12% aluminum, 14–30% nickel, 5–35% cobalt, and the balance iron

Cobalt chromium tungsten alloys containing 42–65% cobalt, are very hard and corrosion resistant They are used for cutting tools and hard facing

Cobalt is employed as the matrix, or binder, for tungsten carbide Amounts of 3–20% provide the toughness and shock resistance required to make the hard carbide of practical value in drill bits and machine tools Addition of 5–12% cobalt to standard high speed steel improves the cutting efficiency at elevated temperatures, and such tools are used in heavy machining

The artificially produced radioisotope cobalt 60 may be used in place of x rays or radium in the inspection of materials to reveal internal structure, flaws or foreign objects It is usually prepared by neutron irradiation of metallic cobalt It is employed in cancer therapy and as a radioactive tracer in biology and industry *See* RADIOISOTOPE (BIOLOGY)

Glass to-metal seals can be made with alloys approximating 18% cobalt, 28% nickel, and 54% iron An alloy of 36 5% iron, 9 5% chromium and 54% cobalt has practically zero coefficient of expansion A dental and surgical alloy known as Vitallium containing essentially 65% cobalt, 30% chromium, and 5% molybdenum or tungsten is not attacked by body liquids and does not irritate tissues

Major compounds and their uses. Cobalt (II) chloride nitrate and sulfate are all formed by the interaction of the metal, oxide, hydroxide, or carbonate with the corresponding acid There are three main oxides of cobalt gray cobaltous oxide, CoO, black cobaltic oxide Co_2O_3 formed by heating compounds at a low temperature in excess of air, cobaltosic oxide, Co_3O_4 the stable oxide formed when salts are heated in air at temperatures which do not exceed 850°C Most common cobalt salts are derivatives of cobalt(II), the higher valence state being encountered only in complex coordination compounds An important naturally occurring cobalt coordination compound is vitamin B_{12}, the anti pernicious anemia factor Many cobalt salts in solution exhibit remarkable color changes, depending on temperature, concentration, and presence of other ions These have been ascribed to changes in hydration or solvation, or to the presence of complex ions

In the glass and ceramic industries, small quantities of cobalt oxide are used to neutralize the yellow tint resulting from the presence of iron in glass, pottery, and enamels Larger quantities are used to impart a blue color to these products Cobalt oxide is used in enamel coatings on steel to improve the adherence of the enamel to the

Cobalt linoleates, naphthenates, and resinates are excellent driers for paints and varnishes Cobalt catalysts have been patented for many industrial reactions, such as Fischer Tropsch synthesis and the Oxo process

Cobalt sulfate is sometimes added to nickel plating baths to improve smoothness brightness, hardness and ductility of deposits

Cobalt compounds, such as the chloride, are added in very small amounts to livestock feeds salt licks, and fertilizers in many parts of the world where a cobalt deficiency exists in the soil and natural vegetation This prevents serious diseases of cattle and sheep, such as pining, which result from cobalt deficiencies

Analytical methods. Small quantities of cobalt are readily determined colorimetrically using various complexing agents or ammonium thiocyanate, or the element may be analyzed spectrographically or polarographically Larger amounts of cobalt are best determined by electrodeposition analysis For intermediate quantities satisfactory procedures are the gravimetric method employing a separation with nitrosonaphthol and ignition to Co_3O_4 and the potentiometric titration method wherein cobalt is oxidized in ammoniacal solution by potassium ferricyanide *See* TRANSITION ELEMENTS [R S Y]

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Cobaltite

A mineral having composition (Co,Fe)AsS Cobaltite is one of the chief ores of cobalt It crystallizes in the isometric system, commonly in cubes or pyritohedrons resembling crystals of pyrite There is perfect cubic cleavage The luster is metallic and the color silver white but with a reddish tinge The hardness is 5 5 (Mohs scale) and the specific gravity is 6 33 Cobaltite is usually found as disseminations in metamorphic rocks or in veins associated with other cobalt and nickel minerals Notable occurrences are at Skutterud, Norway, Lunaberg Sweden, Ravensthorpe, Australia, and Cobalt, Ontario, Canada *See* COBALT [C.S HU]

Cobra

Any of about ten species of venomous snakes, mostly of the genus *Naja*, of the family Elapidae These snakes, found in the Old World, have short, stout, grooved, poison fangs

The spectacled, or hooded, cobra, *Naja naja*, is the most common of the Indian species, and is the one that is best known Although not nearly as venomous as the krait, Russell's viper, and others, it is responsible for the majority of the 25 000 deaths occurring each year from snake bite in India More spectacular is the large king cobra, *Ophiophagus* (*Naja*) *hannah*, which reaches a length of 15–18 ft Although cobras abound in India and the Malay area, seven of the ten species occur in Africa Best known of the African species is the Egyptian cobra or asp, *Naja haje* *See* SQUAMATA [J.D B]

Coca

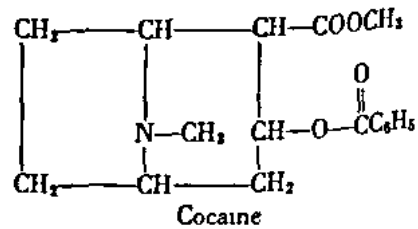
A native of Peru and Bolivia, *Erythroxylon coca*, is a shrub from which the alkaloid, cocaine is obtained The leaves of coca, either alone or mixed with lime and the ashes of some plant such as quinoa, are chewed by the natives The use of coca, in moderation, enables the user to resist fatigue and thus it is possible for him to endure long periods of labor without either food or drink Coca chewing becomes a habit which leads to weakness, sickness, and even death Cocaine is used for local anesthesia and as a tonic in digestive and nervous disorders It is habit forming and should be used only by order of a physician Coca is cultivated extensively in South America Ceylon, Java and Formosa *See* COCAINE, GERANIALES [P D.S]



Flowering branch of coca (*Erythroxylon coca*) (*From H Kramer, Applied and Economic Botany, published by the author, 1914*)

Cocaine

An alkaloid obtained from the leaves of *Erythroxylon coca* and related species Explorers of South America as early as 1532 reported that the natives ascribed to the coca leaves a power to increase endurance The local anesthetic properties of co-



Cocaine

caine were demonstrated first by F Wohler in 1860 In 1884 C Koller reported his results with cocaine in ophthalmological practice thereby introducing local anesthesia

Cocaine valuable as it is as a local anesthetic has several clinical and commercial disadvantages It is a habit forming drug and as such is restricted under the narcotic laws It also produces undesirable side effects in the patient In addition it cannot be sterilized in pharmaceutical preparations without undergoing some decomposition Consequently cocaine has been displaced to a considerable extent by other local anesthetics such as procaine *See* ALKALOID [S M K]

Coccidia

A subclass of the class Telosporidea These protozoans are typically intracellular parasites of epithelial tissues in both vertebrates and invertebrates The group is divided on the basis of life cycles into two orders the Adeleida and Eimerida Both schizogony and sporogony are important multiplicative processes in the coccidian life cycles The life histories are of two general types (1) those species which require two hosts for the complete life cycle (for example *Hepatozoon muris*) and (2) those having one host species in which the infective stages are filth borne *Eimeria* is an example of the second type of life cycle which is more common to nearly all coccidians than the first type and is of economic importance in livestock and wildlife as well as of direct concern to man *See* ADELEIDA EIMERIIDA [E R BE]

Coccidioidomycosis

An infectious disease of man and animals caused by a fungus *Coccidioides immitis* This mycotic infection is endemic in the southwestern United States although it is known to occur in Mexico and Central and South America The microorganism has been isolated from soil in endemic areas Naturally occurring infections caused by *Coccidioides immitis* have been seen in cattle rodents and dogs in endemic areas

This disease has two forms most frequently recognized primary pulmonary and disseminated Primary pulmonary coccidioidomycosis is the form that most uninfected persons coming in contact with *Coccidioides immitis* acquire It is estimated that more than 50% of these individuals do not develop any symptoms When symptoms do occur they are usually mild and are often diagnosed as a cold or influenza This form of the disease however may be severe and can be manifested by a wide range of signs and symptoms which include fever chills cough chest pain and headache Cavity formation may take place as well as pleural effusions An allergic reaction may also be noted characterized as a rule by development of large tender reddish nodules on the legs *See* HYPERSENSITIVITY

Approximately one patient in 1000 with primary pulmonary coccidioidomycosis will have a dissemination of the organisms from the lungs to bones viscera and central nervous system In these instances the mortality rate is very high

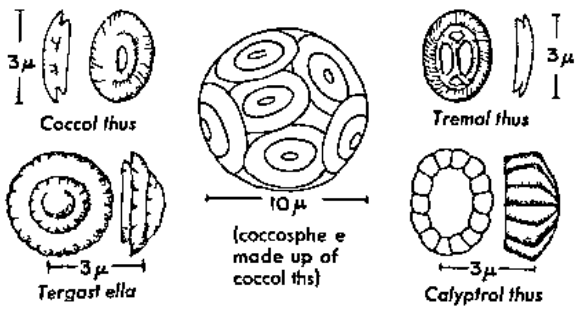
Cutaneous coccidioidomycosis in most instances is believed to be secondary to a pulmonary lesion However there are cases reported of a primary cutaneous form of this disease acquired by injury to the skin followed by invasion of the fungus In these instances the lesions are similar to the sporotrichotic chancre

Coccidioides immitis will grow on most mycological media When seen in tissues the organism is a spherule containing endospores In vitro cultures however regardless of temperature yield a white to buff colored cottony mold The organism produces innumerable arthospores which are highly infectious to the laboratory worker and for this reason only experienced mycologists should handle cultures *See* EUMYCETES

Antigens have been developed for use in the precipitin and complement fixation test Using these serological tools it is possible to follow the course of the disease and to determine the patient's prognosis Treatment of disseminated coccidioidomycosis is not satisfactory although recent reports indicate that the antibiotic Amphotericin B may be useful in some instances *See* ANTIGEN AMPHOTERICIN B COMPLEMENT FIXATION TEST PRECIPITIN TEST [L D H]

Coccolithophorida (Coccolithidae)

A class of unicellular marine flagellates of the phylum Chrysophyta possessing a spherical shell (coccosphere) which consists of minute calcareous platelets (coccoliths) cemented together The coccoliths are usually a few microns in diameter and

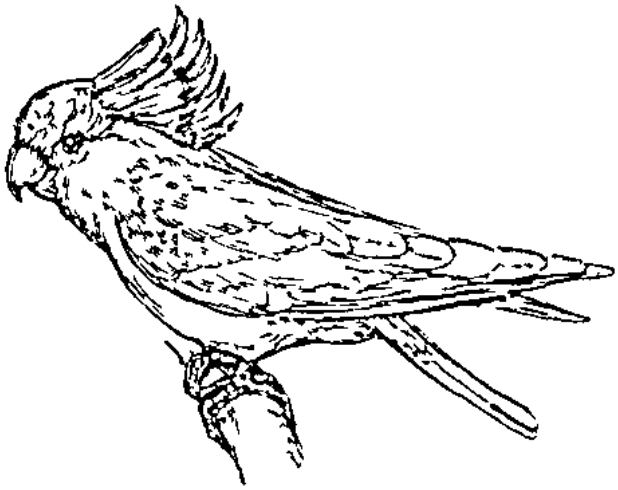


Coccosphere and var ous coccol iths (*After Jones 1956 and from P veteau 1952*)

are discoidal spherical or button shaped with various perforations and patterns of ornamentation Classification of fossil coccolithophores is based on the coccoliths which make up considerable portions of many limestones and chalks from the Jurassic to Recent About 30% of the modern globigerina ooze of the sea floor consists of coccoliths *See* CHRYSOPHYTA MICROPALEONTOLOGY [D J J]

Cockatoo

Any member of the family Kakatoidae order Psittaciformes and closely related to the parrots



Cockatoo *Kakatoe* sp (*From E L Palmer, Fieldbook of Natural History McGraw H ll, 1949*)

forests of Australia Tasmania New Guinea and the islands of the Indian Ocean

Cockatoos have long tails rounded at the end and high arching beaks They frequently have erectile crests of long brilliant feathers They live in flocks feeding upon seeds nuts, fruits and insect larvae Several species are caged as pets and most individuals can be taught to speak a few words *See* PSITTACIFORMES [J D B]

Cockcroft-Walton accelerator

An electrostatic particle accelerator utilizing as a source of high voltage a transformer and an array of rectifiers and condensers giving voltage multiplication These machines will accelerate any charged particle and provide beam currents of several milliamperes *See* PARTICLE ACCELERATOR

The high voltage supply (Fig 1) consists of two stacks of series connected condensers One stack is at a steady potential (except for ripple) with one terminal connected to ground and the other to the load One terminal of the second condenser stack is connected to a transformer If the peak voltage of this transformer is $\pm V$, the voltage of all points along this stack oscillates over a range of approximately $2V$ Charge is transported through the rectifiers and passes stepwise up through the condenser stacks to the terminal Terminal voltage for no load is $2VN$, where N is the number of stages It is steady except for ripple due to stray capacitance and power drain.

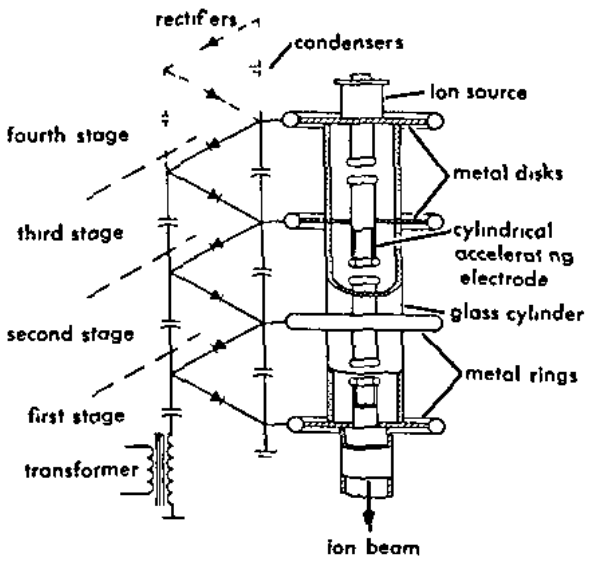


Fig 1 Schematic diagram of three stage Cockcroft Walton machine Dashed lines show how a fourth stage could be added

Cockcroft Walton machines are more numerous than any other type of particle accelerator Many in the 100-kv to 500-kv range are used to accelerate deuterons or tritons for bombardment of deuterium or tritium targets to provide intense sources of energetic neutrons Most of the machines constructed before 1940 utilize high voltage vacuum-tube rectifiers and 60-cycle power Many machines constructed later utilize selenium rectifiers, relatively low values of V, and relatively high values of N To reduce ripple, power to some machines is

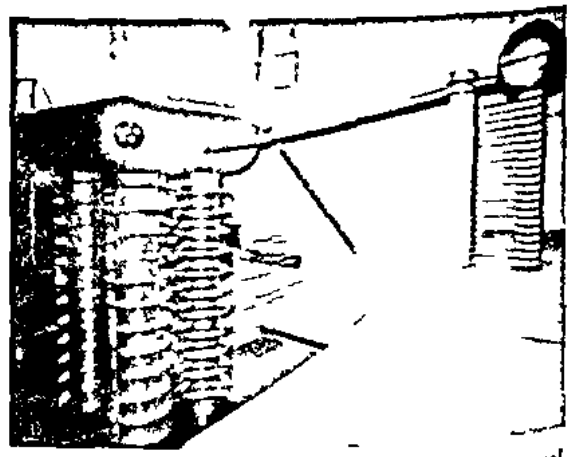


Fig 2 Five hundred kilovolt Cockcroft Walton accelerator at the University of Iowa This machine utilizes selenium rectifiers in 22 voltage multiplier stages. Input power is at a frequency of 750 cps. The accelerating tube is to the extreme right Near the accelerating tube is a stack of porcelain insulators which serve to support leads connecting accelerating tube electrodes to voltage multiplier stages

furnished at a frequency up to a few thousand cycles per second

Voltages attainable by these machines when operated in air at atmospheric pressure are limited by electrical breakdown between adjacent parts A 1 000 000 volt machine must be housed in a large room The N V Philips Gloeilampenfabrieken have enclosed accelerators of the Cockcroft Walton type in pressure tanks to improve performance and reduce space requirements In 1958 at the University of Basel Switzerland a Cockcroft Walton machine in a large pressure tank was operated at 4 000 000 volts

Cockcroft Walton accelerators having a wide range of both peak voltage and current handling

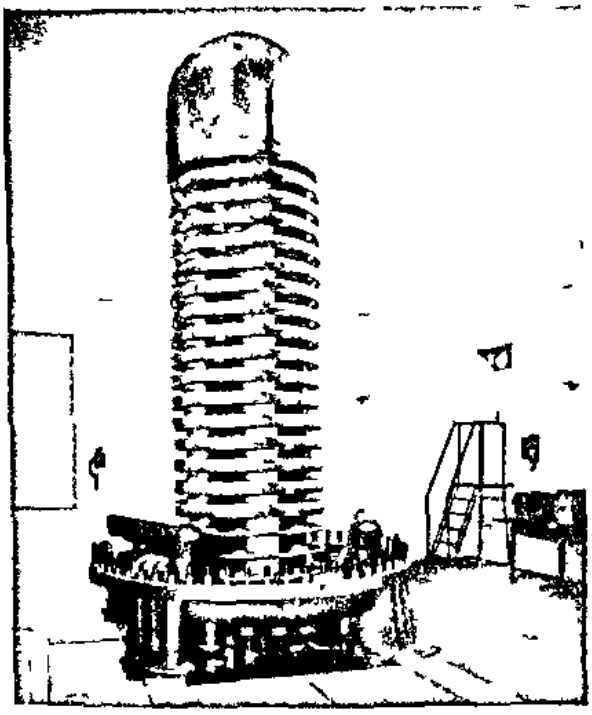


Fig 3 Four million volt accelerator of the Cockcroft Walton type at the laboratory of P Huber University of Basel, Switzerland This machine was built by the Emil Haefely Co, Ltd, Basel The enclosing steel tank (not shown in picture) is 6 m high by 2 2 m in diameter and utilizes a mixture of nitrogen and carbon dioxide at a pressure of 10 atm Input power is at a frequency of 10 kc/sec

capabilities are now available from a number of commercial firms (Figs 2 and 3) *See* ELECTROSTATICS, RESONANCE TRANSFORMER [RCH]

Bibliography See VAN DE GRAAFF GENERATOR

Cockle

Any of several species of mollusks of the class Pelecypoda, order Eumellibranchia, commonly grouped together in the family Cardudae They are world wide in their distribution

Members of this family have heart shaped, equivalve shells with scalloped or serrated margins The shell is commonly rayed, similar to that of the pecten

Cockles are edible and are utilized for food to a limited extent on both the Atlantic and Pacific Coasts In Europe they are gathered on a commercial scale

The general anatomy and physiology of the cockle is similar to that of the marine clams They range in size from the little cockle (½ in long) to the well known great heart cockle which ranges from 3 to 6 in in length and is found from Virginia to Brazil The great heart cockle is yellowish brown in color and marked with irregular spots of purple and chestnut It prefers sandy bottoms in estuaries where it may form large beds

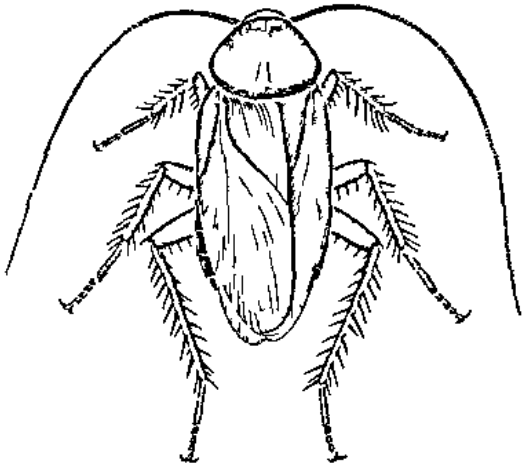
The common cockle is about 3 in long and is yellowish white, sometimes lightly speckled with brown It is found at moderate depths in sandy bottoms from North Carolina southward Best known of the Pacific species are the rock cockles and heart cockles The scientific names of this group are in a state of confusion, and common names are more dependable for purposes of reference *See* CLAM, PELECYPODA [JDB]

Cockroach

Any of the species of the insect family Blattidae, order Orthoptera Cockroaches are among the most widespread of all the insects There are over 2000 species, mostly tropical and subtropical, but about 70 species occur in the United States, several of which are exotic Most cockroaches are forest animals, preferring a warm, humid habitat All are nocturnal and omnivorous For the most part they are of little economic importance, but a few have become household pests

filth such as typhoid and dysentery, none is known to be carried by roaches

Most species of cockroaches are some shade of brown, some are black, and a few in the tropics are green They are flattened oval and have long legs They run with considerable speed Some species are wingless, some have winged males and wingless females, in others both males and females are strong flyers



The American cockroach, *Periplaneta americana*, length to 1½ in (*From E L Palmer, Fieldbook of Natural History, McGraw Hill, 1949*)

Important household pests in the United States include the German roach, *Blatella germanica*, the Oriental roach, *Blatella orientalis*, the brown banded cockroach, *Supella supellectilium*, and the large American roach, *Periplaneta americana*

The German roach, often called water bug or croton bug, is the smallest of the four Like the others, it carries its eggs around in a straw colored ootheca which protrudes from the abdomen until near hatching time The Oriental roach is a little over 1 in long and is shiny black The brown

banded roach is a more recent import and has become well established in the southern United States in recent years It appears to be steadily spreading northward and is difficult to control The Big American roach an exotic species is about 1¼ in long and is widespread although it is easily controlled

Chlordane is the most common and successful insecticide for roach control However chlordane resistant races are now appearing To eliminate these it is necessary to use dieldrin malathion or other new organic insecticides *See* Insecticide Orthoptera [J D B]

Cocoa powder and chocolate

The seeds of the cacao tree are known in commerce as cocoa beans When harvested these seeds have no chocolate flavor Processing is needed to develop it *See* Cacao

Fermentation or curing is carried out in the country of origin immediately after harvesting The pulpy mass containing the seeds is placed in boxes or baskets and permitted to ferment for 3 9 days The temperature may go as high as 50 C during this period The seed is killed and enzymes activated by the heat catalyze reactions which produce the precursors responsible for chocolate flavor that appears later in the roasting process The color of the seed changes from purple to brown and the shell is loosened from the cotyledon *See* Enzyme

After fermentation the beans are sun dried and packed in jute or sisal sacks containing from 120 to 180 lb according to the customs in the country of origin The normal moisture content is in the range of 6–8%. Each seed is enclosed in a hard shell comprising from 10–14% of the total weight. The cotyledon is composed of 50–55% fat 9–14% protein 20–25% starch and 10–15% other carbohydrates

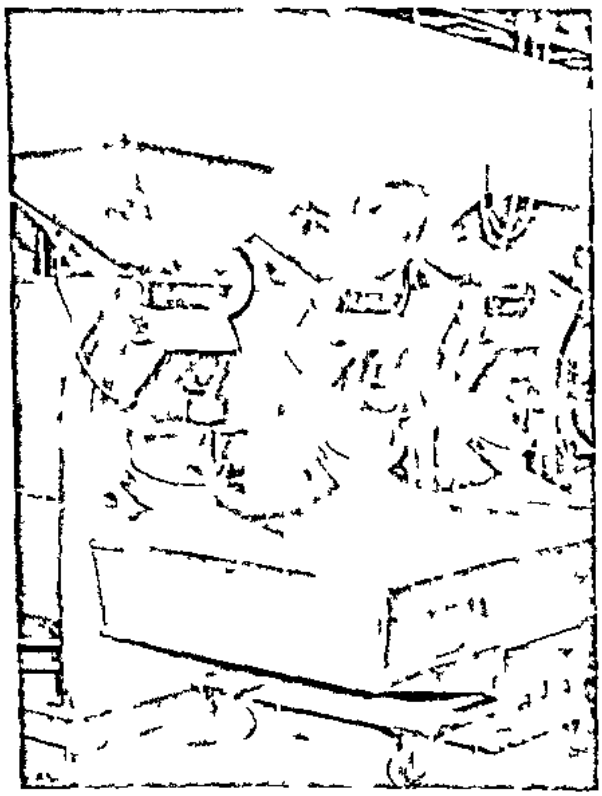


Fig 1 Roasting cacao beans (*Hershey Chocolate Corporation Hershey Pennsylvania*)

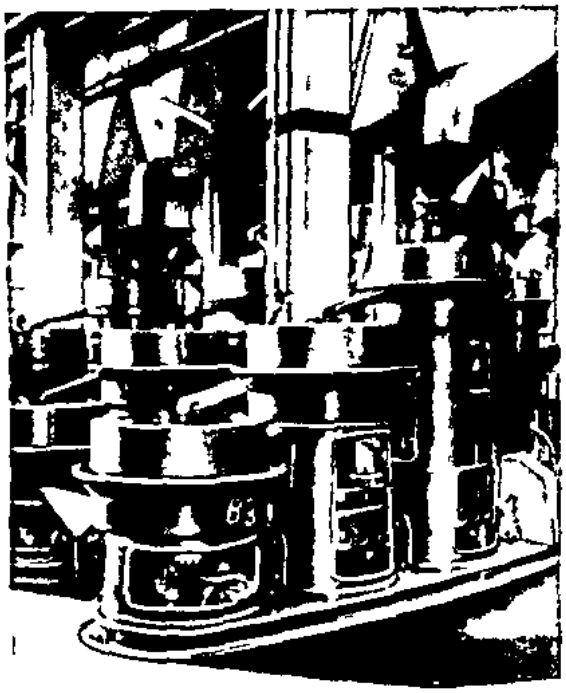


Fig 2 Liquor mills (*Hershey Chocolate Corporation Hershey Pennsylvania*)

Processing technique The beans are first cleaned in machines known as stoners to remove stones and other tramp materials The cleaned beans are then roasted either in batch cylinder roasters or continuous roasters (Fig 1) Roasting develops chocolate flavor not present in the raw bean and also loosens the shell and reduces moisture content to the range of 1–2%. A temperature of 137 8 146°C is reached inside the bean according to individual flavor requirements

The roasted beans are then crushed and winnowed to remove the shell with equipment known as the cracker and fanner The cleaned broken pieces of cotyledon are known as cocoa nibs United States government standards of identity for cocoa nibs limit the shell content to a maximum of 1 75% by weight

For some uses the nibs are treated at this point with alkali to neutralize the natural acids present and enhance color The alkali is applied in water solution time is allowed for absorption and penetration then the nibs are dried or roasted to 1 2% moisture This is known as Dutch processing

The roasted or dried nibs are then ground to produce chocolate (Fig 2) Many types of mills are used the most common being stone disks and steel roll refiners The heat of grinding melts the fat and the ground cell walls are suspended in this fat to

produce a slurry The liquid coming from the mills is known as chocolate liquor or bitter chocolate United States government standards require a minimum of 50% fat content

Liquor is used directly for flavoring other foods and as a base for the manufacture of cocoa powder sweet chocolate and milk chocolate

Cocoa powder manufacture The liquor is passed through special filter presses provided with hydraulic rams to squeeze out additional fat from the cake The resulting presscake is cooled pulverized and sifted to make cocoa powder While some manufacturers still use silk bolting cloth for the sifting operation the majority now employ wind sifters or classifiers which make possible the production of a finer powder

United States government standards classify three types of powder on the basis of fat content breakfast cocoa must have a minimum of 22% fat cocoa is within the range of 10–22% fat and low fat cocoa has less than 10% fat

In Dutch processing United States government standards permit the use of a maximum of 2 91% potassium carbonate or its neutralizing equivalent of other permitted alkalies such as the carbonates or hydroxides of sodium potassium ammonium and magnesium

Cocoa powder is used to flavor candy baked goods ice cream dairy drinks and syrups

Cocoa butter The fat removed by pressing is filtered and is known as cocoa butter It has a melting point of 33 3–34 4°C a yellow color and a slight chocolate flavor and aroma It is widely used in the pharmaceutical and cosmetic industries because of its melting point being solid at room temperature but liquid at body heat The United States Pharmacopoeia has a standard for it However the major use for cocoa butter is in the manufacture of milk chocolate and sweet chocolate

Sweet chocolate Sweet chocolate is made from chocolate liquor by adding sugar and cocoa butter The ingredients are mixed in either melangeurs or paste mixers and then refined by passing the resulting paste over steel roll refiners which grind the sugar to a maximum particle size of 0 0004–0 0016 in according to the quality desired The ground material is then combined with additional cocoa butter and worked to a smooth and viscosity stable paste in machines known as conges The functions of this operation are to wet all dry sugar surfaces with fat to obtain maximum surface exposure to permit volatilization of undesired flavors to permit oxidation of astringent substances and to permit flavor development through heat processing The final sweet chocolate is cast into bars or used in bulk as a coating for confections baked goods and the like United States government standards require that sweet chocolate contain a minimum of 15% chocolate liquor and prescribe the flavoring materials permitted

Milk chocolate Milk chocolate is sweet chocolate containing dried milk solids Because these products have a continuous fat phase moisture must be removed from the milk before incorporating it in chocolate products While roller dried and spray dried milk are frequently used the industry also dries milk in combination with sugar to produce a crumb This permits variations in flavor development such as partial hydrolysis of the milk fat to intensify the milk flavor

The dried milk is incorporated with the liquor and sugar in the paste mixer and ground on roll refiners like sweet chocolate The conging process is used to develop variations in milk chocolate flavor

United States government standards require a minimum of 10% liquor and 12% whole milk solids in milk chocolate As much as 22% whole milk solids is sometimes used in milk chocolate designed for eating as such It is also widely used to coat confections

Confectioner s coatings In recent years many confectioners and biscuit manufacturers have turned to chocolate substitutes made with fats other than cocoa butter This has been done for economic reasons as well as to obtain special effects in their products The fats employed have melting point ranges which fit the particular needs of the product By United States government standards sweet cocoa and vegetable fat coating contains fat with a higher melting point than cocoa butter Sweet chocolate and vegetable fat coating has a fat with a lower melting point than cocoa butter The latter product is used to coat ice cream

See FOOD ENGINEERING FOOD MANUFACTURING

[N W K]

Coconut

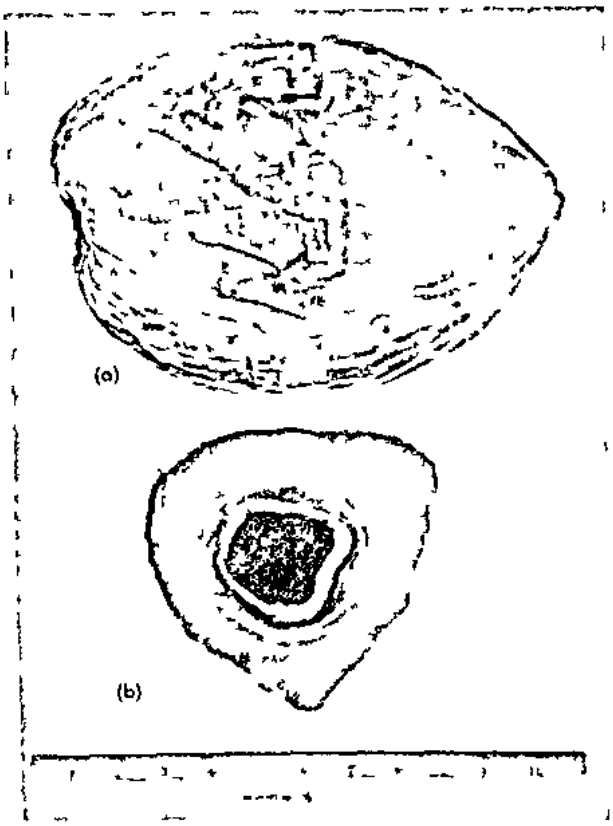
A palm (*Cocos nucifera*) and its fruit common throughout the tropical world

Importance The coconut is one of the most important crops in the world because of its wide distribution and many uses by man It fruits best where humidity is always high and temperatures are below 100°F The Philippine Islands Indonesia Ceylon and the Malay peninsula are the largest commercial producers although there are considerable plantings in the South Pacific islands the West Indies New Guinea Africa and Central and South America

The dried meaty endosperm (copra) and oil extracted from it are articles of extensive world commerce whereas the tree and fruit supply most of the needs of life for natives of tropical islands *See* NUT CROP CULTURE [E F S]

Coconut diseases Several diseases attack the coconut plant Diseases in wild palms adjoining the plantations add to the difficulty of maintaining healthy cultivated stock

Bud rot *Phytophthora palmivora* is controlled to some extent by spraying fertilizing and hygiene Insects and poor nutrition also cause bud failure Deficient nutrition is associated with five diseases lethal yellowing or unknown disease tapering stem or pencil point bronze leaf wilt bitten leaf and little leaf Palms weakened by the last three often have odd symptoms when infected



Coconut (a) Fruit (b) Cross section of fruit shows husk, shell, and endosperm (meat)

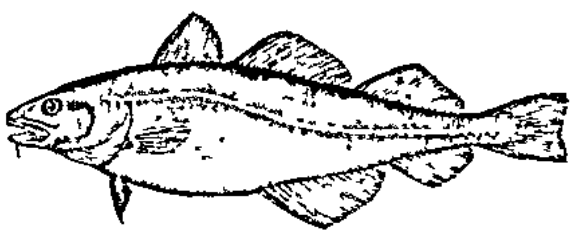
such fungi as *Diplodia*, *Pestalozzia*, and *Ceratocystis* Stem bleeding occurs when *Ceratocystis* enters growth cracks resulting from unbalanced nutrition This and such other fungi as *Ganoderma*, *Fomes*, *Rhizoctonia*, and *Fusarium* may also cause root rot Thread blight *Corticium*, also attacks vigorous palms

Another disease, cadang cadang, resulting from a virus is communicated by *Cicadella* hoppers Red ring, caused by a nematode *Aphelenchoides cocophilus*, spreads easily and may be fatal but it can be stopped by sanitation measures *See* NEMATODA, PLANT DISEASE, PLANT VIRUS [F L W]

Codfish

One of the most important of all food fishes The cod is a large fish frequently weighing 50 lb or more, there is one record of a 211 lb cod over 6 ft long The cod is characterized by small scales, a square tail and soft fins, three of which are dorsal and two anal It has a single barbel under its chin One species, *Gadus morhua*, is found on both sides of the North Atlantic, abounding in relatively shallow water, notably the banks of Newfoundland

The Pacific codfish, *Gadus macrocephalus* is quite [illegible] merci [illegible] of bot [illegible] 000 lb, with a value of over $3 000 000 The Massachusetts fishery accounts for more than half of the total The Scandinavian countries and Great Britain also harvest large quantities of codfish *See* GADIFORMES [J D B]

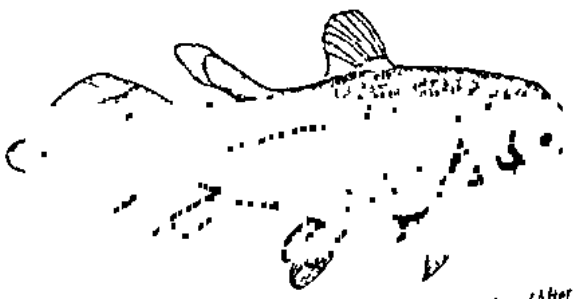


The codfish, *Gadus callarias* length to over 6 ft (From E L Palmer, *Fieldbook of Natural History*, McGraw Hill, 1949)

Coelacanthiformes

An order of lobefin fishes of the superorder Crossopterygii, which diverged from the order Osteolepiformes in Late Devonian times They were common fresh water animals of the Carboniferous and Permian, but in the Triassic, although still numerous, coelacanths appeared in a marine environment They persisted throughout the Cretaceous, after which their fossil record is a blank Capture of a living coelacanth fish off the coast of East Africa in 1938 constituted probably the most surprising and certainly the best publicized zoological discovery of the twentieth century Unfortunately, improper preservation seriously reduced the scientific value of this specimen Continued search ultimately [illegible] material in the Cor [illegible] nce 1952, 1. [illegible] hese are being studied with great thoroughness by French zoologists

The coelacanths differ from the Osteolepiformes in having a rather short, stocky body ending in a three lobed tail with the axial lobe prominent maxillae are lacking, the dermal head skeleton is in large part chondrified, and there are no internal nares



Coelacanth, *Latimeria chalumnae*, 5–6 ft (After J L B Smith, *The Sea Fishes of Southern Africa* Central News Agency, 1949)

The Coelacanthiformes includes a single family Coelacanthidae, with 25 or more genera The Recent coelacanth, *Latimeria chalumnae*, attains a length of more than 5 ft and a weight of at least 170 lb It lives near the bottom at a depth of more than 150 meters A supposed second species of Re-

cent coelacanth *Malania anjouanae* is merely a mutilated individual of *Latimeria chalumnae* that lacks the first dorsal fin *See* CROSSOPTERYGII

[R M B]

Bibliography P P Grasse (ed), *Traite de Zoologie* 1958

Coelenterata

That group of the Radiata whose members typically bear tentacles and possess intrinsic nematocysts The name Cnidaria is also used for this phylum and is preferred by some because the name Coelenterata as first used included the sponges Porifera and the comb jellies Ctenophora as well as the animals called coelenterates

TAXONOMY

The coelenterates are mainly marine organisms and are best known as jellyfish or medusae sea anemones corals the Portuguese man of war small polypoid forms called hydroids and the fresh water hydras Taken together the phylum is divisible into three classes as follows (1) Hydrozoa the hydroids hydras and hydrozoan or craspedote jellyfish hydromedusae (2) Scyphozoa the acraspedote jellyfish and (3) Anthozoa the sea anemones corals sea fans sea pens and sea pansies A classification scheme of the phylum including some representative genera and characteristics of the groups follows See separate articles on each major group in the table

A classification of the phylum Coelenterata

	Characteristics	Representative genera
Class Hydrozoa	Majority marine few species fresh water	
Order Hydroida	Usually colonial well-developed polyp stage	
Suborder Anthomedusae	Athecate polyps	*Tubularia Clava Pennaria Hydra*
Suborder Limnomedusae	Several species commensals hydroids completely naked	*Craspedacusta Gonionemus*
Suborder Leptomedusae	Hydrotheca present	*Obelia Sertularia Plumularia*
Suborder Chondrophora	Polymorphic colonial free-floating	*Velella Porpita*
Order Milleporina	Colonial hydroids polyps dimorphic	*Millepora*
Order Stylasterina	Dactylozooids lack tentacles	*Stylaster Allopora*
Order Trachylina	Polypoid generation reduced or absent	
Suborder Trachymedusae	Hydroid generation unknown	*Liriope Aglantha*
Suborder Narcomedusae	Hydroid generation represented by actinula larva	*Cunina Aegina*
Suborder Pteromedusae	Modified bipyramidal medusae	*Tetraplatia*
Order Siphonophora	Polymorphic colonies planktonic	*Physalia Forskalia Abyla*
Class Scyphozoa	All marine	
Order Stauromedusae	Sessile medusae	*Lucernaria Haliclystus*
Order Cubomedusae	Velarium present tropical subtropical	*Tripedalia Charybdea*
Order Coronatae	Coronal furrow lack ocelli	*Nausithoe Atolla Linuche Periphylla*
Order Semaeostomeae	Pedalia and coronal furrow lacking	*Aurelia Pelagia Dactylometra*
Order Rhizostomeae	Numerous small mouths no marginal tentacles	*Rhizostoma Cassiopea Cephea*
Class Anthozoa	All marine	
Subclass Alcyonaria	Colonial 8 tentacles also Octocorallia	
Order Stolonifera	Stolonic network isolated skeletal calcareous spicules	*Tubipora Clavularia*
Order Telestacea	Calcareous spicules more-or less united	*Telesto*
Order Alcyonacea	Soft corals polyps extend from the coenenchyme	*Alcyonium Xenia Anthomastus*
Order Coenothecalia	Blue coral calcareous skeleton of aragonite	*Heliopora*
Order Gorgonacea	Sea fans skeleton of gorgonin	*Corallium Gorgonia Muricea*
Order Pennatulacea	Sea pens and pansies colony embedded in coenenchyme	*Pennatula Renilla Virgularia*
Subclass Zoantharia	Tentacles and mesenteries hexamerously arranged Hexacorallia	
Order Actiniaria	Sea anemones solitary	*Actinia Metridium Edwardsia*
Order Ptychodactiaria	Solitary sea anemones specialized mesenterial filaments absent	*Ptychodactis Dactylanthus*
Order Corallimorpharia	Resemble corals lack skeleton tentacles radially arranged	*Corallimorphus Corynactis*
Order Scleractinia	True or stony corals solitary and colonial reef formers	*Fungia Astrangia Porites*
Order Zoanthidea	No skeleton solitary or colonial commonly commensals	*Zoanthus Palythoa Parazoanthus*
Order Antipatharia	Thorny or black corals axial skeleton septa single	*Antipathes Dendrobranchia*
Order Ceriantharia	Solitary tube dwellers lack pedal disk	*Cerianthus*

MORPHOLOGY

It is convenient to recognize two basic body forms in this phylum the polyp and the medusa, into which all coelenterates can be classified The two forms have many features in common

Polyp This is a radially, biradially or radiobilaterally symmetrical individual having a longitudinal oral aboral axis and usually sessile The mouth is at the free end and is surrounded by one to many whorls or sets of tentacles which may be hollow or solid The aboral end is commonly developed as an adhesive device for attachment and is conveniently referred to as a base The polyp is covered by an outer layer of epithelial tissue the epidermis lined by a second epithelial tissue layer the gastrodermis and the two layers are united by an essentially noncellular layer the mesoglea The central body cavity is the gastrovascular cavity also called the enteron or coelenteron

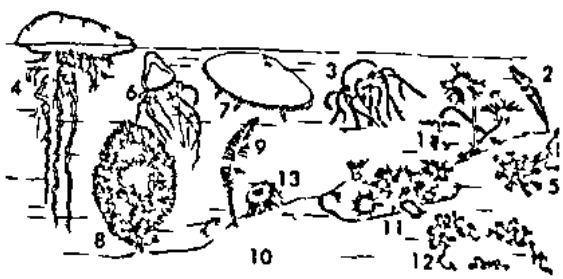


Fig 1 Phylum Coelenterata Some marine representatives in characteristic habitats all reduced but not to same scale 1 *Tubularia* 2 *Plumularia* 3 *Gonionemus* 4 *Physalia* Portuguese man-of war 5 *Halclystus* 6 *Periphylla* 7 *Aurelia* common jellyfish 8 *Gorgonia* sea fan 9 *Pennatula* sea pen 10 *Edwardsia* 11 *Epiactis* sea anemones 12 *Astrangia* stony coral 13 *Cerianthus* (*From T I Storer and R L Usinger General Zoology 3d ed McGraw Hill 1957*)

Medusa This is a tetramerously or polymerously radial individual and

on a stalk or manubrium Instead of directly surrounding the mouth as in the polyp the tentacles are located at the margin of the bell The outer or aboral part of the bell is recognized as the exumbrella and the under or *oral part* as the subumbrella The mouth leads to the central stomach

ring canal at the margin which is *continuous* around the margin and may give rise to centripetal and centrifugal canals The centrifugal canals commonly run from the ring canal throughout the length of the tentacles Special sensory structures such as eye spots or balance organs (statocysts) may occur along the ring canal on the tentacle bases or on special marginal structures The medusa is covered by an outer epidermis the stomach radial ring and other canals are lined by gastrodermis and between these is a layer poor in cells the mesoglea The mesoglea is much thicker and more resilient in medusae than in polyps and is related to their mode of locomotion Swimming or locomotion in medusae is accomplished by sudden contractions of subumbrellar muscles which reduce the volume of the subumbrellar space and thereby force the contained water outward This propels or

In medusae

sheet of tissue

margin of the bell and reduces the effective diameter of the subumbrellar aperture This structure is called a velum and medusae possessing a velum are termed craspedote The resilient and elastic mesoglea is largely responsible for the return of the umbrella to its original form and the medusa is again ready to repeat the muscular contractions which lead to movement The contractions occurring in swimming movements are under the control of the nervous system and are regulated in general by the marginal sensory structures Thus when the marginal sensory structures are removed swimming movements stop, unless the medusa is artificially stimulated When only some of the marginal bodies are removed movement is uncoordinated and erratic

Body form The body form of the medusa is clearly the by product of the firm elastic mesoglea, whereas in the polyp this is only partly so Small coelenterate polyps depend almost entirely upon the rigidity of their tissues for their form but in all larger polyps roughly greater than 1-2 mm body form is also dependent upon the amount of water contained within the gastrovascular cavity Most large polyps possess special ciliated tracts which lead water into the gastrovascular cavity via the mouth This water under a very slight positive pressure literally inflates the polyps as the muscles of the body relax and once the polyp is expanded this water acts as a type of skeleton The skeletal nature of this water is best understood if one compares the polyp and its contained water to an ordinary inflated rubber balloon Thus if a balloon is squeezed in one fashion it extends itself in another and so the polyp by contracting its circular muscles can rapidly extend its length or by contracting its longitudinal muscles can become shorter and fatter The water within the body of the polyp can be trapped by closure of the mouth which helps to make the movements described above possible On strong stimulation leading to a total contraction of a polyp water is expelled through the mouth tentacle tips or special pores in the body wall and expansion can occur again only after sufficient water has been pumped into the polyp to reinflate it

Locomotion Locomotory movements by a creeping of the base of polyps are possible although they are usually very slow perhaps a few inches per day Certain sea anemones such as *Stomphia* and *Boloceroides* can swim in an undirected fash

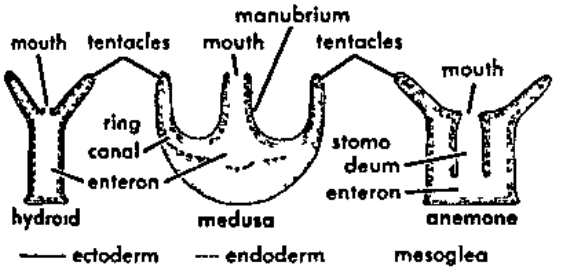


Fig 2 Phylum Coelenterata Comparison of the hydroid polyp, the medusa (inverted), and the anthozoan polyp (*From T I Storer and R L Usinger, General Zoology, 3d ed , McGraw-Hill, 1957*)

ion and some polyps for example *Hydra*, can move in a somersault fashion by alternately attaching the base and tentacles to the substrate Ordinarily locomotion in polyps is restricted to creeping although various other means of locomotion, such as rolling or floating utilize special suctorial devices on the body wall

Nematocysts. The most unique and distinctive feature of coelenterates is the possession of intracellular, independent effector organelles called nematocysts that are also known as stinging cells or nettle cells These structures are used for food gathering and for defense against predators, intruders, or enemies Nematocysts are produced within cells, called cnidoblasts, and may be produced either in situ or at a location some distance from their definitive site in the coelenterate The morphologically simplest coelenterates the Hydrozoa, have nematocysts limited to their outer epidermis, whereas the more complex Scyphozoa and Anthozoa bear nematocysts in both the outer epidermis and inner gastrodermis

Nematocysts have been studied and classified by many workers but it is from the work of Robert Weill that the modern scheme of classification of these structures is taken Weill describes and defines about 17 types of nematocysts Closely related to nematocysts but differing from them morphologically are spirocysts, another kind of intracellular capsule found in certain of the Zoantharia, such as *Metridium*

Spirocysts These structures are thin walled capsules, the wall of which is probably only a single layer thick, and they contain a long unarmed, spirally coiled thread of uniform diameter The reaction of spirocysts to certain dyes differs from that of nematocysts in that spirocysts stain with acid dyes The nematocysts are, by comparison, double-walled capsules of collagenous proteins containing a thread which may or may not be spirally coiled and of uniform diameter throughout its length The thread is usually armed with spirally arranged spines Both spirocysts and nematocysts, on proper stimulation evert their contained threads After a nematocyst has been discharged it cannot be used again The size of nematocysts varies from a few microns to over 1 mm in length Figure 3 illustrates the general morphology and some different types of nematocysts

Classification Nematocysts may be divided into two broad types the astomocnidae with threads which have closed ends and the stomocnidae which have open ended threads The astomocnidae are either adhesive in function or act as lassos to entangle prey The stomocnidae, in general, penetrate the prey or foe on discharge and the capsular contents which are toxic pour out through the open end of the thread The toxin or toxins of nematocysts have not been positively identified They seem to be proteins, protein complexes, or possibly some other substance associated with proteins Contact with nematocyst bearing tissues, leading to discharge of nematocysts and the entry of toxins into the contacting organism, has lethal effects on many small invertebrates and fishes Contact with the Portuguese man of war and certain other coelenterates may cause humans extreme pain, vasomotor dysfunction and even death

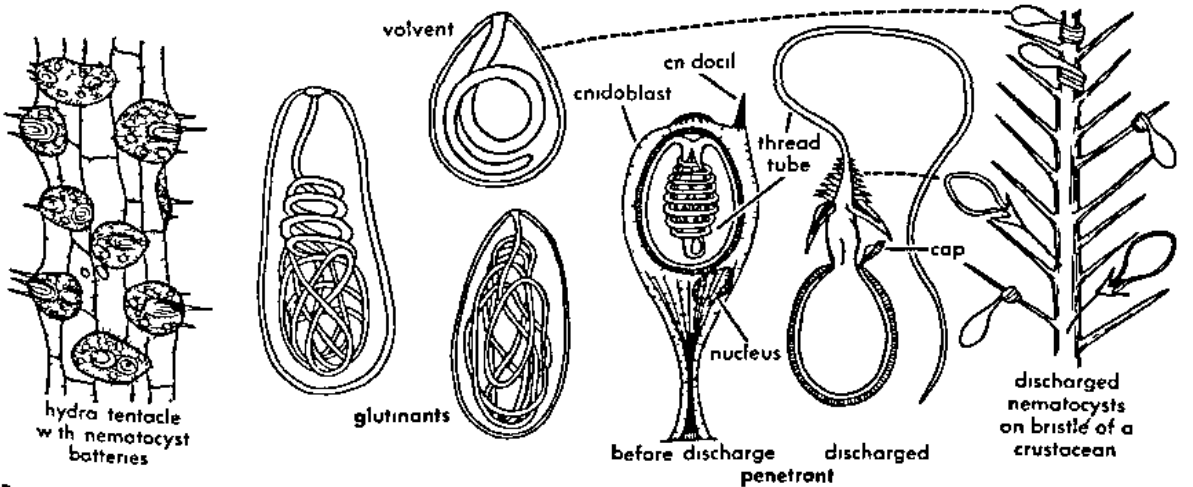


Fig 3 The nematocysts or stinging capsules of *Hydra* (*After Schulze from T I Storer and R L Usinger, General Zoology, 3d ed , McGraw Hill,*

Discharge The discharge of nematocysts is an instantaneous process resulting from contact with the trigger or cnidocil, or from contact between the tissues bearing nematocysts and almost any foreign object The nervous system of the coelenterate does not seem to be involved in this response Chemically clean objects do not cause discharge of nematocysts, although contamination of an inert object with organic materials will cause discharge on contact In life small organisms which are touched by the nematocyst laden tentacles of coelenterates cause massive but very local discharges This is usually sufficient to immobilize the organism being stung or at least to reduce its activities to such a low level that it cannot free itself from the tentacles Subsequently the movements of the tentacles of the coelenterate will carry such a trapped organism to the mouth where it will be swallowed

Other organisms Although intrinsic to coelenterates nematocysts are known to occur in a variety of other organisms Certain flatworms and nudibranchs which feed on coelenterates are able to move these structures without causing their discharge through their own digestive tract and out into their own tissues These foreign nematocysts are oriented in the new site so that the eversible end of the capsule is at the surface Exactly what function these nematocysts now carry out is not clear although they apparently act as defensive structures for the new host Nematocysts have been reported in certain dinoflagellates ctenophores and larvaceans Those in dinoflagellates may be intrinsic although it appears that those in other organisms are of foreign origin It should be noted also that nematocystlike structures occur in one other group of protists besides the dinoflagellates the cnidosporidians

BODY SYSTEMS

The body systems of coelenterates may be divided into the following categories for the purpose of description epithelial, nervous muscular, mesogleal skeletal digestive and reproductive There is no analog of a circulatory system and the functions of respiration and excretion are carried out by each individual cell

Epithelial system In the coelenterates this system is quite simple The outer epithelium or epidermis is in general a single layer of cells varying from a flattened squamous nature to tall and columnar The epidermis is usually ciliated in polyps so that the net effect of the ciliary beat is to move material away from the mouth toward the

as cleaning currents Among the epithelial cells may be found numerous specialized types such as mucous producing cells sensory cells undifferentiated interstitial cells and cnidoblasts Frequently, some of the epidermal cells have a dual function

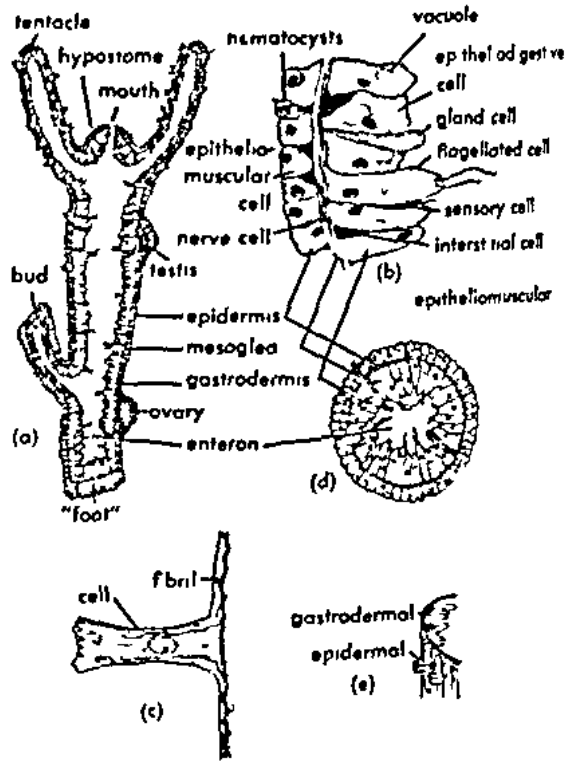


Fig 4 Hydra Structure as seen in microscopic sections (a) Longisection (b) Enlarged cross section (c) Epitheliomuscular cell (*after L H Hyman*) (d) Cross section (e) Fibril arrangement of epithelomuscular cells (*From T I Storer and R L Usinger, General Zoology 3d ed , McGraw-Hill, 1957*)

and the cell base is elongate and possesses contractile fibrils Such cells are described as epithelomuscular cells In simple polyps, such as most hydrozoan polyps the epitheliomuscular cells of the epidermis and gastrodermis represent the total musculature

The gastrodermis, or inner epithelial layer is also abundantly ciliated These cilia move food materials about within the gastric cavity and circulate the contained water Among the gastrodermal cells may be found types identifiable as glandular cnidoblastic, sensory interstitial and epitheliomuscular One of the prime functions of the gastrodermis is digestion and essentially every cell of the gastrodermis is capable of ingesting small food particles

Nervous system. The coelenterate nervous system can be defined as consisting basically of an unpolarized network of bipolar and multipolar neurons The nervous system is subepithelial in location both subepidermal and subgastrodermal and may in some forms consist of two networks in only limited contact with one another and with each specialized either for rapid through conduction or for slower more general spread of conduction The physiology of coelenterate nervous systems has been much studied particularly neuromuscular aspects of it The nervous system is synaptic Where information is available action potential have been demonstrated from single neurons and the fine morphology of synapses and neuromuscular

end plates looks much as it does elsewhere Cross connections between gastrodermal and epidermal nerve nets occur abundantly in the region of the mouth and may occur elsewhere through the mesoglea but this latter point needs clarification In colonial coelenterates the nervous system is continuous from member to member of the whole colony The response of different kinds of colonies to local stimulation varies from complete contraction of the whole colony to only local contraction in the area of stimulation or various intermediate responses In most coelenterates a stimulus at any point causes only a local contraction whereas succeeding stimuli at the same location cause a greater and greater spread in the response Thus with the generally diffuse network a stimulus at any point can be transmitted via the conducting nervous system to all points in the system Simple reflexes such as righting movements swallowing and locomotion are possible and are known The coordination of swimming in medusae is a property of the balance-organs at the bell margin When these controlling structures are removed and a wave of contraction is initiated in a ring shaped piece of the bell of a medusa it is possible to set up a trapped circuit wave of neuromuscular activity to travel around and around the ring One such preparation made from the medusa *Cassiopea* maintained a circuit wave for 11 days travelling at 77 5 cm/sec for a total distance of 457 miles The coelenterate nervous system is of particular interest because it appears to be the first example of a recognizable nervous system in a metazoan that is it is regarded as an example of a primitive nervous system The system is however highly evolved and clearly adapted to coelenterate needs and as such should not be thought of as truly primitive *See* NERVOUS SYSTEM (INVERTEBRATE)

Muscular system The muscular system varies considerably among coelenterates In simple polyps there is an epidermal longitudinal muscle sheath of epitheliomuscular cells and a gastrodermal circular sheath In medusae and in members of the classes Scyphozoa and Anthozoa the musculature has become separated from the epithelial tissue as a subepithelial system The cells are elongate and in some medusae are striated although most coelenterates do not show striated muscle fibers The muscle cells are closely applied to the mesoglea and the mesoglea is folded to accommodate them In many anthozoans a large sphincter muscle develops in the gastrodermal surface at the top of the column and in some anthozoans this muscle becomes secondarily embedded in the mesoglea In medusae where the primary swimming muscles are subumbrellar large muscle bands both circular and radial develop In large anthozoan polyps the epidermal musculature is usually weak whereas heavy gastrodermal circular and longitudinal muscles are developed The musculature of tentacles is quite constant throughout the phylum there being a longitudinal epidermal sheath and a circular gastrodermal sheath

Mesoglea The mesogleal system is represented by a layer between epidermis and gastrodermis which varies from a thin structureless cementing layer the mesolamella of hydrozoan polyps to a highly complex cellular fibrous gelatinous matrix the collenchyme or mesenchyme of the scyphomedusans and anthozoans In hydromedusae the mesoglea is essentially free of cells and fibers Where the mesoglea is well developed as in medusae and some anthozoans it serves as a type of internal skeleton against which muscles may act This is particularly true in medusae where the elasticity of the mesoglea returns the bell to its original shape after each pulsation thus preparing for a new pulsation In anthozoans the mesoglea serves for insertion and origin of muscle cells the skeletal function is largely taken over by the water contained in the coelenteron and the mesoglea is much thinner and less elastic than in medusae

Skeletal system Two different types of skeletons occur in the phylum The first referred to above is of an internal nature and is either the mesoglea against which the muscles operate or the contained hydroskeleton of most polyps Of a quite different nature is the skeleton seen in most hydrozoan polyps some scyphozoan polyps and corals These are exoskeletons formed as secretions of epidermis which support and protect the organisms In the Hydrozoa the skeleton is tubular usually rigid enough to support many polyps in a colonial system and flexible enough to allow bending in waves or currents Sometimes the hydrozoan skeleton is elaborately developed with ornamental cups into which each polyp may withdraw whereas in others the exoskeleton may cover only the column or stalk of the polyp or be variously reduced to the point of being entirely absent These flexible hydrozoan skeletons are made up of sclerified proteins In certain colonial pelagic hydrozoans part of the skeleton may be involved in the development of a floatation device as in *Physalia* or *Velella* Calcareous exoskeletons occur among both the Hydrozoa and Anthozoa and the animals possessing them may be referred to as hydrocorals and madreporarian corals respectively These skeletons may vary from delicately branched structures to massive encrusting formations but in general most of the living animal matter is restricted to the outer layer of skeletal material The polyps themselves occur in cups or depressions in the skeleton and the individuals of the colonies are connected by sheets of living tissue which cover the whole skeleton except at its attachment to the substrate

Still another skeletal type known in the coelenterates is an axial skeleton composed of sclerified proteins It is exceedingly tough and flexible and is characteristic of such anthozoans as gorgonians In another anthozoan group the pennatulaceans or sea pens there is also an axial skeleton which although flexible up to a point is also brittle This latter skeleton is largely calcified The development of axial skeletons has not been studied sufficiently in detail to state clearly the

they are epidermal in origin although this is assumed to be correct A number of different coelenterates such as some hydrozoans and anthozoans also have spicular calcareous structures which may serve for protection from predators or for the reinforcement of areas on a colony These structures may be considered skeletal too in a broad sense

Digestive system The digestive system in coelenterates is developed as a function of the gastrodermis In hydrozoans both polyps and medusae glandular enzyme-producing cells are abundant throughout the gastrodermis These cells secrete proteolytic enzymes into the coelenteron which reduce food objects to a fine particulate state In scyphozoans and anthozoans although glandular cells are common throughout the gastrodermis they tend to be most abundant along the free edges of the mesenteries of anthozoans and on the gastric tentacles of scyphozoans These glandular cells are also the source of proteolytic enzymes which act in the extracellular environment of the coelenteron

After the preliminary physical breakdown of food to small particles has been accomplished these particles are engulfed by gastrodermal cells of all types Food vacuoles form in these cells and definitive digestion of all classes of foods is apparently intracellular The epidermal cells do not have the ability to engulf food particles and the nutrition of all tissues of a coelenterate is apparently dependent upon diffusion of foodstuffs from the gastrodermis to other parts of the body Ameboid wandering cells may play a role as nurse cells particularly in the development of ova but whether such cells are involved in the normal nutrition of epidermal tissue is not known

The phylum is characterized by its carnivorous diet made possible first by the possession of nematocysts which make the predaceous habit successful After food has been trapped movements of the tentacles carry it to the mouth where with the help of ciliary and muscular devices the food is moved to the coelenteron Here extracellular proteases prepare the way for final intracellular digestion No herbivorous coelenterates are known Certain coelenterates may however in a limited sense utilize plant materials as food It is known for example that by products of photosynthesis of symbiotic algae found in the tissues of coelenterates may be traced from the algae to the tissues of the host These materials are incorporated into the animal protoplasm and to this extent the coelenterate may feed ' on the plant Certain anthozoans (some alcyonarians) have never been seen to feed on animal material and these forms also have extremely abundant symbiotic algae and reduced digestive structures Moreover studies on the ecology of coral reefs have suggested that the environment of the reef does not produce enough animal food to support the mass of corals present and this has led to the conclusion that at least some of the food of reef forming corals must be obtained directly from their associated algae instead of from the external environment The degree to which corals are dependent upon their symbiotic algae has not been determined *See* FEEDING MECHANISMS AND DIGESTION

Reproductive system The reproductive system of coelenterates consists of specialized areas of epithelia the gonads which periodically appear and produce gametes In the Hydrozoa the gonads are epidermal whereas in the Scyphozoa and Anthozoa they are gastrodermal The precise location of gonads is variable in the Hydrozoa, being located either on the manubrium or beneath the radial canals in hydromedusans or at almost any point on different hydroid polyps In the Scyphozoa the gonads are located in the floor of the stomach whereas in the Anthozoa they occur along the sides of the mesenteries which subdivide the coelenteron There are no ducts for the sex products or any accessory sexual structures Fertilization usually occurs in the water surrounding the animal although a few coelenterates have their eggs fertilized in situ and may then brood their young In Scyphozoans and Anthozoans the sex products are released to the coelenteron and make their way to the outside via the mouth The sexes are separate in the coelenterates with but few exceptions

REPRODUCTION AND DEVELOPMENT

Asexual reproduction This phenomenon is common throughout the phylum and is accomplished in a variety of ways All colonial coelenterates are the result of the budding of new individuals from existing individuals Some hydroids hydromedusae and anthozoans give rise to free buds which in turn may bud again to produce still more individuals Most hydrozoan medusae are budded from hydroid colonies Small pieces of hydroids may bud from a parent wander about as undifferentiated elongated entities called frustules and in time attach and develop into new individuals or colonies In sea anemones both transverse and longitudinal fission are known methods of asexual reproduction Transverse fission is the normal mode of development of the adult medusa from the larval form in some Scyphozoa and is known as a rare event in hydrozoan polyps

The ability to regenerate lost parts is characteristic of coelenterates Pieces cut from almost any part of polyps will in time grow into new polyps The regenerative powers of medusae are much less well developed and not only will the excised piece not develop but it may not even be replaced by the medusa Gradients of regenerative ability in polyps exist with the ability for a piece to reconstitute a new whole organism decreasing from the mouth to the base *See* REGENERATION (BIOLOGY)

Sexual reproduction The embryology of coelenterates takes slightly differing courses among the many kinds of organisms here involved After fertilization cleavage occurs and usually is total frequently somewhat unequal and the individual cells are not as a rule definitely arranged The first stage is a ciliated blastula The development of the next stage the gastrula follows several courses

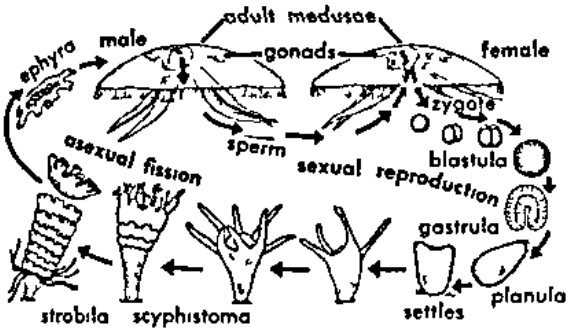


Fig 5 The life cycle of the jellyfish *Aurelia aurita*, class Scyphozoa (*After L Agassiz, from T I Storer and R L Usinger, General Zoology, 3d ed McGraw Hill, 1957*)

such as the wandering in of some of the surface cells the division of the surface layer to produce a second inner layer, or by an infolding of one end of the cell mass The gastrula is a stereogastrula,

planula tends to have a broadened anterior end frequently equipped with an elongate tuft of sensory cilia, and is mouthless This larva if that of a polyp, will attach by its anterior end and develop a mouth and tentacles at its posterior end The planula larvae of medusae which have no attached polypoid stage metamorphose to medusae, the anterior end becomes the exumbrellar surface of the bell and the mouth again develops from the posterior end of the larva In some hydrozoans the planula larva develops tentacles and a mouth while still free swimming and this stage is called an actinula The actinula of some species may attach and develop into a hydroid whereas in others it metamorphoses into a medusa *See* ANIMAL KINGDOM, INVERTEBRATE EMBRYOLOGY REPRODUCTION ANIMAL [C H]

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Coelenterata fossils

Coelenterates as a group have an extraordinarily long fossil record, longer than that of any other animal phylum Within the group the history of the principal classes ranges from relatively complete in the Stromatoporoidea, Conularida, Rugosa, and Scleractinia to spotty and incomplete in the Alcyonaria most of the Hydrozoa, Scyphozoa and various other jellyfish (Fig 1) *See* COELENTERATA

The coelenterates must be an ancient group, and if present theories of their evolutionary pattern are accepted the earliest forms would have been free-swimming medusoid jellyfish Such is indeed the case, for among the handful of authentic Precambrian fossil animals is a primitive medusoid *Brooksella* (Fig 2*a*), from the late Proterozoic (Algonkian) rocks of Arizona a genus also found in the Cambrian Most of the coelenterates known from the succeeding Cambrian strata are also jellyfish

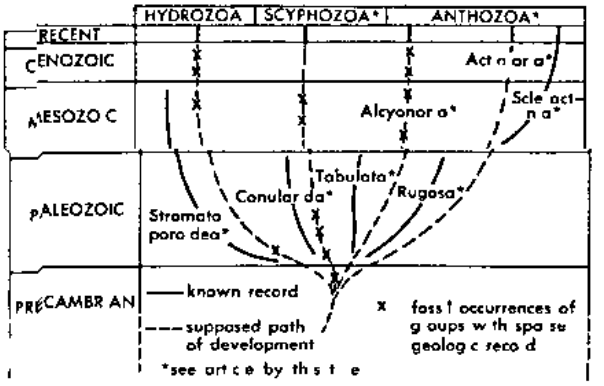


Fig 1 Geologic distribution of the Coelenterates

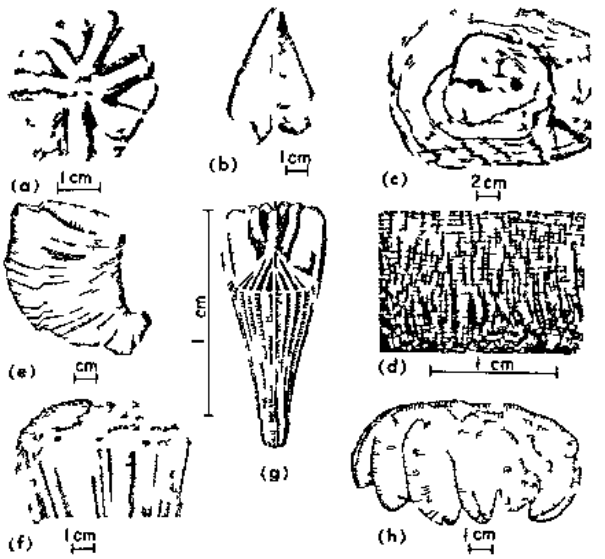


Fig 2 (*a*) *Brooksella*, a Cambrian jellyfish, Alabama (*b*) *Conularia*, a Devonian conularid, New York (*c d*) *Actinostroma*, a Devonian stromatoporoid hydrozoan, Europe in longitudinal section (*d*) (*e*) *Bethanyphyllum*, a Devonian solitary rugose coral New York (*f*) *Favosites*, a Silurian tabulate coral, Sweden (*g*) *Turbinolia*, a Tertiary nonreef building solitary scleractinian coral, England (*h*) *Rhipidogyra*, a Jurassic reef building colonial scleractinian coral, Switzerland (*From R C Moore, ed , Treatise on Invertebrate Paleontology, Geol Soc Am and Univ Kansas Press 1956*)

such as dipleurozoans and conularids (Fig 2*b*) The latter are a remarkable extinct subclass with a generally well preserved thin external chitinophosphatic sheath and are abundant throughout the Paleozoic By Cambrian time a sessile bottom dwelling polypoid stage had appeared in the life cycles of some medusoid lines leading to the large group of the Hydrozoa most members of which lack resistant skeletal structures and hence are extremely scarce as fossils Some hydrozoans however such as the extinct stromatoporoids (Fig 2*c d*) quickly acquired calcareous tissues which supported polyps These forms were prominent among the reef forming organisms of the Paleozoic and Mesozoic Modern hydrozoans with calcareous skeletons such as the milleporids (stinging corals) and the colorful stylasterids (hydrocorals) did not appear until the Cretaceous

In the class Anthozoa the medusoid stage is completely suppressed and the animals are solitary or colonial aggregates of polyps throughout their life cycle except for the initial larval (planula) stage The skeletonless forms the actinians (sea anemones) are almost unknown as fossils although they must have been present in the very early Paleozoic Anthozoans with calcareous structures the corals proper (madreporarians) are among the commonest of fossils from the Ordovician to the present day The three major orders of these are the Rugosa (tetracorals cup corals) Tabulata (honeycomb corals) and Scleractinia (hexacorals) The rugose (Fig 2*e*) and tabulate (Fig 2*f*) corals were the dominant types of the Paleozoic and became extinct at the close of that era while the scleractinians (Fig 2*g h*) appeared suddenly at the beginning of the Mesozoic (Middle Triassic) By Jurassic times scleractinians were constructors of reefs similar to the luxuriant tropical reefs of today and a few (Fig 2*g*) had become adapted to the dark waters of the deep sea and the temperate shallow conditions of the extratropical regions There are about 125 genera of living corals comprising some 600 species [J W WE]

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Coelolepida

An extinct group of Agnatha or jawless vertebrates known from Silurian and Lower Devonian rocks of Europe Asia and North America Their skin was set with minute close fitting scales composed of dentine similar to placoid scales of sharks Since they had no preservable skeleton little is known of their structure and relationships Impressions of gill pouches and other cranial organs in *Thelodus* suggests that it may be related to Heterostraci A relationship to both Heterostraci and Osteostraci has been claimed for the flat bodied *Cephalopterus Phlebolepis* has a more fusiform shape and shows little resemblance to any other Agnatha *See* AGNATHA HETEROSTRACI OSTEOSTRACI OSTRACODERMI [R H DE]

Coelom

The coelom is the mesodermally lined body cavity of most animals above the flatworms and nonsegmented roundworms Its manner of origin provides one basis for classifying the major higher groups

Annelida Annelids arthropods and molluscs have a coelom which develops from solid mesodermal bands Within the trochophore larva of annelids a single "pole cell" proliferates two strips of mesoblast lying on either side of the ventral midline These bands subdivide transversely into bilateral solid blocks the somites Each somite then splits internally to form a hollow vesicle the cavity of which is the coelom The somitic vesicles of each side expand until their surfaces become apposed above and below the gut thus forming its supporting mesenteries The anteroposterior surfaces of contact between somites form the septa between segments of the body In some of the annelids which have developed a parasitic mode of life as the leeches septa disappear between segments, and the coelom is much reduced by encroachment of mesenchymatous tissue

Mollusca The molluscs also form bands of mesoderm from a single pole cell but these bands do not segment They split internally to form single right and left coelomic sacs but the cavities are soon reduced and the surrounding mesoblast dispersed as separate cells many of which become muscle The only remnants of the coelom in the adult are the pericardial cavity and the cavities of the gonads and their ducts

Arthropoda In arthropods paired bands of mesoblast may proliferate from a posterior growth center or may separate inward from a blastoderm superficial layer of cells on the ventral surface of the egg These bands divide into linear series of somites which then hollow out Their cavities represent the coelom The upper wall of each somite moves dorsally to meet its partner from either side and fuse into a longitudinal tube the heart The outer and inner somitic walls give rise to muscles of the body wall and gut respectively The lower wall may form fat body or move into the appendages to form excretory organs or glands In adult arthropods the coelom persists only as small cavities within the segmental excretory organs or glands and as the cavities of the gonads and gonoducts

Echinodermata and Chordata Echinoderms and chordates constitute a second major group characterized by the origin of the coelom from outpockets of the primitive gut wall In echinoderms one pair of bilateral pouches evaginates and separates from the archenteron or primitive digestive cavity Each pouch constricts into three portions not homologous to the metameres of other animals Of these the left middle coelom assumes major importance giving rise to the water vascular system and primordia of the radii of the adult Contributions to the stone canal and the axial sinus are made by the left anterior coelom The rearmost cav

ities become converted into the main perivisceral coelom of the adult

Protochordata The protochordates of the groups Hemichorda and Cephalochordata exemplified by *Balanoglossus* and *Amphioxus*, respectively, have three coelomic pouches formed by separate evaginations of the archenteral roof The first or head cavity is single and median in origin, the others bilateral and paired In hemichordates the head cavity remains single as the cavity of the proboscis and has a pore to the exterior on each side The second pouches form cavities within the collar and also acquire external pores The third pair is contained within the trunk and forms the major perivisceral cavity

Cephalochordata In cephalochordates, the head cavity divides into lateral halves The left side communicates, by a pore, to an ectodermal pit called the wheel organ The second pair of pouches forms the first pair of mesoblastic somites, and the third pouches subdivide transversely to give rise to the remainder of the linear series of somites The upper or myotomic portion of each somite remains metameric and forms the segmental muscles As it enlarges, the coelomic space is displaced ventrally and expands above and below the gut to form the perivisceral cavities and mesenteries as described for annelids However, the transverse septa perforate and disappear between adjacent somites so that a continuous anteroposterior body cavity is formed on either side of the gut

Vertebrata In vertebrates, the mesoderm arises as a solid sheet from surface cells that have been involuted through the blastopore Lateral to the notochord, beginning at about the level of the ear, the mesoderm subdivides into three parts (1) the somites, (2) the nephrotomic cord, temporarily segmented in lower vertebrates, which will form excretory organs and ducts, and (3) the unsegmented lateral plate The coelom arises as a split within the lateral plate In lower vertebrates, the split may continue through the nephrotome into

of the other side, thus forming the body cavity and mesenteries of the gut *See* ANIMAL KINGDOM GASTRULATION, INVERTEBRATE EMBRYOLOGY

[H L H]

Coenopteridales

A heterogeneous group of fossil fernlike plants which arose during the Devonian, flourished during the Pennsylvanian and Early Permian, and disappeared before the Mesozoic Although common in Paleozoic petrifactions, the coenopterids are incompletely known, usually occurring as fragmentary stems, frond parts, or fructifications *See* PETRIFACTION

Most coenopterids were small shrubby, or scrambling plants, and occasionally epiphytic A few (*Clepsydropsis*, *Zygopteris*) were small trees with "false trunks" formed by thick mantles of adventi

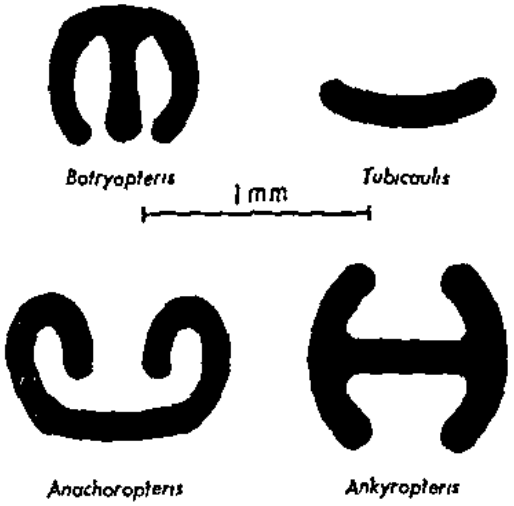


Fig 1 Diagrammatic cross sections of petiolar vascular strands of representative coenopterid genera, oriented so the parent stem would appear below each diagram



Fig 2 Side view reconstruction of *Biscalitheca musata*, a unique coenopterid sporangium with dorsiventral symmetry, two lateral, multiseriate annuli, and small nests of thickened cells in the sporangial wall (*From S H Mamay, Am J Botany, 44(3) 236, 1957*)

tious roots The stems usually branched dichotomously and had single, cylindrical, angular, or lobed protosteles without secondary wood However, *Zygopteris* and *Cladoxylon* produced secondary wood, *Cladoxylon* was polystelic *See* STELE

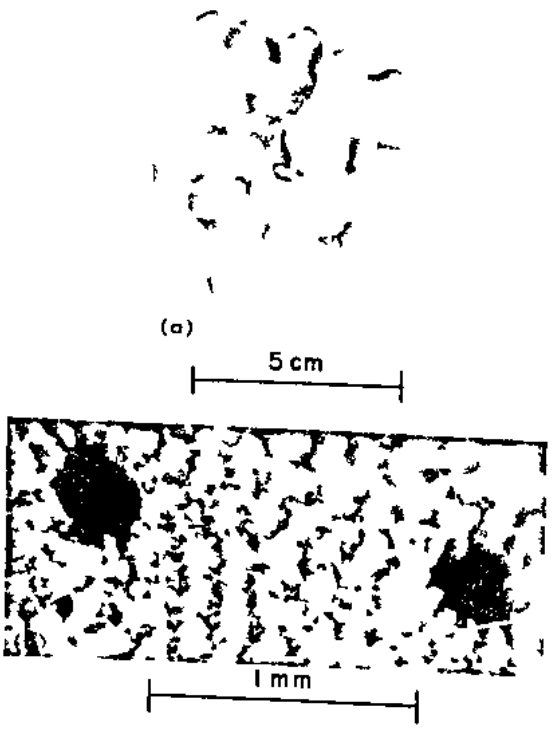
Coenopterid fronds known mainly from petrified petioles, had distinctive vascular strands, useful in identifying genera (Fig 1) Some genera produced flattened laminae, but in others, such as *Stauropteris*, the "frond" was a three-dimensional branching system without photosynthetic blades

Coenopterid fructifications varied considerably, and some were very complex (Fig 2) Fructifications terminated naked branchlets (*Stauropteris* and others) or, if borne on flattened pinnules, they were marginal (*Chorionopteris*) or superficial (*Corynepteris*) Some had annuli, or dehiscence mechanisms (*Botryopteris* and others), some had none (*Stauropteris*, *Chorionopteris*) Fructifications also varied in sporangial wall thickness and number of sporangia in a sorus Only one genus *Stauropteris*, was heterosporous (produced spores of two types) It ordinarily produced two functional megaspores in megasporangia that apparently were shed intact superficially simulating the seed habit

Coenopterid classification is difficult because of incomplete fossil records They usually are divided into two or more families on the basis of vascular anatomy and frond architecture but fructification morphology suggests more complex interrelationships Despite changing classifications their admixture of primitive psilophytic and fernlike features indicates the coenopterids to be psilophytalean derivatives some of which possibly were ancestral to modern ferns *See* PALEOBOTANY PSILOPHYTALES [S H M]

Coenothecalia

An order of the class Alcyonaria The Coenothecalia have no spicules but form colonies with a massive skeleton composed of fibrocrystalline aragonite fused into lamellae The skeleton is perforated by both numerous wide cylindrical cavities occupied by the polyps and narrow ones containing the solenial systems (see illustration) In the calyx of the polyp septalike structures of stony coral or pseudosepta are formed



(a) Skeleton of *Heliopora coerulea* Pallas (b) Enlarged skeleton

The order includes a few genera of which *Heliopora* or the blue coral is often found on coral reefs *See* ALCYONARIA [K A]

Coenurosis

An infestation by a coenurus the metacestode of the genus *Multiceps* The coenurus attains the diameter of an inch or more and is most common in sheep rabbits, and other herbivores They become infested while browsing on vegetation contamina with eggs of the parasite Coenuri occurring in s cutaneous spaces and muscles cause less dam than those in the brain or spinal column The l ter type of infestation found mainly in sheep r cause the animal to stagger or circle and su animals are said to be giddy from which ari es t term gid tapeworm The infestation is rare in ma cure requires surgical removal of the coenur *See* CYCLOPHYLLIDEA [R S F

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Coenzyme

An organic cofactor or prosthetic group (nonpr tein portion of the enzyme), whose presence i r quired for the activity of many enzymes In add tion many enzymes need metal ions such as coppe manganese and magnesium for activation Th prosthetic groups attached to the protein of th enzyme the apoenzyme may be regarded as di sociable portions of conjugated proteins (*see* PRO TEIN) The coenzymes usually contain vitamins a part of their structure (*see* VITAMIN) Neither the apoenzyme nor the coenzyme moieties can function singly since dissociation of the two results in in activation

In general the coenzymes function as acceptors of electrons or functional groupings such as the carboxyl groups in α keto acids which are removed from the substrate Some of the well known coenzymes are mentioned below Diphosphopyridine nucleotide (DPN or coenzyme I) and triphosphopyridine nucleotide (TPN or coenzyme II) function as hydrogen acceptors in dehydrogenases Thiamine pyrophosphate or cocarboxylase the prosthetic group of carboxylase is responsible for the decarboxylation of α keto acids in the body Flavin mononucleotide (FMN) and flavinadenine dinucleotide (FAD) act as hydrogen acceptors in aerobic dehydrogenases Pyridoxal phosphate also known as codecarboxylase and cotransaminase serves as coenzyme for various racemases in reactions involving the decarboxylation of α amino acid and also functions in transamination Iron protoporphyrin (hemin) acts as coenzyme of catalase peroxidases cytochromes and hemoglobin Uridine diphosphateglucose or uridine diphosphoglucose (UDPG) is the prosthetic group of the enzyme which converts galactose to glucose Adenylic acid functions with enzymes in phosphorylation Adenosine triphosphate the phosphorylated derivative of adenylic acid serves as coenzyme in transphosphorylation reactions Coenzyme A (CoA) a coenzyme in certain condensing enzymes acts in acetyl or other acyl group transfer and in fatty acid synthesis and oxidation *See* ADENOSINETRIPHOSPHATE (ATP), ADENYLIC ACID CYTOCHROME, DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN), TRIPHOSPHOPYRIDINE NUCLEOTIDE (TPN) URIDINE DIPHOSPHOGLUCOSE (UDPG), *see also* BIOCHEMISTRY ENZYME [M B MC.]

Coffee

Commercially coffee is the most important caffeine beverage plant in the world It is a shrub or small tree of the genus *Coffea* and a native of Abyssinia There are 45 species but only 3 are of commercial importance Nine tenths of the world supply of coffee is obtained from the Arabian species *Coffea arabica* (Fig 1) of which there are about 15 varieties Coffee is strictly a tropical crop requiring a hot moist climate The fruit is a small spherical drupe (berry) containing two seeds the coffee beans The coffee berries are picked by hand and the pulp and membranes are removed The coffee beans are then graded and packed in burlap bags Finally the beans are roasted to develop the aroma flavor and color desired *See* RUBIALES [PDS]

Coffee diseases There are more than 350 known diseases of coffee and new ones are still being discovered on *Coffea arabica C canephora C liberica* and *C excelsa* in widely separated tropical lands Probably no crop grows under more varied conditions or is subjected to so many unknown diseases

The leaf rust *Hemileia vastatrix* one of the great plagues of man's crops at first eliminated coffee from many Eastern countries However it never became established in the Occident In Africa and the Orient control is now obtained by sprays and there are new plants selected for resistance American leaf spot *Mycena citricolor* is very serious but it is found only in the Americas whereas *Cercospora* leaf spot and the leaf rot *Pellicularia koleroga* occur in both hemispheres The latter are controlled by spraying

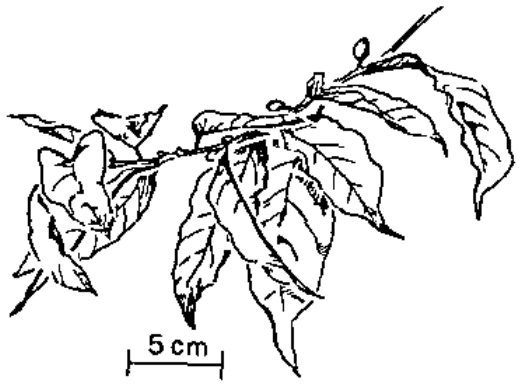


Fig 1 *Coffea arabica* (L H Bailey *The Standard Cyclopedia of Horticulture* vol 1 Macmillan 1937)

Fruit stem and branch infections are injurious Wilts and trunk cankers caused by *Gibberella Nectria* and *Ceratocystis* are troublesome Probably six *Rosellinias* a few *Fusaria* two *Armillarias* and fungi like *Fomes Ganoderma* and *Polyporus* attack roots Root and trunk infections are reduced by good cultural practices Coffee is also affected by a half dozen viruses two bacteria and numerous parasitic mistletoes *See* BACTERIA FUNGI PLANT VIRUS *see also* PLANT DISEASE CONTROL [FLW]

Coffee processing Coffee is the beverage prepared by controlled extraction from ground roasted beans with hot water Beans are produced in tropical or subtropical climates

Coffee beans are the largest agricultural import of the United States In 1957 2 750 000 000 lb or 58% of world export came to the United States From this approximately 140 000 000 000 cups of beverage were prepared In 1957 more than 50 countries exported 4 750 000 000 lb of beans Latin America accounted for about 73% of the export of which Brazil and Colombia exported more than half

Blending Green beans are packed and transported in hemp bags The commercial unit is 60 kilograms about 132 lb On arrival at the roasting plant beans from many sources are crudely *blended to achieve a particular flavor*

Cleaning The beans are cleaned both before and after roasting Pneumatic separators remove dust lint strings hulls and other light material from the green beans Batches of 12 bags or about 1500 lb are fed through the cleaner and the beans are completely mixed One modern unit will handle 5000 lb an hour

Roasting Roasting is the most important operation in coffee processing because it develops the flavor Modern automatic control makes possible precise transfer of energy from a source to the beans To roast 1500 lb of beans approximately 525 000 British thermal units must be delivered in 54 minutes

Systems now employ externally heated gases of combustion mainly nitrogen carbon dioxide and water vapor circulated at extremely high velocities to scrub off insulating gas films and permit rapid heat penetration In batch roasters energy at relatively low temperatures 800–900°F develops fine flavor and a uniform brown color in about 12 minutes In continuous roasters energy is transferred even more efficiently (Fig 2) Temperature is reduced to about 500°F and roasting time to about 5 minutes

Light roasts are attained at bean temperatures of 380–390°F medium roasts 400°F and dark roasts 425–430°F At 450°F excessive decomposition of fiber and oils occurs

At the end of batch roasts water at the rate of 1 gal per 100 lb is sprayed onto the beans to check or quench the roast after which the beans are dumped and rapidly air cooled Beans roasted continuously are only air cooled

Stoning The second cleaning operation is called stoning Roasted beans have only half the density of green beans (20 versus 40 lb/ft^3) and are lifted by air currents away from heavy material stones and other debris The beans are deposited in specially designed bins which prevent segregation as the beans pass to the grinders

Grinding There are two types of grinding mills, the plate or compactor, and the roll or granulator The plate mill tends to crush particles and yield a higher proportion of fine material than does the granulator with its cutting action Most grinds contain particles ranging in size between 0 023 and 0 055 in

Packaging Can packs in which the initial vacuum is about 29 in retain flavor for many months Some can packs are pressurized with inert gas for flavor retention Flexible containers made of paper laminated with plastic film or aluminum foil are not vacuumized nor are they gas tight So storage life is much shorter

Instant coffee Soluble or instant coffee manufacturing now utilizes about 20% of the green beans imported

Preliminary processing is the same as for regular coffee The roasted beans, however, are equilibrated to a higher moisture content 7–10%, and ground very coarsely to eliminate fines

Liquid coffee is made by passing water at temperatures up to 300°F through ground beans in a series of extracting towers (as many as eight) with at least one stage of partial hydrolysis under pressure This yields an extract containing about 30% solids From 30 to 35% of the grounds is removed

After filtration the extract is usually spray dried in systems that yield hollow beads of solids But the extract also can be dried in a low temperature vacuum system The moisture content is reduced to less than 3%

The product is hygroscopic and must be held and packaged under conditions of low humidity

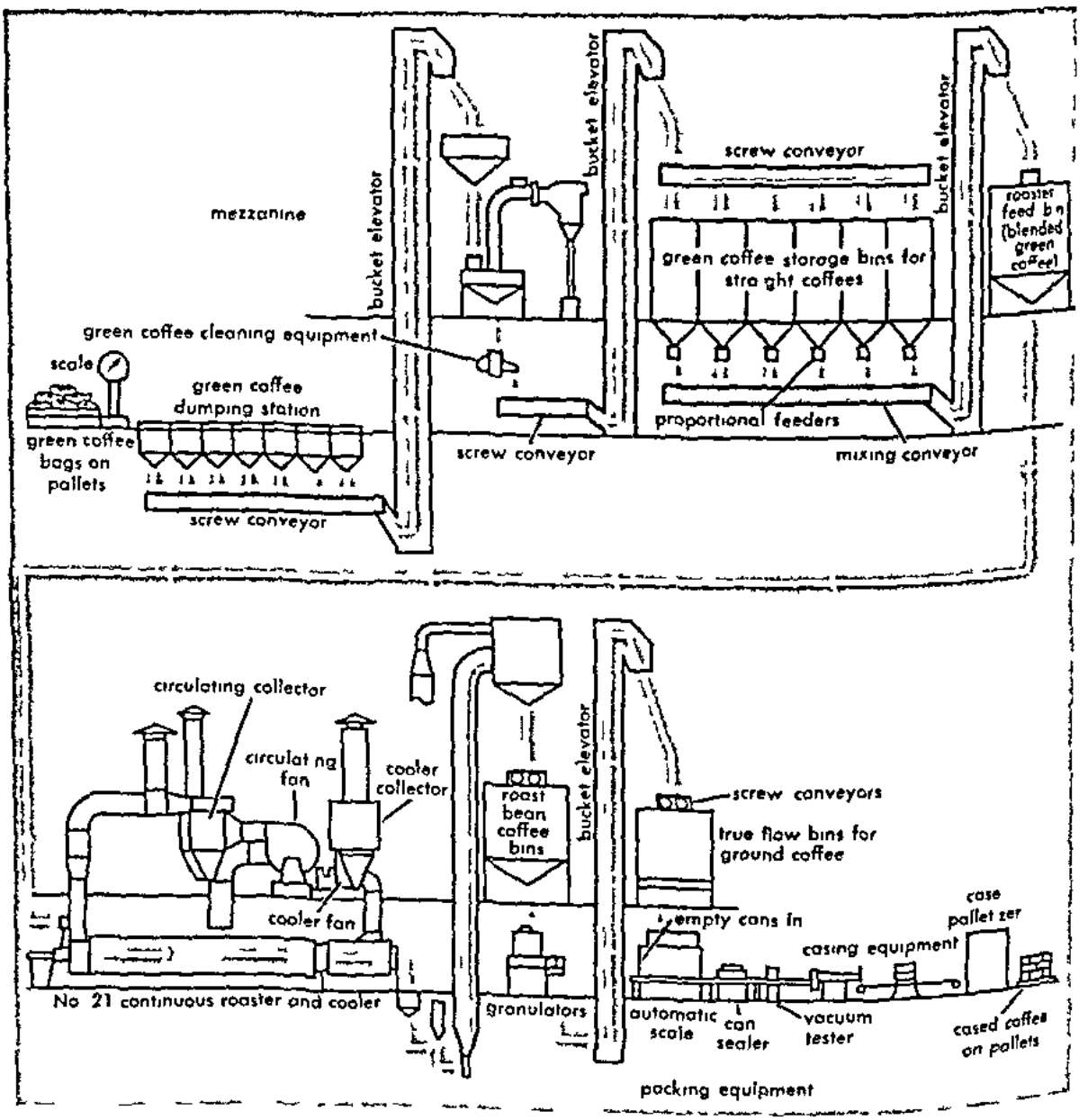


Fig 2 Modern continuous roasting plant (*Jabez Burns and Sons Inc*)

Manufacturers are attempting to return aroma lost during processing and much research is under way

Decaffeinated coffee Decaffeinated coffee, both regular and instant, is prepared from green beans that have been softened by steam, extracted with low boiling chlorinated solvents, then steamed again to remove residual solvent, and dried

[EEL]

Cofferdam

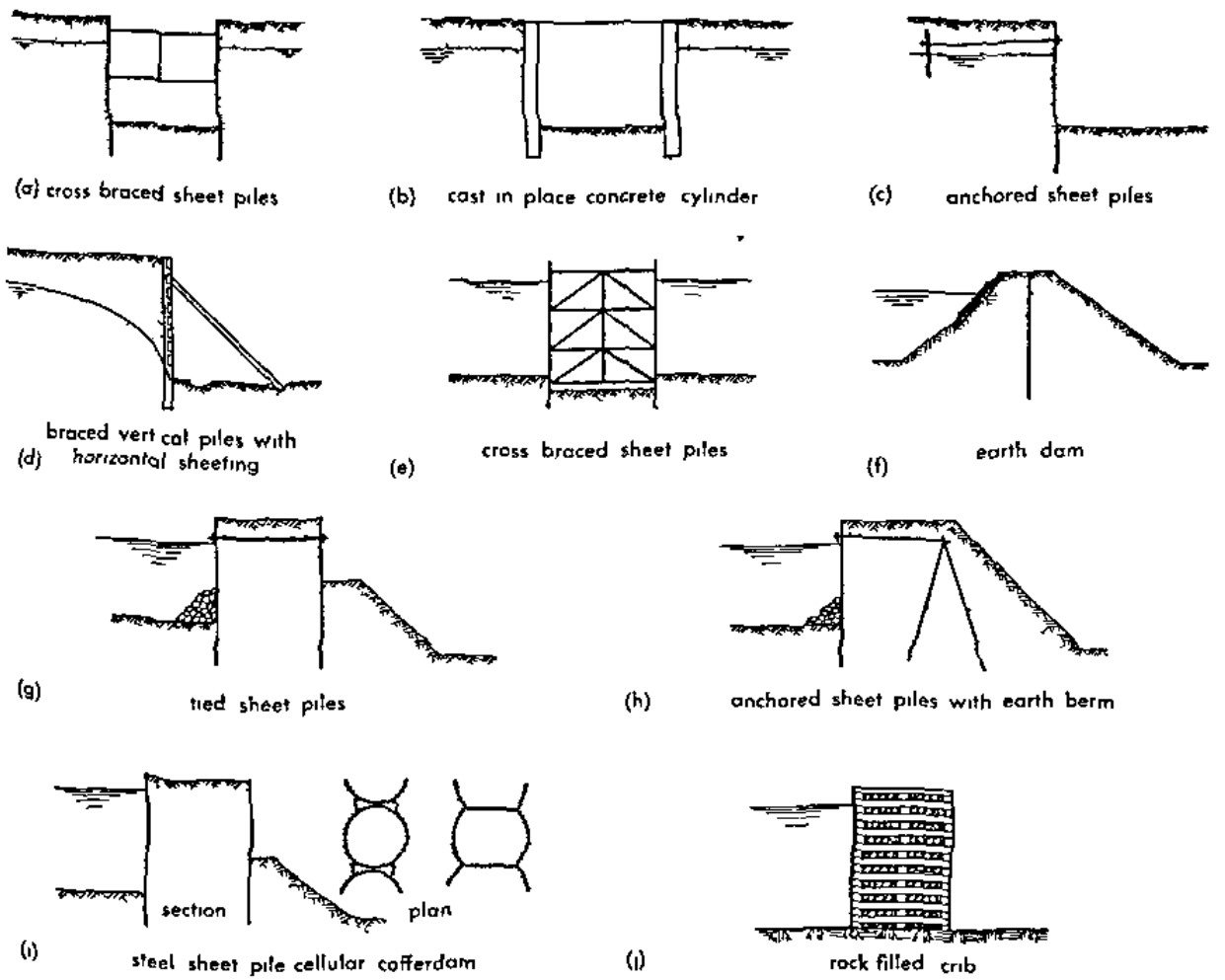
A temporary, wall like structure to permit dewatering an area and construction of foundations, bridge piers, dams, and like structures in the open air Cofferdams are classified according to function and type of construction The type of construction is dependent upon the depth, soil conditions, fluctuations in the water level availability of materials working conditions desired inside the cofferdam and whether the cofferdam is situated on land or in water Cofferdams on land may also be designed to support the sides of an excavation

Where the cofferdam structure can be built on a layer of impervious soil (which prevents the passage of water), the area within the cofferdam can be completely sealed off Where the soils are pervious, the flow of water into the cofferdam cannot be completely stopped and the water must be pumped out periodically and sometimes continuously

Types of cofferdams. *The illustration shows the* types of cofferdam construction. (*a*), (*b*), and (*e*) are used to enclose small areas, such as individual bridge piers or small foundations, where cross bracing to the opposite wall is practical, the other types are for large areas required for dams, river locks, or large buildings, where cross bracing is impractical or undesirable

Sheeted cofferdams are made of sheets of steel, timber, or concrete, driven vertically or placed horizontally The sheeting may be made reasonably watertight by using interlocking, overlapping or grouted joints In gravel or boulders, where sheeting cannot be driven to the required depth, steel piles are driven into the ground and timber sheeting is placed horizontally against the vertical piles (*d*) as the excavation progresses Watertight cofferdams on land are designed to resist the pressure of the earth and the full hydrostatic head of the water When a watertight cofferdam is not required hydrostatic pressures may be reduced by permitting seepage between the sheets

Another type of cofferdam suitable for use in gravel or boulders is constructed of cast in place



Types of cofferdams Types (*a*), (*b*) (*c*) and (*d*) are used on land, the others are used in water

concrete The illustration (*b*) shows this type in a cylindrical form Braced straight walls may be used for large areas

Most sheet pile cofferdams with the exception of the cellular type (*i*) require a soil into which the sheets may be imbedded to give the walls stability The cellular cofferdam consisting of interlocking steel sheet piling driven as a series of interconnecting cells is independently stable when filled and may be constructed on either rock or soil The cells of the circular type may be filled individually The cells of the straight wall diaphragm type must be filled systematically to avoid a differential height of fill that would deform the diaphragms

The filled crib (*j*) is an open boxlike structure of timber precast concrete or fabricated steel sections filled with a suitable material A rock filled crib is suitable for construction on a rock bottom in swiftly flowing waters Sheeting or an impervious core provides the necessary watertightness Earth dams (*f*) can be constructed of soil or rock but if pervious a cutoff is required to control seepage

Use of cofferdams When cofferdams are required for year round construction in waters subject to flooding they are made sufficiently high to exclude the flood waters If overflow is to be permitted then the cofferdam fill and the bottom of the dewatered area must be protected against scour (eroding action of the water) Scour can also be prevented along the stream side of cofferdams in swiftly flowing waters by protecting the stream bed (*g h*) The berm (embankment) shown in the illustration (*g*) and (*i*) on the dewatered side furnishes stability and reduces the flow of water under the cofferdam

One of the deepest large area cofferdams was used at Grand Coulee Dam going down approximately 90 ft in depth The cofferdam shown in the illustration (*b*) has been used to form a mine shaft 220 ft deep Type (*d*) was used extensively in subway construction in New York City

Special applications of interconnecting steel sheet pile cells similar to cellular cofferdams are sometimes employed as groins jetties piers and breakwaters

A nautical application of the term cofferdam is a watertight structure used for making repairs below the waterline of a vessel The name also is applied to void tanks which protect the buoyancy of a vessel [E J Q]

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Cohesion (physics)

The tendency of parts of a body of like composition to hold together Cohesion therefore requires that work must be done to separate or move together parts of a body Cohesion is a characteristic property of matter and arises from intermolecular attractive forces (*see* INTERMOLECULAR FORCES) The existence of cohesion in gases and liquids is evident from the fact that when the molecules are brought sufficiently close together the former can be converted to a liquid and the latter to a solid The nature of the solid state is itself evidence of the existence of attractive forces between molecules The theory of cohesion in solids is discussed later in this article

Cohesion in matter controls many properties The well known Joule-Thomson effect is attributable to the self cooling of gases on streaming from a higher to a lower pressure and the work done in overcoming the attractions Liquefaction of a gas is a result of crowding together of the molecules until the attractive forces become sufficiently high to give a liquid structure Liquids possess surface tension because of the unbalanced inward pull on the molecules of the surface Thermal expansion and compressibility of liquids and solids are controlled by cohesion When thermal expansion takes place it does so by acting against attractive forces Thermal expansion will be small when cohesive force is large Compression must act against repulsive forces Compression will be small when the cohesive force is large because the cohesive force is balanced by an equal repulsive force It is apparent that change of state such as vaporization of a liquid or melting of a solid is indicative that the application of thermal energy has changed the attractive forces holding the parts of the liquid or solid together in the original states

Cohesion in the strict sense implies that the body in question contains like parts If the body contains unlike parts then a boundary or interface between the two dissimilar materials exists In such cases the attractive forces at these boundaries are more properly referred to as adhesive *See* ADHESION MOLECULAR

F London conceived of molecular attraction as due to an instantaneous arrangement of nuclei and electrons with dipole moments London's theory may be viewed as involving temporary existence of small polarized bodies giving a net attraction between molecules The force of this attraction is inversely proportional to the seventh power of the distance between neighbors The concept of cohesion includes the existence of a repulsive force when parts of the body are separated by only a very small distance Thus for a given state the mutual potential energy of the atoms or molecules attains a minimum value and their distance apart is at an equilibrium Work must be done to separate or to move them closer together

Cohesion is often used incorrectly as a term to denote strength of materials Strength of a body is a complicated property dependent on many factors Only when frictional and adhesional factors arising from other sources are eliminated can cohesion be considered as the property determining the strength of a body [D J BC]

Cohesion in solids The cohesive energy in solids may be defined as the difference between the energy per atom of a system of free atoms at rest far apart from each other and the energy per atom of the solid

The forces which are primarily responsible for the cohesion of solids vary between the different solid types In molecular crystals which include solidified gases and many organic compounds the binding of the atoms into molecules is strong but the binding of the molecules to each other is weak Van der Waals forces are primarily responsible In ionic crystals for example NaCl (sodium chloride) the binding is due to the electrostatic attraction between the charged atoms Collapse of an ionic crystal is prevented by a short range repulsion of the ions due fundamentally to the Pauli exclusion principle In covalently bonded materials of which diamond is a good example cohesion results from the sharing of valence electron pairs between neighboring atoms In metals the binding has a more complicated explanation which is quantum mechanical in nature *See* CHEMICAL BINDING IONIC CRYSTALS

The alkali metals are considered in detail here because they are the simplest and most thoroughly studied of all the metals The cohesion results from a redistribution of the valence electrons the distribution of the core electrons in the solid is essentially the same as in the free atom The cohesive energy may be computed as the difference between the average energy of a valence electron in the solid and the electron s energy in a free atom There are two principal contributing factors the boundary correction and the Fermi energy The energy of the lowest state of a valence electron in the solid is lower than in the free atom principally because of a reduction in the kinetic energy The boundary condition on the wave function of this state is that it be flat that is have a vanishing radial derivative on the boundary of the atomic sphere (more precisely a vanishing normal derivative on the surface of the polyhedral atomic cell)

The kinetic energy of the electron in the lowest state in the solid is given by

$$\frac{\hbar^2}{2m}\int_0^{r_s}\left|\frac{dR}{dr}\right|^2 r^2\,dr$$

where R is the radial part of the electron wave function r_s is the sphere radius m is the mass of the electron and $\hbar$ is Planck s constant h divided by 2π The kinetic energy is reduced in comparison to its value in the free atom because $dR/dr = 0$ for $r = r_s$ in the solid but not in the free atom In addition to this effect there is a contribution to the cohesion because of the compression of the valence electron distribution into a region of more negative potential energy The boundary correction amounts to approximately 3 17 ev per atom in sodium for a value of r_s corresponding to the observed lattice spacing

According to the Pauli exclusion principle only one electron of each spin can be in any state Consequently the electrons occupy a Fermi distribution with energies increasing from that of the lowest state The average energy of this distribution the Fermi energy can be compared to the effective mass of the electrons is known except for lithium however no great error will result if the electrons are treated as free The Fermi energy is 2 05 ev per atom in sodium The contribution from the Coulomb interactions of the valence electrons with each other turns out to be small when all effects are included [J C]

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Coil

One or more turns of wire used to introduce inductance into an electric circuit At power line and audio frequencies a coil has a large number of turns of insulated wire wound close together on a form made of insulating material with a closed iron core passing through the center of the coil This is commonly called a choke and is used to pass direct current while offering high opposition to alternating current

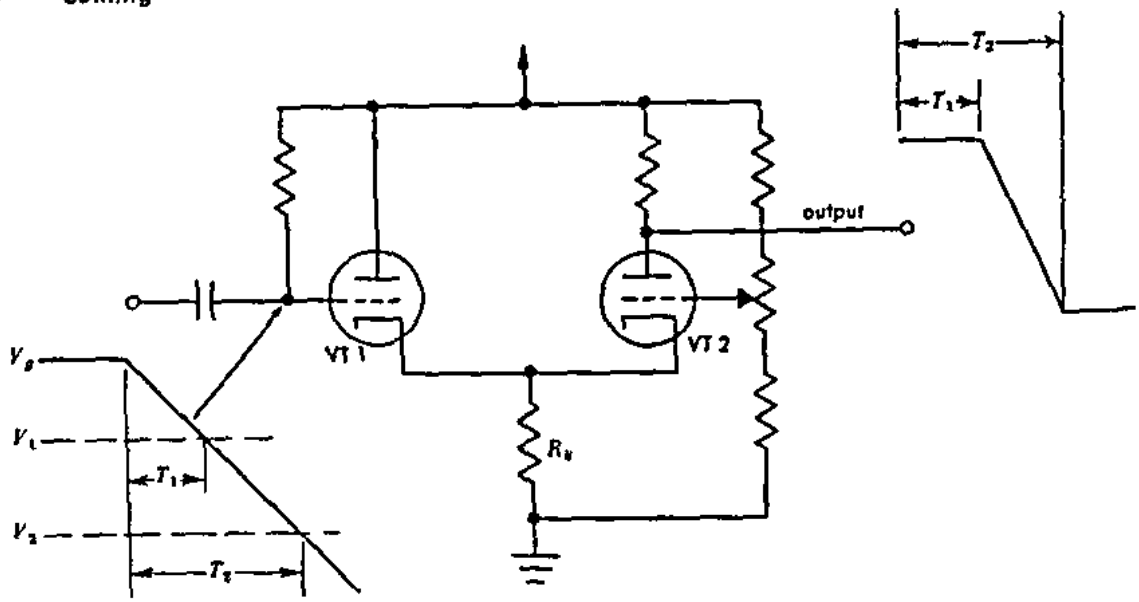
At higher frequencies a coil may have a powdered iron core or no core at all The electrical size of a coil is called inductance and is expressed in henries or millihenries In addition to the resistance of the wire a coil offers an opposition to alternating current called reactance expressed in ohms The reactance of a coil increases with frequency *See* INDUCTOR REACTOR ELECTRIC [J MR]

Coincidence amplifier

An electronic amplifier that functions only when two or more inputs are simultaneously applied Such amplifiers might function on the direct basis of either time selection or voltage selection The control amplifier in a transmission gate (*see* GATE CIRCUIT) is an amplifier that operates on the basis of time selection where a control voltage occupying a specific time interval is used as an enabling waveform to allow the amplifier to operate properly

A linear amplifier used to amplify a section of a waveform either above or below a prescribed voltage limit is a coincidence amplifier that operates on a voltage selection basis Limiting and clipping circuits that combine amplification with the function may be considered as coincidence amplifiers

A simple example of a coincidence amplifier is shown in the illustration The input saw tooth waveform starts from a zero grid cathode voltage on VT 1 with the absolute input voltage V_p The grid cathode voltage of VT 2 is sufficiently negative so that VT 2 is nonconducting In this region VT 1 acts as a cathode follower When the input voltage reaches V_1 level VT 2 starts to conduct and the tubes function as a cathode coupled amplifier When the input level reaches V_2 VT 1 cuts off and the output remains constant Amplification takes place for a time $T_2 - T_1$ corresponding to the



Simple coincidence amplifer

dence circuits with their gains magnified many times by the use of positive feedback are used as elements in linear delay circuits (*see* TIME DELAY CIRCUITS) Where such feedback is used and interest is primarily in a pulse or other indication at the time a desired level is reached rather than reproduction of the input waveform the term comparator is more often applied *See* COMPARATOR CIRCUIT

The term coincidence circuit rather than coincidence amplifier is often applied where a circuit with more than one input causes an output pulse to appear only if input pulses are applied simultaneously to all inputs Such a circuit is referred to as an AND circuit in digital computer terminology Here the interest is only in the existence of an output pulse which does not necessarily reproduce the shape of any of the inputs *See* WAVE SHAPING CIRCUITS [C M C]

Coining

A cold metal working process in a press type die Coining is used to produce embossed parts such as badges and medals and for minting of coins It is also used on portions of a blank or workpiece to form corners indentations or raised sections frequently as part of a progressive die operation The work is subjected to high pressure within the die cavity and thereby forced to flow plastically into the die details The absence of overflow of excess metal from between the dies is characteristic of coining and is responsible for the fine detail achieved However because this action requires highly accurate dies and die pressures which are higher than usual only essential surfaces are coined *See* METAL FORMING [R L F]

Coir

A natural coarse brown fiber obtained from the husk of the coconut It is stiff but elastic Because of its resemblance to horsehair it is used for stuffing upholstered furniture Coir is also suitable for cordage sailcloth and coarse mattings *See* COCONUT FIBER NATURAL [M D F]

Coke

A coherent cellular, carbonaceous residue remaining from the dry (destructive) distillation of a coking coal It contains carbon as its principal constituent together with mineral matter and residual volatile matter The residue obtained from the carbonization of a noncoking coal such as subbituminous coal lignite or anthracite is normally called a char Coke is produced chiefly in chemical-recovery coke ovens but a small amount is also produced in beehive or other types of ovens

Uses and types Coke is used predominantly as a fuel in the blast furnace in which it also serves to support the burden As the fuel it supplies the heat as well as the gases required for the reduction of the iron ore It also finds use in other reduction processes, the foundry cupola and househeating About 91% of the coke made is used in the blast furnace, about 4% in the foundry, about 1% for water gas about 1% for househeating and 3% for other industries such as the manufacture of calcium carbide, nonferrous metals and phosphates About 1700 lb of coke is consumed per ton of pig iron produced in the blast furnace and about 200 lb of coke is required to melt a ton of pig iron in the cupola

Coke is classified not only by the oven in which it is made chemical recovery or beehive but also by the temperature at which it is made High temperature coke used mainly for metallurgical purposes is produced at temperatures of 900–1150°C Medium temperature coke is produced at 750–900°C whereas low temperature coke is made at 500–750°C. The last two cokes are used chiefly for househeating particularly in England The production of these is rather small as compared to high temperature coke and usually requires special

equipment Coke is also classified according to its intended use such as blast furnace coke foundry coke water gas coke and domestic coke

Cokes are produced from a wide variety of coals and their properties vary accordingly The intended use of the coke usually governs the character or properties of the coke made

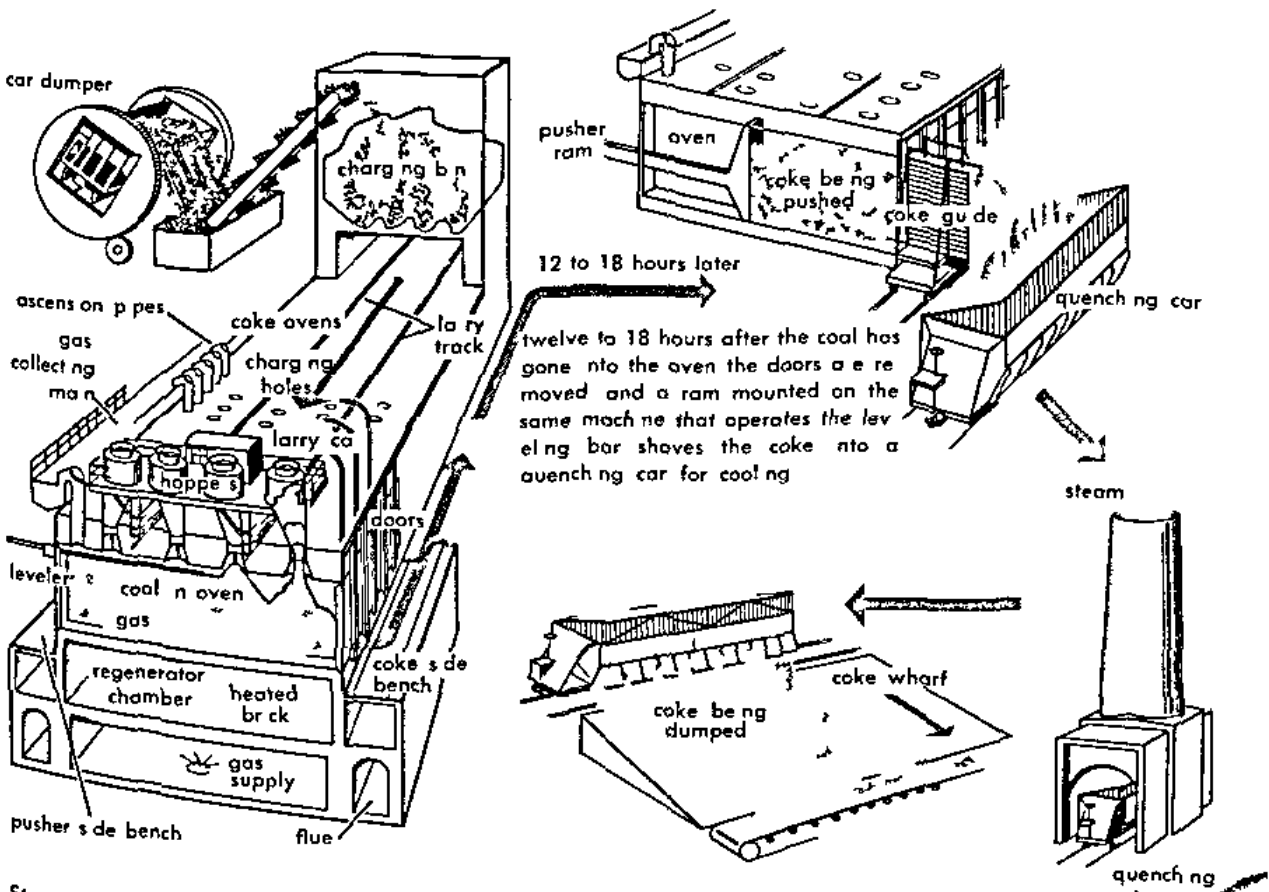
Production The United States has approximately 16 000 chemical recovery ovens distributed among 80 plants capable of producing a total of about 80 000 000 tons of coke per year Beehive oven coke production has fluctuated between 2 000 000 and 8 000 000 tons per year since about 1940 depending principally upon the demands of the blast furnaces

Coke is formed when coal is heated in the absence of air During the heating in the range of 350–500°C, the coal softens and then fuses into a solid mass The coal is partially devolatilized in this temperature range and further heating at temperatures up to 1000–1100°C reduces the volatile matter to about 1% The degree of softening attained during heating determines to a large extent the character of the coke produced

In order to produce coke having desired properties two or more coals are blended before charging into the coke oven Although there are some exceptions high volatile coals of 32 38% volatile matter content are generally blended with low volatile coals of 15–20% volatile matter in blends containing 20–40% low volatile coal In some cases charges consist of blends of high medium and low volatile coal In this way the desirable properties of each of the coals whether it be in impurity content or in its contribution to the character of the coke are utilized The low volatile coal is usually added in order to improve the physical properties of the coke especially its strength and yield In localities where low volatile coals are lacking the high volatile coal or blends of high volatile coals are used without the benefit of the low volatile coal In some cases particularly in the manufacture of foundry coke a small percentage of so called inert coal such as fine anthracite coke fines or petroleum coke is added

In addition to the types of coals blended the carbonizing conditions in the coke oven influence the characteristics of the coke produced Oven temperature is the most important of these and has a significant effect on the size and the strength of the coke In general for a given coal the size and shatter strength of the coke increase with decrease in carbonization temperature This principle is utilized in the manufacture of foundry coke

Properties The important properties of coke that are of concern in metallurgical operations are its chemical composition such as moisture volatile matter ash and sulfur contents and its physical character such as size strength and density For the blast furnace and the foundry cupola coke of low moisture volatile matter ash and sulfur content is desired The moisture and the volatile mat



Steps n the product on of coke from coa

ter contents are a function of manner of oven operation and quenching whereas ash and sulfur contents depend upon the composition of the coal charged Blast furnace coke used in the United States normally contains less than 2% volatile matter 85 90% fixed carbon 7 15% ash and 0 5–1 5% sulfur If the coke is intended for use in the production of Bessemer or acid open hearth iron the phosphorus content becomes important and should be less than 0 01%

The requirements for foundry coke in analysis are somewhat more exacting than for the blast furnace The coke should have more than 90% fixed carbon less than 8 9% ash content and less than 0 75% sulfur

Blast furnace coke should be uniform in size about 2½–5 in but in order to utilize more of the coke produced in the plant the practice has been in addition to charge separately into the furnace the smaller sizes after they were closely screened into sizes such as 2½ × 1¾ in 1¾ × 1 in down to about ¾ in in size

The blast furnace coke should also be uniformly strong so that it will support the column of layers of iron ore coke and stone above it in the furnace without degradation Standard test methods such as the tumbler test and the shatter test have been developed by the American Society for Testing Materials for measuring strength of coke

Foundrymen prefer coke that is large and strong The coke for this purpose ranges in size from 3 to 8 in and larger The maximum size used usually is about one twelfth of the diameter of the cupola High shatter strength is desirable

Other important requirements of foundry coke are high reactivity toward oxygen so that carbon dioxide is produced with high heat evolution and low reactivity toward carbon dioxide so that the amount of carbon monoxide formed is minimized

The requirements for coke intended for house heating vary in different localities Usually the coke is of a narrow size range and the size used depends upon the size and type of appliance In general a high ash softening temperature is desirable (more than 2500°F)

Coke intended for water gas generators should be over 2 in in size and should have an ash content below 10% and a moderately high ash softening temperature *See* CHARCOAL COAL COAL CHEMICALS DESTRUCTIVE DISTILLATION FUEL PYROLYSIS [M P]

Coking (petroleum refining)

A process for thermally converting the heavy residual bottoms of crude oil entirely to lower boiling petroleum products and by product petroleum coke The heavy residual bottoms cannot be catalytically cracked principally because the metals present are

in the United States the demand for heavy fuel oil has remained nearly constant for a number of years while demands for gasoline heating oil and other products have increased substantially To meet this shift in demand refiners have resorted to deeper vacuum flashing visbreaking solvent deasphalting and coking The major products from coking are fuel gas gasoline gas oil and petroleum coke Generally speaking the gasoline is of poor quality and must be further treated before use in modern premium fuels The gas oil is commonly used as catalytic-cracking feed stock

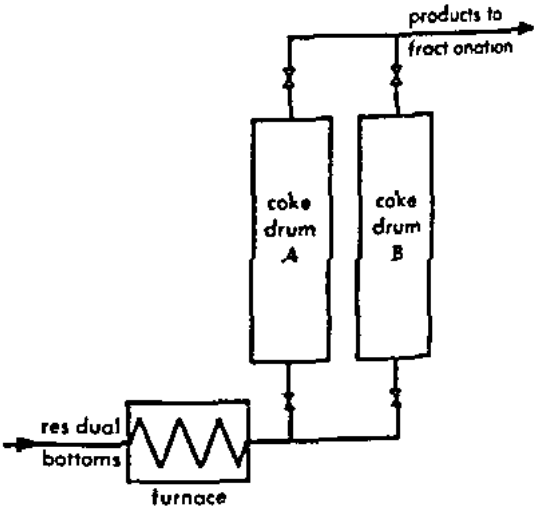


Fig 1 Delayed coking—simplified flow plan

The two coking processes in commercial use are delayed coking and fluid coking In delayed coking (see Fig 1) residual bottoms are heated to temperatures of about 900°F in a conventional furnace The hot oil is charged directly to the bottom of a large coke drum A where the coking reaction takes place Coke is deposited in the drum while the lighter products are removed overhead to fractionation Approximately every 24 hours hot oil is diverted to the second coke drum B and coke is removed from drum A by hydraulic drilling In fluid coking (see Fig 2) residual bottoms are charged

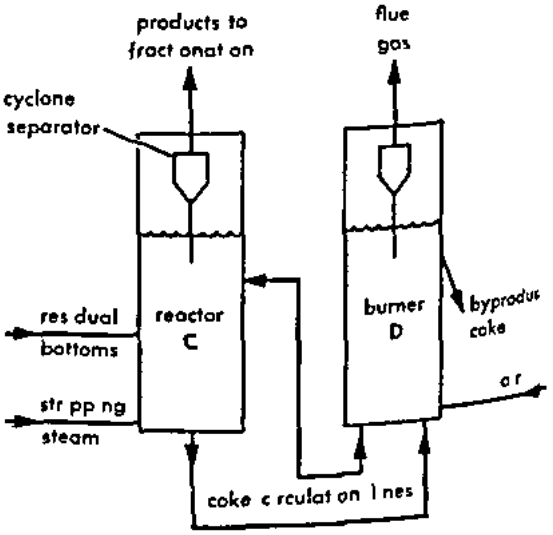


Fig 2 Fluid coking—simplified flow plan

d rectly to the reactor C containing a bed of flu idized coke particles at about 950°F The hot coke particles supply the heat of reaction and also a surface for coke deposition Converted light prod ucts are removed overhead through cyclone sepa rators to fractionation The coke particles are con tinuously circulated between the reactor C and the burner D In the burner D air is used to burn a portion of the coke produced and thereby maintain the system in heat balance Normally more coke is produced in the reactor than is required for heat balance The excess coke is continuously withdrawn from the burner as by product petroleum coke

Petroleum coke is used principally as fuel or after calcining for carbon electrodes The crude from which the coke is produced governs its chemi cal composition (high sulfur crudes yield high sulfur cokes) However all petroleum cokes are characterized by low total ash contents *See* CRACK ING PETROLEUM PROCESSING [J F MO]

Cola

A tree *Cola acuminata* of the sterculia family (Sterculiaceae) and a native of tropical Africa Its fruit is a star shaped foll cle containing eight hard seeds the cola nuts of commerce These nuts are an important masticatory in many parts of tropical Africa They have a caffeine content twice that of coffee and are reputed to increase greatly the user s stamina and endurance The nuts also con tain an essential oil and a glucoside kolanin which is a heart stimulant Cola nuts in combination with

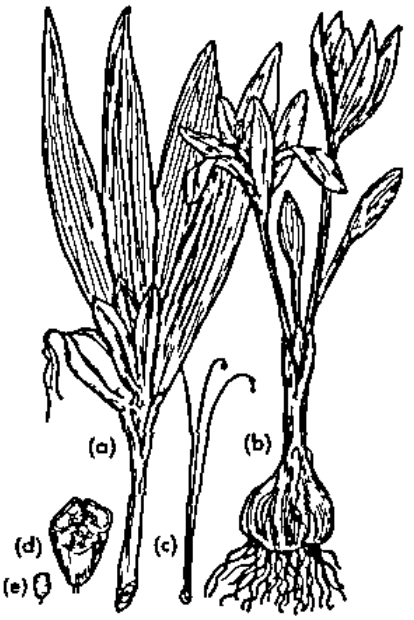


Cola (*Cola acuminata*) (a) Seed (b) Section of fruit showing seed (c) Cluster of fruits (*From P DeJanvlle Atlas de Poche des Plantes Utiles des Pays Chauds Librairie des Sciences Naturelles 1902*)

an extract from coca are used in the manufacture of the beverage coca-cola Cola is now cultivated in West Africa Jamaica Brazil India and other parts of tropical Asia *See* MALVALES [P D S]

Colchicine

An alkaloid contained in the corm (underground stem) of the autumn crocus *Colchicum autumnale* of the lily family (Liliaceae) In medicine the drug is used principally in the treatment of gout



Colchicum autumnale (a) Closed capsule (b) Open capsule (c) Styles (d) Section of capsules (e) Seed (*From J Pereira The Elements of Materia Medica and Therapeutics 3d ed vol 2 Blanchard and Lea 1854*)

Colchicine has a specific influence on the division of plant chromosomes and has been much used by geneticists and plant breeders to bring about dou bling of chromosomes thus producing tetraploid plants Most of the colchicine used comes from Holland Italy Yugoslavia and Hungary *See* LILIA LES [P D S]

Cold, common

A disease caused by a specific virus even though similar symptoms occur in other virus diseases

The causative virus 30–60 millimicrons in diam eter is killed by ether and by lyophilization but is stable to freezing on dry ice In vivo it will grow only in man and chimpanzees in human embryonic lung tissue culture it multiplies without cytopatho genicity Some strains are cytopathogenic in mon key kidney tissue cultures *See* CULTURE TISSUE LYOPHILIZATION

The virus entering via the upper respiratory tract produces typical cold symptoms and histo-pathology of mucous membranes The average in dividual has two to four attacks annually Transi tory natural immunity exists

The disease occurs throughout the world with highest attack rates in winter and spring Members of isolated communities have more severe colds and a higher incidence of infection when a cold is introduced It has been suggested that the virus circulates constantly in most communities usually

producing only abortive disease or a temporary carrier state All ages are equally susceptible but children spread the virus more readily than do adults

Bacterial vaccines antihistamines and attempts at air sterilization have not been successful in preventing colds *See* ANIMAL VIRUS [J L M]

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Cold storage

The storage of perishables at low temperatures usually above freezing by the use of refrigeration to increase the storage life In general the lower the temperature the longer the storage life If temperatures are maintained below the freezing point of the product stored it is called freezer storage Most fruits and many other products however are damaged by freezing and cannot be stored in freezer storage A cold storage plant is a large insulated building with its attendant refrigeration equipment for storage of commodities at low temperatures *See* FOOD PRESERVATION PACKING HOUSE REFRIGERATION [H M HF]

Cold cathode tube

An electron tube that depends upon means other than thermionic emission from a hot cathode for at least the initial source of electrons to start the tube conducting The means employed may be photoemission high field emission or secondary emission Once conduction has been established localized heating of the cathode may produce some thermionic emission Such tubes are commonly gas filled with the exception of a few high voltage rectifier and x ray tubes some amplifier type cold cathode vacuum tubes have been investigated *See* ELECTRON EMISSION

Diodes The simplest cold cathode tube is a diode or two electrode tube It is usually used for voltage regulation Emission from a cold cathode is not great but the current in the tube is increased by filling the tube to a low pressure with neon or some other inert gas Emission at low voltages is aided by placing a point or probe on the cathode This produces an intensification of the electric field which starts the current Emission is also aided by covering the cathode or negative electrode with some material that emits electrons with relative ease Such materials are some of the rare earth elements such as cesium

Because of the presence of gas in the tube the voltage across the tube will be constant with current over a wide current range This is because a

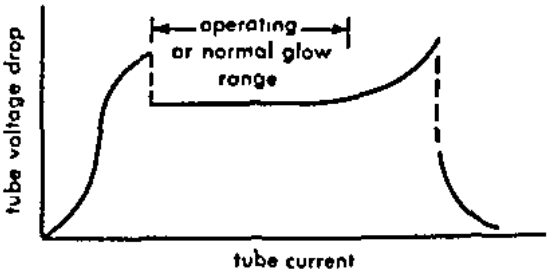


Fig 1 Gas-tube discharge characteristics

all of the gas is ionized at a certain level As a result the voltage current characteristics of such tubes have the form shown in Fig 1 A slightly higher than normal voltage is required to start the current in the tube, however, after the discharge is initiated the voltage remains substantially constant over a wide range of current This is because accumulative ionizations within the tube will maintain the discharge at a lower potential than is needed to start it

Cold cathode, voltage regulator gas discharge tubes can be made with operating voltages constant at levels ranging from 50 to 150 volts The corresponding currents range from several milliamperes (ma) to about 100 ma, though commonly the currents are in the 30- to 50-ma range The voltages necessary to start the current flow will commonly be 20–30% higher than the operating voltages *See* VOLTAGE REGULATOR TUBE

Cold cathode gas triodes. The cold cathode gas triode is a three electrode tube which has found use in telephone-dialing circuits There are three active electrodes a cathode, starting electrode and an ode Any one of these can control the current starting conditions A typical electrode geometry is shown in Fig 2 It is possible to make the anode positive relative to cathode but not enough to start a current flow If however, the starting electrode is made a little positive relative to the cathode a current flow will be started between it and the cathode and the resulting ionization will trigger a current flow from cathode to anode The resulting control characteristic is shown in Fig 3 There are six possible conditions of current flow, the breakdown characteristics of which are indicated by the closed hexagonal figure Ordinarily, only section A of the curve is used

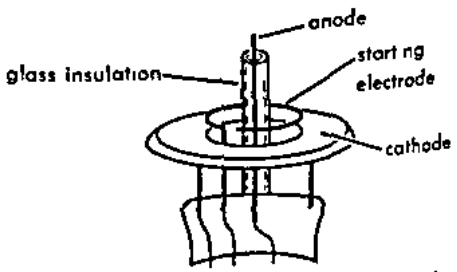
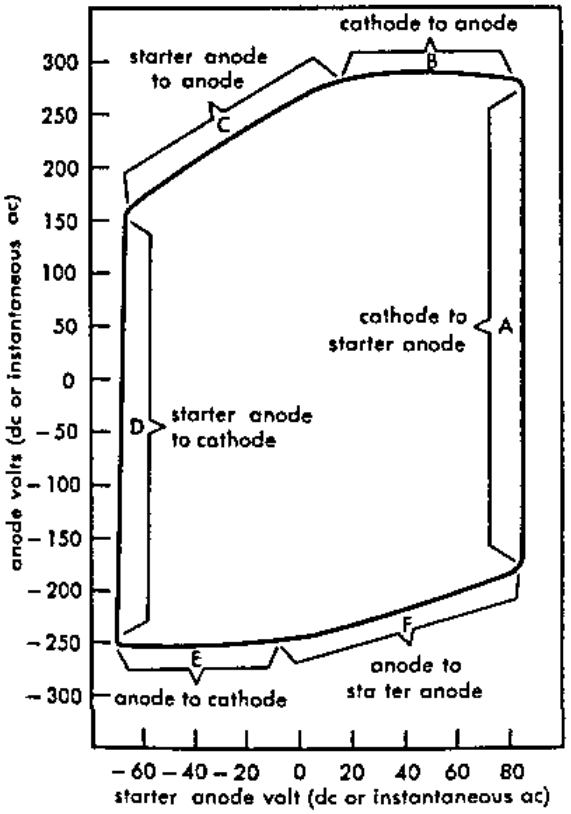


Fig 2 Construction of the cold-cathode triode (*From F E Terman, Radio Engineers' Handbook McGraw Hill, 1943*)

Field emission tubes. It is possible to obtain cold emission from a sharp point in a vacuum when the voltage gradient is large enough to pull electrons out of the metal without heating it This u



Fg 3 Control character st cs of the cold cathode tr ode (*From F E Terman Rad o Eng neers Hand book McGraw H ll 1943*)

ally requires a point with a radius of curvature of the order of a millionth of an inch With such a point it is possible to get electric fields of the or der of millions of volts per inch in the immediate vicinity of the point When this occurs the emis sion will be dependent upon the field in the same fashion that the emission from thermionic cathodes is dependent upon the temperature

Tungsten points are invariably used The tubes must be highly evacuated much more so than or dinary vacuum tubes otherwise the emitting point will become contaminated and not emit satisfac torily Tremendous current densities can be ob tained by this means although the total currents are of the order of fractions of an ampere Field emission has been used in certain high voltage rec tifier tubes and also in certain high voltage x ray tubes *See* ELECTRON TUBE [K R S]

Coleoidea

A subclass of cephalopod mollusks listed in certain taxonomic schemes in contrast to the subclasses Nautiloidea and Ammonoidea This subclass in cludes all living cephalopods except *Nautilus* One extinct order the Belemnoidea and four living or ders Sepioidea Teuthoidea Vampyromorpha and Octopoda comprise the subclass The coleoids were formerly known as the Dibranchiata because they have but two gills The octopods have eight arms or tentacles whereas the remaining groups formerly known as the Decapoda have ten arms The Vam pyromorpha have two retractile filaments which have been interpreted as being arms in addi tion to the eight regular arms *See* AMMONOIDEA BELEMNOIDEA NAUTILOIDEA OCTOPODA SEPIOI DEA TEUTHOIDEA VAMPYROMORPHA [C B C]

Coleoptera

The largest order of the animal kingdom with over 250 000 described species Members of this order are commonly called beetles but one large group the Curculionidae and allied families are called weevils This name frequently appears in the Bible in reference to small insects particularly grain pests Coleoptera comprise about one fourth of all described animals They are defined as holometabo lous insects (having complete metamorphosis) the adults usually have two pairs of wings The an terior pair the elytra are either hard and horny or leathery This pair is of little use in flight and meets in a straight line down the back when at rest The hind wings are membranous with a system of veins Definite folding patterns allow them to be concealed beneath the elytra when not in use

The mouthparts with transversely movable mandibles are fitted for biting Coleoptera not having these features are the members of the sub family Nemognathinae (Meloidae) which have greatly elongated maxillae that form a poorly fitted tube presumably used for sucking nectar In one extremely rare species belonging to the family Lathridiidae (and sometimes considered as the separate family Aculognathidae) there are well developed sucking mouthparts

The beetle body is usually hard and either smooth or sculptured It is usually covered with fine hair and rarely covered with scales In a few cases adult females may be larviform Some adult males may have the elytra reduced to very small leathery flaps in which case the hind wings are large and fan shaped as in the Stylopidae some times considered as a separate order Strepsiptera The larvae are heterogenous combining the char acteristics of the larvae of the order Neuroptera some Hymenoptera and some Lepidoptera and are therefore undefinable in brief terms The pupae are incomplete in that they have free appendages and do not form a puparium The eggs of most species are indistinguishable from those of other insects

CLASSIFICATION

The order is divided into suborders superfami lies and families as listed phylogenetically in Ta ble 1 There is no general agreement among au thors as to the details of this classification but the essential features are included

ANATOMY

External anatomy The general features of in sects are also found in the Coleoptera There are six legs in the adult stage and the body is divided into three parts head thorax and abdomen The meso- and metathorax are obscured above by

Table 1 Families of Coleoptera

Classification	Common name	Distribution	No of species*
Suborder Archestemata			
Cupedidae	Reticulated beetles	General but discontinuous	19
Micromalthidae	Telephone-pole beetle	North America and by commerce	1
Suborder Adephaga			
Rhysodidae	Wrinkled bark beetles	General but discontinuous	125
Cicindelidae	Tiger beetles	World wide	1,300
Carabidae	Ground beetles	World wide	19 000
Omophronidae	Savage beetles	General but discontinuous	61
Paussidae	Flat horned beetles	Old and New World tropics	300
Amphizoidae	Trout-stream beetles	North America on Pacific Coast and Tibet	5
Haliplidae	Crawling water beetles	General but discontinuous	103
Hygrobiidae	Squeaker beetles	Australia China Europe	4
Dytiscidae	Predaceous diving beetles	World wide	2 100
Gyrinidae	Whirligig beetles	World wide	423
Suborder Haplogastra			
Superfamily Hydrophiloidea (=Palpicornia)			
Staphylinidae	Rove beetles	World wide	20 000
Pselaphidae	Ant loving beetles	World wide	3 300
Silphidae	Carrion beetles	World wide few in tropics	575
Leptodiridae	Small carrion beetles	World wide	450
Leptinidae	Mammal nest beetles	Europe and North America	7
Platypsyllidae	Beaver parasite beetle	Europe and North America	1
Clambidae	Minute beetles	General but discontinuous	40
Leiodidae (=Anisotomidae)	Round carrion beetles	World wide few in tropics	400
Sphaeritidae (=Microsporidae)	Minute bog beetles	Southern Europe and Southern North America	6
Platypsyllidae	Nipponese beetle	Japan	1
Ptiliidae (=Trichopterygidae)	Feather winged beetles	World wide	300
Limulodidae	Horseshoe crab beetles	New World Africa Australia	20
Scymaenidae	Antlike stone beetles	World wide	1,200
Scaphidiidae	Shining fungus beetles	World wide	250
Catapochrotidae	No common name	Araxestal	1
Brathinidae	Grass root beetles	North America	2
Superfamily Histeroidea			
Histeridae	Clown beetles	World wide	2 500
Syntelidae	Sap-flow beetles	Japan East Indies Mexico	4
Sphaeritidae	False clown beetles	North America Europe Central Asia	2
Superfamily Scarabaeoidea (Lamellicornia)			
Lucanidae	Stag beetles	World wide	800
Passalidae	Peg beetles	World tropics with few exceptions	500
Scarabaeidae	Lamellicorn beetles	World wide	12 500
Suborder Polyphaga			
Superfamily Tenebrionoidea (Heteromera)			
Nilionidae	False ladybird beetles	South America	22
Tenebrionidae	Darkling beetles	World wide	11 000
Lagriidae	Long jointed bark beetles	General but discontinuous	575
Allecullidae	Comb-claw beetles	General but mostly tropics	1 100
Monommidae	No common name	Tropics	100
Othniidae	False tiger beetles	North and South America East Asia Malaya	16
Salpingidae (Pythidae Aegialitidae)	Narrow waisted bark beetles	World wide	275
Tetrotharcidae	No common name	Queensland	1

*These figures represent the number of species known to be described at the time of the latest catalog for each family some of these catalogs were published as long ago as 1910 Therefore the total number of described species is actually much greater and is conservatively estimated at 300 000

Table 1 Families of Coleoptera (Cont.)

Classification	Common name	Distribution	No. of species*
Pyrochroidae	Fire-colored beetles	General in Northern Hemisphere	120
Trictenotomidae	No common name	India and Malaysia	12
Melandryidae (Serropalpidae Scraptiidae)	False darkling beetles	World wide	510
Cephaloidae	False longhorn beetles	North America East Siberia and Japan	8
Oedemeridae	False blister beetles	World wide	1 200
Pedilidae	False ant loving flower beetles	World wide	225
Anthicidae	Antlike flower beetles	World wide	1 550
Euglenidae	Antlike leaf beetles	World wide mostly tropical	700
Petriidae	No common name	Transcaspia	3
Cossyphodidae	Lively ant guest beetles	Africa and Oriental regions	11
Superfamily Lymexylonoidea			
Lymexylonidae	Ship-timber beetles	General but discontinuous	40
Telegeusidae	Long lipped beetles	Western United States	3
Superfamily Lampyroidea (Malacodermata)			
Karumiidae	Termitelike beetles	Persia Argentina Costa Rica	5
Brachypsectridae	No common name	Texas	1
Drilidae	Female firefly beetles	Old World mostly tropical	90
Phengodidae	Fire beetles	New World	50
Cantharidae	Soldier beetles	World wide	3 500
Lycidae	Large-winged beetles	World wide	2 850
Lampyridae	Firefly beetles	World wide	1 200
Superfamily Meloidea including Strepsiptera			
Meloidae	Blister beetles	World wide	2 000
Mordellidae	Tumbling flower beetles	World wide	740
Rhipiphoridae	Wedge-shaped beetles	World wide	250
Stylopidae (Strepsiptera)	Parasitic beetles	World wide	300
Superfamily Elateroidea (Sternoxia)			
Rhipiceridae (Sandalidae)	Cedar beetles	World wide	175
Cebrionidae	Robust click beetles	World wide	250
Elateridae	Click beetles	World wide	7 000
Throscidae	False metallic wood boring beetles	World wide	195
Cerophytidae	No common name	Europe United States Central America and northern South America	5
Perothopidae	No common name	United States	3
Eucnemidae (Melasidae)	False click beetles	World wide	1 075
Superfamily Buprestoidea			
Buprestidae	Metallic wood boring beetles	World wide	11 500
Superfamily Cleroidea			
Ostomidae (Temnochilidae)	Bark gnawing beetles	World wide	550
Cleridae	Checkered beetles	World wide	2 300
Melyridae (Dasytidae Malachiidae)	Soft winged flower beetles	World wide	4 000
Superfamily Dermestoidea			
Derodontidae	Tooth neck fungus beetles	North America Europe Asia	10
Nosodendridae	Wounded tree beetles	Old World	30
Dermestidae	Skin beetles	World wide	550
Thorictidae	Ant blood beetles	Europe Asia Africa	80
Superfamily Bostrichoidea			
Anobiidae	Death watch beetles	World wide	950
Ptinidae (Gnostidae Ectrephidae)	Spider beetles	World wide	450
Bostrichidae	Powder post beetles	World wide	460
Lyctidae	False powder post beetles	World wide	65

Table 1 Families of Coleoptera (Cont.)

Classification	Common name	Distribution	No. of species*
Superfamily Cucujoidea (Clavicornia)			
Nitidulidae	Sap-feeding beetles	World wide	2 190
Rhizophagidae (Monotomidae)	Root-eating beetles	World wide	10
Protocucujidae	No common name	Chile and Australia	2
Sphindidae (Aspidiphoridae)	Dry fungus beetles	Northern tropics	25
Hypocoprida e	No common name	North America and Europe	5
Cucujidae (Hemipeplidae Silvanidae)	Flat bark beetles	World wide	1 000
Helotidae	*Metallic sap beetles*	*Old World tropics*	80
Phycosecidae	No common name	New Zealand Australia and Egypt	5
Propalticidae	No common name	Old World tropics	12
Cryptophagidae	Silken fungus beetles	World wide	760
Biphyllidae	False skin beetles	World tropics	200
Byturidae	Raspberry fruitworms		
Languriidae	*Lizard beetles*	World wide	400
Phalacridae	Shining flower beetles	World wide	510
Cisidae	Minute tree-fungus beetles	World wide	240
Orthoperidae (Corylophidae)	Minute fungus beetles	World wide	290
Discolomidae	Tropical log beetles	Tropics only	30
Latheridiidae (Aculognathidae)	Minute brown scavenger beetles	World wide	500
Colydiidae (Adimeridae Monoedidae)	Cylindrical bark beetles	World wide	1 380
Mycetophagidae	Hairy fungus beetles	World wide	190
Jacobsoniidae (Sarothridae)	False snout beetles	Sumatra Seychelles	2
Superfamily Dascilloidea (Fossipedes)			
Dascillidae	Soft bodied plant beetles	World wide	210
Helodidae	Marsh beetles	World wide	325
Eucinetidae	Plate-thigh beetles	General but discontinuous	25
Superfamily Byrrhoidea			
Byrrhidae	Pill beetles	*World wide*	180
Superfamily Dryopoidea			
Psephenidae	Water penny beetles	General but discontinuous	25
Ptilodactylidae	*Toed winged beetles*	General but discontinuous	175
Chelonariidae	No common name	General but discontinuous	45
Heteroceridae	Variegated mud loving beetles	World wide	135
Limnichidae	*Minute false water beetles*	World wide	70
Dryopidae (Parnidae)	Long toed water beetles	World wide	180
Elmidae	Drive beetles	World wide	270
Georyssidae	Minute mud loving beetles	General but discontinuous	20
Cyathoceridae	*Horn s beetle*	Central America	1
Superfamily Coccinelloidea			
Endomychidae	Handsome fungus beetles	World wide	620
Mycetaeidae	Minute fungus beetles	World wide except Australia	35
Coccinellidae	Ladybird beetles	World wide	3 800
Erotylidae	Pleasing fungus beetles	*World wide*	1 500
Superfamily Curculionoidea			
Cerambycidae	Longhorn beetles	World wide	15 000
Chrysomelidae	Leaf beetles	*World wide*	23 000
Mylabridae	Pea and bean weevils	World wide	900
Anthribidae	Fungus weevils	World wide	2 300
Brentidae	Straight snouted weevils	World wide	1 300
Curculionidae	True weevils or snout beetles	World wide	40 000
Platypodidae	*Ambrosia beetles*	*World wide*	350
Scolytidae (Ipidae)	Bark beetles	World wide	1 100

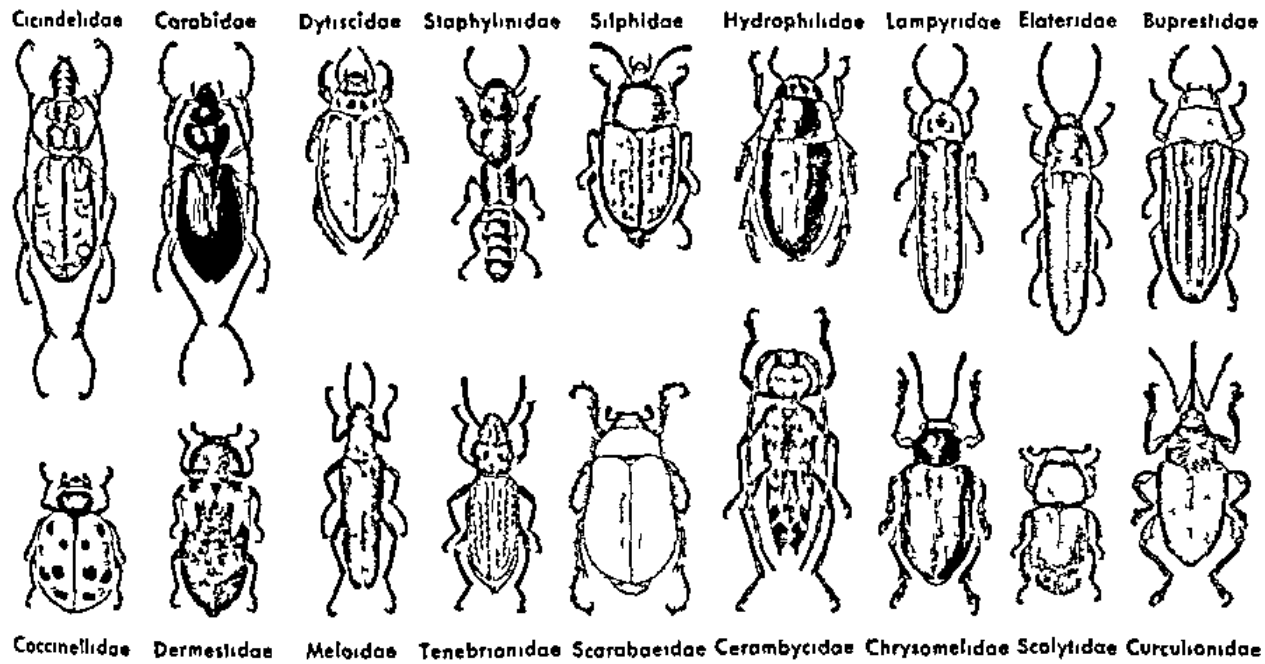


Fig 1 Representative Coleoptera (*T I Storer and R L Usinger, General Zoology, 3d ed , McGraw-Hill 1957*)

tra, leaving the pronotum as the prominent dorsal feature of the thorax

The head This structure varies greatly in form It is always sunken into the prothorax which covers it to varying degrees, and to which it is joined by a membrane The hind portion of the head is usually slightly narrowed However, in some species the part behind the eyes is sharply narrowed thus forming a neck In others it becomes gradually narrowed and much elongated In one large group the head is elongated in front of the eyes This group includes the weevils or snout beetles, and a few representatives of many other families In most species there are two grooves, or sutures, on the under surface of the head These are the gular sutures, the area between them is the gula The top of the head, termed the front, is composed of several fused sclerites (A sclerite is any piece of the external body of an insect surrounded by sutures) The clypeus, bearing the upper lip or labrum is attached beneath the front The head usually bears two comparatively large compound eyes and, rarely, three small ocelli, one pair of antennae, and the mouthparts In a few species of the Gyrinidae and the Cerambycidae, the compound eyes are each divided thus forming four instead of the usual two The mouthparts include the labrum mandibles, maxillae, and labium The latter two parts bear appendages called palpi, which have three to five segments or, rarely, are reduced to one or two segments The form of the antennae varies greatly from group to group

The thorax This is the middle portion of the body, divided into three segments, each bearing appendages The prothorax bears the prothoracic legs the mesothorax the elytra and the mesothoracic legs, and the metathorax the flying wings and the metathoracic legs The prothorax is often freely movable but it may be firmly united to the mesothorax The thorax is composed of definite sclerites the shape and position of which vary from group to group Because these parts are homologous they are useful in the classification of genera and higher categories Particularly useful in classification is the position of the coxal cavities into which the legs are inserted When the coxal cavities are enclosed behind, by either the junction of the prosternum and the epimeron, or by the meeting of the epimera they are referred to as "anterior coxal cavities closed behind" When there is no sclerite behind the coxal cavities, they open directly on the next thoracic segment and are referred to as "anterior coxal cavities open behind" These two conditions, which serve to distinguish families subfamilies, and tribes, appear independently throughout the order

Wings The anterior wings of Coleoptera, the elytra are greatly modified in various groups of the order Usually they are hard or horny They are held side by side over the abdomen The hind edges generally join to form a median dorsal line along the abdomen The line of junction, formed when the elytra are in repose, is termed the suture When the wings are in flying position, the leading edge is called the lateral margin The portion of the elytra along the leading edge which is bent down or inflexed, is called the epipleural fold The elytra often lock together at the base by means of an intricate mechanism which can be opened when the elytra are raised and then spread apart They usually cover most of the abdomen often extending beyond the apex In one large group in particular, the Staphylinidae, as well as in many other widely separated groups the elytra are shortened thus

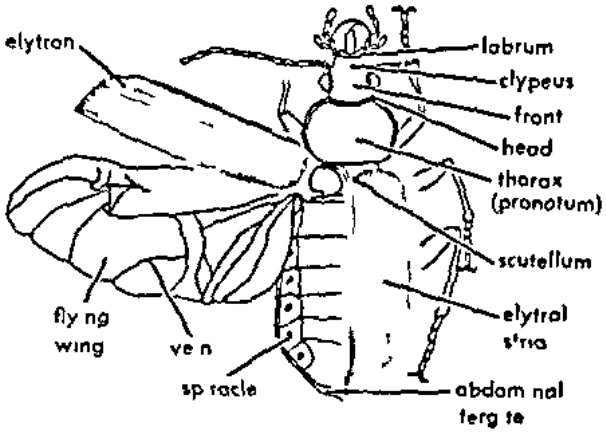


Fig 2 Carabidae dorsal view (Diagrammatic)

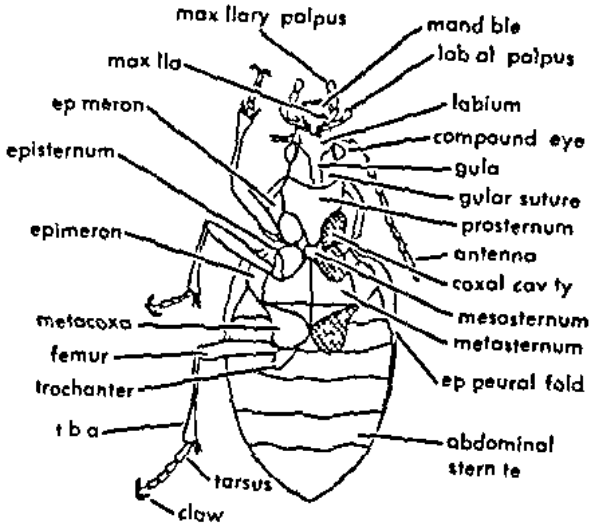


Fig 3 Carabidae ventral view (Diagrammatic)

exposing several of the abdominal segments Between the elytra and immediately behind the prothorax there is a small triangular shaped structure the scutellum

The posterior wings or flying wings are membranous Veins cross their surface and serve as supporting structures These wings are carefully folded under the elytra when not in use Both the arrangement of the veins and the folding patterns of the wings are extremely important characteristics These provide clues to the interrelationships of the various groups because both the veins and the folding patterns are homologous conditions Sometimes the flying wings are greatly reduced or lacking The elytra in such cases are usually fused along the suture permanently covering the dorsal abdomen

Legs The basic structure of legs is the same throughout the entire class of insects including the beetles The legs consist of five parts the coxa trochanter femora tibia and tarsus In beetles the coxae vary considerably in shape being round oval elongate conical or rarely cylindrical The number of tarsal segments varies throughout the order but is always constant for a particular genus or higher group The tarsal formulas are useful in classification and are written to indicate the number of tarsal segments for one of each pair of thoracic legs as 5 5 5 5 5-4 4-4 4 and so f Therefore the formula 5 5-5 indicates that t are 5 tarsal segments in each of the pro- m and metathoracic legs The shape of the tarsal ments claws and legs also varies from group group

Abdomen The abdominal sternum is a more less heavily sclerotized series of plates It is most visible portion of the abdomen since the gum is usually hidden by the wings and elytra basic number of abdominal segments is nine E segment has a pair of spiracles the first pair larger than the second to eighth while the ninth usually very obscure or absent The most frequ number of visible abdominal sternites is five T is a reduction of the basic number of nine ments They have been modified as follows first is absent or fused with the metasternum of thorax the second and third are usually fused appear as one (the first visible segment) ments 4 5 and 6 are therefore visible segments 3 and 4 segment 7 is visible segment 5 the eigh is usually visible but is partly or entirely dra into the seventh, the ninth is greatly modified a part of the genitalia or is absent Often both eighth and ninth segments are modified in vari ways and function as a part of the copulatory gans

Genitalia The genitalia appear as appendag near the posterior or caudal end of the body Th are situated between the ninth and tenth sternite Those of the male consist of two parts the media lobe or penis, and the tegmen composed of basal piece and one pair of parameres or later lobes and rarely the tegmenite The parts of the male genitalia are the paraprocts proctiger sub fer coxite and stylt The genitalia project fr the membrane which connects the ninth sterni below the anus and the tenth sternite The tent sternite is rarely visible as a sclerotized stru tur In many groups the form of the male genital s extremely useful for separating species and highe categories The female genitalia have been studied at the family level but are rarely used for the separation of species

Internal anatomy and physiology The alimentary tract is complete and varies in length depending upon the food habits and preferences of the adult Three primary divisions are present the stomodeum the mesenteron or stomach and the proctodeum or intestine The stomodeum which typical consists of a pharynx that leads from the mouth cavity and opens into an esophagus which may be extended into a crop This is followed by a proventriculus equipped with heavily sclerotized grinders or teeth on the wall The mesenteron often called the ventriculus shows considerable variation The caecae are attached as outer pockets to this portion of the alimentary canal A large part of the mesenteron is sometimes covered with small papilliform or elongate pockets In most

cases these structures are the crypts of epithelial regenerative cells rather than true caecae The proctodeum is the posterior ectodermal part of the alimentary canal The anterior end of this structure is approximately marked by the bases of the Malpighian tubules or excretory organs which are diverticula of the proctodeal walls The proctodeum terminates in a rectum which is usually differentiated and sometimes has papillae

Digestion All segments of the alimentary tract show peristaltic or churning movements which serve to mix the contents and carry them along to the other sections There is a great variety of digestive structures and processes in the order and a wide variety of food is used The digestive enzymes which hydrolyze the food into products capable of absorption are secreted partly by the salivary glands and partly by the glands of the midintestine All segments in spite of the cuticular lining of the fore and hindgut take part in absorption to a varying degree The stomodeum takes in food and stores it in the crop In some species of the Carabidae and in similar forms the principal seat of digestion is the crop The grinding teeth of the proventriculus of many forms serve to break the food into finer particles and thus function as a gizzard The mesenteron is the only portion of the alimentary tract lacking a cuticle It is lined however by a delicate sheath called the peritrophic membrane

The proctodeum is lined by a cuticle which is thinner and more readily permeable to water than that of the stomodeum The anterior end of the proctodeum is closed by a pyloric sphincter The Malphigian tubules are located at the anterior end of this section sometimes in front of but usually just behind the sphincter The main function of the proctodeum is water absorption while that of the Malphigian tubules is excretion The hind part of the proctodeum serves as a rectum in which the dry feces are stored and passed at more or less regular intervals Those beetles that feed on wood have bacteria and in some cases fungi living in a symbiotic relationship in the gut and aiding in the digestion of wood

Respiration Respiration in beetles as in other insects is accomplished by the diffusion of gases through the tracheal system This is controlled by the spiracles the external openings of the tracheal tubes which may be opened and closed for both gas regulation and water conservation In the presence of some noxious gas the beetles may close their spiracles and keep them closed for many hours preventing the gas from harming the internal tissues In very active species such as strong flyers air sacs are part of the tracheal system These not only allow more air into the body but also act as air reservoirs during adverse conditions Aquatic beetles have several accessory structures to aid their respiration while underwater Before submerging they use fine silky hairs on the antennae and legs to trap air in pockets located under the elytra The action of the spiracles is controlled by the amount of lactic acid in the blood When the oxygen level is decreased lactic acid increases affecting the nervous centers which in turn cause the spiracles to open The nervous centers which control both the action of the spiracles and the pumping or ventilating action of the abdomen are located in the abdominal ganglia The abdomen even when removed from the beetle will still respond to oxygen deficiency The respiratory system is not entirely independent of the circulatory system The support of the blood is still necessary in supplying oxygen to every cell despite the distribution of fine tracheoles or airways The hemolymph (circulatory fluid) may contain pigments that take up oxygen carry it to oxygen deficient cells and then exchange this gas for carbon dioxide The hemocytes (blood cells) themselves do not carry oxygen

Light producing organs which are closely connected to the physiology of the respiratory system are known in three families of beetles the Lampyridae Elateridae and Phengodidae Almost all the species of the Lampyridae have light producing organs on the ventral surface of the abdomen in the imago or adult some of the larvae also have them Only the tropical genus *Pyrophorus* of the Elateridae have such organs These are located both on the posterior corners of the pronotum and on the median ventral region of the first visible abdominal sternite The larvae and larviform females of *Phengodes* (Phengodidae) have a row of light organs along the sides of the abdomen *Phrixothrix* (a genus similar to *Phengodes*) has in addition a red light on its head *See* BIOLUMINESCENCE

Circulation The primary function of the circulatory system is to carry nutritive materials to the organs and tissues of the body Its respiratory function is comparatively insignificant Like that of other arthropods it is an open type of system so called because the blood is not entirely contained in vessels but flows into open spaces the sinuses or lacunae The blood or hemoplasma is composed of hemolymph and free floating cells the hemocytes It contains either in the hemolymph or in the hemocytes a pigment which is usually yellow in color but may be greenish or reddish

The blood moves forward from the heart to discharge from the dorsal vessel into an open hemo



Fig 4 A fire beetle *Pyrophorus pellucens* Eschscholtz one of the remarkable luminous Elateridae of tropical America It is brown with yellow prothoracic luminous spots (E O Essig College Entomology Macmillan 1942)

coele in the region of the brain This insures an adequate nutrient supply for the central region of the nervous system The release of blood in this area builds up the blood pressure in the anterior end of the beetle This increased pressure in turn causes the backward flow of blood The heart beats in a regular wave of contraction producing a definite pulse rate Various factors such as temperature change respiratory movements and stage of development of the beetle all affect this rate Therefore there is no 'normal' pulse for all conditions The rhythmic contractions of the heart are controlled by the muscles themselves without extrinsic nerve control The heart will beat normally for a time even when entirely removed from the body There is however a double innervation through nerve fibers running along the side of the heart which insures the coordination of the beats Reversal of the heart beat has been observed many times in beetles and other insects and appears to be quite normal although the exact cause is unknown Warming the anterior end of the insects or blocking the ostia will bring about this effect

The blood itself is usually slightly acid but varies from a pH of 6 2 to 7 2 Beetles have the ability to regulate their osmotic pressure probably through the release of amino acids This makes them adaptable to a variety of media The blood of various beetles clots in 5–10 min clotting is particularly rapid in vesicant species whose blood may contain cantharidin It is also rapid in other species which are subject to reflex bleeding Particularly in those species which exhibit catalepsy when disturbed the femoratibial articulation undergoes excessive contraction that causes drops of blood to ooze out at the knees

Nervous system The nervous system of the Coleoptera consists of a series of ventral ganglia which tend to concentrate anteriorly and which are connected by nerve trunks The subesophageal and thoracic ganglia even though near one another usually remain distinct The abdominal ganglia on the contrary vary greatly with no metameric relationship to the abdominal segments Eight ganglia is the maximum number they may unite into one or more ganglia or may even fuse with the thoracic ganglia

Sense organs At least six distinct groups of sense organs occur hair organs sense pores sensilla campaniformia sensilla placodea eyes and rod bearing sense organs or sensilla scolopophora This classification is based on structure rather than function, because it is very difficult to determine the particular function of each type of these organs The antennae combine several of the above sense organs and have a multiple function Compared to that of mammals the vision of beetles is poor but compared to other insect groups many of the Coleoptera have good eyesight There is apparently a correlation between visual acuity and the number of retinal elements or facets at least as far as resolving power is concerned It has been shown that the degree of resolution of the eye of *Lampyris* with about 2500 facets is approximately 1 60 or 1/80 that of the normal human eye Tactile organs are abundant, as described above So far as is known the equilibrium of beetles is dependent upon the pressure or weight of the body upon the legs Beetles of various groups produce sound in at least three different ways It is therefore safe to assume that they also hear or at least respond to sonic vibrations Taste sensations have been demonstrated in *Dytiscus*, and they are able to recognize the same four basic tastes known to man bitter sweet sour, and salt Smell or chemical perception is usually confined to the antennae

Reproduction All beetles are bisexual that is, the sexes are separate The internal reproductive organs of the male consist of three parts a pair of testes a pair of lateral ducts termed the deferent canals whose extremities may be dilated to form a seminal vesicle and an ejaculatory canal The testes are rarely enveloped in a common membrane but are usually either simple tubes or bunched follicles In the female the ovaries are formed of a highly variable number of ovarioles disposed unilaterally in a cluster The ovarioles are polytrophic in most groups A polytrophic egg tube is one in which groups of nurse cells accompany the egg cells The two lateral oviducts unite in a common canal the oviductus communis which terminates in the vagina Ordinarily a copulatory bursa is present formed as a diverticulum of the vaginal wall A seminal receptacle, accompanied by an accessory gland usually communicates with the oviductus communis by means of a narrow canal In species with a copulatory bursa a canal leads the spermatozoa directly from the seminal receptacles to the oviductus communis so that fecundation of the eggs may occur at the time of laying Both sexes are not always present however and in a few groups parthenogenesis occurs and males are unknown

In many beetles a courtship pattern is evident. This includes dances and fights among the males particularly among those species with horned males During such fights the female stands aside and moves the antennae, an action indicating that a secretion of odors may be involved Among the known sexual attractions are odors and light organs

The physiological factors controlling fertility and fecundity are temperature endocrine secretion and nutrition in both adult and larval stages. The rate of egg production varies with temperature It accelerates with temperature increase up to a certain level and then drops off rapidly as temperature increases further Temperature also affects sperm development

Embryology. All Coleoptera are holometabolous because they have complete metamorphosis They pass through the egg larval and pupal stages before reaching sexual maturity

Egg stage The egg is laid by various methods and in many different places Because of the small size and the obscure location of the eggs little is

known about them They are rarely seen except with species reared in the laboratory Hatching time varies from a few days to several months de pending upon the season in which the eggs were laid In a few cases the females and sometimes even the males tend their eggs They protect them and assure an ample supply of food for the hatch ing larvae

Like all known arthropod eggs those of the bee tle are meroblastic having a large amount of yolk with cleavage of the nucleus occurring in a cyto plasmic area in the center of the egg Cleavage is superficial The blastoderm is formed by the migra tion of the cleavage nuclei through the yolk to the periphery of the egg where the cells become dif ferentiated A few nuclei return to the central mass as yolk cells a few remain at the periphery as yolk cells Very early in the development of the egg two protective envelopes or membranes are formed—an outer serosa and an inner amnion These membranes are a necessity in all terrestrial eggs

Larval stage The young larvae are very active from the time they gnaw their way out of the shell They differ radically in appearance from their par ents by having no wings They do have a definite head and a thorax with three clearly defined seg ments each with a pair of legs In the abdomen all nine abdominal segments are distinctly visible and usually the abdominal spiracles are also visible The larval stage is the growing stage and during this period of life the beetle increases several times in size and weight In order to accommodate to each size increase the larva molts or sheds its outer integument periodically Usually molting oc curs 3 times however in some groups it may occur as many as 10 or even 15 times

Most of the beetle species have larvae that are soft and white except for the head which is usu ally heavily sclerotized and brownish in color Gen erally the body possesses a few setae sometimes it has spines A few groups such as the Elateri dae are rather heavily sclerotized throughout and deeply pigmented The larvae of some Chrysomeli dae are very spiny and heavily armed

Pupal stage After the larva has passed through several moltings and has reached its maximum growth it pupates or changes into the pupa stage When the last larval skin is loose it may be dis carded or it may be retained to form part of the pupal shell Thus the pupae of beetles are either exarate (with free appendages) or coarctate (cov ered by the hardened exuviae of the last larval in star) The transition from the larval stage to the pupal stage is remarkable It usually takes place in rude cocoons or in cells in wood or debris The chamber is much larger than that of most other in sect groups which allows the inmate to expand its wings and elytra before leaving its shelter The t me necessary for this transformation varies from only a few minutes to several hours

The larvae at the end of the last stage show the first signs of pupation by becoming immobile They shorten in length swell and eventually form what are known as prepupae Inside the last skin many remarkable changes take place such as a complete breakdown of tissues a reorganization of muscles the development of new parts and changes in the elongate and develop appropriately for some spe cial mode of travel Finally the pupa is complete and closely resembles the adult After the final shaping and hardening of the exterior the mature adult is ready to emerge It sheds its pupal skin and crawls out into a new world ready for a new life

This is the normal life cycle but there are many groups which do not mature in exactly this manner In some groups the egg is retained in the oviduct Here the larva is formed and eventually is born as an active animal a condition known as viviparity In some Cantharidae the larvae hatch prematurely as legless immature prelarvae a phenomenon known as fetometamorphism Neotony or repro duction in the larval stage occurs in *Micromalthus* Hypermetamorphism in which one or more stages have been interpolated between the full grown larva and the adult is seen in Dytiscidae and Bru chidae Some larvae are modified for a parasitic life

ECOLOGY

The beetles occupy all animal habitats except the ocean where their absence is conspicuous even though a few littoral species are known A few beetle larvae breed in driftwood but none is actually at home in the ocean proper Fresh water forms are numerous but certainly not abundant either in number of species or as individuals In all terrestrial habitats some beetles are found

The majority of beetles are plant feeders They eat roots stems leaves flowers and fruits of plants They feed on both dead and living plant material and dead and living animal matter such as dung skins and stored animal products Several groups are parasitic on other insects or animals and many are predators on living insects snails and other small organisms

Beetle damage falls into four main categories damage to crops stored products and wood and in a few rare cases attacks on man himself The bene fits from beetles are more subtle Scavenger beetles aid in the removal of carrion foliage beetles keep down weeds or noxious plants and others feed on decomposing plant matter The role of beetles in nature s balance is an important factor largely be cause of their great numbers in a given habitat Unfortunately relatively little work has been done on the ecology of beetles in comparison to other groups For instance very little is known about the aquatic beetles in regard to the role of such factors as pH mineral content of the water organic mat ter flow of water light and aquatic predators The exchange of gases and water vapor and the

mechanisms that have evolved for these processes are the major factors in the ecological distribution of beetles The amount of oxygen required the ability to withstand severe oxygen deficiency, and the oxygen utilization are characteristic for each species though subject to variation Oxygen use is largely controlled by the degree of development of the spiracles and the hardness of the integument Hard compact forms can withstand long exposure to oxygen deficiencies and to desiccation because of their impervious integument and their ability to close the spiracles firmly Under such conditions of deprivation these beetles remain inactive Presumably this conserves remaining oxygen in the body by slowing down metabolic activity The larvae of many species and the adults of some live in situations where free oxygen appears to be greatly limited Scarabaeid larvae live for long periods deep in the soil possibly even below the water table Tenebrionids and cucujids live in flour where oxygen circulation must be greatly limited Wood boring and seed boring species are in situations where oxygen diffusion at best is slow Such forms as these either have a low oxygen demand in comparison with other animals or are able to utilize bound oxygen in minerals or organic compounds

Very active species such as fireflies tiger beetles certain ground beetles and others require more free oxygen When such species are confined in a closed jar without a renewed supply of air they will die in a few hours These same species die very rapidly on exposure to cyanide Such beetles will drown when submerged in water upon examination water will be found in the tracheal system The meager data now available on the oxygen demand of beetles are insufficient to formulate many significant generalizations

Beetles can withstand wide ranges of temperature without apparent ill effects The distribution of the various species is affected by the mean temperature of each geographical area and as these change so does the range of the species Typical arctic species will be active at much lower temperatures than tropical species and will be unable to survive the higher temperatures of the tropics, the converse is also true In temperate regions where there is a much greater daily temperature fluctuation than in either the tropics or the arctic regions the effect of temperature is more noticeable Diurnal species are less active and prefer to remain hidden during the cool of the night and on cold days Similarly nocturnal forms seem to avoid the heat of the day The many factors affecting the activities of beetles prevent stable conclusions about temperature effects However the fact that there is renewed beetle activity on warm winter days indicates a considerable temperature effect

Light is also a factor influencing the habits or behavior of beetles Those species found in debris, soil, or under stones are averse to light Species found on flowers or in similar sunny places display positive phototropism (are attracted to light) This leaves unexplained the apparently paradoxical attraction of nocturnal beetles to lights at night

Preferred habitats. The interrelationships of beetles with members of their own kind and with other organisms are so complex that only the most general statements can be made These interrelationships form the subject of much of the field of beetle ecology All beetle species have a certain preferred habitat and will be found most abundantly in that habitat Some members of the same species may also be found outside the preferred habitat so that the presence of one or a few individuals in some unusual location is not conclusive. The following classification of beetle habitats is one of convenience It is based both on the general trend of habitat types found throughout the order progressing from primitive to advanced habitats, and on the more or less clear cut lines of habitat preference shown by the beetles

- *A* Ground
  - 1 On surface
    - *a* Beneath stones and wood
    - *b* In rotting plant material
  - 2 Beneath surface
    - *a* In loose stones and gravel
    - *b* In soil (wet, upland, and desert)
- *B* Aquatic and semiaquatic
  - 1 Beneath surface along margins of bodies of water, intertidal
  - 2 Surface and diving
- *C* In association with other animals or their by products
  - 1 Dung
  - 2 Carrion
  - 3 In animal nests
  - 4 Ectoparasites
- *D* In other animals as parasites
- *E* In stored animal products
- *F* Plant associations
  - 1 Fungus
  - 2 Stems, foliage, and flowers
  - 3 Seeds
  - 4 Sap
  - 5 Bark
  - 6 Roots
  - 7 Wood borers
    - *a* In living wood
    - *b* In rotting wood
  - 8 Stored plant products

Protective devices The most widely distributed form of protection among beetles is coloration that blends into the background (homochromy) There are additional forms of protection found among some groups The well known leaf shaped carabid of India is an example of homotypy or resemblance of shape to the background. The weevils of the genus *Lithinus* resemble both in shape and color a growth of fungus or lichen on a spiny twig Aposematic coloration (flash and warning devices) are found in some buprestids, which spread their wings and elytra to expose

bright colors on the abdomen Aposematic colora tion and the many examples of mimicry are the more complicated protective measures Defensive organs such as horns and pincer type mandibles may be present These usually are only secondary sexual structures which are used principally in courtship if at all There are no stingers known among the beetles but many forms are known to emit noxious gases from anal glands Others pos sess oil or vesicating glands that poison or at least irritate predators Cataclysmic bleeding has often been observed among various beetles and is pre sumed to be a protective device also

Symbiosis Many examples of the relationship between two species known as symbiosis occur among beetles The recesses of ant and termite nests and to a lesser extent those of the social wasps and bees have been attractive harbors to many beetles despite the normally hostile presence of the real owners of these domiciles There are over 1000 species of beetles known to be involved in symbiosis or some modification of this relationship

Food for such inquilines is abundant in the de- bris and waste from the nest The helpless larvae and pupae of the hosts the crippled and weakened members of the community as well as the colonial larder are sources of food for the invader The per manence of the nest and the protection from ma rauders or other enemies is afforded by an ordinar ily highly effective organized colonial defense Stinging and fighting powers are exercised by the workers special fighting castes may even be pres ent An optimum temperature and humidity in many cases is maintained throughout the year In fact such domiciles especially those of ants and termites seem to offer every inducement for a life of indolent luxury to any beetle that can take ad vantage of it at least in every respect except one namely the presence of the natural owners who have a very highly developed sense of property right A variety of relationships result from these associations

The most numerous of the varied and specialized beetles that are symbiotic with social insects are the myrmecophiles or ant guests The termito philes or termite guests also have many known species Some of these have reached the ultimate evolutionary stage of symbiosis symphily In sym phily guest beetles exude an alluring fluid and be come living luxuries assiduously cultivated by their hosts Ants and termites develop a strong ap pet te or even passion for these exudates and this has rightly been compared to the use of dope or alcohol by man The symphiles often possess trich omes tufts of golden or reddish hair growing on diverse parts of their bodies especially around the openings of the glands that secrete the prized aro matic substances The hairs become saturated with the exudate and are eagerly licked by the hosts

The beetles are variously modified for life as symphiles Their antennae may be transformed as in *Adrenes* a pselaphid beetle into long cylindri cal clubs used for stroking the ants to solicit at tention or they may show the diverse compact shapes of the paussids In the latter case they serve as handles which the ants seize in order to drag the beetle around The mouthparts of the beetles are reduced and usually fitted to receive offerings of liquid food Their abdomens may exhibit what is known as physogastry or excessive enlargement caused by great increase of fatty or exudate tis sues the enlargement of the alimentary tract or of the reproductive organs Physogastry may occur in larvae as well as in adults

The sphecophiles (wasp guests) and melhto philes (bee guests) are few in number and are ei ther synechthrans (predators or scavengers) or synoeketes (mostly scavengers)

Parasitism Both ecto and endoparasites are represented in the order Coleoptera Two entire families the Stylopidae (also often considered as the separate order Strepsiptera) and the Rhipi phoridae are entirely endoparasitic Two small families the Leptinidae and Platypsyllidae are entirely ectoparasitic Several other families have some ectoparasitic members In addition there are 15 families having members which have been im plicated as pseudoparasites of man and domestic animals In all cases reported these are accidental parasites of man but there are several cases of beetles acting as intermediate hosts for parasites of man and domestic animals

Social life *Associations gregarious living by* many members of the same species at least during part of their life cycle are fairly frequent There are several instances of a fairly well developed family life but other than these little can be found to illustrate any development of societies among the beetles *Popilius disjunctus* (Ill) is the best example of subsocial life among the beetles The parents of these beetles live together with the larvae in very rotten wood The males and females triturate and prepare particles of the wood as food for the larvae The families keep together by strid ulatory signals which may be heard outside of the log and which serve as a means for locating such colonies

PALEONTOLOGY

For some unknown reason very few fossilized beetles have been found The earliest known fossil evidence of beetles is in Upper Permian rocks Sev enteen orders of insects had appeared in the rock strata before the Coleoptera To date 7 families representing 12 species have been described from Permian rock The Mesozoic and Cenozoic eras have an abundance of fossil beetles About 4000 are known for the two periods which represents only about 1 3% of the living beetle fauna All the beetles of the Mesozoic era have been assigned to modern families and it is probable that all the ma jor modern families had developed by the end of this era Many of the species from the Cenozoic beds are identical with those living today The bee-

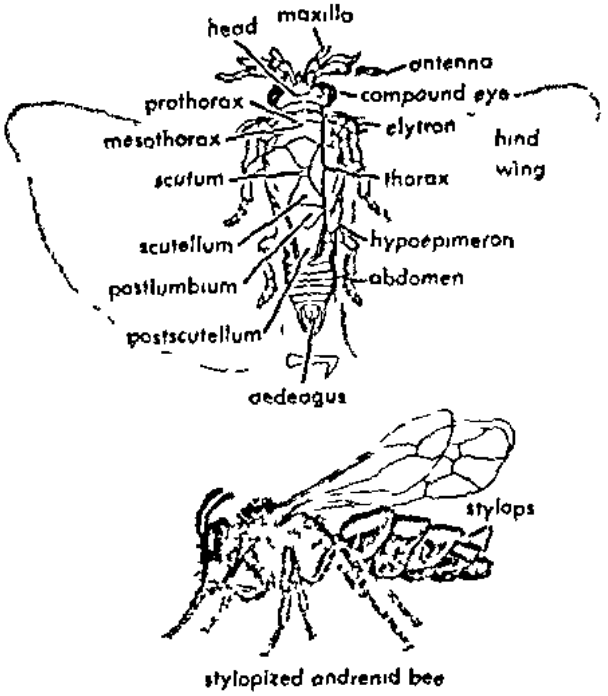


Fig 5 Strepsiptera Important characteristics and life cycle (*E O Essig College Entomology, Macmillan, 1942*)

tles are generally considered to have arisen from the order Megaloptera

COMMON SPECIES

Compared with some other orders of insects the beetles have very few serious pest species yet some species are the costliest of insect pests (*Table 2*) Many beetles that are not pests are equally well known The tiger beetles (*Cicindela* spp) are well known for their bright colors and active flight in sunny glades The common bombardier beetle (*Brachinus* spp) emits a cloud of acrid smoke when disturbed in its rocky haven, an attribute shared by several other genera of the ground beetles (Carabidae) The predaceous diving beetles (*Dytiscus* spp , Dytiscidae) the whirligig beetles (*Gyrinus* spp , Gyrinidae), and the giant larvae of the water scavenger beetles (*Hydrophilus* spp , Hydro- [illegible] of our fresh- [illegible] datory [illegible] d into [illegible] ything else in sight they will eat each other

The dung beetles (members of the family Scarabaeidae, including the sacred scarab of Egypt) roll balls of dung inside which they place their eggs The dung provides the food for the developing larvae The rove beetles (*Creophilus maxillosus*, and others, Staphylinidae) and the carrion beetles (*Silpha* spp , Silphidae) appear in large numbers at the first signs of putrefaction of animal flesh One group, the sexton beetles (*Nicrophorus* spp , Silphidae), even outwits the flesh flies by burying small dead bodies before the flies can lay their eggs on the carcass A near relative of these beetles, the beaver beetle (*Platypsyllus castoris*) has gone one step further and become an external parasite of the beaver

Most noticeable to the gardener naturalist are the many phytophagous beetles such as the white grubs (larvae of many Scarabaeidae) in the soil, the June beetles and May beetles (also Scarabaeidae) which eat the foliage, or the many species of the very large families, Chrysomelidae and Curculionidae

The fireflies (*Photinus* spp , Lampyridae) are much in evidence on warm summer nights A search through the forest litter on these same nights will reveal the glowworm, the larvae of some of the lampyrids and the wingless larviform females of Phengodidae Closely related to these insects are the Cantharidae, some members of which

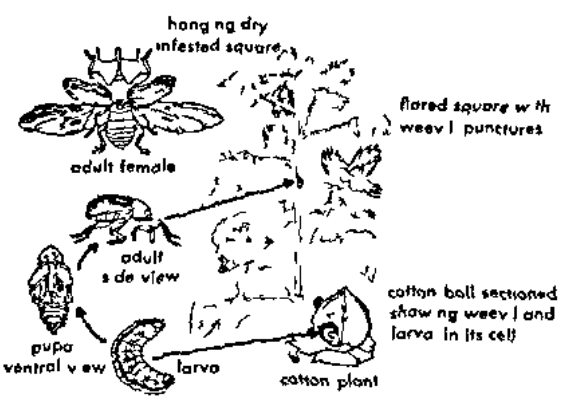


Fig 6 The cotton boll weevil, *Anthonomus grandis* Boheman (*C H Metcalf, W F Flint, and R L Metcalf, Destructive and Useful Insects, 3d ed , McGraw Hill, 1951*)

Table 2. Beetles of economic importance

Name	Damage
Scarabaeidae	
Asiatic garden beetle (*Autoserica castanea*)	Larvae pests of garden crops were introduced from Asia in 1922
Rose chafer (*Macrodactylus subspinosus*)	Larvae feed on roots of many garden crops adults a pest in gardens east of Rocky Mountains particularly harmful to roses
Leaf chafers (*Phyllophaga* spp.)	Many species are pests larvae feed on living roots adults feed on tree foliage particularly hardwood shade trees
Japanese beetles (*Popillia japonica*)	Serious pest of members of the rose family including many fruits introduced from Asia into New Jersey in 1916 has since spread through eastern United States
Tenebrionidae	
Confused flour beetles (*Tribolium confusum*)	Common pest of food products especially flour grains beans dried fruit nuts chocolate and pepper
Yellow mealworm (*Tenebrio molitor*)	Pest in grain bins particularly attacks farinaceous products that are in poor or decaying condition
Meloidae	
Blister beetles (*Epicauta* spp.)	Several species are pests of field crops often called old fashioned potato bugs because they were serious pests before the advent of the Colorado potato beetle
Elateridae	
Wireworms (*Conoderus* spp. *Clenicera* spp. *Melanotus* spp.)	Larvae live in soil and are serious pests of field crops including tobacco corn potatoes and beans
Buprestidae	
Flatheaded apple-tree borer (*Chrysobothris femorata*)	Important widely distributed pest of apple fruit shade and forest trees kills many each year
Ostomidae	
Cadelle (*Tenebroides mauritanicus*)	Pest of grain also larvae cut holes in bolting cloth sacks and cartons
Dermestidae	
Larder beetle (*Dermestes lardarius*)	Pest of pantries and kitchens feed on meat cheese and similar products
Carpet beetles (*Anthrenus scrophulariae* *Attagenus piceus*)	Common and serious pest of homes feed on rugs upholstered furniture padding clothing curtains and other fabrics
Anobiidae	
Cigarette beetles (*Lasioderma serricorne*)	Pest in many products stored about the home including cereals and spices
Common furniture beetle (*Anobium punctatum*)	Pest in wood of furniture introduced from Europe
Deathwatch beetle (*Xestobium rufovillosum*)	Pest in the timbers of old houses adults devour wood and strike heads against wood with clicking noise thus superstition that ticking presages death in the family
Drugstore beetle (*Stegobium paniceum*)	Pest of herbs and spices, other stored vegetable products
Coccinellidae	
Mexican bean beetle (*Epilachna varivestis*)	Pest of snap and Lima beans and other legumes
Cerambycidae	
Roundheaded apple-tree borer (*Saperda candida*)	Severe pest of apple and other fruit trees bore into bark sapwood and heartwood
Locust borer (*Megacylene robiniae*)	Destructive pest of locust trees especially those in the open
Chrysomelidae	
Colorado potato beetle (*Leptinotarsa decemlineata*)	Serious pest of potato throughout United States and Canada exported to Europe feed on the foliage of the potato tomato and eggplant
Striped cucumber beetle (*Acalymma vittata*)	Important pest of cucurbits east of Rocky Mountains feed on stems and leaves throughout growing season
Spotted cucumber beetle (*Diabrotica undecimpunctata howardi*)	Pest even more destructive of cucurbits than striped cucumber beetle also very destructive to corn oats wheat rice rye sorghums alfalfa beans and other crops distributed throughout North America
Mylabridae	
Bean weevils (*Acanthoscelides obtectus*)	Most injurious pest of all varieties of garden beans feed on seeds making them unfit for food or planting
Curculionidae	
Boll weevil (*Anthonomus grandis*)	Most important pest in agriculture destroy flowers and fruit of cotton plant
Rice weevil (*Sitophilus oryzae*)	Most destructive pest of stored grains
Plum curculio (*Conotrachelus nenuphar*)	Destroys plums peaches cherries apricots and apples east of the Rockies
Scolytidae	
Native elm bark beetle (*Hylurgopinus rufipes*)	A vector of Dutch elm disease of American elm also damage tree itself

produce an irritating substance cantharidin known as Spanish fly. A few other groups of beetles produce similar irritants and have earned the name blister beetles (Meloidae) by causing blisters and rash when squeezed against the human skin.

The well known click beetles (Elateridae) are the delight of children and can be found in any woodpile. When placed on their backs they flex the prothorax against a notch in the mesosternum so as to catapult themselves several inches into the air in an attempt to land on their feet. The flexing movement causes a clicking noise.

The ladybird beetles (Coccinellidae) are among the most beneficial of all animals because they feed on the very destructive scale insects that cause great damage to fruit trees.

This vast group of animals exhibits many star tling biological phenomena not found elsewhere in the animal kingdom *See* INSECT PHYSIOLOGY IN SECTA SOCIAL INSECTS *see also* CLEAVAGE EM BRYONIC OVUM PLANT DISEASE [R H A]

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Coliiformes

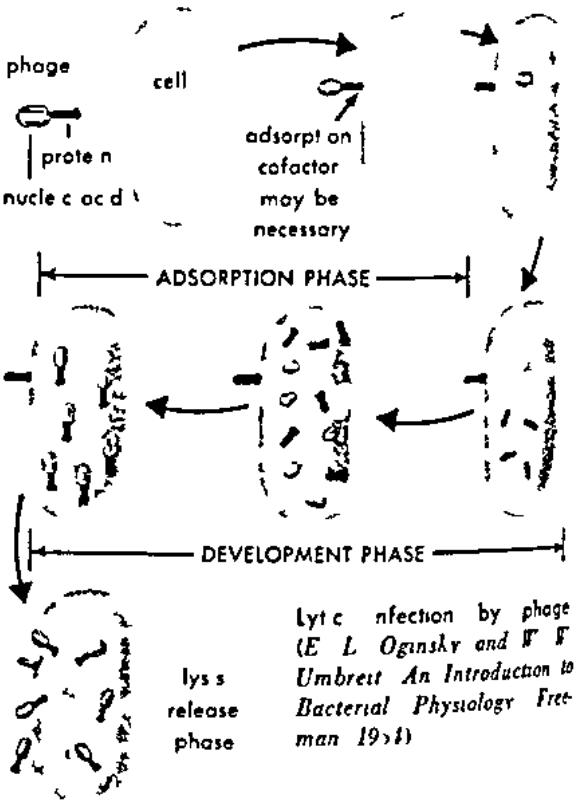
An order of birds containing the six species of the single family Colidae the colies or mousebirds of Africa The latter name is derived from the appear ance of these birds which are brownish or grayish have long tails and have a hal it of scurrying along branches In locomotion the entire tarsometatar sus is frequently used to support the bird s weight all four toes are directed forward the outer two somewhat laterally The relationships of the Coli iformes are uncertain some structural features and habits such as use of the bill in climbing sug gest a distant affinity with the parrots Colies are primarily frugivorous and travel in close flocks during the nonbreeding season *See* AVES [K C P]

Coliphage

Any bacteriophage able to infect the bacterium *Escherichia coli* Many are phages able to attack more than one strain of this organism The T series of phage (T1 T7) propagated on a special culture of *E coli* strain B have been used in extensive studies from which most of the knowledge of phages is derived

A typical phage particle is shaped something like a spermatozoon The outer skin or shell con sists of protein and encloses contents of deoxyri bonucleic acid (DNA) This DNA can be sepa rated from the protein by osmotic shock and it is then found that the protein shell alone can cause death of a bacterium when adsorbed to the cell surface This does not constitute a true infection however since no new phage is formed

The usual lytic infection of a *coli* B cell by a T phage proceeds as follows The phage is adsorbed by its tail to the cell surface Following this ad sorption the phage DNA gains access to the cell The protein skin has now served its purpose and if desired can be removed from the cell surface without affecting subsequent events Phage in an infectious state no longer exists it is now spoken of as vegetative phage and will remain in this state during its life cycle until the production of new infective particles occurs Immediately following the injection of the DNA the metabolic activities of the cell are profoundly altered Normal growth ceases abruptly although respiration continues at a steady rate Cell enzymes still function but their activity is now redirected and controlled by in



Lyt c nfection by phage (*E L Ogins ky and W F Umbreit An Introduction to Bacterial Physiology Free man 19 4*)

formation supplied by the phage DNA New pro tein synthesis can be detected at once this is not bacterial protein however but phage protein which is to serve later as part of the new phage particles Synthesis of bacterial ribonucleic acid (RNA) ceases Bacterial DNA breaks down and after about 10 min phage DNA begins to make its ap pearance formed in part from the bacterial DNA and in part from new synthesis This new DNA is incorporated with the phage protein to make new phage which can now be detected as an infectious unit In another 10 min or so lysis occurs after more phage has accumulated within the cell The time will vary with different phages The infectious phage released in numbers of 100 or more par ticles is able to infect susceptible bacteria *See* BACTERIA LYSOGENIC, BACTERIOPHAGE NUCLEIC ACID [P B C]

Colitis

An inflammation of the large bowel or colon due to one or more of several causes which may produce gross and microscopic changes of similar appear ance If the precise causative agent rema ns unknown that form of the disorder is called non specific colitis *See* GASTROINTESTINAL TRACT DISOR DERS

Nonspecific ulcerative colitis is common and may produce severe changes in the bowel Middle aged adults are most often affected and at present mul tiple contributing factors are blamed for the d ease Intensive investigation of many bacter a viruses fungi allergies developmental defects nu tritional deficiencies and other suspected cau e

have revealed no universally acceptable etiologic agents

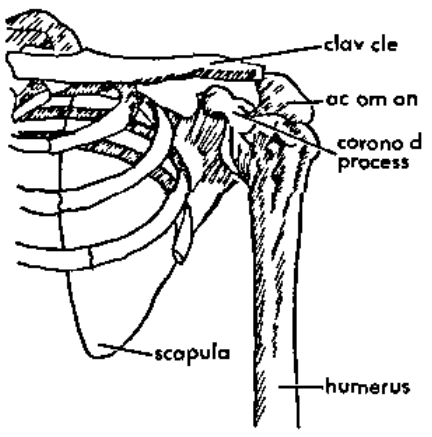
Small hemorrhages in the lower part of the bowel usually mark the early stages These develop into tiny abscesses which increase in size number and distribution Sloughing of the mucosal lining hemorrhage development of fistulae perforations and related changes are typical The symptoms of abdominal pain bleeding diarrhea and those symptoms related to specific complications tend to become chronic or to recur

Other identifiable agents may cause specific forms of colitis some of wh ch have very characteristic pathologic or clin cal features These include tuberculosis amebic and bacillary dysentery typhoid fever staphylococcal infections and mercury poisoning *See* AMEBIASIS BACILLARY DYSENTERY STAPHYLOCOCCUS TUBERCULOSIS

In any case of colitis careful studies should be made to isolate a causative agent Various brief relatively benign cases of colitis occur frequently probably as a result of mild viral or bacterial infections food poisoning or intolerances and emotional stresses Colitis may also be secondary to other disease or injury notably as a local response to tumor formation [E G ST]

Collarbone

The clavicle wh ch extends from the sternum or breastbone to the acromion process of the scapula or shoulder blade These paired bones aid in connecting the upper limb to the trunk and act as supports for the shoulder so that more precise arm movements are obtained The doubly curved clavicle is slightly flattened and each end broadens to form appropriate articulating surfaces



Collarbone (*From W T Foster Anatomy Foster Art Serv ce*)

The third of the collarbone nearest the sternum acts as a line of attachment for the lateral neck and certain chest muscles The center third lies just beneath the skin and is therefore exposed The outer third is a region of attachment for the deltoid and trapezius muscles of the shoulder

The clavicle is a frequent site of fracture usually in the exposed portion In rare instances there may be congenital absence of one or both clavicles *See* MUSCULAR SYSTEM SKELETAL SYSTEM [E G ST]

Collard

A cool season biennial crucifer (*Brassica oleracea* var *acephala*) similar to nonheading cabbage Collard is of Mediterranean origin and is grown for its rosette of leaves Kale and collards differ only in the form of their leaves both have been referred to as coleworts a name taken from the Anglo Saxon term meaning cabbage plants

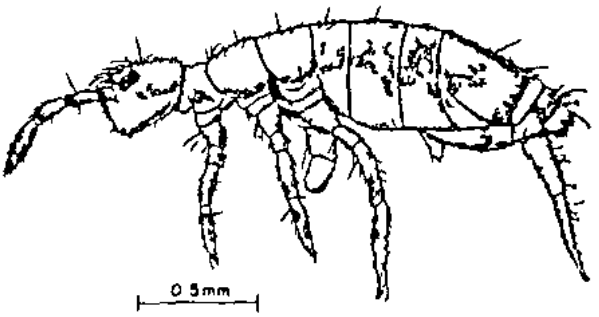


Collard Brass ca oleracea var acephala (*From L H Ba ley ed The Standard Cyclopedia of Hort culture vol 1 Macmillan 1937*)

Propagation is by seed Cultural practices are similar to those used for cabbage however collards are more tolerant of high temperatures Georgia and Vates are popular varieties Collards are moderately tolerant of acid soils Harvesting is usually 75 days after planting Important production centers are in the southern United States where collards is an important nutritious green especially during winter months *See* CABBAGE KALE PAPAVERALES VEGETABLE GROWING [H J C]

Collembola

An order of primitive insects commonly called springtails belonging to the subclass Apterygota These tiny insects do not undergo a metamorphosis They have six abdominal segments some of which may be ankylosed to give an apparently smaller number The tarsi are united with the tibiae and a pretarsus is present wh ch bears a dorsal median claw and usually a ventral clawlike appendage The ventral tube always occurs on the first abdominal segment and connects with the mouthparts



A collembolan *Entomobrya cubensis* (From J W Folsom Proc U S Nat Museum 72(6) plate 6 1927)

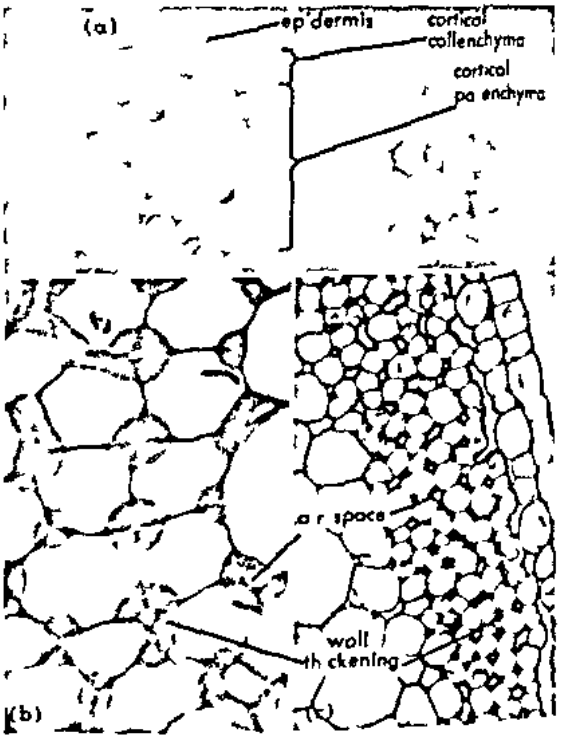
through a ventral canal consisting of two integumentary folds which overlap Appended to the fourth abdominal segment in most of the species is a spring or furcula This consists of a basal piece and two apical parallel structures which end in hooks Another pair of structures united at the base occur ventrally on the third abdominal segment These bear teeth which engage with the furcula and hold it beneath the body When released the spring flies backward catapulting the insect Two families Sminthuridae and Actaletidae have simple tracheal systems while the others breathe through the integument Collembola live in humid places often in leaf mold Some species are active at cool temperatures hence another common name snowflea is used The earliest known insect fossil *Rhyniella praecursor* is thought to belong to this order [H B M]

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Collenchyma

A primary or early differentiated supporting tissue of young shoot parts appearing while these parts are still elongating It is located near the surface usually just under the epidermis When observed in transverse sections it is characterized structurally by cell walls that are intermittently thickened generally in the corners or places of juncture of three or more cells (*see* CELL WALLS IN PLANTS) Collenchyma is typically formed in the petioles and vein ribs of leaves in the elongating zone of young stems and the pedicels of flowers

As in parenchyma the cells in collenchyma are living and may contain chloroplasts and starch grains (*see* CHLOROPHYLL) The cell wall of a



Jimson weed (*Datura stramonium* L) (a) Transverse section of stem at low magnification showing epidermis cortical collenchyma and cortical parenchyma (b) Transverse section of stem at higher magnification showing thickenings on collenchyma cell walls and air spaces surrounded by wall thickenings (c) Transverse section of collenchyma at highest magnification showing lamellation or layering of the cell wall forming the corner thickening (*Photograph by W S Walker*)

of water (*see* CELLULOSE PECTIN) In some studies collenchyma cell walls were found to contain 60–70% water by fresh weight in a variety of species studied Electron micrographs and histochemical techniques suggests that the cellulose and pectic compounds are present in alternating layers Another striking feature of collenchyma cell walls is their plasticity They are capable of great elongation during the period of growth in length of the plant Despite this elongation the characteristic thickening of the wall continues to increase In crease in cell wall thickness combined with an increase in wall surface is a striking growth phenomenon not as yet properly explained The plasticity of collenchyma is associated with a tensile strength comparable to that shown by fibers of sclerenchyma The combination of strength and plasticity makes the collenchyma particularly effective as a strengthening tissue in developing stems and leaves having no other supporting tissue at that time *See* EPIDERMIS PLANT, FLOWER (BOTANY) LEAF (BOTANY), PARENCHYMA, STEM (BOTANY) [R L HU]

Bibliography *See* PLANT ANATOMY

Collision

Any interaction between particles aggregates of particles or rigid bodies in which they come near enough to exert a mutual influence generally with exchange of energy The term collision as used in physics does not necessarily imply actual contact

In classical mechanics collision problems are concerned with the relation of the magnitudes and directions of the velocities of colliding bodies after collision to the velocity vectors of the bodies before collision When the only forces on the colliding bodies are those exerted by the bodies themselves the principle of conservation of momentum state

that the total momentum of the system is unchanged in the collision process This result is particularly useful when the forces between the colliding bodies act only during the instant of collision The velocities can then change only during the collision process which takes place in a short time interval Under these conditions the forces can be treated as impulsive forces the effects of which can be expressed in terms of an experimental parameter known as the coefficient of restitution which is discussed later *See* CONSERVATION OF MOMENTUM, IMPACT (IMPULSIVE FORCE)

The study of collisions of molecules atoms and nuclear particles is an important field of physics Here the object is usually to obtain information about the forces acting between the particles The velocities of the particles are measured before and after collision Although quantum mechanics instead of classical mechanics should be used to describe the motion of the particles many of the conclusions of classical collision theory are valid *See* SCATTERING EXPERIMENTS ATOMIC AND MOLECULAR SCATTERING EXPERIMENTS NUCLEAR

Classification of collisions Collisions can be classed as elastic and inelastic In an elastic collision mechanical energy is conserved that is the total kinetic energy of the system of particles after collision equals the total kinetic energy before collision For inelastic collisions however the total kinetic energy after collision is different from the initial total kinetic energy

In classical mechanics the total mechanical energy after an inelastic collision is ordinarily less than the initial total mechanical energy and the mechanical energy which is lost is converted into heat However an inelastic collision in which the total energy after collision is greater than the initial total energy sometimes can occur in classical mechanics For example a collision can cause an explosion which converts chemical energy into mechanical energy In molecular atomic and nuclear systems which are governed by quantum mechanics the energy levels of the particles can be changed during collisions Thus these inelastic collisions can involve either a gain or loss in mechanical energy

Consider a one dimensional collision of two particles in which the particles have masses m_1 and m_2 and initial velocities u_1 and u_2 If they interact only during the collision then an application of the principle of conservation of momentum yields

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

where v_1 and v_2 are the velocities of m_1 and m_2 respectively after collision

Coefficient of restitution It has been found experimentally that in collision processes

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

where e is a constant known as the coefficient of restitution the value of which depends on the properties of the colliding bodies The magnitude of e varies from 0 to 1 A coefficient of restitution equal to 1 can be shown to be equivalent to an elastic collision while a coefficient of restitution of zero is equivalent to what is sometimes called a perfectly inelastic collision From the definition of e one can show that in a perfectly inelastic collision the colliding bodies stick together after collision as two colliding balls of putty or a bullet fired into a wooden block would do The preceding equations can be solved for the unknown velocities v_1 and v_2 in the one dimensional collision of two particles

The concept of coefficient of restitution can be generalized to treat collisions involving the plane motion of smooth bodies—both of particles and larger bodies for which rotation effects must be considered For these collisions experiments show that the velocity components to be used in the equation for e are the components along the common normal to the surfaces of the bodies at the point where they make contact in the collision For smooth bodies the velocity components perpendicular to this direction are unchanged Use of this result and the principle of conservation of momentum are sufficient to solve two dimensional collision problems of smooth bodies For collisions of smooth spheres the velocity components to be used in the equation for e are those on the line joining the centers of the spheres Velocity components perpendicular to this direction are unchanged

Center of mass coordinates A simplification of the description of both classical and quantum mechanical collisions can be obtained by using a coordinate system which moves with the velocity of the center of mass before collision (Since for an isolated system the center of mass of the system can be shown to be unaccelerated at all times the velocity of the center of mass of the system of particles does not change during collision) The coordinate system which moves with the center of mass is called the center of mass system while the stationary system is referred to as the laboratory system The description of a collision in the center of mass system is simplified because in this coordinate system the total momentum is zero both before and after collision In a two particle collision the particles therefore must be oppositely directed after collision and the magnitude of one of the velocities in the center of mass system can be determined if the other is known *See* CENTER OF MASS [P W S]

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Colloid

A system of which one phase is made up of particles having dimensions of 10–10 000 angstroms and is dispersed in a different phase Some examples of colloidal systems are shown in the table

The unique properties of colloids are due primarily to the large surface areas of the dispersed phase One of the results of this large surface area

Types of colloidal system

Dispersed phase	Dispersing phase	Example
Solid	Solid	Some alloys
Solid	Liquid	Suspensions (muddy water)
Solid	Gas	Smoke, air borne dust
Liquid	Solid	Butter, gels
Liquid	Liquid	Emulsions (milk, mayonnaise)
Liquid	Gas	Fog, aerosols
Gas	Solid	Solid foams (marshmallow)
Gas	Liquid	Foams

is the adsorption of ions and other materials (*see* ADSORPTION) The adsorbed ions impart an electric charge to the colloidal particles so that they repel each other Lyophobic colloids exhibit little affinity between the dispersed phase and the solvent lyophilic colloids are strongly associated with the solvent

Many colloids occur naturally Others can be prepared by breaking large pieces of material into smaller pieces as with a colloid mill which consists of two accurately machined disks rotating in opposite directions at very high velocities while nearly touching each other Some colloids can be prepared by condensation methods in which atoms or molecules are induced to aggregate from solution or in which atoms or molecules are condensed from the vapor state

There are three important types of colloids small solid particles having the same internal structure as the bulk solid phase (sulfur suspensions in water) aggregates formed from smaller molecules (soaps in water) and large molecules that are of colloidal size (proteins and high polymers)

Optical properties Colloidal particles are so small that they cannot be seen directly in visible light even with an optical microscope They can be detected by viewing them at an angle to the incident light path (*see* TYNDALL EFFECT ULTRAMICROSCOPY) The electron microscope furnishes a means by which the sizes and shapes of colloidal size particles can be determined *See* MICROSCOPE ELECTRON

Separation of colloids Because colloids are so small in size they cannot be separated by filtration through paper or porous porcelain crucibles They can be separated from solvent and dissolved substances by dialysis and ultrafiltration (*see* DIALYSIS ULTRAFILTRATION) Air borne colloidal particles can be separated by special techniques *See* AEROSOL ELECTROSTATIC PRECIPITATOR

Apparent molecular weights It is possible to determine the weight average molecular weight of colloidal particles in solution by light scattering and viscosity measurements The number average molecular weight can be determined by osmotic pressure measurements For details *see* POLYMER PROPERTIES

Other more specialized aspects of colloidal properties and surface phenomena are discussed in other articles *See* DONNAN EQUILIBRIUM, ELECTROOSMOSIS, ELECTROPHORESIS, EMULSION, FOAM GEL, MICELLE, SMOKE, SURFACE PHENOMENON ULTRACENTRIFUGE

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Colon

The large intestine In man the colon is about 5 ft in length and begins in the right lower abdomen at the ileocecal valve, at which point the small intestine ends A blind pouch the cecum extends downward 2–3 in below the valve The appendix is the narrow final portion of the cecum From the valve the colon passes upward (ascending colon) to the undersurface of the liver, where it turns sharply to the left From this hepatic flexure the transverse colon extends across the abdomen to the region of the spleen where it takes a sharp downward turn The descending colon passes from the splenic flexure to about the level of the crest of the left hip where it becomes the S-shaped sigmoid colon This continues downward to the terminal 5–6 in of the large bowel (rectum) which empties into the anal canal

The inner surface of the colon consists of thick glandular mucosa surrounded by a connective tissue submucosa containing nerves blood vessels and lymphatics The next outer coat is the smooth muscle muscularis and surrounding this is the outermost serosa The serosa consists of loose connective tissue and an adherent layer of peritoneum

The function of the colon is to hold the food wastes (feces) while absorbing water and salts from them *See* DEFECATION, DIGESTIVE SYSTEM

[EGST]

Color

A general term that refers to the wavelength composition of light with particular reference to its visual appearance Since light is a form of electromagnetic wave motion it may be analyzed in terms of its energy at each wavelength throughout the visible spectrum At one extreme is pure or monochromatic light with all of its energy concentrated at a single wavelength At the other extreme is white light with an even distribution of energy throughout the spectrum In the general case light is described as being of a certain color because of a preponderance of energy at some one or more regions within the visible wavelength range from about 380 to 720 millimicrons (mμ)

The color of a given light may result from the mode of its emission Thus an incandescent source may emit red (predominantly long wave) light at low temperature or a glowing gas may emit light at various discrete wavelengths depending upon the electrons in its outer shells More often the wavelength distribution of the light is primarily dependent on the selective effects of such processes as reflection refraction or absorption An object such as a book for example may be described as having a certain color if its surface reflects more light at

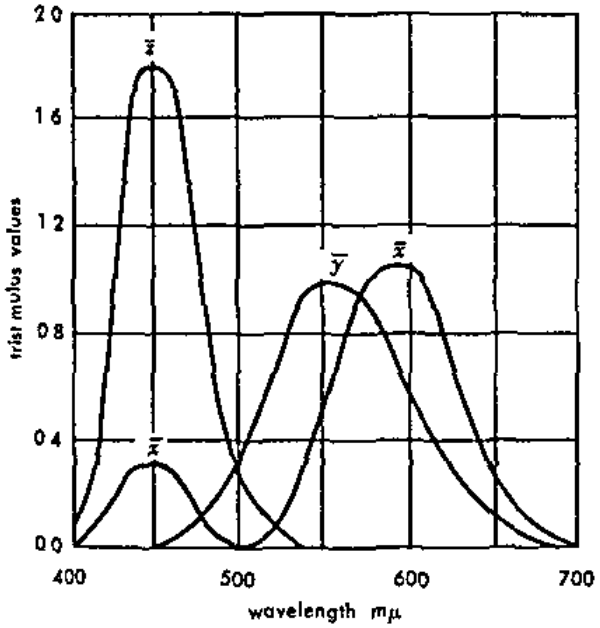


Fig 1 The primaries used for colorimetry with the International Committee on Illumination system These curves show the relative amount of each of the primaries necessary to match any part of the visible spectrum (*Adapted from A C Hardy, ed Handbook of Colorimetry, M I T Press 1936*)

certain wavelengths than at others to the eye of an observer

Colors may be specified by names but this is unsatisfactory for scientific purposes because people differ in the names they assign to the various colors The precision of color naming has been improved by the construction of standard sample plates for which one can be designated as approximately matching the unknown color when judged under standard conditions of illumination

Colorimetry This term is used to designate present day methods of color specification This is a system originally developed on the basis of the color judgments of average human observers but it is now standardized to involve objective and physical measurements exclusively Colorimetry starts with the trichromatic theory of color vision which states that three primary colors may be chosen in such a way that combined in various proportions, they can match any unknown color Basically then, colorimetry consists in the designation of the three primaries and a determination of the amount of each that must be used to produce the required color

The most widely used system of colorimetry is that of the International Committee on Illumination (ICI) The primaries in this system are not used as real colors They are merely three functions of wavelength that have certain features found to be convenient for the designation of color The primaries are shown in Fig 1

In this figure the abscissa values are the wavelengths of light in the visible region of the spectrum (*see* VISION). The ordinate values describe three primary colors in terms of the relative amount of each that is required to match a given wavelength of light For example, a blue light of 480 mμ is matched by a mixture of the three primaries such that $x = 1$, $\bar{y} = 15$ and $\bar{z} = 78$ It must be emphasized that these three primaries exist only as a mathematical abstraction defined in terms of the curves in Fig 1 Unlike real colors they can be combined to describe satisfactorily the color mixture data without the necessity for using negative numbers and without elaborate procedures of transformation from one set of primaries to another

The use of the ICI primaries may best be illustrated by a sample problem Suppose that it is necessary to describe quantitatively the color of a certain paint when viewed under illumination by a standard tungsten light source, that is a tungsten lamp operating at a certain filament temperature The first step is to measure the reflectance of the paint for every wavelength of light throughout the visible spectrum This is done objectively by the use of a spectrophotometer and its value at a given wavelength λ is symbolized as R_λ The next step is to multiply R_λ by the relative amount of light L_λ emitted by the standard light at the same wavelength The product $R_\lambda L_\lambda$ describes the amount of light actually emerging from the paint

Next $R_\lambda L_\lambda$ is multiplied by the amount of the first primary at the same wavelength, this product, $R_\lambda L_\lambda \bar{x}_\lambda$, is computed for all wavelengths throughout the spectrum in small steps such as every 5 mμ The procedure is repeated for $\bar{y}$ and $\bar{z}$ at each wavelength Three sums, X, Y, and Z, are then found such that

$$X = \Sigma R_\lambda L_\lambda x_\lambda \qquad Y = \Sigma R_\lambda L_\lambda y_\lambda \qquad Z = \Sigma R_\lambda L_\lambda \bar{z}_\lambda$$

The relative amounts of the x primary may now be written as

$$x = \frac{X}{x + y + z}$$

Similarly

$$y = \frac{Y}{x + y + z} \quad \text{and} \quad z = \frac{Z}{x + y + z}$$

Chromaticity diagram The color aspect of the paint specified in terms of the three numbers x, y, and z is called the chromaticity of the paint The significance of this term is made clear by the chromaticity diagram shown in Fig 2

This diagram shows the various monochromatic lights of the spectrum and certain other points as given by their values of x and y The ordinate is the fractional amount of the y primary and the abscissa is the fractional amount of the x primary in any color designated by a point on the diagram No provision on the diagram is necessary for z, since it is always true that $x + y + z = 1$ and consequently the chromaticity is uniquely determined by x and y

*In addition to the chromaticity, it may be de*sired to know the photometric luminance of the sur

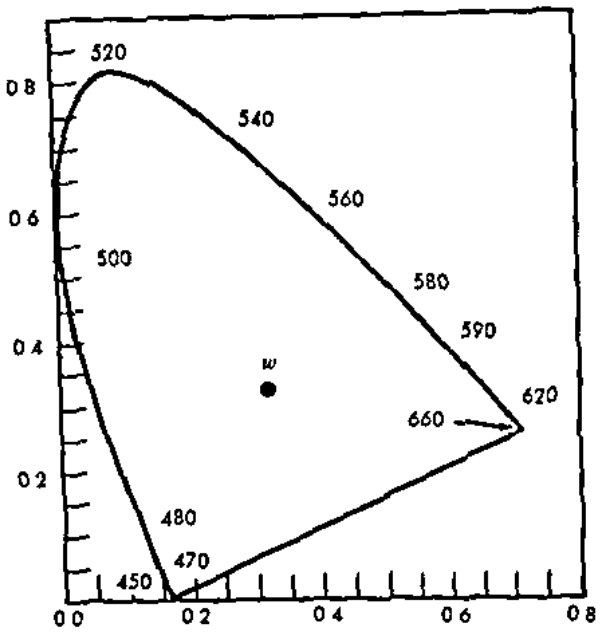


Fig 2 The International Committee on Illuminat on chromatic ty diagram The colors of the spectrum are ind cated along the curve whose ends are jo ned by a stra ght l ne that represents the purples The point w des gnates a white composed of equal amounts of the three primaries (*Adapted from* A C Hardy ed *Handbook of Colorimetry M I T Press 1936*)

face being described Luminance is the brightness or number of candles per square meter emitted by an object in the direction of the observer The three quantities x y and luminance are then adequate to describe the color sample for the standard observer under the designated source of illumination

The chromaticity diagram may serve to illustrate a number of other aspects of color First if two colors are located on the diagram the mixture of the two will result in a color that is approximately at the midpoint of the straight line connecting the two points Complementary colors are any two colors that are found on opposite sides of the center or achromatic point of the diagram A mixture of the two in the appropriate proportions can be made to yield white Three real primary colors can be chosen from the spectral locus such that most but not all of the points on the diagram can be arrived at by appropriate mixtures of the three

The white point W on the diagram is the result of equal amounts of x y and z An equal energy spectrum of light is also represented by point W This point may be considered the point of zero purity of color excitation Maximum purity is found at all points on the spectral locus and on the straight line designating the purples that are obtained by mixture of the lights at the red and blue ends of this locus In general the excitation purity of any one point on the diagram is given by the

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locus of pure purples

One more feature of the ICI system of colorimetry is of interest This is that the $\bar{y}$ curve shown in Fig 1 expresses the relative luminosity of the various wavelengths of the spectrum Thus the $\bar{x}$ and $\bar{z}$ factors contribute nothing to luminosity but are of value in relation to chromaticity alone

It must be emphasized that the color mixtures treated by the chromaticity diagram are mixtures of light and not of paints or pigments Mixtures of paint are known as subtractive mixtures for the reason that each paint absorbs light selectively at certain regions of the spectrum and mixing two paints results in a greater absorption of light Mixtures of light on the other hand are additive The luminance of the mixture is approximately the sum of the separate luminances of the component lights

The procedure to be used for additive color mixing depends on the arrangement for producing the color If the color is on a surface such as in colored papers or in dyed or painted materials then mixture can be achieved by rapidly alternating a view of one surface with a view of the other as in the familiar color top or rapidly revolving motorized color wheel At very high rates of alternation the two colors appear to be fused because the eye can not resolve them temporally If the colors are produced by an optical system of refraction interference or selective absorption arrangements can usually be made to superimpose the two beams by the use of projection on a common screen or by using a partially reflecting and partially transmitting mirror to direct both beams along a common path into the eye *See* BLACK, COLOR VISION, COLORIMETRY GRAY WHITE. [L A R]

Color centers

Point lattice defects of various types which produce optical absorption bands in otherwise transparent crystals The defects are caused by ionizing radiation electrolysis of the crystal and so on The simplest type of color center is one called an *F* center The designation *F* center comes from the German word *Farbe* which means color Color centers are of most interest in alkali halide crystals although they occur in a few other materials for example quartz

Color centers have been under laboratory investigation since the 1890s One of the most active studies has involved the electrical properties of colored crystals data has been obtained by the use of magnetic resonance and other techniques Theoretical physicists have calculated wave functions for electrons trapped in color centers

F centers in alkali halides are probably the most extensively studied and best understood of all imperfections in solids The *F* center optical absorption band (*F* band) in sodium chloride occurs toward the blue end of the visible spectrum which makes the colored crystal appear yellow under transmitted light Colored potassium chloride on the other hand appears magenta *See* ABSORPTION (ELECTROMAGNETIC RADIATION)

Origin of centers Figure 1 shows the absorption bands due to color centers produced in potassium bromide by exposure of the crystal at the temperature of liquid nitrogen (81°K) to intense penetrat

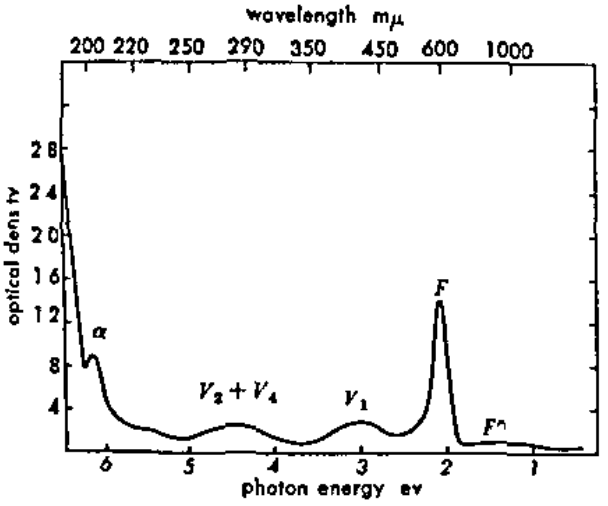


Fig 1 Absorption bands produced in a KBr crystal by exposure to x rays at 81°K Optical density is equal to $\log_{10}(I_0/I)$, where I_0 is the intensity of incident light and I the intensity of transmitted light Measurements were made with monochromatic light of various wavelengths plotted horizontally in wavelength units and in energy units (electron volts ev) The steep rise in optical density at extreme left is due to intrinsic absorption in the crystal (modified slightly by the existence of the *F* centers)

ing x rays Several prominent bands appear as a result of the irradiation The *F* band appears at 600 mμ and the so called *V* bands appear in the ultraviolet Uncolored alkali halide crystals may be grown readily from a melt with as few imperfections as one part in 10^5 In the unirradiated and therefore uncolored state they show no appreciable absorption from the far infrared through the visible to the region of characteristic absorption in the far ultraviolet (beginning at about 200 mμ in Fig 1) Color centers may be introduced into such crystals by other means than exposure to penetrating radiation The most important of these is a method known as additive coloration in which the

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arise because of light absorption at defects dispersed throughout the lattice Their extinction arises solely because of the absorption of light associated with electronic transitions at the centers On the other hand colloidal particles each consisting of many atoms dispersed through an optical medium also produce color bands In this case if the particles are large enough the extinction of light is due to both light scattering and light absorption Colloidal gold is responsible for the color of some types of ruby glass Colloids may also form in alkali halide crystals for example during heat treatment of an additively colored crystal which contains an excess of alkali metal

Atomically dispersed centers such as *F* centers are part of the general phenomena of trapped electrons and holes in solids (*see* TRAPS IN SOLIDS)

The accepted model of the *F* center is an electron trapped at a negative ion vacancy, whereas its antimorph, the V_1 center, is thought to be due to a hole trapped at a positive-ion vacancy Many other combinations of electrons holes and clusters of lattice vacancies have been used to explain the various absorption bands observed in ionic crystals The models shown in Fig 2 for *V*, *M*, and *R* centers are tentative whereas those given for the *F* and *F'* centers are widely accepted

Impurities can play an important role in color center phenomena Certain impurities in ionic crystals produce color bands characteristic of the foreign ion For example, hydrogen can be incorporated into the alkali halides with resultant appearance of an absorption band in the ultraviolet known as the *U* band In this case the *U* centers interact with other defects The rate at which *F* centers are produced by x irradiation is greatly increased by the incorporation of hydrogen the *U* centers being converted into *F* centers with high efficiency

F centers *F* centers may be produced in uncolored crystals by irradiation with ultraviolet light x rays γ rays and high speed particles and also by electrolysis However, one of the most convenient methods is that of additive coloration Alkali halide crystals may be additively colored by heating to several hundred degrees Centigrade in the presence of the alkali metal vapor then cooling rapidly to room temperature The *F* band that re

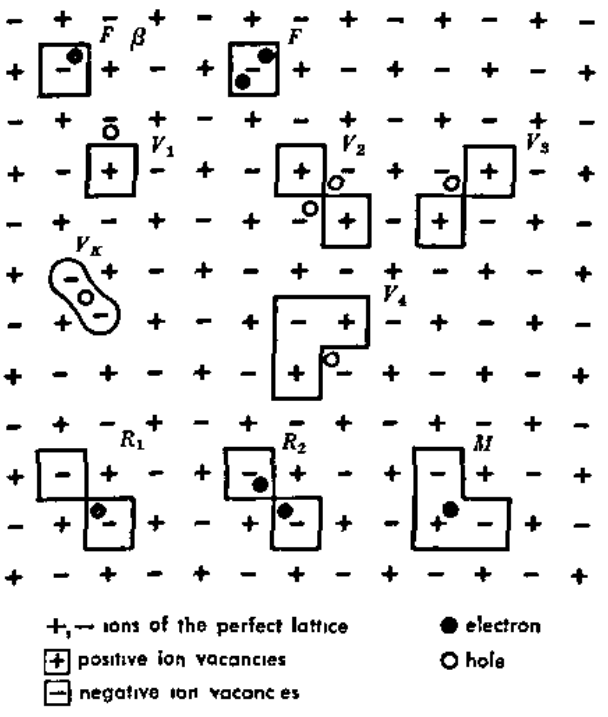


Fig 2 Proposed models for several color centers in an ionic crystal The letter β adjacent to the *F* center in first row signifies disturbing influence of *F* centers on the tail of the fundamental absorption band The center marked V_K in third row is a kind of self trapped hole which has been identified by both spin resonance and optical studies

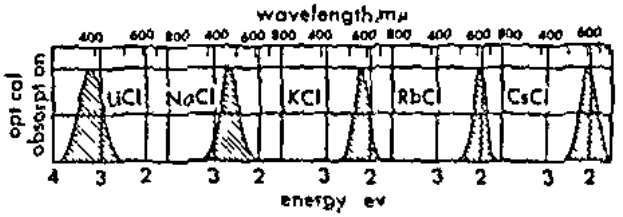


Fig 3 *F* bands in several different alkali halide crystals

sults is the same as that produced by irradiation and is dependent upon the particular alkali halide used not upon the alkali metal vapor For example the coloration produced in KCl is the same whether the crystal is heated in potassium or in sodium vapor This and other evidence indicate that excess alkali atoms enter the crystal as normal lattice ions by donating an electron to accompanying negative ion vacancies to form *F* centers Figure 3 shows the position of the *F* band in several different alkali halides

Both the width and the exact position of the *F* band change with temperature in the manner shown in Fig 4 This behavior can be explained in terms of the thermal motion of the ions surrounding the center Thermal motion is most important at high temperatures whereas at low temperatures the width of the absorption band becomes less and approaches a constant value which prevails down to the very lowest temperatures

Concentration of centers The height of the absorption maximum and the width at half maximum may be used to calculate the concentration N of absorbing centers For KCl classical theory gives the concentration as

$$N = 1.3 \times 10^{16} AH \text{ cm}^{-3}$$

where A is the maximum absorption in cm^{-1} and H is the half width of the absorption band in ev The numerical factor in this equation depends upon the material under consideration and is given for KCl The general relation between absorption characteristics and defect concentration is slightly more complicated but is nevertheless useful to determine concentrations below the limit of detection by chemical means

Shape of the F band Refined measurements of the *F* band at low temperatures show

short wavelength side and a tail at longer wavelengths The shoulder has the appearance of a small extra peak sometimes called the *K* band It has been proposed that the *K* band is in agreement with the energy level scheme of the *F* center An electron in the vicinity of a negative ion vacancy should have a ground state and one or more excited states below the bottom of the conduction band The main absorption peak corresponds to excitation of

of excited states below the conduction band *See* PHOTOCONDUCTIVITY

Luminescence At low temperatures the excited electron in an *F* center can decay to the ground state with resulting luminescent emission *F*-center luminescence with high efficiency has been found to occur in KCl and KBr at low temperatures *See* LUMINESCENCE

Magnetic resonance experiments Perhaps the most detailed information on *F* centers comes from electron spin resonance experiments From these the extent and character of the wave function of the electron trapped at the halogen ion vacancy can be obtained The electron is not highly localized but is spread out over the six neighboring alkali ions and to some extent over more distant neighbors Paramagnetic resonance measurements give the concentration of *F* centers in a sample so that a reliable value of the oscillator strength for the *F* band can be found This has been done in the case of additively colored NaCl and KCl

***F'* centers** When a crystal containing F-centers is irradiated at low temperature with light in the *F* band itself the *F* absorption decreases and a new band known as the *F'* band appears (see Fig 5) Experiments have shown that for every *F'* center created two *F* centers are destroyed The *F'* center consists of an *F* center which has [illegible] electric [illegible] band

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***V* centers** As Fig 1 shows absorption bands arise in the ultraviolet as well as in the visible portion of the spectrum when KBr is irradiated

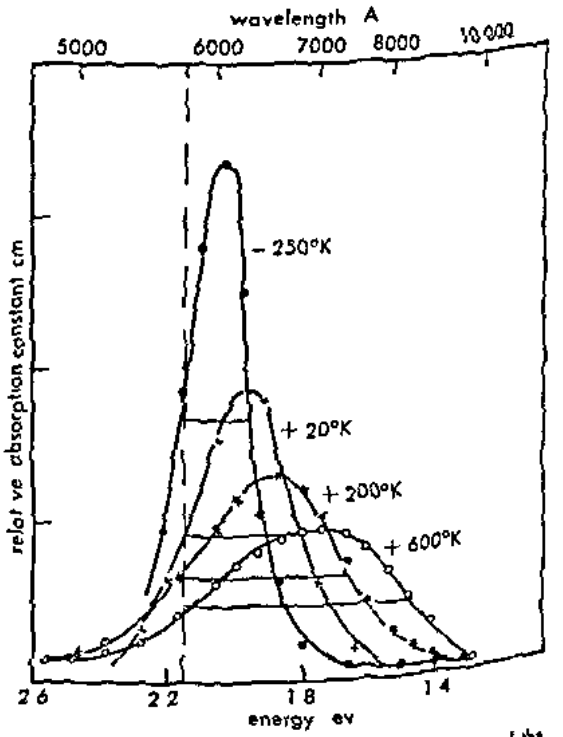


Fig 4 Variation with temperature of the width of the *F* band in KBr

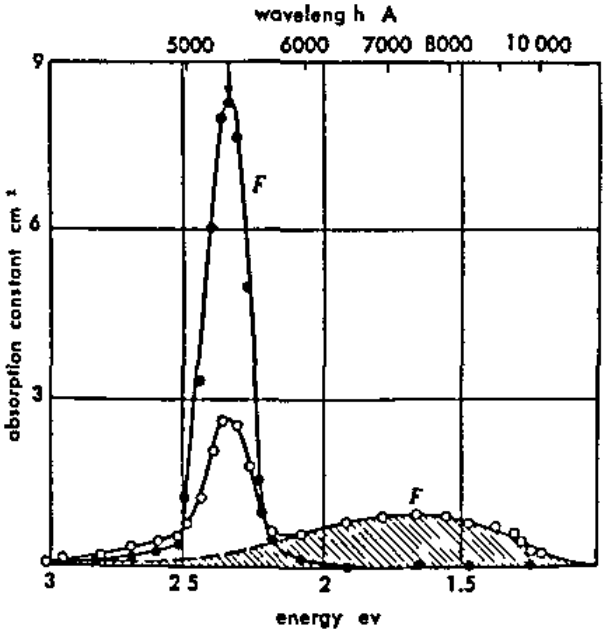


Fig 5 The F and F bands in KCl at 235°C The F band was produced by irradiating the crystal with light of wavelength shown by the arrow at the center of the F band Such light causes the F band to bleach as the F band grows (*After H P Gilck*)

while cold These so called V bands are apparently not present in crystals additively colored by the alkali metal vapor Irradiation of a crystal produces both electrons and holes so that bands associated with trapped positive charges are to be expected in addition to electrons trapped at negative ion vacancies (F centers)

V bands can also be produced at least in the case of KBr and KI by introduction of an excess of halogen into the crystal V bands are less well understood than centers ascribable to trapped electrons Tentative models for V centers which show holes trapped at single positive ion vacancies and at clusters of vacancies are given in Fig 2 The symmetry of these models as deduced from experiments using polarized light can be an important factor in deciding between them

Crystals containing V centers have been studied by spin resonance techniques with the result that a center not previously observed optically has been identified This center sometimes referred to as the V_A center (see Fig 2) is due to a hole trapped in the vicinity of two halogen ions which have become displaced from their normal lattice position to form a Cl_2^- molecule ion (in the case of KCl) It has been found in several different alkali halides and its optical absorption has been detected Although a great deal is known about the nature of the center the conditions for its formation and stability are as yet unknown *See* CRYSTAL DEFECTS PHOTOLYSIS (PHOTOCHEMISTRY) [F C BR]

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Color television

The transmission and reception of transient visual images in full color The system in use in the United States is compatible with monochrome or black and white television Compatibility means that the system produces programs in color on color receivers and in black and white on monochrome receivers Also color receivers will receive monochrome pictures when these are being transmitted *See* TELEVISION

Color transmission contains two basic components luminance (brightness) information the vital ingredient for monochrome and chrominance (color) information which in color receivers actuates supplementary circuits to add the color to the brightness component

Any visible color may be accurately reproduced by proper selection and mixing of luminance values of a maximum of three primary colors provided that no combination of two of them will produce the third This requirement is met by a choice of red green and blue as the primary colors These are the colors chosen for television and are called the display primaries

Color cameras In a color camera an optical system separates the red green and blue image components of a picture and focuses the three components on the face of separate but identical color camera tubes Thus the output of one tube is responsive to the red light image another to the green and another to the blue The outputs of the three camera picture tubes are combined in suitable circuitry to extract the luminance component of the composite picture This corresponds to a monochrome picture In separate color coding circuits the color components are encoded prior to modulating a chrominance subcarrier *See* TELE

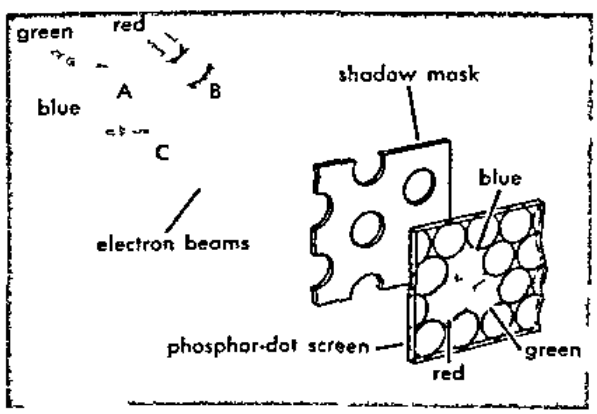


Fig 1 Color reproduction in a kinescope

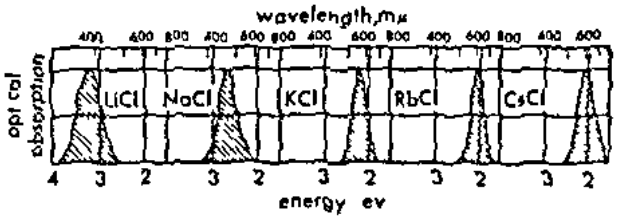


Fig 3 *F* bands in several different alkali halide crystals

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$$N = 1.3 \times 10^{16} AH \text{ cm}^{-3}$$

where *A* is the maximum absorption in cm^{-1} and *H* is the half width of the absorption band in ev The numerical factor in this equation depends upon the material under consideration and is given for KCl The general relation between absorption characteristics and defect concentration is slightly more complicated but is nevertheless useful to determine concentrations below the limit of detection by chemical means

Shape of the F band Refined measurements of the *F* band at low temperatures show that it is not a simple bell shaped curve as originally presented In fact, it is found to contain a shoulder on the short wavelength side and a tail at longer wavelengths The shoulder has the appearance of a small extra peak sometimes called the *K* band It has been proposed that the K band is in agreement with the energy level scheme of the *F* center An electron in the vicinity of a negative ion vacancy should have a ground state and one or more excited states below the bottom of the conduction band The main absorption peak corresponds to excitation of the electron from the 1s ground state to an excited 2p state The K band is thought to be due to transitions to the conduction band itself *F* center photoconductivity measurements tend to confirm the idea of excited states below the conduction band See PHOTOCONDUCTIVITY

Luminescence At low temperatures the excited electron in an *F* center can decay to the ground state with resulting luminescent emission *F*-center luminescence with high efficiency has been found to occur in KCl and KBr at low temperatures See LUMINESCENCE

Magnetic resonance experiments Perhaps the most detailed information on *F* centers comes from electron spin resonance experiments From these the extent and character of the wave function of the electron trapped at the halogen ion vacancy can be obtained The electron is not highly localized but is spread out over the six neighboring alkali ions and to some extent over more distant neighbors Paramagnetic resonance measurements give the concentration of *F* centers in a sample so that a reliable value of the oscillator strength for the *F* band can be found This has been done in the case of additively colored NaCl and KCl

F′ centers When a crystal containing *F*-centers is irradiated at low temperature with light in the *F* band itself the *F* absorption decreases and a new band known as the *F′* band appears (see Fig 5) Experiments have shown that for every *F′* center created two *F* centers are destroyed The *F′* center consists of an *F*-center which has captured an extra electron Important photoelectric effects occur during conversion of *F* to *F′* centers and during irradiation of alkali halides with *F* band light

***V*-centers.** As Fig 1 shows absorption bands arise in the ultraviolet as well as in the visible portion of the spectrum when KBr is irradiated

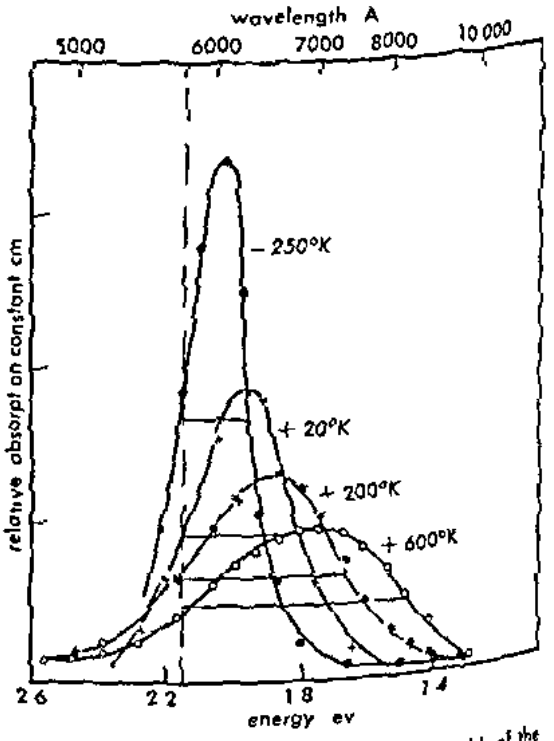


Fig 4 Variation with temperature of the width of the *F* band in KBr

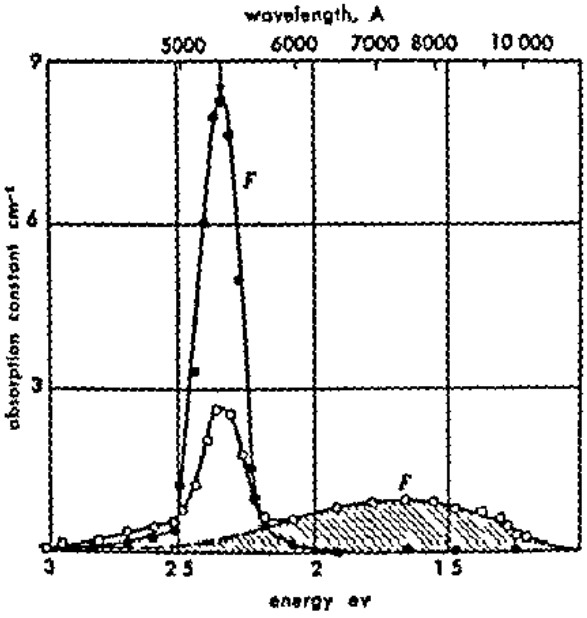


Fig 5 The F and F bands in KCl at 235°C The F band was produced by irradiating the crystal with light of wavelength shown by the arrow at the center of the F-band Such light causes the F band to bleach as the F band grows (After H Pick)

while cold These so-called I bands are apparently not present in crystals additively colored by the alkali metal vapor Irradiation of a crystal produces both electrons and holes so that bands associated with trapped positive charges are to be expected in addition to electrons trapped at negative ion vacancies (F centers)

V bands can also be produced at least in the case of KBr and KI by introduction of an excess of halogen into the crystal V bands are less well understood than centers ascribable to trapped electrons Tentative models for V centers which show holes trapped at single positive ion vacancies and at clusters of vacancies are given in Fig 2 The symmetry of these models as deduced from experiments using polarized light can be an important factor in deciding between them

Crystals containing V centers have been studied by spin resonance techniques with the result that a center not previously observed optically has been identified This center sometimes referred to as the V_A center (see Fig 2) is due to a hole trapped in the vicinity of two halogen ions which have become displaced from their normal lattice position to form a Cl_2 molecule ion (in the case of KCl) It has been found in several different alkali halides and its optical absorption has been detected Although a great deal is known about the nature of the center the conditions for its formation and stability are as yet unknown *See* CRYSTAL DEFECTS PHOTOLYSIS (PHOTOCHEMISTRY) [F C BR]

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Color television

The transmission and reception of transient visual images in full color The system in use in the United States is compatible with monochrome, or black and white television Compatibility means that the system produces programs in color on color receivers and in black and white on monochrome receivers Also color receivers will receive monochrome pictures when these are being transmitted *See* TELEVISION

Color transmission contains two basic components luminance (brightness) information the vital ingredient for monochrome and chrominance (color) information which in color receivers actuates supplementary circuits to add the color to the brightness component

Any visible color may be accurately reproduced by proper selection and mixing of luminance values of a maximum of three primary colors provided that no combination of two of them will produce the third This requirement is met by a choice of red green and blue as the primary colors These are the colors chosen for television and are called the display primaries

Color cameras In a color camera an optical system separates the red green and blue image components of a picture and focuses the three components on the face of separate but identical color camera tubes Thus the output of one tube is responsive to the red light image another to the green and another to the blue The outputs of the three camera picture tubes are combined in suitable circuitry to extract the luminance component of the composite picture This corresponds to a monochrome picture In separate color coding circuits the color components are encoded prior to modulating a chrominance subcarrier *See* TELE

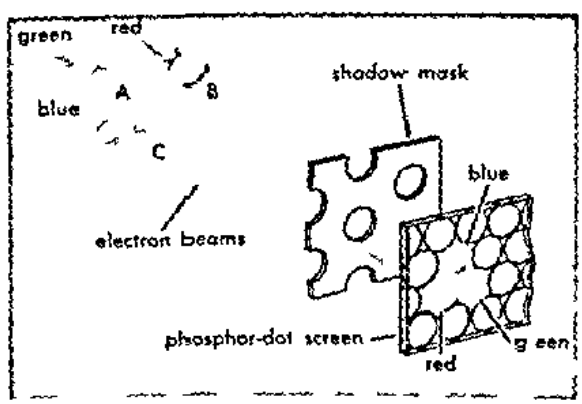


Fig 1 Color reproduction in a kinescope

VISION CAMERA *See* TELEVISION CAMERA TUBE

Chrominance subcarrier In developing the compatible color system it was necessary to find a means of transmitting the color signal components without interfering with the reception of other signal components Study showed that the monochrome television frequency band is not fully utilized The information is concentrated at discrete frequency intervals through the channel corresponding to the harmonics of line field and frame frequencies with gaps between These gaps were utilized to add the color information It was essential however that these color signals always fall precisely into the gaps to avoid mutual interference This was accomplished by employing a modulated chrominance subcarrier derived from the same primary frequency source as the deflection synchronizing frequencies so it would always be exactly related and locked to the synchronizing frequencies The desired frequency relationship exists when the chrominance subcarrier frequency is an odd multiple of one half the line frequency The effects otherwise visible of this added chrominance signal are then minimized because on alternate frames the signals reverse (go alternately dark and bright) The persistance of human vision is such that these effects are then of no practical significance The chrominance subcarrier frequency is 3 579545 megacycles In transmission it is substantially suppressed and only its color sidebands containing the color information are transmitted in the gaps The color sidebands are obtained by modulating the color subcarrier in phase or amplitude or both simultaneously corresponding to the hue and saturation of the color Hue is the attribute of color perception by which a color is classified as red yellow green blue purple or the like Saturation is the attribute of any color perception which classifies a color as strong or intense as contrasted with weak or pastel

The subcarrier may be viewed as a vector which is modulated in amplitude depending upon the saturation of the color and in phase depending upon the hue of the color with the full range of hues spanning 360° Since variations in phase produce changes in hue the phase of the locally produced color subcarrier used for synchronous demodulation must correspond closely with the phase of the original subcarrier vector which was modulated or false colors are produced

Color burst This is that portion of the composite color signal comprising a few cycles of a sine wave of chrominance subcarrier frequency which is used to establish a reference for demodulating the chrominance signal Since the chrominance subcarrier is substantially suppressed in transmission it is necessary to produce one of the same frequency and phase in the receiver for chrominance signal demodulation The receiver subcarrier is locked in phase and frequency to the transmitter subcarrier by transmitting a short burst of the unmodulated original subcarrier and using it to control the subcarrier produced in the receiver This burst is transmitted immediately following each horizontal synchronizing pulse while the picture is blanked out It is so called because it consists of only about 9 cycles and is transmitted during only a small fraction of one horizontal interval

The luminance signal chrominance sidebands, subcarrier burst and the horizontal and vertical synchronizing signals are all used to modulate the picture carrier For color reproduction all are utilized at the receiver Monochrome receivers contain no responsive color circuitry and therefore are blind to the chrominance sideband signals and the subcarrier burst *See* TELEVISION TRANSMITTER

Color kinescope In a monochrome kinescope (picture tube) a single electron gun produces an electron beam about 01 in in diameter As the beam scans the phosphor surface the bombardment of the phosphor produces white light by fluorescence The brightness is controlled by an electron valve or grid which changes the electron beam density

In a color kinescope three electron guns displaced in an equilateral triangle produce three electron beams which move in exact synchronism and converge to a common point on a perforated metal plate the shadow mask (see Fig 1) The intensities of beams A, B and C are controlled by the voltage corresponding to the green red and blue components respectively of the color picture. Beam A passes through a hole in the shadow mask and bombards a precisely located phosphor dot which produces green light Beam B passes through the same hole from a different direction to bombard separately a dot which produces red light, and beam C passes through the same hole to bombard a third dot which produces blue Rapid scanning of hundreds of thousands of these holes and dots produces the color picture image When these three colors are present in the correct relative intensities the eye at a distance perceives the combination as white When these intensities are not balanced the dominant colors appear and create the chromatic components of the picture The manner in which red green and blue light combine to produce other colors or white is illustrated in Fig 2 *See* KINESCOPE

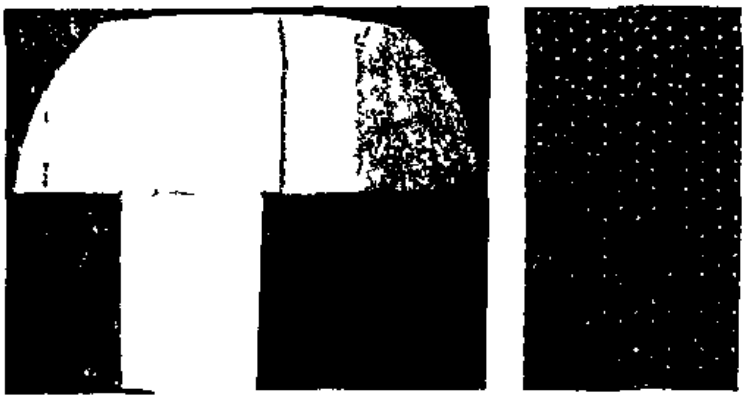
Color reception In the color receiver the incoming composite signal goes through frequency and amplitude selective circuits to separate the brightness component the color components the horizontal and vertical beam synchronizing components and the color subcarrier bursts The brightness component is applied simultaneously to each of the three electron guns The red green and blue color signal voltage components are obtained by electrical processing (decoding) and are applied to the three respective kinescope electron guns They combine with the luminance component voltage to produce beam intensities which reproduce the original picture when the beams bombard their respective color responsive phosphor dot An electrical gating circuit opens for a short time to permit the chrominance subcarrier bursts to be

Zinc sulfide phosphors taken under ultraviolet light Only red, green, and blue are used in color television picture tubes



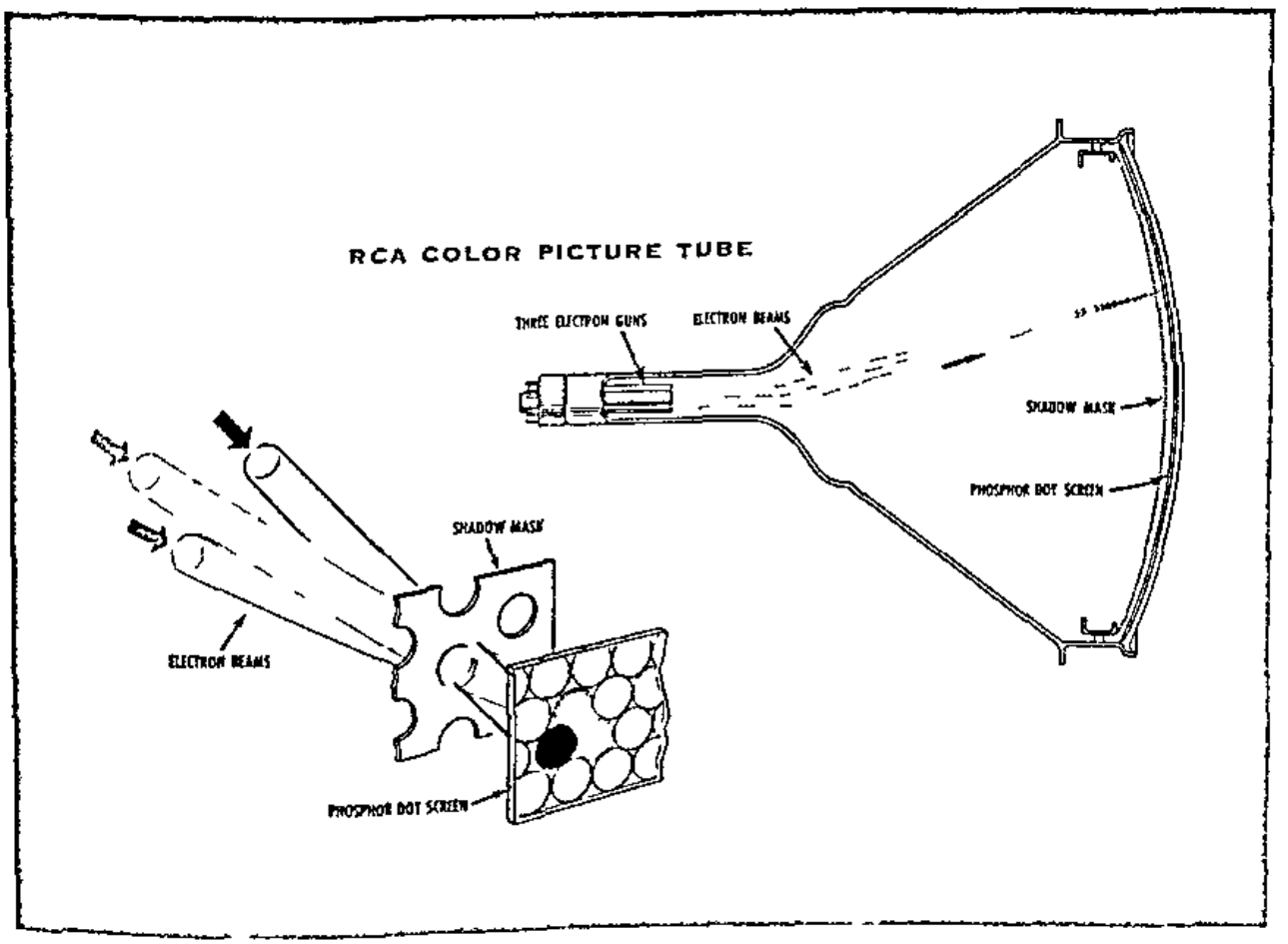
Color test pattern on face of color television picture tube shows how different colors repro duce At bottom is a white panel

Close up of white area on color picture tube shows that it is really composed of many in dividual red, green, and blue dots at the correct relative intensities There are 300,000 dots of phosphor on the face of a standard color picture tube—100 000 of each color As relative intensities are changed, the dominant colors appear and create the chromatic com ponents of the picture



Shadow mask color picture tube has separate electron gun for red, green, and blue beams The three beams move in synchronism and converge at a common point on a perforated metal plate in front of the phosphor screen The beams then diverge and strike precisely located phosphor dots The relative intensities of the beams determine the dominant color produced

Rad o Corporation of America



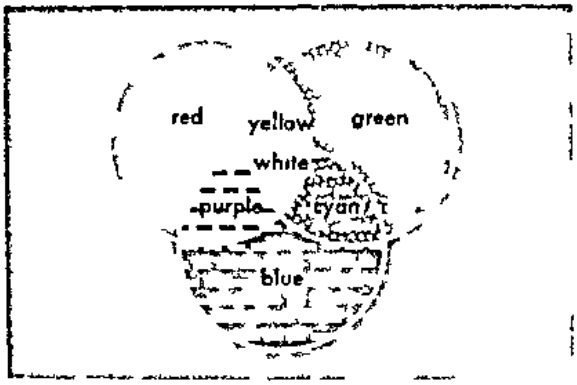


Fig 2 The primary color mixing process

applied to the local subcarrier oscillator following each horizontal synchronizing pulse *See* TELEVISION RECEIVER [R F GU]

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Color temperature

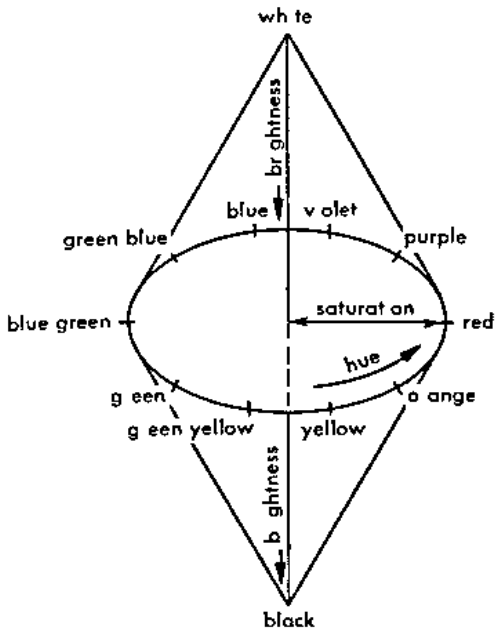
The color temperature of a solid surface for example a lamp filament is the temperature of a so called black body from which the radiant energy has essentially the same spectral distribution as that from the surface *See* BLACK BODY HEAT RADIATION INCANDESCENCE [H G S P J W]

Color vision

The ability to discriminate lights on the basis of their wavelength composition It has been found in man in other primates and in certain species of birds fish reptiles and insects These animals may all be assumed to have visual receptors that respond differentially to the various wavelengths of visible light It is conceivable that each single receptor may react to each wavelength of light with a qualitatively different response Much more plausible however is the hypothesis that the receptors differ one from another in some fundamental way so that each is especially sensitive to light of a particular wavelength composition As far as human vision is concerned the commonly accepted view is that there are three or more types of cone receptor the cones of each type possessing a pigment that selectively absorbs light from a particular region of the visible spectrum *See* VISION

If the wavelength composition of the light is known its color can be specified However the reverse statement cannot be made Reference to the chromaticity diagram shows that a given color may usually be produced by any one of an infinite number of combinations of wavelength (*see* COLOR) This fact supports the fact that there are not many different types of color receptor Each type is capable of being aroused by light from a considerable region of the spectrum rather than being narrowly tuned to a single wavelength of light The success of the trichromatic system of colorimetry using only three primary colors shows indeed that normal color vision may involve only three types of cone receptors with spectral sensitivities having their peaks respectively in the red green and blue regions of the spectrum The number of such curves and their possible shapes have long been subjects for study but as yet no one has been able to produce direct evidence of any structural differences among cones

Color is usually presented to the individual by the surfaces of objects on which a more or less white light is falling A red surface is one that absorbs most of the short wave light and reflects the long wave light to the eye The surface colors are easily described by reference to the color solid shown in the diagram—the central or vertical axis defines the lightness or darkness of the surface as determined by its over all reflectance of white light the lowest reflectance being called black and the highest white The circumference denotes hue related primarily to the selective reflectance of the surface for particular wavelengths of light The distance from central axis to periphery indicates saturation a characteristic that depends chiefly on the narrowness or purity of the band of wavelengths reflected by the surface At the center of the figure is a medium gray surface one which exhibits a moderate amount of reflectance for all wavelengths of light Colors that are opposite one another are called complementaries for example yellow and blue red and blue green purple and green white and black Two complementaries when added together in the proper proportions can



A solid diagram for illustrating the appearance of surface colors (From N L *Munn Psychology 2d ed Houghton Mifflin 1951*)

oppose one another to produce a colorless white or gray Various contrast effects also attest to the opposition of the complementaries Staring at a bright red surface against a gray background for example results in the appearance of a blue green border around the red this is an example of simultaneous contrast Similarly when a red light is turned off there is frequently a negative after image that appears to have the opposite color blue-green

A set of primary colors can be chosen so that any other color can be produced from additive mixtures of the primaries in the proper proportions Thus red green and blue lights can be chosen to produce white purple yellow or any of the various intermediate colors Three color printing color photography and color television are examples of the use of primaries to produce plausible imitations of colors of the original objects

Color blindness Color blindness is a condition of faulty color vision This appears to be the normal state of animals that are active only at night It is also characteristic of human vision when the level of illumination is quite low or when objects are seen only at the periphery of the retina In rare individuals known as monochromats there is total color blindness even at high light levels Such persons are usually deficient or lacking in cone receptors so that their form vision is also poor

Dichromats are partially color blind individuals whose vision appears to be based on two primaries rather than the normal three Dichromasy occurs more often in men than in women because it is a sex linked recessive hereditary condition (*see* HUMAN GENETICS) One form of dichromasy is that of protanopia Protanopes appear to lack the normal red sensitive receptor Red lights appear dim to them and cannot be distinguished from dim yellow or green lights A second form is deuteranopia In

green A third and much rarer form of dichromat is the tritanope Tritanopia involves a confusion among the greens and blues

Many so called color blind individuals have trichromatic vision of a sort but fail to agree with normal subjects with respect to color matching or discrimination tests Protanomaly is a case of this type in which there is subnormal discrimination of red from green with some darkening of the red end of the spectrum Deuteranomaly is a mild form of red green confusion with no marked brightness loss Nearly 8% of human males have some degree of anomalous or dichromatic color vision as a result of hereditary factors, less than 1% of females are color defective A few forms of color defect result from abnormal conditions of the visual system brought on by poisoning drugs or disease

Color blindness is most commonly tested by the use of color plates in which various dots of color define a figure against a background of other dots The normal eye readily distinguishes the figure but the colors are so chosen that even the milder forms of color anomaly cause the figure to be indistinguishable from its background Other tests involve the ability to mix or distinguish colored lights or the ability to sort colored objects according to hue

Theories. Theories of color vision are faced with the task of accounting for the facts of color mixture contrast, and color blindness

Young Helmholtz theory This theory assumes the existence of three types of color receptor that respond to short, medium and long waves of visible light respectively Primary colors are those that stimulate most successfully the three types of receptor, a mixture of all three primaries is seen as white or gray A mixture of two complementary colors also stimulates all three Blue light for example stimulates the blue sensitive receptors hence its complementary color is yellow which stimulates both the red receptors and the green Protanopia results from the loss of the red receptor Deuteranopia is not so simply accounted for however Loss of the green receptor would result in low brightness as well as color confusion and this is not always found to be the case

Hering theory The Hering theory is an opponent colors theory In its simplest form it states that there are three basic types of receptor, but that each is duplex in its responsiveness Thus there is a yellow blue receptor, a red green receptor and a black white receptor The theory obviously was inspired by the opposition of colors that is exhibited by simultaneous contrast, after images and complementary colors A major objection lies in the fact that no such dual response receptors have yet been identified either in vision or in any other sensory modality sense However, opponent responses are common enough in the central nervous system Well known examples are polarization and depolarization of cell membranes excitation and inhibition of nerve impulses or reciprocal innervation of antagonistic response mechanisms

Other theories Various forms of stage theory or zone theory of color vision have been proposed One form combines the principles of the Young Helmholtz and Hering theories It proposes that (1) there are three or more types of cone receptor (2) the responses of red sensitive, green sensitive and blue sensitive receptors (and possibly others) are conducted to the higher visual centers, (3) at the same time interactions are occurring at some stage along these separate conducting paths so that strong activity in a red response path inhibits, for example, the activity of the other response paths and (4) [illegible] specific to the time [illegible] int number [illegible] id at subsequent times the blue and green mechanisms are less inhibited so that blue green after images and borders are commonly experienced as an opponent reaction to strong red stimulation

Another form of stage theory assumes the existence of five types of cone receptor, the three described above plus one specifically sensitive to yel

low light and another that is broadly responsive to all wavelengths within the visible spectrum Ac cording to this theory the interaction stage in volves more specific opposition between the yellow and blue elements on the one hand and the red and green elements on the other There is specific elec trophysiological evidence for this arrangement in the retinas of certain fish A fine tipped electrode records the activity of one type of cell A given type becomes relatively depolarized in response to

another type broadly sensitive throughout the spectrum exhibits only hyperpolarization alone in response to any light

Central factors While the retinal receptors play a major role in color discrimination the retina alone cannot account for all the observed phenom ena Central nervous system factors are evidenced by the fact that a red light in one eye and a green light in the other can be fused to produce an ap pearance of yellow Further evidence of central ef fects is found in the phenomenon of color con stancy The greenness of trees or the redness of bricks is only slightly less vivid when both are viewed through dark or yellow goggles a black cat in the sunshine reflects more light to the eye than a white cat seen by indoor illumination Color vision like other forms of perception is highly de pendent on the experience of the observer and on the context in which the object is perceived *See* NERVOUS SYSTEM [L A R]

Colorimetric analysis

A method of chemical analysis based on the visual identification and comparison of colored solutions This is perhaps better called color comparison since the analyses of colored solutions can gener ally be made only by comparison of the color of the sample with the color of known standards As the human eye is a relatively poor quantitative detector of light intensity especially in the blue and red re g ons of the visible spectrum visual color compari son methods have relatively poor precision $\pm 10\%$ of the amount of material present is often the best result which can be hoped for In some cases the color of the sample is compared with a series of known solutions treated similarly in other cases a series of permanent color standards covering the range of interest is used

Since the light is seldom passed through a mono chromator or filter the total absorption of light in the visible range is observed In some refined in struments filtered light is used to increase the pre cision of the technique The advantages of visual comparison methods are speed simplicity low cost and the need for only limited training of the opera tor A few examples of common colorimetric meth ods are the *o* tolidine method for residual chlorine in water various organic indicator procedures for the pH of aqueous solutions and the Nessler method for ammonia

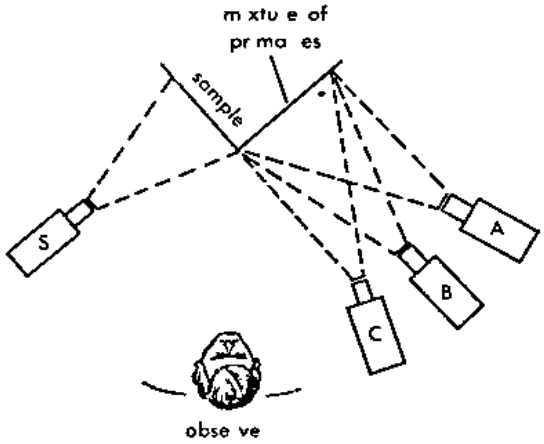
Prior to the wide acceptance and availability of photoelectric colorimeters about 1940 several very complex and fairly accurate visual color compara tors were available Since these instruments are comparable in cost to the photoelectric instru ments but have poorer accuracy they are seldom used today *See* OPTICAL METHODS OF CHEMICAL ANALYSIS SPECTROPHOTOMETRIC ANALYSIS [R F G]

Colorimetry

Any technique by which an unknown color is evalu ated in terms of known colors Colorimetry may be visual photoelectric or indirect by means of spec trophotometry These techniques are widely used in scientific studies involving the appearance of ob jects and lights but are of greatest importance in the color specification of the raw materials and finished products of industry

Visual colorimetry In this type the unknown color is presented beside a comparison field into which may be introduced any one of a range of known colors from which the operator chooses the one matching the unknown To be generally ap plicable the comparison field must not only cover a sufficient color range but must also be continu ously adjustable in color in three independent ways This adjustment may be by (1) superposition of light primaries (for example red green and blue) in any required proportions (additive colorimeters see illustration) (2) successive transmission through primary filters (for example yellow cyan and magenta) of adjustable thickness (sub tractive colorimeters) or (3) a rotating sectored disk whose four differently colored sectors are ad justable in relative area (disk colorimeters) Many colorimeters however provide but a single series of comparison colors and are limited to specimens known in advance to have colors identical or nearly identical to one or another of this single series of colors

Chemical colorimeters measure the concentration of a known constituent in solution by comparison with colors of a few solutions of known concentra



The g ven color n S s matched by the add t on of any three pr mar es in A B and C Th s dev ce is called a tr color meter

tions of that constituent Interpolation among these fixed colors is provided by continuous variation of thickness of solution through which the light must pass on its way to the eye of the operator *See* COLORIMETRIC ANALYSIS

Indirect colorimetry In this type the light leaving the unknown specimen is split into its component spectral parts by means of a prism or diffraction grating and the amount of each component part is separately measured by a photometer (*see* SPECTROPHOTOMETRIC ANALYSIS) The quantity evaluated is spectral radiance of a light source spectral transmittance of a filter (glass plastic gelatin or liquid) or spectral reflectance of an opaque body

From spectrophotometric data such as these it is possible to predict the amounts of known light primaries (red green blue) required to produce the color of the specimen by superposition This prediction is made by using the color mixture functions (CIE standard observer) recommended for this purpose in 1931 by the International Commission on Illumination (CIE) These functions give the amounts of the light primaries required by the standard observer to match unit radiance of each part of the spectrum in turn The prediction is found by adding up for the whole visible spectrum the amounts of red primary appropriate to the unknown specimen and then doing the same thing for the appropriate amounts of green and blue primaries

Photoelectric colorimetry In this type the light leaving the specimen is measured separately by three photocells The spectral sensitivity of these photocells is adjusted usually by color filters to conform as closely as possible to the three color mixture functions for the average normal human eye (CIE standard observer) The responses of the photocells give directly the amounts of red green and blue primaries required to produce the color of the unknown specimen for the kind of vision represented by the three photocells Photoelectric colorimetry is used primarily for the control of the colors of manufactured articles to a preestablished tolerance

Metamers If two objects have the same color because the light leaving one of them toward the eye is spectrally identical to that leaving the other any type of colorimetry serves reliably to establish the fact of color match If however the two lights are spectrally dissimilar they may still color match for any one observer and such pairs of lights are called metamers Normal color vision differs sufficiently from person to person so that a metameric color match for one observer may be seriously mismatched for another On this account the question of color match of spectrally dissimilar lights can be reliably settled only by the indirect method which uses spectrophotometry combined with a precisely defined standard observer Examples are the color matching of a fluorescent lamp to an incandescent lamp or the matching of a specimen colored by one set of dyes or pigments to a specimen colored by a different set *See* COLOR COLOR VISION, FILTER COLOR [D B J]

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Columbiformes

An order of birds containing 3 families of which the best known is that of the pigeons and doves (Columbidae) containing almost 300 species Pigeons are virtually cosmopolitan but are most abundant in tropical regions Most lay white eggs in a few the shells are lightly pigmented Incubation is shared by the sexes the male by day and the female by night The newly hatched young are at first fed a regurgitated glandular secretion of the crop called "pigeon milk" Well known species include the domestic pigeon descended from the rock dove (*Columba livia*) of Eurasia, the extinct but formerly fantastically numerous passenger pigeon (*Ectopistes migratorius*), the domestic ring dove (*Streptopelia risoria*), and the crowned pigeons (*Goura*) of New Guinea long in demand for their lovely head plumes Sharing with pigeons the habit unique among birds of drinking directly without tilting the head back are the superficially partridgelike sand grouse (Pteroclidae) of arid parts of the Old World The extinct family Raphidae of the Mascarene Islands included the famous dodo (*Raphus cucullatus*) *See* AVES [K C P]

Columbite

A mineral with composition $(Fe,Mn)Cb_2O_6$ Tantalum substitutes for columbium (niobium) in all proportions and a complete series extends to tantalite $(Fe,Mn)Ta_2O_6$ Columbite without some tantalum is rare iron and manganese also vary considerably in their relative amounts It crystallizes in the orthorhombic system in short prismatic crystals There is perfect side pinacoid cleavage The hardness is 6 (Mohs scale) and the specific gravity is 5 2 for pure columbite both increase with increased amounts of tantalum The luster is submetallic and the color iron black Columbite is found in granite pegmatites and in detrital deposits derived by their disintegration

Columbite is the chief ore mineral of columbium and is found in small amounts in many pegmatites throughout the world The chief producing countries are the Belgian Congo and Nigeria where it is recovered from decomposed granite *See* NIOBIUM TANTALITE, TANTALUM [C S HU]

Column

A relatively long member in compression Columns are classified according to behavior under load and in terms of slenderness ratio The slenderness ratio of a column is L/r, the ratio of length L to ra

dius of gyration r about principal axes of the sec tion

Columns are also differentiated according to conditions of end restraint such as free or pin end and position wholly fixed or fixed only against rota tion The type of loading is defined as axial or ec centric with respect to the centroids of the end sections Columns are used in such structures as bridges buildings and aircraft structures They are also used in machinery as for example pistons connecting rods and other slender elements

Column design A column is designed to sup port a required load in compression Columns of different slenderness ratio behave differently under load and thus the criteria for maximum capacity d fier Long columns those with high slenderness ratio become unstable at a critical load usually the maximum resistance with compressive stresses less than the elastic limit so that failure is a phe nomenon of elastic instability The column buckles with a lateral deflection or with a twist Columns of intermediate length with slenderness ratios be tween long columns and short blocks develop in elastic stresses with ultimate failure by inelastic buckling Short blocks have such dimensions that lateral deflections can be neglected failure being determined by the yield strength of the material

The load capacity of columns is further influ enced by the properties of the material end condi tions initial crookedness defects and residual stresses particularly in the intermediate range of slenderness

Elastic buckling Abrupt increase of lateral de flection of a compression member at a critical load while the stresses are wholly elastic constitutes elastic buckling An initially straight column under axial load remains straight until a condition of neu tral equilibrium is reached when the column will continue to support the full load with considerable lateral deflection A small increase of load above this condition of neutral equilibrium causes a large increase in deflection leading to collapse

Leonhard Euler s expression for the critical buck ling load P of an ideally straight axially loaded column with no rotational restraint at the ends is $P = \pi^2 EI/L^2$ from which the critical average stress S is

$$S_{cr} = \pi^2 E/(L/r)^2$$

where E is modulus of elasticity of the perfectly elastic material I is the moment of inertia L/r is the slenderness ratio and r is the least radius of gyration of the section Euler s formula is directly applicable to the design of long columns whose safe load is Euler s predicted critical load divided by a factor of safety Elastic buckling loads for col umns with other restraining conditions modifying the elastic curve are found by using the length be tween points of contraflexure of the deflected mem ber as the effective length KL where $K = 1$ for ro tat onally free ends $K = 0.5$ for both ends fixed $K = 2$ for one end fixed with the other free to ro tate and translate and $K = 70$ for one end rota tionally fixed with the other only fixed in position The buckling load depends only on the stiffness E and the slenderness ratio KL/r which is determined by end conditions In aircraft design end condi tions are designated restraint coefficients C $1/k^2$ with $P = C\pi EI/L^2$ The coefficient is taken to provide partial restraint for various types of end connections

Eccentrically loaded columns Off axis loads subject a column to combined bending because of end moments and axial load Deflections are pro duced immediately on application of the load and increase rapidly until the beam yields under com pression because of the combined loading with in elastic buckling ultimately producing the collapse Buckling may be accompanied by twisting depend ing upon the shape of the section lateral bracing and slenderness

An estimate of the load capacity can be made according to either initial yield or relations involv ing ratios of actual to ultimate thrust and moment called interaction formulas (*see* BEAM COLUMN) When initial yield under the combined stress is as sumed to be the critical condition leading to col lapse the corresponding load is taken as a mini mum value of the collapse load The limiting average stress for design is defined by the secant formula derived for free end columns of material having a distinct yield point loaded with equal end moments As used actual load eccentricity is in creased to account for crookedness defects acci dental eccentricity and the effect of residual stresses This formula is prescribed in bridge spec ifications for steel with modifications to provide for effective length and double eccentricity

Interaction formulas are more convenient for general application They depend upon the for mulas adopted for predicted column and bending resistance

Inelastic buckling When compressive stress in the column reaches the elastic limit before elastic buckling develops any sudden increase of deflec tion or twist leads to collapse The behavior of col umns under inelastic stress depends on the shape of the stress strain curve as determined by testing a short length of the actual column section Because of residual stresses caused by unequal cooling of rolled sections structural rolled steel has a propor tional limit approximately half the yield point for annealed material and the stress strain curve has a gradual knee similar to alloy steels aluminum or magnesium alloys (*see* STRESS AND STRAIN) Euler s formula is not applicable to these materials be cause the modulus of elasticity E is not constant An analytical approach called the tangent modulus theory leads to prediction of the buckling load

The tangent modulus formula also known as the Engesser formula is a modification of Euler s for mula

$$S_{cr} = \frac{\pi^2 E_T}{(KL/r)^2}$$

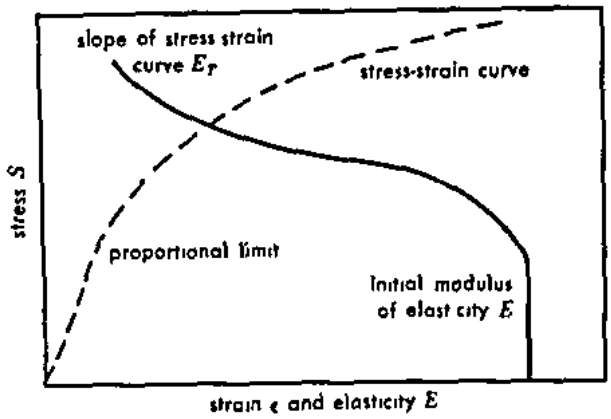


Fig 1 Stress strain curve for an aluminum alloy

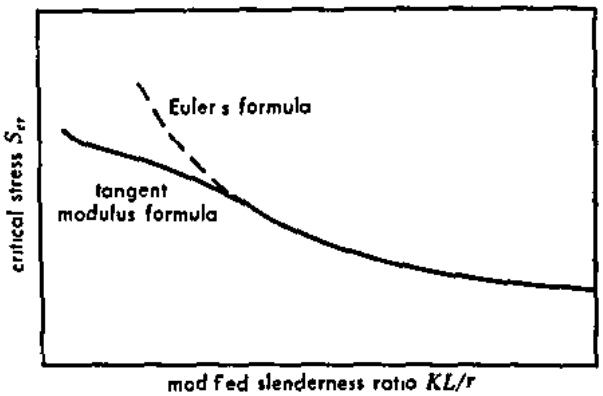


Fig 2 Column resistance to inelastic buckling

where E_T is the slope of the stress strain curve at the critical stress (Fig 1) Values of E_T and stress S are interdependent Solution is accomplished by trial or graphically for a given value of KL/r Also values of $r\sqrt{E_T/S}$ are consistent with particular values of KL/r and a curve can be constructed to represent column resistance (Fig 2) The resist ance curve in the inelastic range can be repre sented by a parabola For columns of wide flange steel sections, in which residual stress is an impor tant factor, a recommended column strength equa tion is

$$S_{cr} = S_y - \frac{S_y^2}{4\pi^2 E}\left(\frac{KL}{r}\right)^2$$

where S_y is the stress of the material at its yield point

Local buckling Relatively thin elements of a column section may buckle locally in a series of waves or wrinkles before the member as a whole buckles elastically The outstanding legs of thin angles thin flanges of channels or thin plates con necting parts of the section are susceptible to lo cal buckling Thin wall tubes buckle in a similar manner Usually local buckling reduces the load ca pacity of the member, but redistribution of stresses may produce conditions favorable to increased col umn loads The likelihood of local buckling can be predicted by the theory of flat plates which in volves the thickness to width ratio and edge sup porting conditions *See* PLATE, STRUCTURAL

Shear is produced in columns by (1) variation of bending moment associated with initial and buck ling curvatures causing a shear force (2) lateral external forces and (3) lateral forces transmitted by distortion of the connecting members of frame of which the column forms a part An allowance for shear is taken as 2-2½% of the axial load for col umns composed of aluminum alloys or structural steel In rolled sections the web provides shear re sistance whereas in open web members resistance is provided by lacing or batten plates

Lacing A system of diagonal bars connected to the elements of an open web column forms a truss capable of resisting transverse shear (Fig 3) These bars tying the separated elements together are usually inclined at 45° or 60°, and are designed to act in either tension or compression For long columns of this type, the effective length is in creased empirically The slenderness ratio of the flange elements between lacing bar connections is limited by specification to avoid local buckling

Batten plates Alternatively, flat plates can be attached transversely to the flange of an open web column at intervals along the length (Fig 4) These batten plates serve as ties holding the ele ments in position and, together with the column flanges they form a continuous frame resisting transverse shear The flanges and plates are sub ject to bending and shear Because of flexibility of

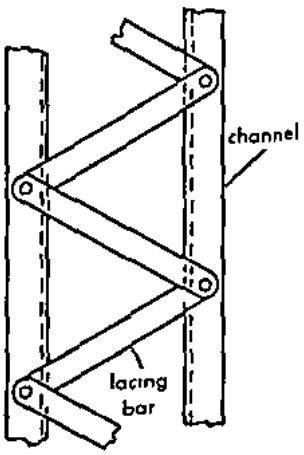


Fig 3 Laced-channel section

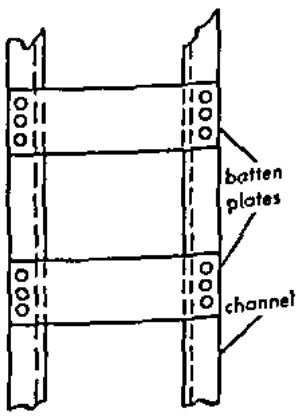


Fig 4 Batten plates

the column the effective length determining buck ling strength is increased The unsupported length between batten plates is limited to provide smaller slenderness in the flange elements than in the over all column to avoid local buckling

Twist buckling The dimensions and shape of a column section should provide a large radius of gyration to reduce KL/r and increase the allowable stress A large radius of gyration requires that the area be spread far from the centroid and for a given area the elements of the section become thin Columns with open sections composed of thin ele ments particularly angle and T sections are sus ceptible to failure by local buckling or by twist ing

A short compression member may fail by twist ing of the section while the axis remains straight This is called primary torsional buckling in which the member becomes torsionally unstable at a con dition of neutral equilibrium similar to a long col umn in bending The critical load may be deter mined by energy methods Columns which bend upon approaching *maximum load are subjected* to transverse shear which may also produce twist buckling if the shear center does not coincide with the centroid Local buckling strength determined by plate theory gives an approximation of the twist buckling load

Column base plates Column loads and moments are transferred by base plates to footings and foundations The plate must be large enough to distribute the load without excessive bearing stresses The column is connected to the plate by welded or riveted angle connections Where no mo ment is involved the connection only maintains alignment The pressure of the plate on the founda tion is nonuniformly distributed and depends on relative stiffnesses

An approximate design procedure assumes uni form pressure and cantilever action of the plate projecting beyond the column boundaries Anchor age is not required for axially loaded columns or when the resultant pressure due to moment and load falls within the mid third of the base width However bolts are used to position the column Where lateral forces such as wind pressures are involved the resultant moment requires anchor bolts [W J KR]

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Combinations and permutations

Out of n numbered objects a_1 a_2 a_n one ob ject may be chosen in n ways out of the remaining $n-1$ objects a second object may be chosen in $n-1$ ways and so on Thus the number of differ ent ordered samples of k elements (k tuples) equals

$$(n)_k = n(n-1)(n-2)\cdots(n-k+2)(n-k+1)$$

tion in a new order Hence the number of reorder ings or permutations of n objects equals

$$n! = n(n-1)(n-2)(n-3)\cdots 3\cdot 2\cdot 1$$

($n!$ is read n factorial)

A sample (subpopulation) of k elements without regard to order is called combination Thus the $k!$ reorderings of a sample of size k yield the same combination whence the number of k combinations of n elements equals $(n)_k/k!$ This number is called the binomial coefficient and is written in ei ther of the forms

$$\binom{n}{k} = C_k^n = \frac{n(n-1)(n-2)\cdots(n-k+1)}{1\cdot 2\cdot 3\cdots k} = \frac{n!}{k!(n-k)!}$$

Choosing k objects out of n is equivalent to par titioning the n objects into two groups of sizes k and $n-k$ without regard to order More generally n objects may be partitioned into a first second rth group of size s_1 s_2 s_n respec tively (where $s_1 + s_2 + \cdots + s_r = n$) in

$$n!/(s_1!\ s_2!\cdots s_r!)$$

ways This multinomial coefficient gives also the number of distinguishable permutations in the case where the n given objects (for example the letters of the word Mississippi) are divided into r groups such that the objects within each group are indis tinguishable (In fact each such permutation is a partitioning allotting the n places to the r different groups)

Binomial coefficients and factorials are widely used outside combinatorial analysis Factorials are related to the Gamma function by $n! = \Gamma(n+1)$ Stirling s formula $n! \sim (2\pi)^{1/2} n^{n+1/2} e^{-n}$ provides an excellent approximation (underestimating with a relative error of about $1/12n$) Binomial coeffi cients may be approximated by the normal den sity *See* DISTRIBUTION (PROBABILITY) GROUP THEORY [W F]

Combining volumes, law of

This law states that when gases take part in chemi cal reactions the volumes of the reacting gases and those of the products if gaseous are in the ratio of small whole numbers provided that all measure ments are made at the same temperature and pres sure The law is illustrated by the following reac tions

1 One volume of chlorine and one volume of hydrogen combine to give two volumes of hydrogen chloride

2 Two volumes of hydrogen and one volume of oxygen combine to give two volumes of steam

3 One volume of ammonia and one volume of hydrogen chloride combine to give solid ammonium chloride

4 One volume of oxygen when heated with solid carbon gives one volume of carbon dioxide

It should be noted that the law applies to all re actions in which gases take part even though

The law of combining volumes was put forward on the basis of experimental evidence and was first explained by Avogadro's hypothesis that equal volumes of all gases and vapors under the same conditions of temperature and pressure contain identical numbers of molecules *See* AVOGADRO NUMBER

The law of combining volumes is similar to the other gas laws in that it is strictly true only for an ideal gas though most gases obey it closely at room temperatures and atmospheric pressure Under high pressures used in many large scale industrial operations such as the manufacture of ammonia from hydrogen and nitrogen the law ceases to be even approximately true *See* GAS [T C W]

Combustion

The burning of any substance whether it be gaseous liquid or solid In combustion a fuel is oxidized evolving heat and often light The oxidizer need not be oxygen per se The oxygen may be a part of a chemical compound such as nitric acid (HNO_3) or ammonium perchlorate (NH_4ClO_4) and become available to burn the fuel during a complex series of chemical steps The oxidizer may even be a nonoxygen containing material Fluorine is such a substance It combines with the fuel hydrogen liberating light and heat In the strictest sense a single chemical substance can undergo combustion by decomposition with emission of heat and light Acetylene ozone and hydrogen peroxide are examples The products of their decomposition are carbon and hydrogen for acetylene oxygen for ozone and water and oxygen for hydrogen peroxide

Combustion of solids and liquids The combustion of solids such as coal and wood occurs in stages First volatile matter is driven out of the solid by thermal decomposition of the fuel and burns in the air At usual combustion temperatures the burning of the hot solid residue is controlled by the rate at which oxygen of the air diffuses to its surface If the residue is cooled by radiation of heat combustion ceases The first product of combustion at the surface of char or coke is carbon monoxide This gas burns to carbon dioxide in the air surrounding the solid unless it is chilled by some surface Carbon monoxide is a poison and it

health

Liquid fuels do not burn as liquids but as vapors above the liquid surface The heat evolved evaporates more liquid and the vapor combines with the oxygen of the air

Spontaneous combustion This occurs when certain materials are stored in bulk The oxidizing action of microorganisms often produces the initial heat As the temperature increases air trapped in the material takes over the oxidation process liberating more heat Because the heat cannot be dissipated to the surroundings the temperature of the material rises still more and the rate of oxidation increases Eventually the material reaches an ignition point and bursts into flame Coal is subject to spontaneous combustion and is generally stored in shallow piles to allow the heat of oxidation to dissipate

Combustion of gases At ordinary temperatures molecular collisions do not usually cause combustion At elevated temperatures the collisions of the thermally agitated molecules are more frequent. More important as a cause of chemical reaction is the greater energy involved in the collisions Moreover it has been reasonably well established that there is very little combustion attributable to direct reaction between the molecules Instead a high energy collision dissociates a molecule into atoms, or free radicals These molecular fragments react with greater ease and the combustion process proceeds generally by a chain reaction involving these fragments An illustration will make this clear The combustion of hydrogen and oxygen to form water does not occur in a single step

$$2H_2 + O_2 = 2H_2O$$

In this seemingly simple case some fourteen reactions have been identified A hydrogen atom is first formed by collision, it then reacts with oxygen molecules

$$H + O_2 = OH + O$$

forming an OH radical The latter in turn reacts with a hydrogen molecule

$$OH + H_2 = H_2O + H$$

forming water and regenerating the H atom which repeats the process This sequence of reactions constitutes a chain reaction Sometimes the *O atom* reacts with a hydrogen molecule to form an OH radical and another H atom

$$O + H_2 = OH + H$$

Thus a single H atom can form a new H atom in addition to regenerating itself This process constitutes a branched chain reaction Atoms and radicals recombine with each other to form a neutral molecule either in the gas space or at a surface after being adsorbed Thus chain reactions may be suppressed by proximity of surfaces and the number and length of the chains may be controlled by regulating the temperature the composition of the mixtures and other conditions Under certain conditions where the rate of chain branching equals or exceeds the rate at which chains are terminated the combustion process speeds up to explosive proportions, because of the rapidity of molecular events a large number of chains are formed in a short time so that essentially all of the gas undergoes reaction at the same time, that is an explosion results The *branched* chain type of explosion is similar in principle to atomic explosions of the fission type where more than one neutron is generated by the reaction between a neutron and a uranium nucleus Another cause of explosion in gaseous com

bustion arises when the rate at which heat is lib erated in the reaction is greater than the rate at which the heat dissipates to the surroundings The temperature increases accelerates the reaction rate liberates more heat and so on until the entire gas mixture reacts in a very short time This type of explosion is known as a thermal explosion There are cases intermediate between branched chain and thermal explosions which depend upon the type and proportion of gases mixed the temperature and the density

During slow combustion intermediate products can be isolated Aldehydes acids and peroxides are formed in the slow combustion of hydrocarbons and hydrogen peroxide is formed in the slow combus tion of hydrogen and oxygen At the relatively low temperature of combustion of paraffin hydrocarbons such as propane butane and ethers a bluish glow is observed This is due to emission of light from activated formaldehyde formed in the process This glow is called a cool flame

In the gaseous combustion and explosive reac tions described above the processes proceed simul taneously throughout the vessel The gas mixture in a vessel may also be consumed by a combustion wave which when initiated locally by a spark or a small flame travels as a narrow intense reaction zone through the explosive mixture The gasoline engine operates on this principle Such combustion waves travel with moderate velocity ranging from 1 ft/sec in hydrocarbons and air to 20–30 ft sec in hydrogen and air The introduction of turbu lence or agitation accelerates the combustion wave The accelerating wave sends out compression or shock waves which are reflected back and forth in the vessel Under certain conditions these waves coalesce and change from a slow combustion wave to a high velocity detonation wave In hydrogen and oxygen mixtures the speed is almost 2 mi/sec The pressure created by detonation can be very high and dangerous

Combustion mixtures can be made to react at lower temperatures by employing a catalyst The molecules are adsorbed on the catalyst where they may be dissociated into atoms or radicals and thus brought to reaction condition An example is the catalytic combination of hydrogen and oxygen at ordinary temperatures on the surface of platinum The platinum glows as a result of the heat liberated in the surface combustion *See* CHAIN REACTION CHEMICAL EXPLOSION AND EXPLOSIVE FLAME FREE RADICAL FUEL, KINETICS (CHEMICAL)

[BL]

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Combustion chamber

The space at the head end of an internal combus-tion engine cylinder where most of the combustion takes place

Spark ignition engine In the spark ignition en gine combustion is initiated in the mixture of fuel and air by an electrical discharge (*see* SPARK PLUG) The resulting reaction moves radially across the combustion space as a zone of active burning known as the flame front The velocity of the flame increases nearly in proportion to engine speed so that the di tance the engine shaft turns during the burning process is not seriously affected by changes in speed

For high efficiency it is desirable to burn the mixture as quickly as possible while the piston is near top center position (constant volume com bustion) Short burning time is achieved in modern combustion chambers by a combination of several factors The spark plug is located in a central posi tion so as to minimize the distance the flame front must travel The chamber itself is made as compact as possible for the required volume to keep the flame paths short A compact chamber presents less wall area to the enclosed volume thereby re ducing the heat loss from the flame front Since the motion of the flame depends upon transferring heat from the flame to the adjacent layers of unburned mixture the reduced heat loss increases the flame velocity One of the most important methods for increasing flame velocity is to provide small scale turbulence in the cylinder charge This is often done by designing the chamber so that part of the

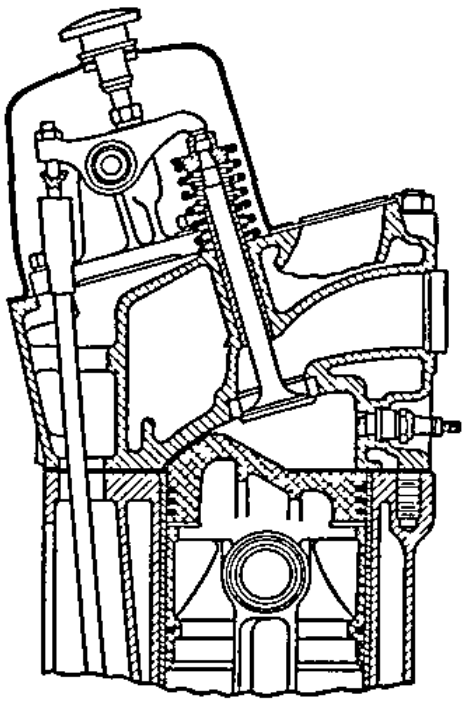


Fig 1 Combustion chamber for spark ignition engine (From L C Lichty Internal-combustion Engines 6th ed McGraw-Hill 1951)

piston head comes close to the cylinder head at top center position (Fig 1) The so-called "squish" that results forces the mixture in this region into the rest of the combustion chamber at high velocity The turbulence produced by this motion increases the rate of heat transfer from the flame to the unburned mixture greatly increasing the flame velocity

Occasionally a high burning rate or too rapid change in burning rate gives rise to unusual noise and vibration This is called engine roughness Roughness may be reduced by using less squish and by shaping the combustion chamber to control the area of the flame front A short burning time is helpful in eliminating knock because the last part of the charge is burned by the flame before it has time to ignite spontaneously (*see* COMBUSTION KNOCK)

For high power output the combustion chamber shape must permit the use of large valves with space around them for unrestricted gas flow (*see* VALVE TRAIN) Some compromise may be necessary between the requirements for high efficiency high output and freedom from combustion knock

Compression ignition engine In compression ignition (diesel) engines the fuel is injected late in the cycle into highly compressed air mixing must take place quickly if the fuel is to find oxygen and burn while the piston remains near top center Rapid mixing is particularly important in the smaller sized engines which are usually operated at higher rotative speeds In simple combustion chambers mixing can be improved by producing a general swirl in the cylinder so that the air is moving relative to the fuel spray during injection Swirl is often produced by masking part of the periphery of the inlet valves or by giving an angle to the inlet ports so that the air enters with a tangential component of velocity This circular motion persists until injection takes place swirl velocity increases with the higher inlet velocities present at high engine speeds In this way mixing becomes more rapid as the time available for mixing becomes less

In some compression ignition engines a considerable fraction of the cylinder air is forced into a small auxiliary chamber (pre chamber) during the compression stroke The entrance to the auxiliary chamber may be a short tangential passage which imparts a rapid swirl to the air in the chamber (Fig 2) The fuel is injected into the swirl

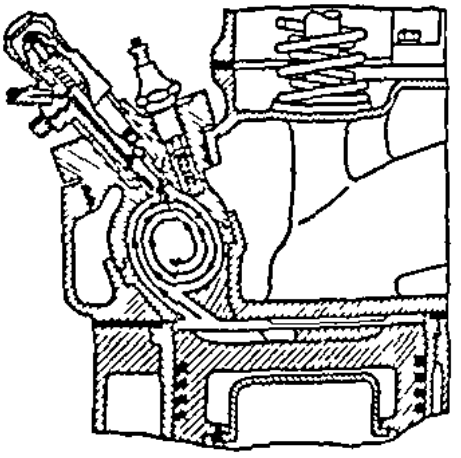


Fig 2 Combustion chamber for diesel engine with high swirl pre-chamber (*From J B Fisher Development of a combustion chamber for medium and high-speed diesel engines SAE Journal 57(5) 59–60 1949*)

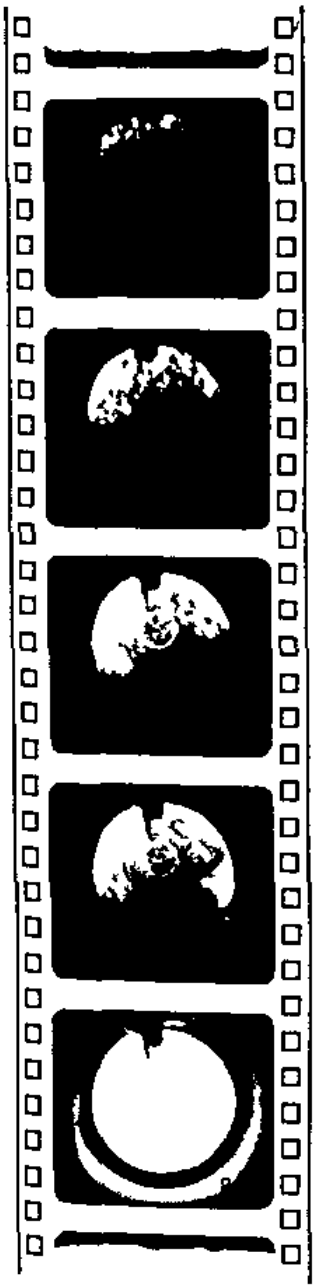
In compression ignition engines the injected fuel ignites from contact with the hot cylinder air after a short delay There is no flame front travel to limit the combustion rate and if mixing of fuel and air is too thorough by the end of the delay period high rates of pressure rise result and the operation of the engine is rough and noisy To avoid this condition the pre chambers of most compression ignition engines operate at high temperature so that the fuel ignites soon after injection begins This reduces the amount of fuel present and the degree of mixing at the time ignition takes place

High rates of pressure rise can also be reduced by keeping the fuel separated from the main body of the air until the end of the delay Rapid mixing must then take place to insure efficient burning of the fuel near top center A combustion chamber which appears to accomplish this separation and subsequent mixing operates as follows The fuel is injected into a small auxiliary chamber which contains only a small fraction of the total air in the cylinder The explosion, with its resulting high pressure in the pre-chamber forces the burning fuel into the main combustion space at high velocity The shape of the combustion space causes the fuel to mix rapidly with the main air charge In this chamber the mixing rate probably does not increase with engine speed (ARR)

Combustion knock

In spark ignition engines knock is the sound and other effects associated with ignition and rapid combustion of the last part of the charge to burn before the flame front reaches it

As the flame travels from the spark plug toward the far end of the combustion space the gas behind the flame front heated by combustion expands and rapidly compresses the unburned mixture ahead of the flame In this way the temperature of the unburned mixture is raised above its self ignition temperature Time consuming chemical reaction must take place in this gas however before actual ignition takes place If the flame front travels rapidly enough to consume the unburned mixture before these reactions are completed normal combustion without knock takes place If the reactions proceed too rapidly or if the flame front travels too slowly the entire last part of the charge may burn almost instantaneously producing a strong pressure wave which is reflected back and forth across the combustion space at the speed of sound The motion of the cylinder head and walls under



Photographic sequence shows (top to bottom) slow normal fuel burning terminating in rapid knock combustion

the action of this shock wave causes the high pitched sound known as combustion knock (Some authorities refer to the above phenomenon and its effects as detonation although the process is not the same as detonation in explosives)

The results of combustion knock or engine detonation include undesirable noise and over heating or mechanical damage to engine parts such as pistons and spark plugs Most of the power loss commonly attributed to combustion knock is probably an indirect effect the result of overheated spark plug electrodes, which ignite the mixture far in advance of the normal ignition spark

Effect of engine Because of these undesirable effects, much effort is made to avoid combustion knock Any change in engine design or operating conditions that lengthens the delay period tends to allow the flame to burn the last part of the charge normally The delay period may be lengthened by reducing the temperature or pressure to which the last part of the charge is subjected during the time of flame travel Closing the throttle retarding the ignition timing, or reducing the compression ratio reduce the pressures and temperatures in the last part of the charge and lengthen the delay, thereby diminishing or eliminating combustion knock The power or efficiency of the engine is reduced by these control measures The delay period may also be lengthened and knock eliminated by using a very rich or a very lean fuel air ratio but again power or efficiency is adversely affected

Another method for reducing combustion knock is to reduce the time required for the flame front to cross the combustion space If the burning time is short the last part of the charge will be consumed by the flame before the delay reactions are completed Burning time may be reduced by using a compact combustion chamber with centrally located or multiple spark plugs One factor in combustion chamber design which is most effective in eliminating knock by increasing flame velocity, is the production of small scale turbulence The usual method of producing turbulence is to design one part of the piston head to come close to the cylinder head at top center forcing part of the charge into the rest of the chamber Some authorities believe that the close approach of the parts increases the cooling of the gas left in the space between them and slows the delay reactions if the last part of the charge is in this quench area

Eliminating knock by a change in one engine variable will often permit a more nearly optimum adjustment of another For example a retarded spark or a rich mixture will permit a wider open throttle to be used which will give more power, a better combustion chamber will permit a higher compression ratio with increased engine efficiency

Effect of fuel. A fuel of high octane number resists combustion knock principally because it has a longer self ignition delay than other fuels under a given set of operating conditions High octane gasoline burns in the same manner and with the same flame velocity as low octane gasoline Combustion knock can thus be eliminated by using high octane fuel without loss of power or efficiency

The long delay of high octane fuel results either from its natural chemical make up, or from the addition of an antiknock material Hydrocarbon fuels with compact molecular structures are less likely to knock One of the most effective antiknock additives is tetraethyllead $Pb(C_2H_5)_4$ which is added to almost all gasoline sold for automobile or aircraft use In general fuels of lower natural octane number show a somewhat greater response to the addition of a given amount of tetraethyllead

High rates of pressure rise or sudden increases in the rate of pressure rise sometimes produ noises, which are confused with combustion k

In spark ignition engines these effects may be caused by abnormally high burning rates In compression ignition engines they may be caused by the rapid combustion of the first part of the fuel to be injected *See* BURNING VELOCITY MEASUREMENT, OCTANE NUMBER [A R R]

Combustion wave measurement

Observation of the transient phenomena accompanying combustion When an explosive mixture is ignited a zone of reacting material propagates through the mixture The flow of heat and chemical reactants from the ignition source into adjacent layers of the mixture causes a self sustaining process to occur usually manifest as a flame this phenomenon is the combustion wave Since combustion can occur under diverse conditions many types of measurement have been applied to the combustion wave

The rate at which the wave moves through the mixture is the flame speed *See* BURNING VELOCITY MEASUREMENT

Measurement of the intermediate reactants and the products of combustion is needed for an understanding of the chemical reactions that sustain combustion waves For example a mixture of hydrogen and oxygen will support a combustion wave in which the product of combustion is water The intermediate reactants include hydrogen and oxygen atoms and hydroxyl radicals Evidence for the hydroxyl radicals is found from spectroscopic measurements *See* SPECTROSCOPY OF COMBUSTION

The temperature rise that accompanies a combustion wave can be measured by various techniques those based on (1) radiation and absorption properties of gases (2) temperature sensitive probes (3) velocity of sound through gases (4) *critical flow* velocities of gases and (5) dissociation reactions of certain gases

By the usual definition the temperature of a gas *refers* to molecules in thermodynamic equilibrium In a system undergoing active combustion *molecules* can gain excess energy in their vibrational and rotational degrees of freedom Under these nonequilibrium conditions it is not possible to define a unique temperature

Spectroscopic measurement of band spectra can *give temperatures* based on vibrational and rotational motion Other spectroscopic methods include line reversal and two-color *pyrometry*

Temperature sensitive probes include the familiar thermocouple By the use of adequate shielding and corrections *temperatures of* low velocity flames can be accurately measured, however these devices are not entirely satisfactory for complex flames having a large *temperature* distribution Compensated hot wires have also been used with transparent flames in regions where combustion is complete

The flow of gases through the combustion wave is an important aid to understanding the shape and structure of the wave Illumination of fine particles of magnesium oxide flowing through the flame gives information on direction and velocity of gas flow [R S S]

Comet

One of the two major types of bodies moving in closed orbits about the Sun As compared to planets and asteroids—the other major group—comets are characterized by their more eccentric orbits and greater range of inclination to the ecliptic

Appearance and model Comets are nebular in appearance and frequently show a tail Only part of a comet s light is due to reflected sunlight the rest comes from solar energy which is absorbed by cometary gases and reradiated and probably from exothermic reactions of some cometary constituents

The visible phenomena and the dynamical behavior of comets are frequently variable and complex It is helpful to have a physical model to which these observations can be related One generally accepted model particularly suitable for this purpose was proposed by F L. Whipple Whipple suggested that the main core of comets from which the tail and nebulous coma arise is a conglomerate of ices including water H_2O, ammonia NH_3, methane CH_4, and carbon dioxide CO_2 coarsely mixed with meteoric material At large solar distances this mass remains inactive but as the comet approaches the Sun, the ices are heated and vaporized These vapors carry some of the meteoric *solids* (*see* METEOR) with them as they proceed away from the comet and into the coma and tail

Discovery and designation From 1940 to 1956, 94 new comets were discovered In the same period another 51 periodic comets have reappeared The great majority of the new discoveries and all of the rediscoveries were made by photographic observations The percentage of photographic discoveries has steadily increased over the years as more powerful instruments and more sensitive photographic emulsions have become available

Cometary nomenclature was standardized by the International Astronomical Union A comet receives three designations to distinguish it from its fellows Upon discovery it is assigned a temporary name consisting of the year of discovery followed by a lower case letter, the first discovery of the year being a the second b and so on Thu 1948l 1948 A permanet has osest to the Sun (*see* CELESTIAL MECHANICS) This final designation consists of the year of perihelion passage followed by a Roman numeral which specifies the order in which the comets of that year passed perihelion In the case of 1948k discovery was made after perihelion and its permanent designation is Comet 1947VIII indicating that it was the eighth comet to pass perihelion in 1947

In addition to this formal designation it is customary to name the comets after the discoverer

Comet 1947VIII is also known as Comet Wirtanen If the discovery is made independently or jointly by more than one observer the several names are applied although no more than three names are allowed The need for such a rule is easily understood when one realizes that some naked eye comets have been discovered almost simultaneously by dozens of individuals

In a few special instances a comet is named not for the discoverer but to honor an individual responsible for important research on the object The well known Halley s comet is such a case (*see* ENCKE S COMET, HALLEY'S COMET)

Observations An observation of a comet consists of a specification of its apparent position on the celestial sphere at a given instant In the case of a photographic observation the right ascension and declination of the comet are measured by referring to the fiducial system provided by adjacent stars whose positions are known A photograph made with an astronomical telescope of moderately long focal length can be measured to an accuracy of about 0 1 second of arc

Six orbital parameters are necessary to describe the motion of a comet about the Sun Three observations are sufficient to supply these six quantities because each observation consists of independent measures of two coordinates When three observations of sufficient angular separation have been made a preliminary orbit is determined This initial orbit provides information necessary to compute an ephemeris—a prediction of the comet's future positions—to facilitate further observations and to ensure that the comet will not become lost during extended periods of poor weather or during its passage behind the Sun

e of the eed the to simplify the computations with the first three observations A more precise or definitive orbit is necessary to study changes in the orbit caused by planetary perturbation and to determine the relationship of this orbit with that of other comets and planets

After *several months* or *rarely several years* when the comet has moved to great distances from the Sun and is no longer observable all the observations which may number in the hundreds are employed to determine the definitive orbit

If the only force acting on the comet were due to the Sun the orbit would be described by a conic section However the comet may be perturbed by planets or by the force of reaction from the expulsion of material from the comet In addition the nebular nature of the comet can cause systematic errors in the observed positions which make the orbit appear to depart from a conic section For these reasons it it sometimes necessary to compute several orbits each of which is applicable to a certain small arc of the orbit These orbits or orbit if only one is required to match the observations satisfactorily are true Keplerian orbits and are conditioned to be tangent to the comet s actual motion at a particular date This osculating orbit as it is called has also the same spacial velocity as the comet on that date With the osculating orbit as a starting point, one can carry the comet's position forward in time taking into account the perturbations produced by planets and make improved predictions as to the time and location of reappearance of a periodic comet

The orbits of comets can be divided into two groups on the basis of their periods The short period group (periods less than 200 years) contains orbits that exhibit a strong preference for the plane of the solar system the planes of long period comets are quite randomly distributed

Comet families Orbits of short period comets are generally direct that is the motion about the Sun is in the same sense as the planets Direct and indirect orbits are found in about equal numbers among the long period comets

Aphelia of nearly half of the short period comets correspond closely to Jupiter s orbit All of these observations are generally consistent with the theory that short period comets have been thrown into their present orbits as a result of planetary perturbations particularly by Jupiter Attempts to demonstrate that other comet families exist and are associated with the other major planets have not met with success

period comets and the various members of the group may arrive at the vicinity of the Sun at intervals of several years or even several centuries The period of each comet is so long as to leave no possible doubt that each is indeed a separate body traveling in the same orbital plane and not the return of a single shorter period comet

Table 1 Orbital parameter of members of a comet group

Comet	ω	Ω	i	q AU	e
1668	110°	359°	144°	0 067	1
1843I	82	1	144	0 006	99991
1880I	86	6	140	0 005	1
1882II	70	346	142	0 008	99991
1887I	58	325	178	0 010	1
1945VII	51	322	137	0 006	1

The largest such group contains the members shown in Table 1 Although it is hardly possible to justify the inclusion of any single member six comets (out of a total of about 325 long period comets known) with such a remarkable consistency of orbital parameters must have some generic relationship The extremely small value of perihelion distance q in astronomical units (AU) is a striking characteristic of the group Four of the six comets of smallest q are found in this group

For the skeptic to whom such statistics are unsatisfactory one can point out the exceptional ex

amples supplied by Comet Biela (1852III) and Comet Taylor (1916I) Both objects were observed before and after they separated into two bodies In these cases the splitting was apparently a forerunner of complete disintegration, Comet Biela was observed at one perihelion passage after disruption (1852) and has not been seen since Comet Taylor has never been observed since that passage

into two subgroups those of hyperbolic and those of elliptical orbits If comets approach the center of the solar system along hyperbolic orbits they originated outside the solar system and represent travelers from interstellar space

Nineteen comets are known with well determined orbits that are slightly hyperbolic and at least three comets have orbits with eccentricities so close to unity that observational errors being what they are the orbits might be hyperbolic

By extending the observed orbits backwards in time Elis Stromgren and others have shown that in all but 2 of the 22 comets mentioned above the orbits were perturbed into hyperbolic form by the major planets as the comets approached perihelion These comets had definitely elliptical orbits although of very long period before their last perihelion passage

In the other two cases the computed departure from unity of the eccentricity is less than the probable error of the determination Thus there is no example of a truly hyperbolic comet

That these facts are probably true can be deduced more simply With respect to its immediate stellar neighborhood the Sun moves with a velocity of 20 kilometers per second True interstellar comets would be expected to display at least a portion of this velocity If they did so the orbits would be unambiguously hyperbolic Furthermore if the Sun were sweeping up interstellar comets in this fashion the direction of the Sun s motion should be apparent in the aphelion direction of long period comets This is not observed

Anatomy and dimensions A comet is usually described as consisting of three sections This sectioning serves to separate various cometary phenomena as well as to describe the appearance of the object as seen through a telescope or on a photographic plate The bright head or coma is a nebulous object of finite angular size Within this it is often possible to see one or more stellarlike objects called the nuclei The third component the tail may appear as an anisotropic extension of the coma or may have structure that alone would serve to distinguish it from the coma

The nucleus is too small to allow a direct measurement of size but approximations may be made from the intensity of the reflected sunlight Diameters of from 1 to 100 km are found The coma may be detected at distances of from 10^3 to 10^5 km from the nucleus and tails have been observed to extend nearly 10^8 km from the nucleus

Both coma and tail are composed of gases of a density far less than is obtainable by the best laboratory techniques They are almost perfectly transparent Most of the mass is contained in the solid nucleus which represents the permanent body Upper limits on the mass of the nucleus have been found by noting the absence of perturbative effects on Earth and planets by close-passing comets Had Lexell s Comet of 1770 possessed a mass as great as 10^{-6} that of Earth it would have caused a measurable change in Earth's orbital period when it passed within 2.4×10^6 km of Earth No change was observed Similarly the same comet passed inside the orbit of Jupiter s satellites without any noticeable effect

Cometary brightness The brightne s of a comet depends in part on its distance from the Sun and from Earth For a solid body of given reflectivity and size the apparent brightness resulting from reflected sunlight is given by an equation of the form

$$J = (1/r^2)(1/\Delta^2)F(\phi) \qquad (1)$$

where r is the Sun comet distance and Δ i the Earth comet distance and $F(\phi)$ is a function of the phase angle described by the triangle Earth comet–Sun This expression which is applicable to solid bodies such as planets and asteroid is meaningless for comets because of the diffusion of light by the gaseous coma and by the changes in the coma as the comet approaches to small solar distances The phase angle of a comet seldom affects its total brightness as does the phase of the Moon or of an inferior planet

Because of this investigators have usually replaced Eq (1) by the empirical statement

$$J = 1/\Delta^2 r^n \qquad (2)$$

and have determined exponent n in an attempt to specify the rate of growth of the coma as a function of solar distance From over 4000 ob ervations of comets N T Bobrovnikoff found that the form of Eq (2) satisfactorily described the brightne s data and that on the whole n does not tend to vary with solar distance However, the value of n determined for specific comets shows a wide range of variations extending from $n = 11.4$ for Comet 1932V to $n = -1.8$ for Comet 1917II The mean value for all comets $n = 3.26$ departs appreciably from the $n = 2$ reflection law The departure is in the sense that is explainable by an increased release of the cometary gases as the comet approaches the Sun

Cometary spectra The total light from a bright comet may exceed that of every heavenly body except Sun and Moon Several fainter comets visible to the naked eye occur each decade It would seem that a number of sufficiently bright comets were available for spectrographic study However the light of a comet is dispersed over a considerable angular dimension and only a small fraction of the light can be fed through the slit of a spectrograph Furthermore comets are usually at their brightest

when near the Sun s position in the sky so that the background light may severely limit the length of the photographic exposure For these reasons data on comet spectra have accumulated slowly

Spectra obtained with objective prisms preserve all of a comet s light but suffer from overlapping images of the various emission lines as a result of the finite angular size of the comet

The spectrum of reflected diffused and scattered sunlight including the solar Fraunhofer absorption lines is observed in all parts of the comet In general this is most conspicuous near the nucleus and *least in the tail*

Spectra of the following compounds and ions have been identified in comets CN C_2 CH CH_2 CO N_2^+ NH OH CO^+ and possibly OH CH NH_2 and SiO_2

The most prevalent aspects of all cometary spectra are the bands arising from CN and the Swann bands of C_2 Both appear primarily in the coma The C_2 system of bands lies in the visible region and accounts for most of the visual brightness of the comet The radical CN (usually referred to as cyanogen but not to be confused with the true cyanogen molecule C_2N_2) emits primarily in the violet and ultraviolet region

The ultraviolet bands arising from OH and NH are also localized in the coma In the nucleus and in the coma region immediately surrounding it are found the molecules CH CH and NH

The tail spectrum indicates the presence of several ions CO N CO_2^+ and CH with CO the most prominent by far The presence of these ionized molecules is easily understood in terms of the extremely low density of the tail When a molecule is photoionized by shortwave radiation from the Sun it remains in that state until an effective deionizing collision occurs between the ion and an electron Under such conditions of density collisions are exceptionally rare and the molecule may remain ionized for a considerable period

Tails and jets The dimensions and brightness of comet tails vary both with the individual comet and with its distance from the Sun Some faint comets never develop a detectable tail Bright comets usually begin to develop tails when they approach to within 1 or 2 astronomical units of the Sun At that distance solar heating is sufficient to vaporize the ices In general the tail becomes increasingly conspicuous until perihelion is reached

As an approximation it may be said that tails point away from the Sun Thus when a comet of high eccentricity approaches the Sun the tail follows and when the comet is departing the tail leads This phenomenon was early attributed to the pressure exerted by solar radiation on the small particles comprising the tail this explanation is satisfactory in some cases However as with size and brightness the form and motions of the tails are extremely varied Light pressure alone cannot account for all observations

Three general types of tails are recognized Those of type I are straight and show considerable structure in the form of condensations and long thin streamers The streamers may have a length of 1000 times the thickness Spectra of type-I tails consist of bands from ionized CO N_2^+ CO_2^+ and CH Observations of specific condensations show that this type tail is acted upon by a repulsive force centered at the Sun of several hundred to several thousand times the Sun s gravitational attractive force

Type II tails are curved The motions are imposed by a repulsive force equal to or slightly larger than the Sun s gravitational force These *tails appear fuzzy and have little structure* The curvature is concave towards the direction of motion of the nucleus

Type-III tails are similar to those of type II in appearance but the repulsive force is less than that of type II tails

In all cases the tail material is closely confined to the plane of the orbit In comets that show more than one type of tail or which show type I streamers the various structures disappear when Earth passes through the plane of the comet orbit It is as though one were looking at a sheet of paper edgewise

Two explanations are offered for the two dimensional nature of the tail These explanations are not mutually contradictory and certainly both are important First the material is ejected from the comet at velocities of at most a few kilometers per second Comet velocity about the Sun at Earth s distance is in the order of 42 km per second Even if the material is ejected perpendicularly to the comet s orbit the inclination of the tail material would not differ greatly from that of the comet

Second the maximum heating of the nuclear surface takes place at the subsolar point of the comet the point through which the radius vector to the Sun passes For any surface and particularly for a rough surface the preferred direction for escaping particles is the perpendicular and this also lies in the plane of the orbit

The eventual appearance of the tail will depend on the rate at which gas or dust is ejected from the comet the vector velocity of ejection and the repulsive force experienced by the particles The repulsive force may not be constant from particle to particle As a consequence the tail can take on a composite form such as in Comet Mrkos (1957d)

Type I tails characterized by large repulsive forces cannot be explained by the action of light pressure alone It is probable that corpuscular radiation from the Sun mostly electrons and protons is an efficient source of the repulsive force Observational tests of this hypothesis have been made by L F Bierman Regions of the Sun may emit particles whose effects are observable at Earth in the form of auroral and magnetic activity (*see* SUN) Occasionally these solar regions remain active for more than a revolution of the Sun about its axis (about 25 days) In such cases the phenomenon at Earth is repeated each time the active solar re-

approaches the proper orientation with Earth This same periodicity was seen in the acceleration of type I tails of Comet Whipple Fedtke and Halley's Comet In the former comet the existence of substantial solar activity was verified by the occurrence of a major magnetic storm at Earth The time of occurrence of the storm and the tail accelerations were consistent with the solar distance of comet and Earth

Acceleration of the tail molecules by simple bombardment by the solar corpuscular streams may not be sufficient Bierman suggests that the coupling of the ionized solar and tail components may be strengthened by magnetic fields associated with the solar streams The same forces may explain the tight bundles of matter forming the streamers in type-I tails

The material which eventually forms the tail may on occasion be seen to leave the nucleus The emitted material takes the form of sharply defined jets broad fans or nearly isotropic and concentric halos Velocities of ejection between 0 5 and 3 0 km per second have been determined from studies of the growth of these features At larger solar distances (greater than 2 0 AU) the activity is rare At smaller distances (less than 0 5 AU) there may be profuse emission of material but distinguishable features such as jets are seldom observed They are apparently washed out by the emission activity of the nucleus as a whole

Origin and nature of comets In terms of the size of the planetary system (39 AU from the Sun to Pluto) the range of distances over which comets are visible (rarely over 6 AU) is rather small However, many observed comets are of long period during each revolution they may spend thousands of years at thousands of astronomical units from the Sun Any one such comet seldom approaches to within 2 or 3 AU of the Sun (rather than twice that distance where it would probably be unobserved) at a particular instant in history when a man happens to be observing and recording such events Short period comets may make only a limited number of perihelion passes before they are destroyed by evaporation or disrupted by solar tidal action Yet, on the average several comets are observed each year How many comets are there? Where do they come from? How is the supply of short period comets maintained in the face of the solar attrition? These questions as well as the cosmological questions regarding the formation and the constitution of comets, are representative of the major problems to which the astronomer applies the observational data

Jupiter's effect on cometary orbits The orbital elements of a comet making a close approach to



Tail of Comet Mrkos on August 19 1957 showed wide variety of formations Single straight type I tail is primarily emission from positively ionized carbon monoxide Underlying continuum of most of the tail is sunlight scattered by dust Lack of detail in coma is a consequence of long exposure necessary to record tail structure (*Photograph by Alan McClure*)

Jupiter (or Saturn) may undergo severe changes as a result of the perturbative effect of the planet Examples are not altogether rare The period of Lexell s comet was considerably reduced to 5 6 years by a close approach to Jupiter in 1767 and was subsequently greatly increased by a second approach in 1779 the comet has not been observed since

Ten other comets since Lexell s comet have been observed to exhibit a large decrease in period after a close Jupiter encounter Two of these at a later time were again perturbed by Jupiter into long period orbits It is possible for perturbations to result in an orbit of similar shape but rotated in space for the period to be shortened for the period to be lengthened or for the comet to be thrown into a hyperbolic orbit Comets with perihelion distance before capture of between 4 and 5 AU are most susceptible to large effects resulting from Jupiter encounters

A J J Van Woerkom has investigated both the observed loss of comets from Jupiter s family through perturbations and destruction and the expected addition to the family by the capture of parabolic comets by large perturbations Table 2 summarizes these results

Table 2 Effect of Jupiter on cometary orbits

	Perturbation	D sruption
Loss	20 per century	3 per century
Ga n	15 per century	?
Net loss	approx mately 3 per century	

The discrepancy between loss and gain may be explained by assuming a larger number of comets with perihelion distance in the vicinity of Jupiter s orbit than would be expected by an extrapolation of the observed numbers of long period comets in the observable range of 2 AU from the Sun Van Woerkom also suggested the possibility that each captured comet eventually supplies more than one short period comet in that it might be disrupted into several pieces by solar tidal forces Such cometary mitosis has been observed on several occasions

Less drastic but still important changes occur when a more distant approach to a major planet takes place Van Woerkom has also investigated these changes and finds that on the average a comet with a perihelion distance of 1 AU will undergo a change in the reciprocal semimajor axis $(1/a)$ of 5×10^{-4} (in reciprocal astronomical units) and that a positive or negative change is equally likely Thus whatever the initial distribution of semimajor axis this effect will tend to diffuse the distribution Some comets suffering a sufficient number of negative changes will be thrown into hyperbolic orbits and be lost from the solar system Other comets will eventually be thrown into short period orbits and possibly, be destroyed by solar ablation Through one mechanism or the other long period comets that come near the Sun (and are observed) eventually disappear Van Woerkom suggests that they will be effectively eliminated in several million years This being the case either the long period comets were born only a few million years ago—an unlikely hypothesis—or the supply of observable long period comets is replenished by some mechanism

J H Oort has shown that a cloud of comets in orbit about the Sun may extend to a distance of about 10^5 AU a distance comparable to that between stars in the galaxy At distances greater than this perturbative effects of other stars would be effective in removing a comet from the Sun s control Oort has further shown that passing stars although not effective in stealing the Sun s comets can cause orbital perturbations that reduce the perihelion distance of a comet and thus bring it into the planetary region At this point a comet comes under the influence of Jupiter and undergoes further orbital changes as described above To supply new long period comets at the observed rate the cloud must contain about 2×10^{11} comets The total mass in the cloud is estimated to be 10^{27} grams or about one tenth of the earth s mass Throughout the lifetime of the solar system—approximately 3×10^9 years—the comet cloud would have lost less than 15% of its population by stellar encounter

Nature of comets Any model of the structure and composition of comets must satisfy a welter of observational data The model must provide a source of nearly a dozen molecules and radicals emitted from the nucleus in a variety of fashions Many if not all meteors indisputably have their origin in comets (*see* METEOR) An explanation is also required for the dynamical behavior of many comets Secular changes in the orbits specifically of the semimajor axis and eccentricity are well known for several comets The changes are not caused by planetary perturbations and are far too gross to be explained away as a result of systematic errors in observations Encke s comet with a period of 3 3 years has undergone an average decrease in period of nearly 2 hours for each revolution since 1819 (*see* ENCKE'S COMET) Its present position in the orbital ellipse is thus approximately a degree ahead of where it would have been had it maintained a constant period since 1819 Small but unquestionable changes took place in the eccentricity during the same period the orbit becoming more nearly circular These variations have not been constant in time but the direction of change has always been towards a smaller less elongated orbit Other comets such as Comet Wolf 1 and Comet D Arrest behaving in the opposite fashion have well determined increases in semimajor axis

The cometary model proposed by F L Whipple supposes a comet to consist of a large fraction of material capable of supplying the observed molecules or radicals The compounds necessary (H_2O NH_3 CH_4 CO or CO and possibly C_2H_2) exist in the solid phase at large distances from the Sun

($T < 50°K$) Meteoritic material of the 10-cm size range and smaller is mixed with the ices When the comet approaches the Sun for the first time exterior layers of ices quickly vaporize until the outer surface is predominantly nonvolatile meteoritic material which acts as a partial insulator for the interior Eventually sufficient heat diffuses through the loosely packed dirt and vaporizes the ices The escaping vapors may blow some of the dust along as they leave the nucleus The underlying gas may also escape without affecting the overlying solid layer If Sun warmed solid material eventually collapses inward to the sheltered ice it can result in a near explosive ejection of material similar to jets and fans

Whipple has also investigated the delay time that may be expected for the heat front to penetrate to the comet s interior Detailed answers to the problem depend greatly on the estimates of meteoric particle sizes and their distribution through the nucleus With reasonable estimates it may be expected that the transfer time may be appreciable A reasonably long transfer time would be compatible with the observation that comets are often brighter and emit more gas after perihelion passage than they do at the corresponding distance from the Sun before perihelion passage

If the comet is rotating the material may be ejected away from the nucleus in a direction other than toward the Sun The momentum transfer from the emitted gas to the nucleus may then result directly in an acceleration (or deceleration) of a comet rotating in a direct (or retrograde) sense A directed mass loss of this nature of about 0.2% of the total mass per revolution is sufficient to explain the otherwise anomalous behavior of Encke s comet

Observations of the orientations of jets and fans indicate that outgoing momentum is directed toward the Sun The comet receives from this component an acceleration away from the Sun The true orbit of the comet model results from a central force due to the Sun minus the force of the expelled gas and particles Computations of the apparent change in the gravitational constant have been made for 64 comets and found to be statistically negative The extraneous acceleration produced by the outgoing gas is generally more pronounced in comets of small perihelion distance These facts support the icy conglomerate comet model [R E MC]

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Comfort control

The adjustment of the temperature humidity and related environmental factors so that occupants of a designated space feel comfortable. *A feeling of* comfort depends on the activity of the occupants Air over an indoor swimming pool *should* be warmer and more humid than air in a motion picture theater An atmosphere that feels comfortable to active factory workers may feel uncomfortably cool to seated office workers Dust and fumes also affect the comfort of occupants

Comfort can be controlled to some extent by opening or closing the windows of a room or to a great extent by an air conditioning system that adjusts the temperature and humidity of the air filters and deodorizes it and circulates it without creating excessive air velocities Basically comfort control consists of a series of energy balances The corresponding series of machines which carry out these energy balances constitute the air conditioning equipment that changes natural air to meet the comfort requirements of the particular applications (*see* PSYCHROMETRICS)

In energy terms an air conditioning system is a series of independent energy processes so connected that the over all effect is to transfer thermal energy from one place to another In winter the purpose is to distribute heat (sensible and latent) uniformly in the controlled space in summer the object is to remove heat (sensible and latent) from the controlled space and to dispose it in a thermal reservoir—as well water a lake or the outside atmosphere—where its presence is no longer objectionable

Winter Because of the low temperature of natural air during the winter winter comfort control starts with an energy source (fuel or electricity) followed by a means of releasing or liberating that energy (as the process of combustion or the deliberate imposition of a resistance in an electrical circuit) After liberation the high temperature internal kinetic energy must be transferred as heat (by conduction convection or radiation) to a suitable working substance (as air water or steam) The working substance transports the energy from the place of release (as a boiler room) to the place of use (as a heated occupied enclosure) When the energy is delivered to the place of use an energy transformation may occur—as during condensation of the steam in a heating system—and the energy again in the form of heat is transferred to the conditioned space Once the heat is admitted as from a heating panel or a blast coil suitable means must be provided to assure its uniform and comfortable distribution (thermal mixing) so that neither radiant nor convective drafts (stratified or localized regions of thermal differences of a magnitude that can be readily sensed by a clothed occupant) will be experienced The system should be sufficiently synchronized as a whole so that all elements function effectively together and so that the imposed relationship exists between system load (as determined by weather and by the thermal characteristics of the particular structure) and required heating effect (*see* CENTRAL HEATING HEATING COMFORT)

Many equipment arrangements are used for winter comfort control In general however the equip

ment series will parallel the energy process series thus the energy source is the coal pile the oil tank the natural gas pipeline or the entering electrical main Liberation of energy occurs in a furnace either by combustion or electrical resistance and transfer takes place to whatever medium is to be used as a working substance the transfer may occur in a warm air furnace or a steam boiler or may take place indirectly by means of secondary heating plates or coils Transportation of the energy within the working substances is essentially mass movement of the working substance with physical conveyance of the stored (kinetic or potential internal storage) energy

In heating systems the most widely used methods for releasing and distributing heat within the conditioned space are radiators convectors warm surface panels and blast coils radiators most convectors and surface panels use thermal potentials either to set up (the first two types) or to minimize (the third type) natural convection processes of mixing within the room Winter systems are sometimes classified according to working substance and method of distribution (warm air free convection warm air forced convection hot water natural circulation hot water forced circulation steam) and sometimes according to the type of distributing unit (radiator baseboard radiator convector forced convector panel blast coil)

Summer Because of the high temperature of natural air during the summer summer comfort control operates in reverse in energy terms from winter systems (*see* HEAT PUMP) In summer the need is to provide a temperature heat sink (collector) in the controlled space so that the thermal energy released within that space will flow thermally to a collector (*see* AIR CONDITIONING) The thermal energy comes from the occupants and lights from transfer through the walls from solar energy transmission through windows or from either the infiltration or the mechanical introduction of outside air The collector is a device such as a cooling coil or direct expansion evaporator The thermal energy is received in storage (or in part associated as flow work) in the working substance by the collector The working substance may carry the waste energy to a refrigerating system (*see* AIR COOLING) which then pumps the waste energy from its low temperature (slightly less than that of the conditioned room) to a temperature sufficiently high so that it can be disposed of by heat transmission to the outdoor atmosphere or to any other convenient thermal receiver (as a lake or well water or to recirculating water from a cooling tower)

A major difference between summer and winter comfort control is the greater need in summer for close control of the relationship between sensible and latent heat loads Dehumidification at a controlled rate necessitates careful adjustment of the temperature at which cooling occurs The lower the required dew point temperature of the air leaving the conditioner the lower the required coil (or droplet) surface temperature in an approximate sense high latent heat load dictates low dew point temperature high sensible heat load dictates low dry bulb temperature and high total heat load dictates low wet bulb temperature

Central systems A central system provides refrigeration or other cooling effect from a single mechanical refrigeration system The central unit cools a secondary fluid which is then circulated throughout the various spaces that are to be conditioned As a typical example a basement located dichlorodifluoromethane mechanical system might be used to cool water and then circulate the chilled water to individual room cooling units (controlled cooling coils located in air ducts or coils with off on blower attachments) in the rooms of a hotel or department store In other types of central systems the compressor and condenser are large single units but direct refrigeration is supplied by piping leading to and from small evaporators located at the points where cooling is needed and operating in parallel under control of individual expansion valves controlled by room thermostats

Self contained systems Individual package type or unitary mechanical refrigeration systems (consisting of compressor condenser expansion valve evaporator and air blower) constitute self contained systems They may be either separate from or an integral part of a general ventilation system When self contained such units require a direct supply of adequate outside air for make-up purposes this is often accomplished by installing the units in or below windows *See* REFRIGERATION VENTILATION [F W HU]

Communications, electrical

The science and technology by which information is collected from an originating source transformed into electric currents or fields transmitted over electrical networks or through space to another point and reconverted into a form suitable for interpretation by a receiver The commodity transported by a communication system is called information and usually originates either in the brain of a man or in some change in physical environment Information can be generated only by some change when conditions do not change there is no information to transmit A flow of information arises from a source in which changes are more or less continuous The more rapid the changes the greater will be the amount of information generated per unit time A flow of information for a particular time interval constitutes a message

Usually the original message is not in a form which can be readily transported to a receiver It must go through a transformation or coding process to translate it into a usable signal which can be transmitted over a communication channel

A signal is useful only if it can be delivered to a receiver which can interpret and make use of it Corresponding to the two types of sources (man or machine) there will be two types of receivers

(1) the brain of a man (2) a physical device which can respond to the signal or some transformed version of it A decoder is usually necessary at the receiver to transform the signal from the form used in its electrical transportation into a recognizable message

A prototype of any communication system consists of two people engaged in human conversation An idea or message is generated in the brain of the talker (sender) After formulation into a code called language the signal is transformed into nerve impulses (electrical in character) which control the muscular movements of the chest diaphragm the larynx palate tongue and lips This control modulates the acoustic energy produced by the exhalations of the breath past the vocal cords to form the complex sounds referred to as speech

Modulation Modulation is a particular form of coding in which a source of energy is controlled in one or more of its characteristics by a signal The usual purpose of modulation is to produce a new signal in a form which is more appropriate for transmission in the medium available but which retains the message information

The sound emanating from the mouth travels through the air as an acoustic wave A small portion of the energy is intercepted by the ear of the listener where it vibrates the outer ear drum which is coupled in turn to the inner ear The vibrations in the inner ear stimulate the auditory nerves which transmit pulses to the brain where the pulses are decoded into a more or less accurate replica of the original message

In an electrical communication system at least one electrical link is provided Historically the first such system was the telegraph still one of the simplest forms The ideas of the sender must first be reduced to written language form that is coded into an alphabet The sequence of alphabetical characters are in turn translated into a telegraph code of pulses and spaces By hand or machine electric current is controlled (modulated) in accordance with the coded message and conveyed over the electric line At the receiving end a decoding system must be provided to transform the electric pulses first into mechanical movements (either a sounder or a teletypewriter) and then into a written telegram

In telephone communication the system is somewhat simpler The sound emanating from the mouth is transformed by the telephone transmitter into signal variations in electric current which are a reasonable replica of the changing acoustic pressure upon the diaphragm Devices (such as a telegraph key and a telephone transmitter) which use any form of energy other than electric to control or generate electric energy useful for communication or measurement are called transducers The term transducer also applies to a device which transforms or controls energy in the opposite direction Many, but not all transducers are reversible in the direction of their energy transformation A telephone receiver is such a transducer

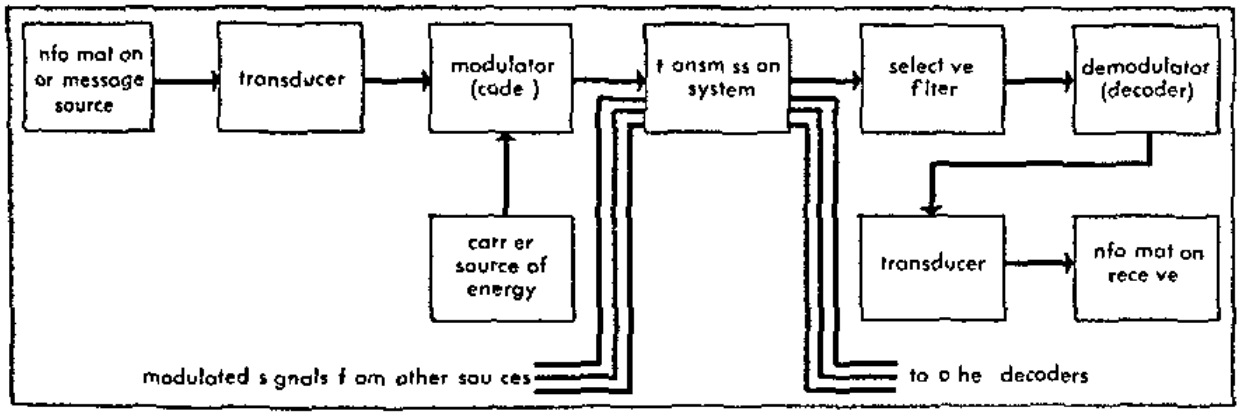
In the simplest telephone system no coding is necessary following the transducer which converts acoustical energy into electric energy However in many electrical communication systems (such as radio and carrier systems on wires) a common medium is used for the transmission of more than one message In this case additional coding and decoding are needed to transform the electrical signals into a form which permits the several different messages to be separated at the receiving end and routed to the proper address (*see* TRANSMISSION THEORY AND METHODS)

In radio and carrier communication a continuous source of alternating current energy of a frequency at least twice that of the highest frequency component in the signal is used to provide a so-called carrier The signal modulates one of the carrier characteristics in a manner dependent upon the instantaneous value of the signal Several forms of carrier modulation are available amplitude angle or pulse modulation Each name refers to the method by which the signal varies the carrier Angle modulation has two subgroups phase- and frequency modulation Pulse modulation has several such subdivisions pulse-amplitude pulse width pulse-position and pulse-code modulation *See* MODULATION

Demodulation At the receiving end of a communication system the decoder generally called a detector or demodulator extracts the signal from the modulated carrier energy in a form which can be presented in acceptable form to the ultimate user after being transformed by the receiving transducer The method of demodulation must always be compatible with the method of modulation just as in speech communication the talker must use a language understood by the listener

Transmission and reception To avoid distortion the overall transmission system including the transmitting and receiving transducers and the electrical transmission medium must have such characteristics that for the overall system the output is directly proportional to the input over a range of intensities and a band of frequencies whose widths depend upon the character of the signal The more rapid the changes in the signal the wider must be the bandwidth of the system *See* BANDWIDTH REQUIREMENTS (COMMUNICATIONS) In the process of modulation not only does the signal control the carrier energy but it also shifts the signal to a new portion of the spectrum whose bandwidth is at least equal to that of the original signal By using different portions of the spectrum available in the transmission medium it is possible to use one medium for a multiplicity of signals At the receiving end selective filters are used to separate a particular signal from its traveling companions and direct it to the appropriate demodulator *See* FILTER ELECTRIC

Noise Signals are subject to deterioration in the process of coding and decoding and through distortion in transmission A further source of deterioration is due to the random fluctuations of energy



Block d agram of a communicat on channel

introduced inadvertently in all parts of the communication system Such fluctuations are called noise irrespective of whether they are of acoustical origin or not *See* NOISE ELECTRICAL

Noise accumulates as the signal passes through successive stages of the system Furthermore if the separation between the source and the receiver is increased the signal received becomes weaker and there is increasing opportunity for the introduction of noise Therefore the ratio of the signal power to the noise power (abbreviated S/N) decreases with increasing separation of source and receiver (*see* SIGNAL TO NOISE RATIO) The ultimate range of any communication system is reached when the S/N drops below a point which can be tolerated The amount of S/N which may be tolerated depends upon the purpose of the communication system the importance of the message and the type of modulation and demodulation For example a listener to a musical broadcast is apt to switch off his set when only a moderate amount of static (a common form of noise) is present while a military communication radio link will be maintained if only a small fraction of the message is intelligible

The method of coding and decoding (modulation and demodulation) has a major influence upon the vulnerability of the system to noise In general the coding systems which can extract usable signals from mixtures involving large amounts of noise are more complicated elaborate and expensive Economic factors and the importance of the communication link determine what system should be used

Communication channel A sequence of equipments transmitting a signal from a source to a receiver is called a communication channel even though it may use elements such as the transmission system in common with other channels A general communication channel will contain the elements shown in the illustration

As inventors obtained improved detection of signals in the presence of noise by more sophisticated methods of modulation and demodulation the question arose as to whether there was an ultimate limit to the improvement possible Out of this and other problems grew the need for a more precise measurement of the information contained in a message and transported in a communication system

Information theory In order to develop a proper theory of information it was necessary to distinguish between the qualitative evaluation of ideas and a specification of information in mathematical terms which could be quantitative A quantitative definition requires that the information content of a book shall be proportional to the number of words used whether it be Shakespeare or trash The pioneer workers in this field were R V L. Hartley C E Shannon and N Wiener The fundamental unit of information they adopted is the bit (an abbreviation of binary digit) which is the specification of a choice between only two alternatives such as yes and no Finer gradations of choice between two extremes can be determined by a sufficient but definite number of such choices (more bits of information) *See* INFORMATION THEORY

Hartley and Shannon have shown that the maximum practicable capacity C in bits per second which a communication channel can handle is

$$C \quad B \log (1 + S/N) \quad \text{bits/sec}$$

where B is the bandwidth in cycles per second and S/N is the power ratio of the signal to the noise

The amount of information transmitted by a message is also measured by the increase in knowledge

mission of an unexpected statement has greater information value than one which coincides with the expected A message It will be hot tomorrow carries more information in January than in July because the normal expectation or probability of a hot day would be different in the two cases There-

communication but also has contributed to a deeper understanding of problems in biology psychology semantics phonetics literature mass communication media and many other fields

For a discussion of major forms of actual electrical communication systems *see* RADAR RADI SOUND REPRODUCTION SYSTEMS

SWITCHING SYSTEMS (COMMUNICATIONS) TELEGRAPHY TELEPHONY TELEVISION

[W L E]

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Communications systems (traffic) design

Electrical communication systems include telephone telegraph teletype picture data transmission and other systems in which electrical impulses originated at one place are to be faithfully reproduced at a distant point Transmission media include wire coaxial cable wave guide and radio

The simplest communication system comprises two stations one or both transmitting to the other over a permanent connection More generally a system consists of a number of stations (parties customers) which require momentary or relatively short time connection to one or more other stations for the purpose of transmitting and receiving information Therefore switching of the connections between the stations is required *See* SWITCHING SYSTEMS (COMMUNICATIONS) SWITCHING THEORY Examples of the great diversity of available switching plans are shown in Fig 1 They range from the simplest full access trunk group between a group of callers and receivers to a nationwide hierarchy of central offices interconnected by networks of one and two way trunks

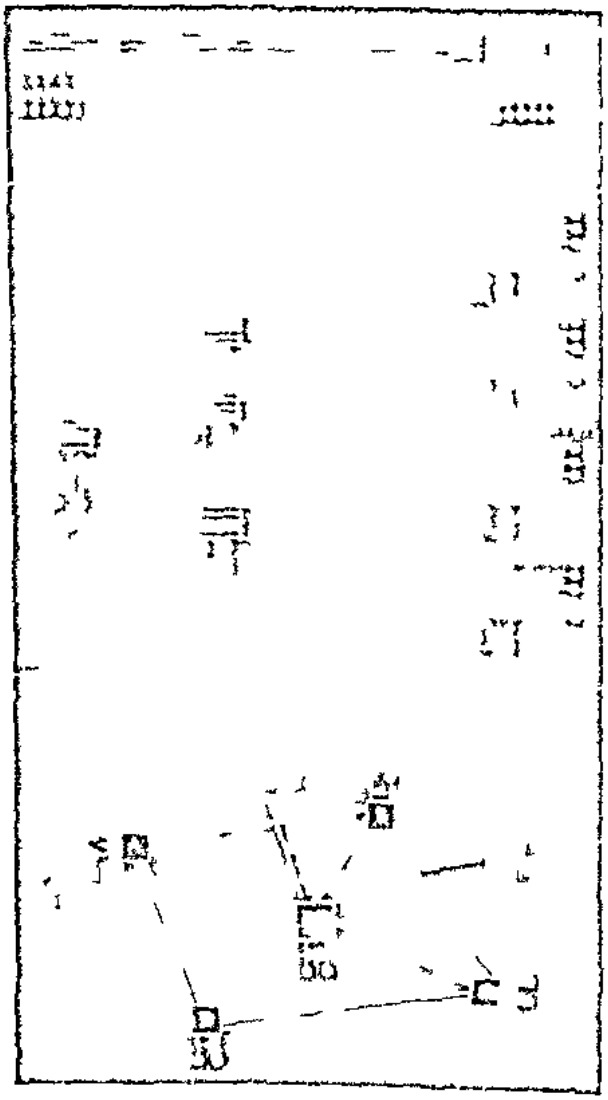


Fig 1 Communication switching systems (a) Simple full-access trunk group (b) Trains of switches to enable any caller to reach a large number of receivers (c) Multioffice switching plan

The principal objective in a communication system is to make it easily and economically possible for any sender (calling party) to reach a desired receiver (called party) and then to converse with him in a satisfactory manner The traffic area of systems design then comprises the allocation of switching equipment and paths in optimum numbers and arrangements to meet the desired grade of service

From the traffic viewpoint the grade of service is commonly specified as the proportion of user requests for service that fail to establish an immediate connection because of a shortage of paths or equipment This is known as the probability of loss or congestion However in systems where callers who find all paths busy continue to request connection the grade of service may more appropriately be measured by the average length of delay experienced or by the probability of a wait longer than some specified interval

The selection of a practicable grade of service requires a balance between the service which users would like to receive and the amount they are willing to pay for it Different groups of users will often attach different values to a given service level therefore within the same system it may be proper and desirable to offer several grades of service with corresponding charges for each

Use of probability theory The theory of probability deals with events whose occurrence is not precisely predictable The origination of demand by communications customers frequently displays a random character Probability theory is therefore employed in communications systems engineering to estimate the grade of service that results when a given amount of communication traffic or load offered to the talking and control paths of a particular switching system

The unit of traffic load a is the erlang named for A K Erlang of Denmark one of the pioneers in the development of traffic flow theory One erlang is that traffic load whose calls if placed end to end will keep one path continuously occupied

When the call origination instants occur at random with respect to one another as is likely when the traffic is contributed by a large number of stations the system is said to have a Poisson input

The most frequently used formulas relating the load offered to a given number of paths and the resulting congestion for Poisson inputs are shown in

the table They are chiefly distinguished by the assumption in column 1 regarding the disposition of calls finding all paths busy

Most frequently used formulas in traffic engineering

Assumed disposition of calls finding all paths busy	Formula relating a = offered load, s = no of paths or servers, E or P = probability of congestion
Erlang E_1 congestion formula	
Calls finding all paths busy disappear from the system and do not return (calls cleared)	$E_{1,s}(a) = \dfrac{a^s/s!}{1 + a + \dfrac{a^2}{2!} + \cdots + \dfrac{a^s}{s!}}$
Poisson loss formula	
Intermediate assumption calls wait a limited time then either disappear or converse for an abbreviated length of time (calls held)	$P(s,a) = \sum_{x=s}^{\infty} \dfrac{a^x e^{-a}}{x!}$
Erlang E_2 delay formula	
Calls finding all paths busy wait as long as necessary to obtain service then converse their normal service time (calls delayed)	$E_{2,s}(a) = \dfrac{(a^s/s!)[s/(s-a)]}{\sum_{x=0}^{s-1} a^x/x! + (a^s/s!)[s/(s-a)]}$

Single stage of switches Figure 2 shows the congestion probabilities predicted by the three formulas in the table when loads of a erlangs are offered to a simple group of s paths Wide differences in grade of service result when calls that do not find immediate service are disposed in the several ways This is because unserved calls which wait either partially or completely produce added congestion for other newly arriving demands

Typical engineering levels in American telephone practice are congestion probabilities of 0 001 0 01 0 02 and 0 03 on simple groups of paths Tabulated values of offered loads which correspond to a wide range of service grades according to the three formulas may be found in the bibliography

An important characteristic of all of the above load loss relationships is the increase in efficiency or load per trunk which may be offered as the group size increases Figure 3 shows this for the Poisson formula for groups working at $P = 0\,01$ congestion A 4 trunk group may be offered 0 82 erlangs or 0 205 per trunk the group efficiency is then said to be 20 5% A 10 trunk group is found to work at 41 3% efficiency and a 100-trunk group at 78 2% efficiency

Figure 3 shows that as far as practicable traffic loads should be assembled in large parcels in order to obtain the advantages of the higher efficiencies of large size trunk groups This basic principle has

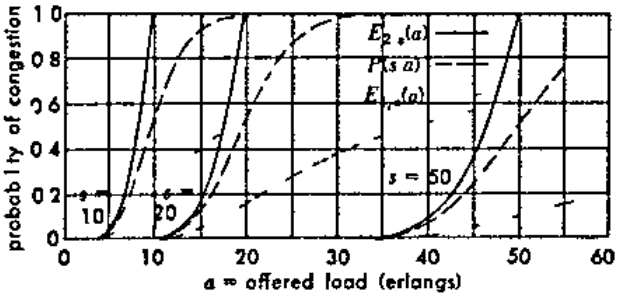


Fig 2 Load-congestion probability relation on s paths under various assumptions of delayed call disposition

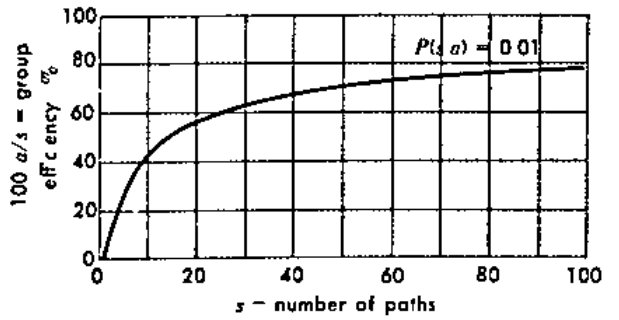


Fig 3 Variation in operating efficiency with trunk group size with Poisson $P(s,a) = 0\,01$

had a profound effect on communications systems design either encouraging the development of large switch sizes (to give full access to large trunk groups) or directing much thought and experimentation to minimizing the efficiency penalty of limited access plans with their smaller and less expensive switches

Each of the formulas in the table has its appropriate application in communications traffic engineering The Poisson formula is customarily used in American engineering practice for congestions of $P = 0\,10$ or less since customer behavior upon finding all paths busy clearly lies intermediate to the two extreme Erlangian descriptions In Europe the Erlang E_1 is the principal congestion formula used for local telephone trunk and facilities engineering

When calls that find all paths busy in a first choice group are permitted to test over a liberally engineered subsequent group estimates of the numbers of calls that overflow are closely given by the Erlang E_1 formula

At the other extreme customers calls which fail to find paths immediately may be stored to await the first opportunity for service They are then handled on a delay basis and the Erlang E_2 formula is used Telegraph and data messages are commonly in this category Also telephone customers may occasionally have to await the availability of a line finder switch or in common control systems of a registering device—as indicated by the lack of dial tone—to accept their dialing pulses

While the probability of delay F_2 is relatively independent of service time distribution (the length of individual messages) the average lengths and distributions of delays are highly sensitive to the character of the service times Engineering curves and tables are published for exponential and constant service times showing average delays and the expected proportions of calls which will have to wait any selected multiple of the average service time before obtaining a path The delays resulting from loads with constant service times are significantly smaller than for exponential service times—in fact the shortest possible delays occur with constant service times

System engineering In engineering large and complex communications systems it is desirable first to set an over all grade of service either in terms of an allowable percentage of messages not obtaining immediate connection or an acceptable delay time The total service penalty is then apportioned among the contributory switching or control stages It is commonly assumed that the over all loss or delay will be the arithmetic sum of the corresponding measures for each component or stage The allocation of loss or delay to each stage should then theoretically be such that an additional unit of investment say a dollar spent for more equipment at any stage will produce the same total service improvement as if it were spent at any other stage This concept can be stated mathematically for a trunking arrangement having several switching stages in tandem However the solution is usually more easily found by graphical methods or by *trial tabulation* since the equipment is often supplied in fixed multiples of units and unit costs may vary with the number ordered

In more complex communication systems the switching train varies tremendously from call to call Theoretically all possible combinations could be enumerated and the whole optimized As a practical procedure however assignment of congestion or delay probabilities to each category of switching *equipment* is a matter of judgment It is customary to assign values that have been found by trial to be reasonably close to the optimum in similar installations

In American telephone practice a typical dial tone speed objective is that no more than 1 5% of the calls should be delayed *over* 3 seconds in the average busy hour of the busy season nor should the over all probability of switching path connection for local calls exceed 0 04 Interoffice trunks

distance telephone lines carrying operator dialed calls are commonly engineered on *a delay basis* Typical busy hour average delay schedules depending on cost per circuit mile termination facilities and other factors are 8 15 and 30 *seconds* When customers are given access to long distance telephone systems the service grade must generally be improved For these systems it is more meaningful to specify the proportion of calls meeting delay since congestion forces the customer to reoriginate his call attempt Typical objective values of congestion probabilities are 0 03 0 05 and 0 10

Teletypewriter interswitching center trunks are commonly engineered on delay bases similar to telephone toll lines

There is a further desirable qualification for equipment engineered to average busy season traffic loads On the highest load days of the year the service in the busy hour should not be intolerably poor nor should a system under overload exhibit a self aggravating type of service decay This requires information on the high load day character of each central office trunk group and other parts of the system Calculations must be made to insure that on such days the service will still be acceptable Considerable choice must be left to the engineer who will apply his special knowledge of the availability of equipment the costs to add facilities by various means the allowances to be made for high load days and other factors so that all can be given proper weight in designing the optimum system layout *See* COMMUNICATIONS ELECTRICAL [R I W]

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Communications systems protection

The protection of wire communication systems equipment and services This includes the electrical protection of lines and station equipment and inductive coordination or the protection against interference from adjacent power lines and equipment

Electrical protection Wire communications systems generally require protection against voltages and currents from lightning *from accidental* energization by power lines and under some conditions from earth potentials from magnetic storms caused by sun spots These systems involve a multitude of closely grouped wires separated by insulation of relatively low dielectric strength The equipment used with these systems must necessarily be small and of relatively low dielectric strength because of the large number of components required in switching centers

The basic methods of protection are (1) to reduce the likelihood of energization through shielding or arranging the lines so they will be less subject to lightning strokes or contact with power wires (2) to use adequate insulation so that physi

cal contact may occur with power wires without energizing the communication plant (3) to increase the insulation of the wires and the conductivity of cable sheaths to minimize damage from power contacts and (4) to install protective devices that prevent damage to persons or equipment as the final protective measure

Protective devices for communications systems generally take the form of protector blocks and fuses The protector blocks usually consist of two small carbon electrodes arranged to be separated by a few thousandths of an inch These electrodes are paired together in a suitable mounting so as to connect each set of protector blocks between the conductor to be protected and the grounded sheath of a cable or a grounding electrode at the equipment location The breakdown voltage of the protector is always much lower than the dielectric strength of the equipment and cables being protected Fuses on the source side of the protector are required in some cases particularly where the protector might otherwise be called upon to carry current above its carrying capacity

Overhead lines Communication circuits supported on wood poles may consist of open wires or metal sheathed cable Lightning strokes to open wire do not generally damage the wire itself and damage to associated equipment is minimized by means of protective devices Cable is more easily damaged by lightning so protection measures are used to minimize damage to the cable and associated equipment

When power and telephone circuits cross each other or are carried on common poles the probability of contact between them is minimized by adhering to recognized high standards of line construction As a further precaution if a contact should occur the protective devices on the telephone system are designed to divert or interrupt that portion of the fault current which could otherwise reach associated telephone equipment

Underground lines Metal sheathed communication cables in underground ducts are not easily damaged by lightning because of the number of cables in the duct run and the resulting high conductivity of these several sheaths in parallel Also the likelihood of strokes to underground cables in duct is greatly reduced by the presence of nearby buildings or adjacent underground metallic piping systems such as water and gas lines and metal sheathed power cables Cables buried directly in the ground may be more subject to direct strokes The exposure is generally highest in areas of high lightning incidence and high soil resistivity (sand gravelly soil or certain rock formations) To reduce the susceptibility of cable damage cable of higher dielectric strength than normal may be used or shield wires may be installed in the ground parallel to the cables

Power contacts with underground or buried communication cables are usually no problem If both systems are underground they are generally in separate ducts Where both are buried they are adequately separated physically

Electrolysis The metal sheath of underground or buried cables may be attacked by electrolytic action and require protective measures The more troublesome sources of electrolytic currents include stray direct current from electrified railways from industries using large amounts of direct current in grounded circuits and from galvanic potentials produced by dissimilar metals in soil electrolytes Electrolysis occurs where current leaves the sheath

can be taken to reduce the likelihood of sheath failures due to electrolysis For stray current electrolysis a practicable remedial measure is to install an adequate bond between the cable affected and the negative side of the source of stray current For galvanic potentials a practicable measure is to install cathodic protection to maintain the cables suitably negative to earth in the affected area Cathodic protection involves the installation of a dc power source usually rectifiers between the cable and a low resistance anode ground In operation the dc source draws current from the cable sheaths and delivers it back to ground through an anode bed installed for the purpose For new construction in areas where electrolysis might reasonably be expected it is generally preferable to install a metal sheathed cable which has an outer insulating jacket such as extruded polyethylene No electrolysis effects will result unless the insulating jacket is damaged mechanically or is punctured by lightning It is then relatively easy to install cathodic protection which will maintain the sheath adequately negative

Telephone set protection To protect the user his premises and the communications equipment telephone sets require protection when the lines serving them are subject to contact with power lines or lightning The protector unit consists of carbon protector blocks connected between each wire and ground (usually the metallic water pipe serving the building) Sometimes a fuse on the incoming wire side of the protector blocks is also necessary The fuse protects the protector against sustained power contact currents which might overheat the protector or its grounding conductor A fuse is not necessary if the installation is subject only to lightning currents or if the building is served by insulated wires that connect to metal sheathed cables on the pole line Generally power wire contacts to aerial grounded sheathed cable do not cause high sustained fault currents into the protector and ground connection at the installations served

Inductive coordination Inductive coordination

tures are parallel for long distances a fault cur rent to ground on the power circuit creates in ef fect a one turn transformer primary The induced voltages may be high enough to result in an elec tric shock hazard to telephone personnel or inter ference to service on the communication plant Re medial measures to reduce the induction or its ef fects include (1) installing effectively grounded shield wires on either or both power and telephone plants (2) using grounded metal sheathed cable on either or both lines (3) moving either line for greater separation to reduce the coupling between them (4) using faster circuit breakers on the power line to reduce the duration of the fault and (5) installing suitable devices in the communi cation plant to reduce the effect of the induced voltages on the services transmitted [LSI]

Community

An aggregation of organisms characterized by a dis tinctive combination of species such as deciduous forest grassland pond mud flat An ecological community is sometimes called a biocenose Each community occupies a particular habitat and to gether with its habitat constitutes an ecosystem A community may be composed of any distinctive combination of plant or animal species When both are included the term biotic community is com monly used Major communities together with their

munities certain organisms called dominants ex ert a commanding role in determining the character and composition of the community On land plants are commonly dominants because they receive the full impact of the climate and environment By re actions on the habitat plants establish the condi tions of light moisture air movement space and other factors under which all other organisms must live The plant dominants are ordinarily the most prominent species and serve as the major source of food substrate and shelter for the animals that are present Thus trees are the dominant species in a forest community while grasses dominate in a prai rie Animals sometimes exert dominance especially in aquatic habitats For instance carp and suckers in ponds may root out all submerged vegetation and make the water so turbid by stirring up the bottom mud that some other species of fish cannot exist Dominance may thus be affected through coactions (interaction of one organism on another) as well as by reactions although this is less common

Community structure The structure of a com munity is evident in various ways in addition to the relation between the dominants and other constitu ent species Terrestrial vegetation is commonly stratified into subterranean ground herb shrub and one or more tree layer societies although tree and shrub strata are absent from some communi ties for instance the grassland The microclimate of each stratum is somewhat different and this, to gether with the variation in substrate divides the animal distribution into two principal layer soci eties subterranean ground and herb-shrub-tree

Community changes Except for tropical rainfor ests seasonal changes of climate during the year bring important changes in the kinds of plants that are active and in the activities of animals In humid north temperate climates different aspects may be recognized hiemal from mid November to mid March, vernal to late May estival to mid Au gust, and autumnal In addition the community changes between day and night especially in the predominant animals that are active Species are commonly divided into diurnal crepuscular (eve ning dawn) nocturnal and arhythmic, or those ex hibiting no periodicity

Species composition Species may be classified in respect to their fidelity to a particular commun ty into exclusive if confined to one community char acteristic if at least 2 or 3 times more abundant in one community than in any other or ubiqu tous in several communities In respect to abundance they may be predominant and member constituents Two aggregations of species in different local ties or habitats are not considered as belonging to d ffer ent communities unless according to some author ties more than 50% of the predominant species in each one are characteristic or exclusive to it alone otherwise they belong to the same community If differences in species composition approach but do not reach the 50% level the two aggregations of species are considered different facIations of the same community Communities are commonly named after two or three dominant or predominant species or the type of vegetation or habitat *See* BIOME

Food chains All organisms fit into food cha ns which may have only three links or trophic levels —such as grass antelope coyote—or as many as five for instance bacteria protozoan rotifer small fish large fish In each community the food chains anastomose in various ways to form a characteris tic food web The community shows functional or ganization and unity in its metabolism in that green plants the producers capture solar energy u ed in the basic manufacture of food and hence are at the bottom of the food chain The next trophic le el is made up of herbivores and higher trophic levels of different types of carnivores both herbi ores and carnivores being 'consumers Saprovores (transformers) feed on all links of the food chain after the organisms die and convert the complex organic matter into nutrients that plants can reab sorb Energy is constantly being lost from ea h trophic level of the community and must be re placed at the producer level However nutrient ele ments such as nitrogen carbon oxygen and phos phorus undergo continuous recycling within the e o system

Community balance The number biomass or number times weight and rate of reproduction of

organisms decrease progressively at higher trophic levels There is an inverse relation between number and size of organisms the *pyramid of numbers* Since each trophic level depends on the surplus production of food by lower trophic levels a balance of nature becomes established within the community Thus the abundance of each species tends to become stabilized or to fluctuate mildly around some definite level A temporary excess or diminution in numbers of any species due to factors external to the community may reverberate throughout the community until a new balance becomes established

Succession Due to fixation of nitrogen by certain bacteria or influx of nutrients from outside the habitat may increase in fertility and new species may invade it These species may modify the physical characteristics of the habitat by decreasing light intensity or monopolizing space or by other factors such as eliminating species already present This may be sufficiently extensive in the course of time decades or centuries to bring a biotic succession of different communities replacing each other until a climax is reached which becomes stabilized under the particular climate Communities do not remain permanently constant because each is dependent upon climate physiography and organic evolution factors which are themselves continuously changing

Organismic concept The organismic concept of the community is that it is a complex organic entity representing the highest stage in the organization of living matter that is cell tissue organ system organism community It behaves as a unit in its relation to other communities response to climate local and geographic distribution and in its evolution It possesses such emergent characteristics as density population dynamics trophic balance dominance and succession beyond those of the individual organisms of which the community is composed On the other hand the individualistic concept considers the community as a chance combination of species that occur together because of similarity in their environmental relations There is no intrinsic interrelation between the species in respect to distribution or evolution The population density of each species is distributed in a form of a more or less normal curve when plotted along the gradient of a given environmental factor and the curves of different species overlap in a heterogeneous or random manner without exact agreement between any two species The community is simply an arbitrary portion of a continuum of constantly changing composition of plant and animal life along environmental gradients that extend from one extreme to another Adherents of both concepts agree however that there exist functional relations between species that occur in the same place and regardless of one's point of view the community is a useful unit for detailed ecological investigation *See* COMMUNITY CLASSIFICATION POPULATION DYNAMICS SUCCESSION ECOLOGICAL [S C K]

Community classification

The arrangement of communities in any of several systems A community is an assemblage of two or more ecologically related species Organisms of a single species would not be regarded as a community but as a population The term ecosystem means a community and its physical environment Communities may be classified in respect to their complexity and extent or magnitude their stage of ecological succession or their primary production Classification provides an orderly basis for describing the distribution of organisms in relation to their physical and biotic environments as well as providing a framework in which community ecology may be studied A community may be thought of as being more than the sum of its component organisms in that it has a definite organization which results in additional attributes At a functional level separate plant and animal communities do not exist because of interactions of the component organisms

The hierarchy based on extent and complexity has at one extreme the biosphere a community consisting of all living organisms on the face of the earth Any organism could theoretically affect the conditions of existence of any other organism in this huge community but on the average the effects would be relatively very minute and would involve a considerable time lag Within the biosphere land surfaces fresh water and salt water provide contrasting conditions for existence and each of these may be termed a biocycle Each biocycle may be conceived of as a community of organisms that share general adaptations which permit their existence in the biocycle Constituents of a biocycle in general affect one another in greater degree because of similarity of adaptation than do constituents of the biosphere

Terrestrial biocycle Within the land biocycle there are major biotic realms which owe their existence to the distribution of land surfaces in a pattern of major continents and to past histories of dispersal of land living organisms A formal classification of the land masses into zoological realms has long been in use and these realms are also biotic ones Each biotic realm has subdivisions in which similarity of climate has resulted in the evolution of similar life forms and generally similar adaptations for example grasslands or deciduous forests Various classifications have been developed for these subdivisions The biome or plant animal formation is a community that corresponds to the ecological climax and its successional stages The biome is not continuously distributed but recurs wherever the climax recurs In another classification the biotic province is a community occupying an area where similarity of climate physiography and soils leads to the recurrence of similar combinations of organisms The biotic province is continuously distributed Biotic provinces are divisible into biotic districts on the basis of lesser differences than those separating provinces Altitudinal

variations in combinations of organisms are recognized as life belts Under another system life zones based theoretically on environmental temperatures are the major units of classification *See* MERRIAM'S LIFE ZONES Boundaries of life zones are crossed going from equatorial regions toward either pole or in ascending highly elevated areas In practice life zones have been mapped largely on the basis of indicator species and in general their boundaries tend to correspond to the boundaries of biomes or biotic provinces

Ecological associations These are the complex of communities which have developed in accord with variations of physiography soil and successional history within the major subdivisions of a biotic realm whether the subdivision is called a biome biotic province or life zone Thus an elm hackberry association may occupy the deep alluvial soils of a river floodplain while an oak hickory association may occupy the adjacent uplands In the concrete sense an association may be referred to as a stand or all of the organisms occurring together at a specific geographic place As the dominant oaks and hickories and their associated plants and animals at a particular spot comprise a stand recurrent combinations of approximately similar constitution throughout the biotic province belong to an abstraction or association type the oak hickory association As in the above example associations are usually given names indicative of a few of their dominant plants since these are usually the most obvious and stable organisms in the community It is possible to recognize subdivisions below the level of the association The organisms living in a rotting log for example would comprise a microstand and in the aggregate these microstands would comprise a microassociation The number of microassociations within an association is potentially great In the hierarchy of classification of communities the degree of interaction of different organisms in the community increases from the top down The greatest interrelationship would be found in the microassociation or association and the least would be found among members of the biosphere

Stage of ecological succession This aspect provides another basis for the classification of communities Succession involves invasion of an area by a pioneer community and modification of the environment by the component organisms through a series of seral stages until a stable climax community is evolved The organisms of each seral stage modify the local conditions of life and so promote succession of a later stage The climax community maintains itself through reproduction of its members as long as the climate remains essentially unchanged The term association is used by some ecologists to refer only to the climax but it is used by others in the more general sense in which it is used above The climatic climax is the end point of succession as determined by regional climatic conditions A subclimax or edaphic climax is a seral stage that is maintained indefinitely short of the climatic climax by some factor such as soil type physiography or fire and which would proceed to the climatic climax if the restrictive factor were removed A disclimax is a community maintained through man's activities A postclimax is a relict of a climax that was developed under regional conditions of greater moisture and maintained under locally favorable edaphic conditions in a region in which the present climatic climax is one related to lesser moisture The preclimax is a relict of drier climatic conditions now found on drier sites *See* TERRESTRIAL ECOSYSTEM

Aquatic biocycles Classification in respect to primary production is useful and has been used principally for aquatic communities A eutrophic community has relatively high primary productivity, or rate at which producer organisms incorporate energy in chemical compounds usable as food an oligotrophic community is one with relatively low primary productivity

Marine and fresh water biocycles may be recognized by the same general kinds of criteria used for the terrestrial biocycle and there is a similar hierarchy of communities of decreasing magnitude and increasing interaction The aquatic biocycles differ from the terrestrial one in the much greater importance of the vertical dimension since water is a sufficiently dense medium to support communities independently of the substrate and since the [illegible] vary greatly with depth [illegible] ically divided into [illegible] and pelagial division (the open sea) The benthal is divided into a littoral zone which is a lighted zone corresponding generally to the continental shelf and extending out to depths of about 200 meters and an abyssal or lightless zone The pelagial division is divided into a neritic region or lighted zone above the littoral and an oceanic region which is above the abyssal The upper level of the oceanic region down to the limits of effective light penetrance for photosynthesis is the euphotic zone Stands and microstands of organisms, comparable in the aggregate to the associations and microassociations of the terrestrial biocycle occur in these subdivisions of the marine biocycle Proponents of the biotic province and biome concepts hold that such divisions can be recognized in the marine biocycle *See* MARINE ECOSYSTEM

The fresh water biocycle It is difficult to classify the fresh water biocycle because of its discontinuous distribution in fragments of various sizes and characteristics The communities of large bodies of water such as the Great Lakes may be relatively stable and permanent while those of small bodies may exist more briefly as seral stages of a terrestrial climax Waters may be divided into lotic or flowing and lentic or standing although one type grades into the other Lotic waters may be roughly divided into pools and rapids Stands and microstands of organisms comprising associations and microassociations in the aggregate are distributed in relation to these divisions of lotic waters

and also in relation to such factors as type of stream bottom depth and physical and chemical characteristics of the water Lentic waters show vertical and horizontal zonation comparable to that of marine waters The littoral zone of ponds and lakes is comprised of shallow water in which light penetrates to the bottom The limnetic zone includes the upper levels of open water down to the level of effective light penetration The profundal zone includes the deep water and bottom below the level of effective light penetration Deep lakes in summer develop a characteristic zonation There is a metalimnion (thermocline) or zone of rapid temperature decrease with increased depth Above this there is an epilimnion or zone of relatively warm water in which mixing occurs as the result of wind action and convection currents Below the thermocline there is a hypolimnion of cold non circulating water Stands and microstands comprising associations and microassociations occur in the various zones of lakes just as they do in other environmental subdivisions *See* FRESH WATER ECOSYSTEM LIMNOLOGY

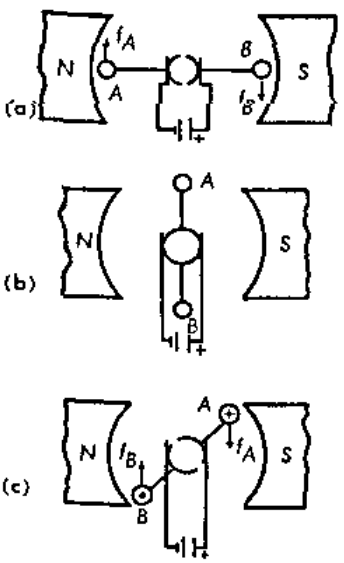
[W F B]

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Commutation

The process of current reversal in the armature windings of a dc electric rotating machine to provide dc at the brushes *See* COMMUTATOR

The basic process of commutation may be explained with the aid of an elementary motor diagram With the rotor position shown at (*a*) in the illustration the battery will force current into conductor *B* and out of conductor *A* to produce a clockwise torque and rotation The generated emf in the conductors is opposite to the direction of current With the rotor position of (*b*) the conductors are not cutting lines of flux no emf is induced in the coil no tangential forces are produced in the coil and the torque is zero With the rotor position of (*c*) the battery will force current into conductor *A* and out of conductor *B* The torque is again clockwise clockwise rotation will continue and the generated emf will have a polarity opposite to the conductor current Note that the coil current and the coil emf are reversed from (*a*) to (*c*) The switching is accomplished by the commutator Practical machines have many coils and many commutator segments on the armature *See* DIRECT CURRENT GENERATOR DIRECT CURRENT MOTOR WINDINGS (ELECTRIC MACHINERY)



Elementary motor with (*a b*) two-segment commutator f_A is the force on conductor *A* and f_B is the force on conductor *B*

For commutation to be sparkless however this apparently simple process presents severe problems First the coil undergoing commutation is short circuited by the brush so the brush must be able to tolerate the circulating current The net voltage induced in the coil while short circuited should be negligible to minimize circulating current Second because of the self inductance of the coil there will be induced in the coil an inductive voltage proportional to the rate of change of current but opposing the change of current This inductive voltage can be minimized by increasing the time allowed for current reversal and by providing a linear variation of current with time

A linear transfer of current is achieved by means of brushes with relatively high resistance which span at least one commutator segment As the commutator segment area covered by a brush changes with armature rotation the accompanying change in contact resistance effects the desired current change This is known as resistance commutation A film forms on the surface of the commutator to aid in the process

In all but small machines narrow interpoles are provided between the main field poles to overcome the inductive voltage induced in the coil under commutation The conductors undergoing commutation cut the interpole flux and a voltage equal and opposite to the inductive voltage is generated in these conductors [A R E]

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Commutator

That part of a dc motor or generator which serves the dual function in combination with brushes of providing an electrical connection between the rotating armature winding and the stationary terminals and of permitting the reversal of the current in the armature windings For explanation of the necessity of this function *see* COMMUTATION

A commutator is composed of copper bars assembled to form a drumlike cylinder which is concentric with the axis of rotation Insulation commonly mica to provide exceptional mechanical and electrical stability is placed between commutator

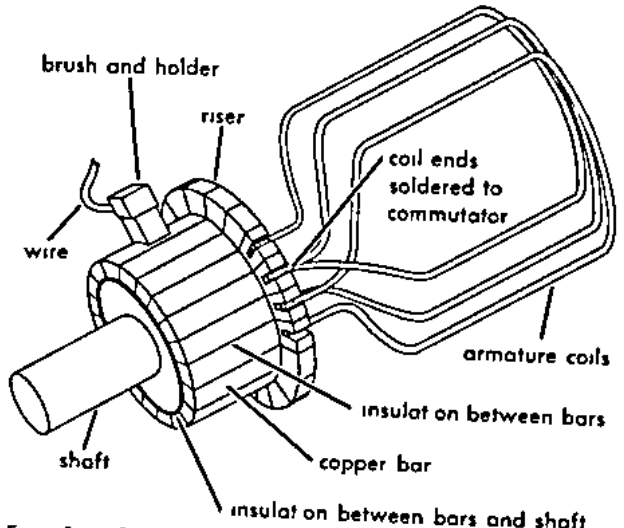


Fig 1 Commutator and brush assembly with coil connections for lap winding

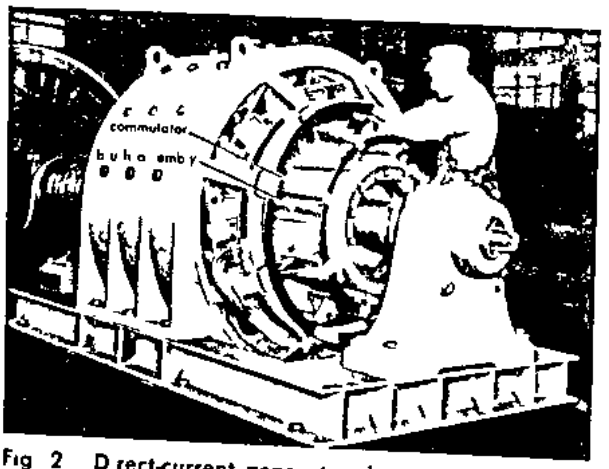


Fig 2 Direct-current generator showing brush assemblies (*Allis Chalmers*)

bars and between the bars and the shaft A diagram of a commutator is shown in Fig 1

Conducting brushes commonly carbon sufficient in size and number to carry the current are spaced at intervals of 180 electrical degrees about the surface of the commutator and held in contact with the surface of the commutator by spring tension In special cases as when only the top or bottom half of a dc motor is accessible only one positive brush set and one negative brush set is used when the armature is wave wound This is permissible as wave windings characteristically have two parallel paths between any two commutator bars separated 180 electrical degrees *See* WINDINGS (ELECTRIC

coil the closely spaced commutator segments may result from deposition of carbon dust from the brushes and from uneven voltage distribution between commutator bars under heavy loading For machines using commutators *see* DIRECT CURRENT GENERATOR, DIRECT CURRENT MOTOR REPULSION MOTOR UNIVERSAL MOTOR

[ARE]

Comparator

A device that measures the deviation of a gaged part from a specific dimension to which the comparator has been preset The dimension preset into the comparator is usually the basic size such as 1 505 in the dimension 1 505 ± 0 005 or 2.000 in 2 000 ± 0 002 A master having this dimension is used for presetting the comparator A comparator may also be set by two masters one for the maximum limit and one for minimum limit Two classes of comparator are in common use one in which the comparison is made visually or optically the other in which comparison is made by contact The three common types of contact comparators are mechanical electrical and pneumatic

Contact comparators Comparators that depend on contact are similar in physical arrangement, differing only in the method of amplifying and indicating the deviation from the master setting The limits of tolerance may be indicated on a dial for visual observation or by a signal such as a light or buzzer or in the case of automated equipment, by actual physical rejection from the lot of those pieces outside of tolerance

A general purpose comparator of the contact type usually consists of (1) a fixed contact point or surface (2) an indicating contact or measuring head and (3) a means for physically maintaining the distance between This last means takes the form of a frame in a gage making external measurements or the form of a plug in a gage making internal measurements The indicator or meter which records the results may be an integral part of the measuring head or a separate unit A general purpose comparator can usually be set with gage blocks as well as with a master (*see* GAGES)

The indicator or measuring head amplifies the lineal movement of the contact point enough so that minute movements are clearly visible Comparator heads are frequently rated by the amount of the magnification thus a 1000 1 comparator would have a 1 in travel of the indicating hand or point or marker for each 0 001 in movement of the contact point

Contact comparators are used to check individual single measurements or groups of single measurements Accuracy depends on the measuring head Several contact comparators can be assembled as a single gaging device to perform multiple measurements Frequently all dimensions on a part are inspected on one machine simultaneously When the amplifying heads in such a machine are arranged to actuate sorting equipment and to separate within tolerance and out of tolerance parts, inspection is automated

Mechanical comparators Movement in mechanical comparators is amplified usually by a rack pinion and pointer or by a parallelogram arrangement Usually mechanical comparators are applied to tolerances of 0 001 in although heads are available which are accurate to 0 0001 in

Electrical comparators Movement in electrical comparators [illegible] general methods The

most popular method consists of a floating core in a solenoid attached to the contact point Lineal movement of the contact changes the penetration of the core into the field of the solenoid coil The resulting change in coil reactance is amplified electrically Electrical comparators are applied to tolerances in the range of 0 00005–0 001 in The accuracy of the instrument itself may be as fine as 0 000001 in

Pneumatic comparators Intermediate in operation between contact and optical comparators are pneumatic units They sense the surface of the part by means of an air stream A precision orifice is brought so close to the surface to be measured that the flow of air from the orifice is restricted (Fig 1) The closer the orifice comes to the surface the greater the restriction a measurement of this restriction in flow is in effect a measurement of this distance Two methods of measurement are employed measurement of the variation in flow and measurement of variation in back pressure Measurement of back pressure is by a conventional though highly accurate pressure gage Measurement of flow is by a tube accurately tapered on the inside from top to bottom in which a round cylindrical bobber is free to move The top or larger end is attached to the gaging orifice The bottom or smaller end is attached to the air source Air is introduced into the bottom flows by the edge of the bobber goes out the top through the gage orifice The amount of air leaving the orifice is the exact amount flowing by the bobber and because the area of the tube varies lineally a variation in flow is made visible by a variation in the height of the bobber in the tube

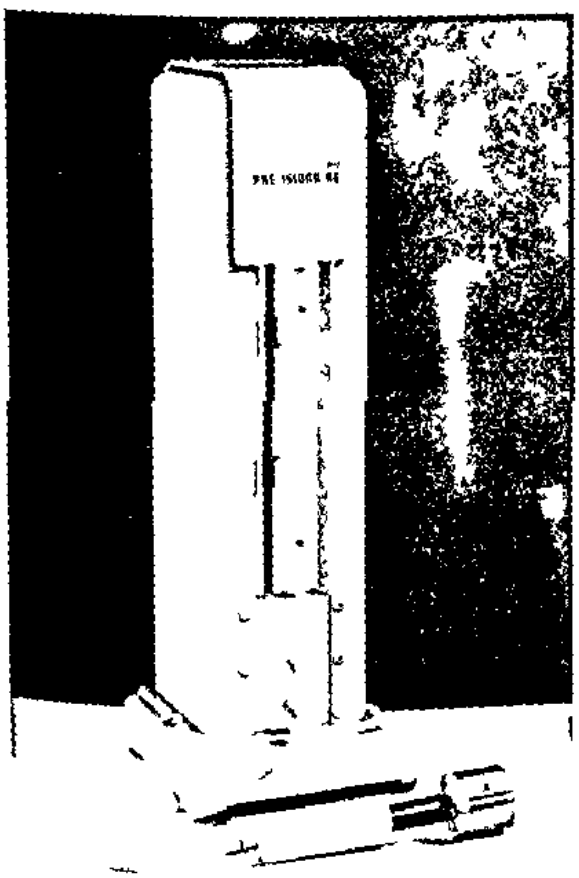


Fig 1 Pneumatic comparator in a plug gage for inspection of an inside diameter (Sheffield Corp)

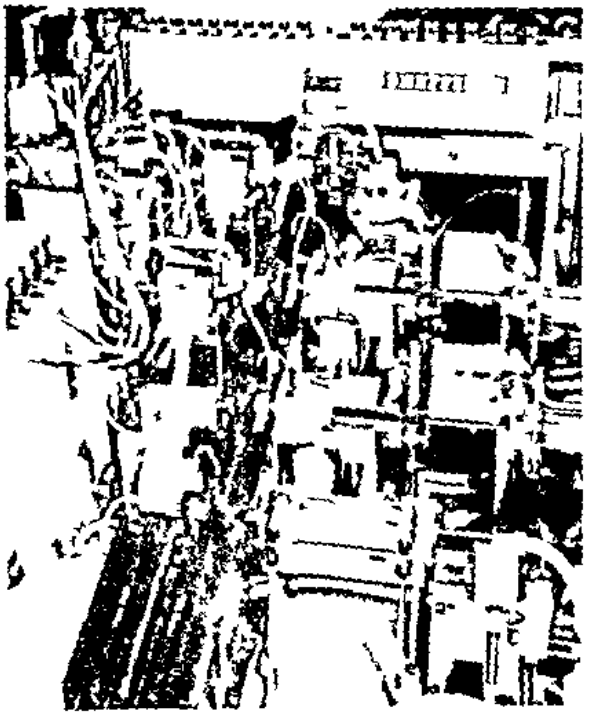


Fig 2 Optical comparator being used to check part against master form drawn on screen (Bausch and Lomb Optical Co)

The range of accuracy of pneumatic gages is approximately that of electric gages

Optical comparators Visual or optical comparators of the general purpose type consist of (1) a light source (2) a stage on which to place the part being inspected (3) a series of lenses and mirrors for magnifying and projecting the shadow of the object and (4) a screen on which the image is projected (Fig 2) The screen is usually a frosted glass Sometimes the master outline is drawn on the screen Some master outlines may be purchased already constructed on the screen—circle diagrams and standard thread forms are examples Sometimes a master form is drawn on vellum or tracing paper to a scale corresponding to the magnification of the optical system and is taped on the screen

Optical or visual comparators are usually used to inspect complex forms or the relationship of one or more individual surfaces For most purposes they are limited to a part tolerance of about 0 001 in To some extent optical comparators are self limiting Most measurements are across parallel or tangential to the surface In general the more accurate surfaces are more highly finished and consequently are more reflective This reflection creates an aberration or fuzziness on the screen which makes accurate identification of the actual surface difficult

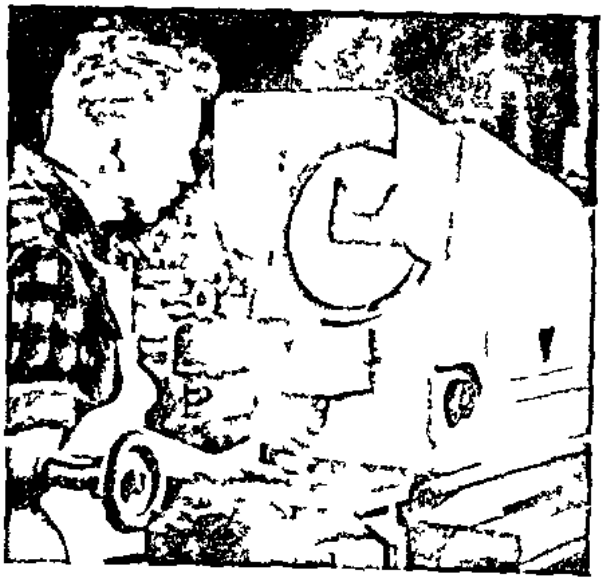


Fig 3 Automated inspection machine for inspecting and classifying ball bearing races (*Sheffield Corp*)

Automated inspection Automated production equipment and automated inspection equipment are interdependent and have developed together The contact type comparator head has been the basic unit of equipment around which automated inspection has been built In some cases individual elements checking individual dimensions are incorporated in the production equipment In others they are assembled in a single machine and this machine is introduced into an automated production line

A machine of this [illegible]
This
or re
The
pass
dime [illegible] are checked They leave the machine by *running down* one of the four troughs in the foreground either accepted or rejected (*see* AUTOMATION)

[R A BO]

Comparator circuit

An *electronic circuit* that produces an output voltage that identifies the point in time at which two input levels reach the same amplitude Most often one level is a variable reference voltage and the other an arbitrary waveform One of the most common applications of the comparator is in the linear time delay circuit (*see* TIME DELAY CIRCUITS) where the inputs consist of a linearly increasing saw tooth waveform and a calibrated dc reference voltage The output which is obtained when the two levels are coincident measures the elapsed time from the start of the saw tooth The clipper and coincidence amplifier can perform the function of the comparator since they can be adjusted so that no output will be obtained until a fixed reference voltage is reached and after that, the input waveform is reproduced (*see* CLIPPING CIRCUIT COINCIDENCE AMPLIFIER) However the term comparator is most often applied to a circuit that does not reproduce the wave shape of the input but rather produces a sharp pulse which accurately defines the point of coincidence Often some form of regenerative circuit is involved

A series clipper (usually termed a pickoff diode for comparator applications) together with a differentiating network and high gain amplifier may be used as a comparator as shown in Fig 1 The diode does not conduct until the level V_R is reached When it does conduct the remainder of the saw tooth waveform appears at its output The time constant of the *RC* differentiating network is sufficiently short so that the initial part of the rise will be produced but the rest of it cannot be maintained The particular amplifier shown is a two-transistor configuration having a relatively high input impedance high gain and low output impedance Vacuum diodes and amplifiers are equally applicable A modification of this circuit replaces the amplifier with a regenerative device such as a cathode coupled multivibrator or a blocking oscillator to increase the gain and therefore speed up the pulse rise at the coincidence point *See* BLOCKING OSCILLATOR MULTIVIBRATOR

Multivibrator comparators There are several ways in which dc or ac coupled multivibrators may be used as comparators The dc cathode-coupled circuit sometimes known as the Schmitt circuit, shown in Fig 2 can function with either a negative going or a positive going input saw tooth waveform In the negative going case initially VT1 is

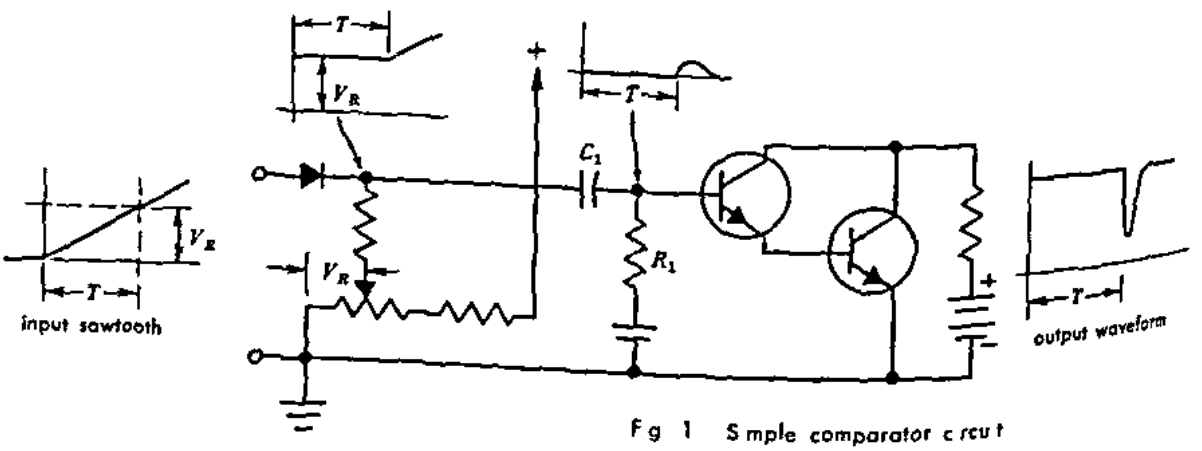


Fig 1 Simple comparator circuit

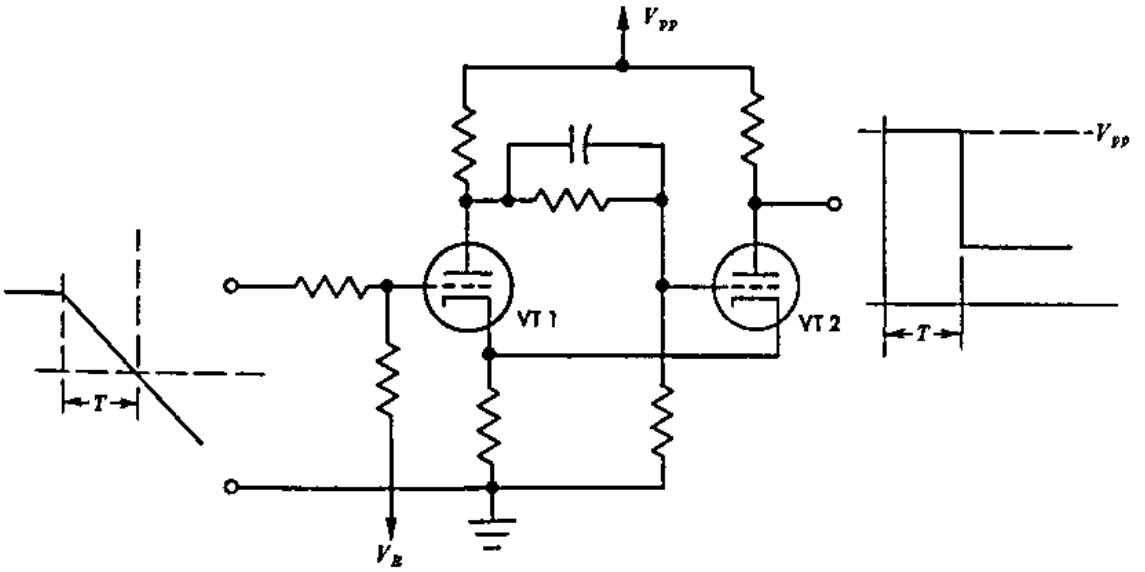


Fig 2 DC-coupled multivibrator comparator

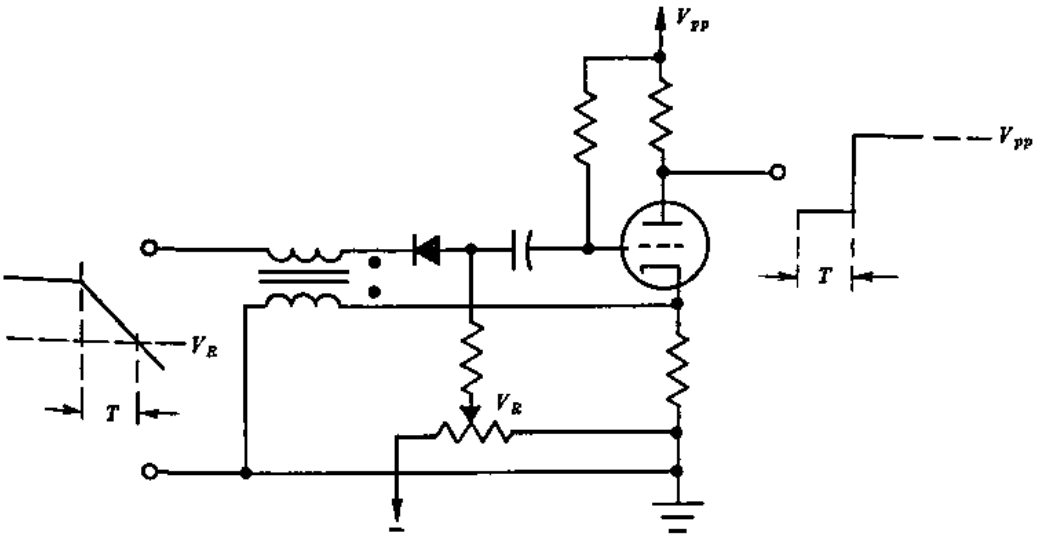


Fig 3 The multiar comparator

conducting heavily and acting as a cathode follower until the potential V_R is reached at which time VT 2 will begin to conduct Since the multivibrator is bistable, the action will be regenerative and the transfer of current will be rapid Therefore a sharp transition will occur at the output, rapidly cutting off VT 1 and driving VT 2 into full conduction

For a positive going saw tooth VT 1 initially will be below cut off, with VT 2 fully conducting In this case, transition will take place when VT 1 begins to conduct

The ac coupled monostable multivibrator also functions as a comparator with a negative-going saw tooth as an input

The multiar. The multiar is a regenerative comparator which combines the pickoff diode and an amplifier with positive feedback through the pulse transformer as indicated in Fig 3 Initially the tube is conducting heavily with its grid at cathode potential The diode is nonconducting When the negative going saw tooth reaches V_R, the diode conducts At this point, the grid drops and the cathode does also, in cathode-follower fashion Positive feedback to the grid through the pulse transformer, which has a step up voltage ratio, causes the action to be regenerative, and a fast pulse is produced

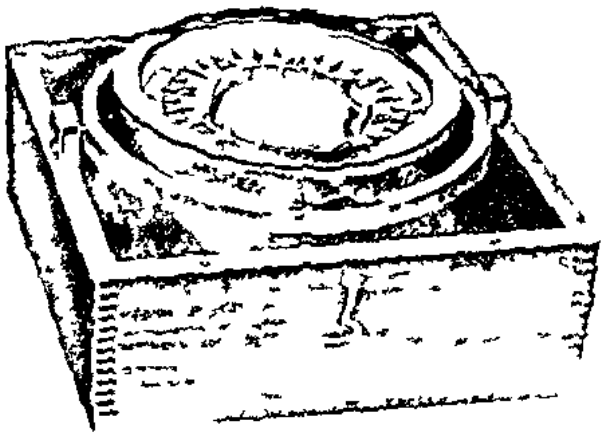
See WAVE SHAPING CIRCUITS [G M G]

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Compass, magnetic

A compass depending for its directive force upon the attraction of the earth's magnetism for a magnet free to turn in any horizontal direction A compass is an instrument used for determining horizontal direction

Principle of operation. The magnetic compass operates on the principle that like magnetic poles repel each other, whereas unlike poles attract each other The earth has internal magnetism similar to that which would result from a short, powerful bar magnet at the center of the earth The lines of



A marine magnetic compass

force connecting the two poles are vertical at two points on the surface of the earth called magnetic poles and horizontal along the magnetic equator a line approximating a great circle nearly midway between the magnetic poles The horizontal component of the earth s magnetic field varies from a maximum on or near the magnetic equator to zero at the magnetic poles.

A simple magnetic compass consists of a magnetized needle mounted so as to be free to align itself with the horizontal component of the earth s field A magnetic compass is unreliable or inoperative in the vicinities of the magnetic poles

Uses Compasses are used to determine the direction in which a craft is pointed the direction of travel on land the direction or bearing of an object and for other purposes Mariners aviators explorers guides scouts surveyors and others have need for a compass *See* NAVIGATION SURVEYING

Direction The primary function of a compass is to indicate a reference direction from which all other directions are derived South is the usual reference direction for astronomers and surveyors

[illegible] seeking and south seeking ends of the compass needle respectively other directions are shown in their correct positions as seen from the center of the compass Most modern navigational compasses mounted permanently in ships aircraft and land vehicles are graduated in degrees from 0° at north clockwise through 360° the graduations are found on a lightweight compass card attached to the directive element Pocket or wrist compasses are usually graduated in compass points the graduations in this instance are found in the case

Errors In addition to such errors as faulty alignment or inaccurate graduation magnetic compasses are subject to two principal errors if the instruments are to be used to determine geographical north and so th [illegible]

Variation
and magnetic

a compass tends to align itself with the magnetic meridian which is the horizontal component of a line of force of the magnetic field of the earth Magnetic meridians do not in general coincide with the geographic meridians which converge at the geographical poles The magnetic meridians converge at the magnetic poles some distance away The magnetic meridians unlike the geographic meridians are not great circles This is true because the magnetic field is not uniform it is distorted considerably by irregularities in the magnetic properties of the materials forming the earth s crust Variation of the compass called declination, depends upon the position of the compass It is determined by magnetic surveys and is published on charts and elsewhere It varies somewhat with time both diurnally (daily) and secularly (long term) *See* GEOMAGNETISM

Deviation The angle between a magnetic meridian and the axis of a compass needle is termed deviation It is caused by local magnetic effects such as magnetism of a ship the magnetic field around a nearby conductor of direct-current electricity or induced magnetism in a nearby tool or pocketknife This source of error generally can be eliminated in a portable compass by using it in a position free from such disturbing influences For permanent installations in ships aircraft, and land vehicles provision is generally made for setting up equal and opposite forces near the compass to neutralize the effects of magnetic influences at the compass The process is called compass adjustment or compass compensation In case the deviation cannot be eliminated completely a deviation table is made up listing the residual deviation on each of a number of headings of the craft Each deviation table applies only to the compass installation for which it was compiled since the deviations are caused by local magnetic effects

[A S M]

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Fro[illegible] 1957? G A [illegible]
Gra[illegible] *Mag*
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netic Compass Adjustment and Compensation, 1944

Compass, radio

A popular term for an automatic radio direction finder used for navigation purposes It is not strictly a compass because it indicates direction with respect to the radio station to which it is tuned rather than to the north magnetic pole The modern radio compass uses a nondirectional antenna in combination with a bidirectional loop antenna to provide a unidirectional bearing indication The navigator thus knows at all times whether he is traveling toward or away from the radio station being used as a reference The antennas are used with a special radio receiver that provides a visual indication of direction on a meter or cathode ray indicator *See* DIRECTION FINDING EQUIPMENT

[J A R]

Complement (serum)

A heat sensitive complex system in fresh human and other sera Complement is important in the host defense mechanism against invading micro organisms and in a variety of laboratory diagnostic tests for the presence of certain diseases Complement (1) lyses antibody coated (sensitized) erythrocytes or certain bacteria, (2) opsonizes sensitized bacteria, (3) alters the rate of aggregation of antigen antibody complexes, (4) immobilizes sensitized spirochetes, (5) combines with various antigen antibody complexes (complement fixation reaction), (6) acts with properdin Complement (C′) has been shown to consist of at least four chemically distinct components, designated C′1 C′2, C′3, and C′4

Components of complement

C′

Dialysis separates		Treatment with yeast inacti vates lypopro tein C′3 (heat stable)	Treatment with ammonia inacti vates mucoeu globulin C′4 (heat stable)
↙ Euglobulin C′1 (heat labile)	↘ Mucoeuglob ulin C′2 (heat labile)		

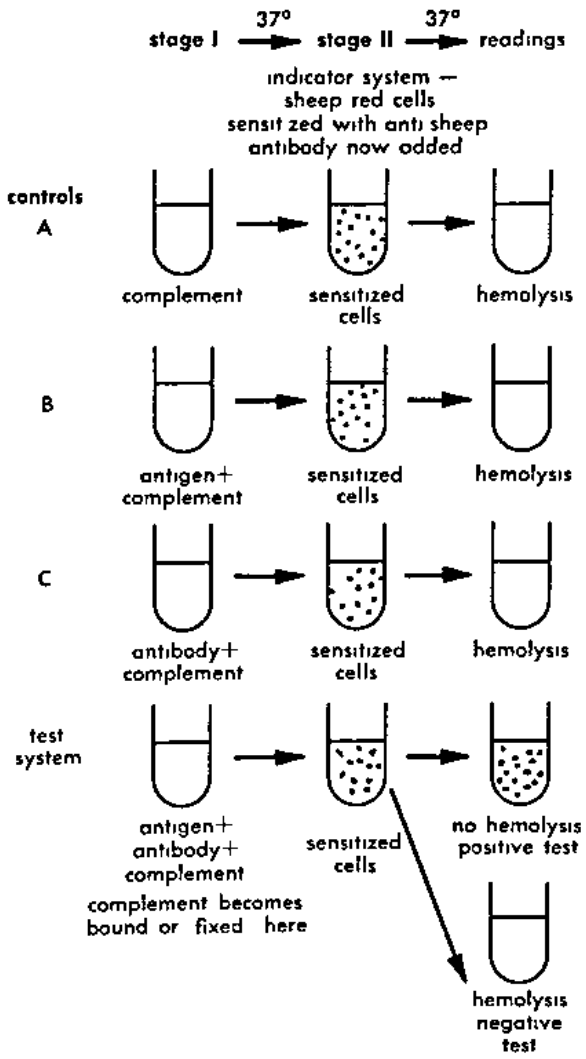
The sera of the various animal species vary considerably in the relative contents of the four components, as well as in their over all complement activities Several complement functions have already been shown to require Ca^{++} (calcium ion) and Mg^{++} (magnesium ion) as cofactors and this has been taken as evidence for the enzymelike nature of complement activity *See* OPSONIN, PROPERDIN [H P T]

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Complement-fixation test

A sensitive reaction used in serology for the detection of either antigen or antibody as in the diagnosis of many bacterial viral, and other diseases, including syphilis It involves two stages (1) the binding or fixation of complement if certain antigen antibody reactions occur, and (2) detection of residual unbound complement, if any, by its hemolytic action on the sensitized erythrocytes subsequently added This is shown in the following diagram

In the first stage either the antigen or the antibody must be supplied as a reagent, with the other of the pair as the test unknown Fresh guinea pig serum is normally used as a complement source Sheep erythrocytes coated with their corresponding antibody (amboceptor or hemolysin) are used in the second stage



Schematic diagram of the complement fixation reaction

The controls A, B and C in the diagram demonstrate that sufficient complement is present to effect hemolysis of the sensitized indicator cells and that neither antigen or antibody added alone will interfere with this by binding complement In the test system the combination of a suitable antigen and antibody in the presence of complement will bind the complement to the complex so that the complement becomes unavailable for the hemolysis of the indicator cells added in stage II If either antigen or antibody is added as a reagent in stage I then the presence of the other in the test unknown added can be detected through its ability to complete the antigen antibody system A lack of hemolysis denotes that the complement is bound This result is termed a positive complement fixation reaction and if the system is controlled against false reactions implies that the antigen (or antibody) assumed to be in the test unknown was actually present Conversely, complete hemolysis of the sensitized erythrocytes implies ultimately, absence of antigen or antibody and is termed a negative complement fixation reaction *See* COMPLEMENT (SERUM), IMMUNOLOGY, LYTIC REACTION [H P T]

Complex compounds

A group of chemical compounds in which a part of the molecular bonding is of the coordinate or chelate type

For a discussion of the nature of the coordinate bond and the stability and the reactivity of complex compounds *see* CHELATION COORDINATION CHEMISTRY This article summarizes the different types of such compounds that are known and discusses their nomenclature, structure, stereochemistry and synthesis

Complex compounds contain a central atom or ion and a group of ions or molecules surrounding it Many simple hydrates, such as $MgCl_2 6H_2O$ are best formulated as $[Mg(H_2O)_6]Cl_2$ because it is known that the 6 molecules of water surround the central magnesium ion Therefore, $[Mg(H_2O)_6]^{2+}$ is a complex ion, $[Mg(H_2O)_6]Cl_2$ a complex compound The charge on this complex ion is 2+, because this is the charge on the magnesium ion and the coordinated water molecules are neutral

Nomenclature The metal complex may be a cation have zero charge or be an anion as is exemplified by the following series of complexes

$[Pt(NH_3)_6]Cl_4$	Hexammineplatinum(IV) chloride
$[Pt(NH_3)_5Cl]Cl_3$	Chloropentammineplatinum(IV) chloride
$[Pt(NH_3)_4Cl_2]Cl_2$	Dichlorotetrammineplatinum(IV) chloride
$[Pt(NH_3)_3Cl_3]Cl$	Trichlorotriammineplatinum(IV) chloride
$[Pt(NH_3)_2Cl_4]$	Tetrachlorodiammineplatinum(IV)
$K[Pt(NH_3)Cl_5]$	Potassium pentachloroammine platinate(IV)
$K_2[PtCl_6]$	Potassium hexachloro platinate(IV)

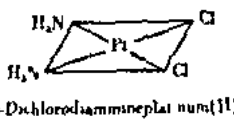
These compounds are named according to rules set up by the Nomenclature Committee of the International Union of Pure and Applied Chemistry Some of the rules are (1) Name the cation first as one word followed by the anion as one word (2) For a cationic complex, name the negative ligands first with an ending of −o, then the neutral ligands, and finally the metal followed by a Roman numeral in parentheses to designate its oxidation state Neutral ligands are named as the molecule, except that H_2O is aquo and NH_3 is ammine (3) The prefixes such as di tri, and tetra are used before simple expressions such as chloro aquo, and oxalato Prefixes such as bis, tris and tetrakis are used before complex expressions such as ethylenediamine 2 2′ bipyridine, and trialkyl phosphine (4) Neutral complexes are named in the same way except that only one word is required (5) Anionic complexes are also named according to these same rules except that an ate ending is used Additional rules are available to name the more complicated compounds, and some of these will be used in the discussion that follows

Coordination numbers of 2–10 have been observed for different complex compounds The most common coordination numbers are 6 and 4 Complexes of a coordination number 6 have an octahedral structure, whereas complexes of a coordination number 4 are either square planar or tetrahedral A few examples of complexes having coordination numbers other than 4 or 6 are given in Table 1

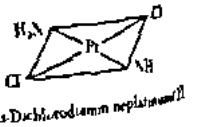
Table 1. Metal complexes with coordination numbers (CN) other than 4 or 6

CN	Complex	Structure
2	$[Ag(CN)_2]^-$, $[Ag(NH_3)_2]^+$	Linear
3	$[Cu(PR_3)_2I]$ $[Au(AsR_3)_2I]$	Planar
5	$[Fe(CO)_4]$ $[Zn(2\,2'\,2''$-terpyridine$)Cl_2]$ $[Ni(PR_3)_2Br_2]$ $[Pd[o$-phenylene-bis-(dimethylarsine)$]_2I]I$	*Trigonal* bipyramid Tetragonal pyramid Pentagonal bipyramid
7	ZrF_7^{3-} NbF_7^{2-}, TaF_7^{2-}	Face-centered trigonal prism
8	$Mo(CN)_8^{4-}$ TaF_8^{3-}	Dodecahedral Archimedean *antiprism*
9	$Nd(H_2O)_9^{3+}$	Face-centered trigonal prism
10	$Cd_2[Mo(CN)_8(H_2O)_2]$	Unknown structure

Structures. *Metal complexes* exhibit various types of isomerism In many ways inorganic stereochemistry is similar to that observed with organic compounds (*see* STEREOCHEMISTRY) Geometrical isomers are common among the inert complexes of coordination numbers 4 and 6 Square planar complexes of the type $Pt(NH_3)_2Cl_2$ exist in two forms,

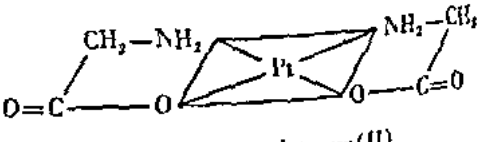


cis-Dichlorodiammineplatinum(II)

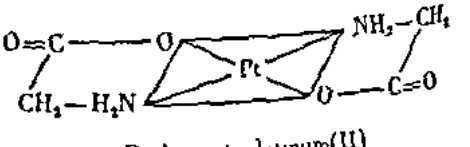


trans-Dichlorodiammineplatinum(II)

Likewise, cis trans isomers of $Pt(NH_2CH_2COO)_2$ type have been isolated

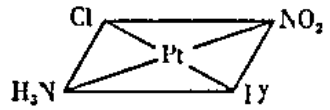


cis Diglycinatoplatinum(II)

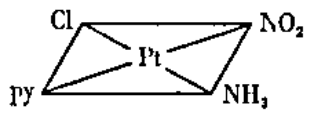


trans Diglycinatoplatinum(II)

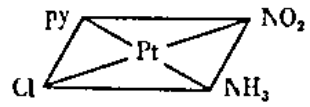
It is apparent from the above examples that the isomer with the same ligands or ligand atoms in adjacent positions is called cis, whereas the trans isomer has its like groups in opposite positions There are also a few examples of geometrical isomers of complexes containing four different ligands,



trans Chloropyridine
trans nitroammineplatinum(II)



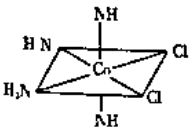
trans Chloroammine
trans nitropyridineplatinum(II)



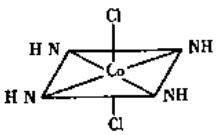
trans Chloronitro-
trans amminepyridineplatinum(II)

Although geometrical isomerism of square complexes is most common with platinum(II) it has also been observed with compounds of nickel(II) palladium(II), and gold(III)

There are many examples of geometrical isomers for 6 coordinated complexes of cobalt(III) chromium(III) and the platinum metals Most of the examples are of the type $[Co(NH_3)_4Cl_2]$

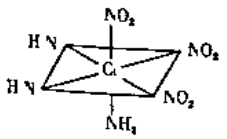


cis Dichlorotetrammminecobalt(III) ion

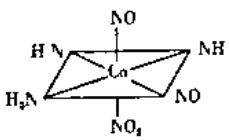


trans Dichlorotetrammminecobalt(III) ion

If three of the ligands differ from the other three then only two isomers are possible

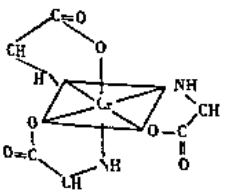


fac-Trinitrotriammminecobalt(III)

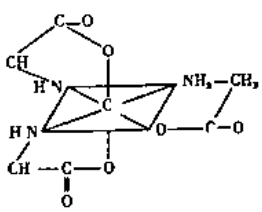


mer-Trinitrotriammminecobalt(III)

Similar isomers are obtained with an unsymmetrical bidentate ligand



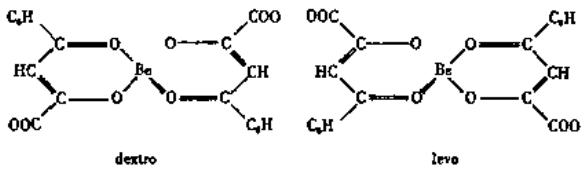
cis-Tris(glycinato)chromium(III)



trans-Tris(glycinato)chromium(III)

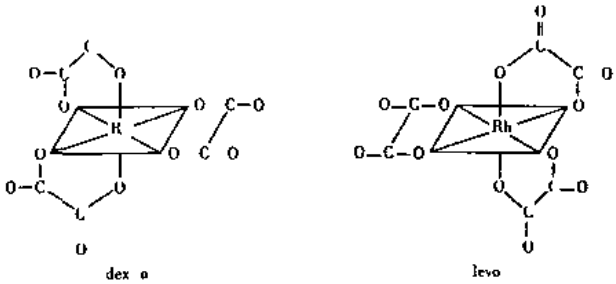
A complex with 6 different ligands such as $[Pt(NH_3)(py)(NH_2OH)(Cl)(Br)(NO_2)]$ can exist theoretically in 15 different geometrical forms In practice it has not been possible to isolate all of these 15 different isomers

Optical isomerism is also fairly common among these compounds For example 4-coordinate tetrahedral complexes containing unsymmetrical bidentate ligands such as bis(benzoylpyruvato) beryllate(II) ion have been resolved



dextro levo

Optically active complexes of this type are likewise reported for boron(III) and for zinc(II) Most of the examples of optical activity occur with 6 coordinated systems containing three bidentate ligands for example trioxalatorhodiate(III) ion

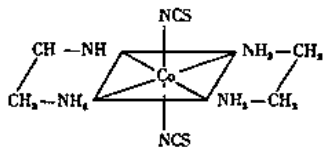


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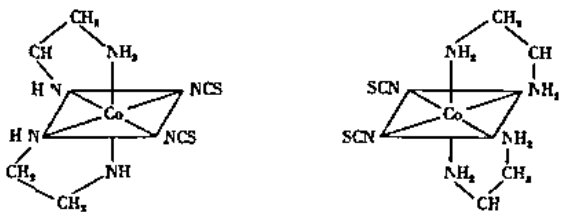
The resolution of 6 coordinated complexes of this

Zn(II)

The cis isomer of a complex containing two bidentate ligands and two monodentate ligands is asymmetric and therefore exists in the form of mirror image isomers whereas the trans form is symmetrical and cannot be optically active



trans-Isothiocyanatobis(ethylenediamine)cobalt(III) ion

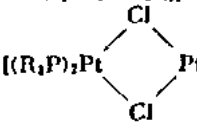
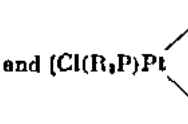


d,l-*cis* Isothiocyanatobis(ethylenediamine)cobalt(III) ion

Since the cis isomer of this type is optically active and the trans isomer is not the successful resolution of one of the isomers is often used as a proof of its cis structure

Other types of isomerism are known for metal complexes and these are given in Table 2

Table 2 Types of isomerism for complex compounds

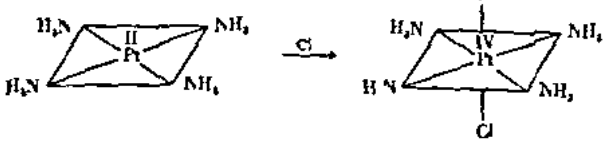
Isomerism	Examples
Geometrical	*cis* and *trans* $[Pt(NH_3)_2Br_2]$
Optical	*d* and *l* $[Ir(NH_2CH_2CH_2NH_2)_3]Cl_3$
Coordination	$[Co(NH_3)_6][Cr(CN)_6]$ and $[Cr(NH_3)_6][Co(CN)_6]$
Coordination position	 $[(R_3P)_2Pt(PtCl_2]$
	 and $[Cl(R_3P)Pt(Pt(PR_3)Cl]$
Hydrate	$[Cr(H_2O)_6]Cl_3$ and $[Cr(H_2O)_5Cl]Cl_2 \cdot H_2O$
Ionization	$[Pt(NH_3)_4Cl]SO_4$ and $[Pt(NH_3)_4SO_4]Cl_2$
Linkage	$[(NH_3)_5Co—NO_2]SO_4$ and $[(NH_3)_5Co—ONO]SO_4$
Polymerization	$[Co(NH_3)_3(NO_2)_3]$ and $[Co(NH_3)_6][Co(NO_2)_6]$

Synthesis The synthesis of metal complexes containing only one kind of ligand generally involves just the reaction of the metal salt in aqueous solution with an excess of the ligand reagent

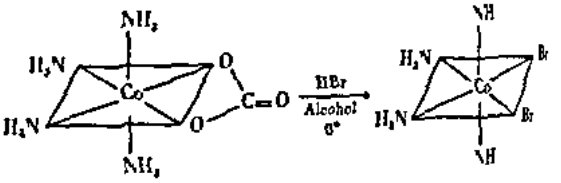
$$[Ni(H_2O)_6](NO_3)_2 + 6NH_3 \rightarrow [Ni(NH_3)_6](NO_3)_2 + 6H_2O$$

The desired complex salt can then be isolated by removal of water until it crystallizes or by the addition of a water miscible organic solvent to cause it to separate Many reactions such as the one cited above occur readily at room temperature For the inert complexes (those slow to react) prolonged treatment at more drastic conditions is often necessary

mixture of cis trans products and these are separated on the basis of their differences in solubility The trans isomers of platinum(IV) complexes are easily prepared by the oxidation of the appropriate platinum(II) compound



The cis isomers of cobalt(III) complexes can sometimes be prepared by the reaction of a carbonato complex with the desired acid

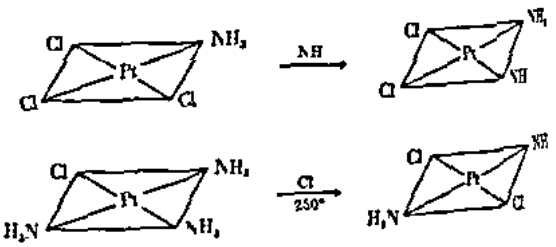


The easiest geometric isomers to prepare are those of platinum(II) For example the cis and the trans isomers of $[Pt(NH_3)_2Cl]$ are prepared as follows

$$K_2[PtCl_4] + 2NH_3 \rightarrow cis\ [Pt(NH_3)_2Cl_2] + 2KCl$$

$$[Pt(NH_3)_4]Cl_2 \xrightarrow{250^\circ} trans\ [Pt(NH_3)_2Cl_2] + 2NH_3$$

The second step in each of these reactions results in the replacement of the ligand trans to a chloro group



This phenomenon that a negative ligand often has a greater labilizing effect on a group in the trans position than does a neutral group for example Cl > NH_3 is called the trans effect Extensive use has been made of this trans effect in the synthesis of desired platinum(II) complexes

Finally the separation of optical isomers of metal complexes involves techniques similar to those used for organic compounds The usual procedure is to convert the racemic mixture into diastereoisomers by means of an optically active resolving agent and then to separate the diastereoisomers by fractional crystallization Nonionic complexes have been resolved by preferential adsorption on optically active quartz or sugars *See* [F B]
AMMINE HYDRATE

Complex numbers and complex variables

The term complex number is used in distinction to the term real number the former involves $\sqrt{-1} = i$ whereas the latter does not Complex numbers were first introduced in connection with algebraic equations the equation $x^2 = -2$ has no solution if x is restricted to real values but has two solutions $x = \pm\sqrt{2}\,i$ where $i = \sqrt{-1}$ if x is permitted to be complex If the coefficients a_1 a_n are complex every algebraic equation

$$z^n + a_1 z^{n-1} + a_2 z^{n-2} + \cdots + a_n = 0 \qquad n > 0 \tag{1}$$

has at least one real or complex root (D Alembert's theorem) It follows by elementary factoring that every such algebraic equation (1) has precisely n roots provided roots are counted according to their multiplicities Indeed if z_1 is a root of Eq (1)

$$z_1^n + a_1 z_1^{n-1} + a_2 z_1^{n-2} + \quad + a_n = 0$$

whence by subtraction

$$(z^n - z_1^n) + a_1(z^{n-1} - z_1^{n-1}) + \quad + a_{n-1}(z - z_1) = 0 \quad (2)$$

If z also is a root of Eq (1) Equation (2) may be written

$$(z - z_1)[z^{n-1} + b_1 z^{n-2} + \quad + b_{n-1}] = 0$$

whence if $n - 1 > 0$ the polynomial $z^{n-1} + b_1 z^{n-2} + \quad + b_{n-1} = 0$ has a root z_2 Continuation of this process yields an equation $(z - z_1)(z - z_2) \quad (z - z_n) = 0$ equivalent to Eq (2)

However the importance of complex numbers goes far beyond their properties as roots of algebraic equations

Complex number system Complex numbers were first used naively without logical justification —and so for that matter were real numbers However the system of complex numbers can be defined rigorously The definition is based on the assumed properties of the real numbers The real number system has important properties relative to the combining of numbers such as

Commutative law for addition

$$a + b = b + a$$

Associative law for addition

$$a + (b + c) \quad (a + b) + c$$

Commutative law for multiplication

$$ab = ba$$

Associative law for multiplication

$$a(bc) = (ab)c$$

Distributive law for addition and multiplication

$$a(b + c) \quad ab + ac$$

In terms of the real numbers $a \ b \ c \ d$ the complex numbers $\alpha \ \beta \ \gamma$ are defined as the totality of ordered pairs $(a\,b)$ of real numbers together with rules of *combination* Thus two complex numbers $\alpha \ (a_1\,a_2) \ \beta \ (b_1\,b_2)$ are said to be equal $(\alpha = \beta)$ if and only if their respective components are equal $a_1 = b_1 \ a_2 = b_2$ It follows that $\alpha = \alpha$ $\alpha = \beta$ implies $\beta \quad \alpha$ if $\alpha = \beta$ and $\beta \quad \gamma$ then $\alpha \quad \gamma$ Addition and multiplication of complex numbers are defined by the equations

$$(a_1\,a_2) + (b_1\,b_2) = (a_1 + b_1 \ a_2 + b_2)$$
$$(a_1\,a_2) \quad (b_1\,b_2) = (a_1 b_1 - a_2 b_2 \ a_1 b_2 + a_2 b_1)$$

It is now easily proved that addition and multiplication are unique and that the laws of combination as enumerated for real numbers also apply to complex numbers Moreover the number $(0\,0)$ has the properties of a zero namely

$$(a_1\,a_2) + (0\,0) = (a_1\,a_2)$$
$$(a_1\,a_2) \quad (0\,0) = (0\,0)$$

In a similar way the number $(1\,0)$ has the properties of a unit namely

$$(a_1\,a_2)(1\,0) = (a_1\,a_2)$$

Subtraction and division can be defined as the inverse processes of addition and multiplication respectively

$$\alpha - \beta = \gamma \quad \text{if and only if} \quad \alpha = \beta + \gamma$$
$$\alpha/\beta = \gamma \quad \text{if and only if} \quad \alpha = \beta\gamma \ \ \beta \neq (0\,0)$$

Then subtraction and division except by $(0\,0)$ are uniquely defined and the usual algebraic laws for them can be established such as $\alpha(\beta - \gamma) = \alpha\beta - \alpha\gamma$

$$\frac{\alpha \quad \gamma}{\beta \quad \delta} = \frac{\alpha \quad \gamma}{\beta \quad \delta}$$

Among the numbers of the complex number system just defined those having the second component zero form a special set and satisfy for instance the equations

$$(a\,0) + (b\,0) = (a + b \ \ 0)$$
$$(a\,0) \quad (b\,0) = (ab\,0)$$

This special set contains the special numbers $(0\,0)$ and $(1\,0)$ and the elements of the set can be placed into one-to one correspondence with the elements of the real number system a correspondence which preserves the operations of arithmetic

$$(a\,0) \sim a \qquad (b\,0) \sim b$$
$$(a\,0) + (b\,0) = (a + b \ \ 0) \sim a + b$$
$$(a\,0) \quad (b\,0) = (ab\,0) \sim ab$$

In the arithmetic operations the numbers such as $(a\,0)$ and $(b\,0)$ cannot be distinguished from the real numbers a and b and henceforth the same notation can be used for the two sets in particular $(2\,0) = 2 \quad (1\,0) = 1 \quad (0\,0) = 0 \quad (-1\,0) = -1 \quad (7\,0) = 7$

It follows from the laws of multiplication that $(0\,1) \quad (0\,1) = (-1\,0) = 1$ that is to say the square of the complex number $(0\,1)$ is the real number -1 This can be expressed as $\imath = (0\,1)$ According to this notation an arbitrary complex number may be written in the form

$$(a\,b) = (a\,0) + (0\,b) = (a\,0) + (0\,1)(b\,0) = a + \imath b$$

That is to say every number of the complex number system can be written as $a + \imath b$ where $\imath = \sqrt{-1}$ Algebraic operations on numbers of the complex number system follow the ordinary rules

Geometric representation Since a complex number is a pair of real numbers these components can be considered as the rectangular (cartesian) coordinates of a point in the plane Each complex number $a + \imath b$ defines a unique point $(a\,b)$ of the plane and conversely each point $(a\,b)$ of the plane represents a complex number $a + \imath b$ Alternately a complex number $(a\,b)$ may be considered to define a unique vector or directed line segment whose components parallel to the x axis and y axis respectively are of algebraic length a and b conversely any vector then is considered to represent the complex number $a + \imath b$ whose components a and b are the components of the vector Addition of two complex numbers is effected by addition of the corresponding vectors according to the

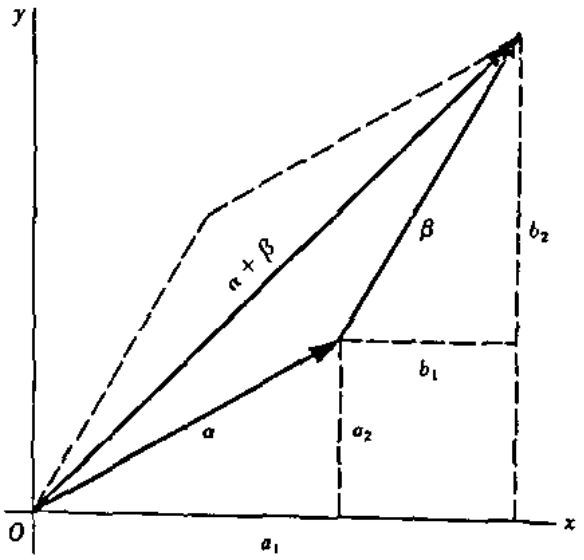


Fig 1

parallelogram law (Fig 1), this gives $(a_1,a_2) + (b_1,b_2) = (a_1 + b_1, a_2 + b_2)$

A vector may also be defined by use of polar coordinates r and θ which represent respectively the length of the vector and its inclination to the x axis, measured positively in the counterclockwise direction from the direction of Ox to the positive direction of the vector (Fig 2) When the vector z is considered to represent a complex number, r $(= |z|)$ is the absolute value or modulus of the number and θ $(= \arg z)$ is its angle or argument The conjugate complex number of z is defined as $\bar{z} = r\,[\cos(-\theta) + i \sin(-\theta)] = r\,(\cos\theta - i \sin\theta)$

The product of two vectors $r_1\,(\cos\theta_1 + i\sin\theta_1)$ and $r_2\,(\cos\theta_2 + i\sin\theta_2)$ according to the definition already given is $(r_1\cos\theta_1\ r_2\cos\theta_2 - r_1\sin\theta_1\ r_2\sin\theta_2) + i\,(r_1\cos\theta_1\ r_2\sin\theta_2 + r_1\sin\theta_1\ r_2\cos\theta_2)$, which by the trigonometric formulas for the sine and cosine of the sum of two angles is $r_1r_2\,[\cos(\theta_1 + \theta_2) + i\sin(\theta_1 + \theta_2)]$ Thus the product of two vectors (complex numbers) is defined as the vector (Fig 3) whose modulus is the product of the moduli of the factors and whose argument is the sum of the arguments of the factors. $|z_1z_2| = |z_1|\ |z_2|$, $\arg(z_1z_2) = \arg z_1 + \arg z_2$

Subtraction and division of vectors are defined as the inverse processes of addition and multiplication, the reader can easily interpret these processes geometrically

Infinity is not an element of either the real or the complex number system

Limits of sequences. An infinite sequence of complex numbers $\alpha_1, \alpha_2, \alpha_3, \ldots$ is said to converge to, or approach, the limit α under the following conditions Let an arbitrary positive ϵ be given, there shall exist N_ϵ such that $n > N_\epsilon$ implies $|\alpha - \alpha_n| < \epsilon$ Geometrically this requirement is as follows Any circular disk with center α contains all but a finite number of the α_n This may be expressed $\alpha_n \to \alpha$ as $n \to \infty$, or $\lim_{n\to\infty} \alpha_n = \alpha$

Functions of a complex variable. The concept of function is primarily that of dependence The complex variable w is a function of the complex variable z if w is determined when z is known Examples $w = 3z + 2i$, $w = 6z^4$, $w = (2z^3 - i)/(5z^2 + 3 + 8i)$ The function $w = f(z)$ approaches the limit w_0, $\lim_{z\to z_0} f(z) = w_0$, as z approaches z_0 provided that whenever a sequence z_n (of which no member coincides with z_0) approaches z_0 one has $\lim_{n\to\infty} f(z_n) = w_0$

Another form of this definition, easily proved equivalent to the first, is the following to every $\epsilon(>0)$ corresponds a $\delta(>0)$ such that $0 < |z - z_0| < \delta$ implies $|f(z) - w_0| < \epsilon$ The function $f(z)$ is continuous at the point z_0 if $f(z_0)$ is defined, and $\lim_{z\to z_0} f(z) = f(z_0)$

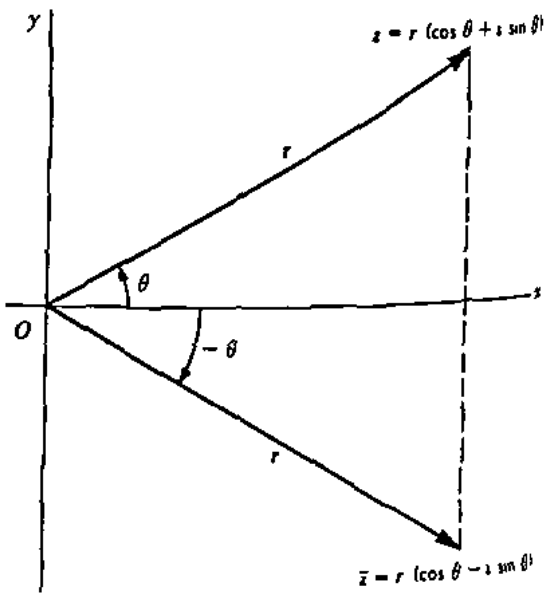


Fig 2

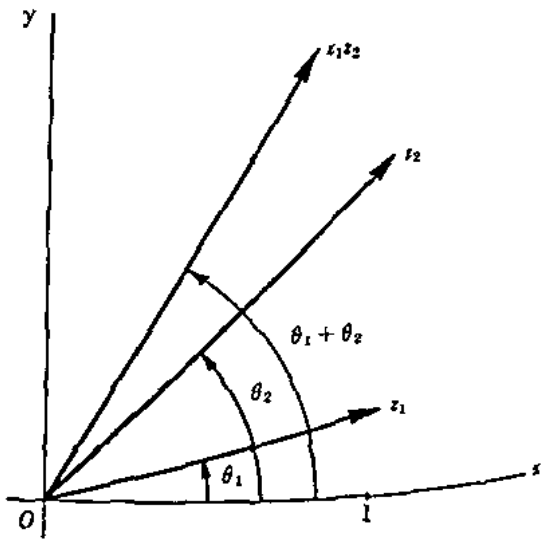


Fig 3

It is then readily shown that if two functions are continuous at a point so are their sum difference product and (if the value of the denominator is not zero) quotient In particular a polynomial $a_0z^n + a_1z^{n-1} + \cdots + a_n$ in z is continuous for all values of z and a rational function $(a_0z^n + a_1z^{n-1} + \cdots + a_n)/(b_0z^m + b_1z^{m-1} + \cdots + b_m)$ of z is continuous for all values of z at which the denominator is different from zero A function is continuous on a set of points E if it is continuous at each point of E

To study a function $w = f(z)$ it is frequently convenient to separate both z and w into real and pure imaginary parts $z = x + iy$ $w = u + iv$ Then one may write $f(z) = u(x\,y) + iv(x\,y)$ where $u(x\,y)$ and $v(x\,y)$ are real functions of the two real variables x and y From the definitions of limit and continuity for such functions it readily follows that $f(\ )$ has a limit $u_0 + iv_0$ as $z \to z_0 = x_0 + iy_0$ if and only if $u(x\,y)$ and $v(x\,y)$ have limits as $(x\,y) \to (x_0\,y_0)$ The function $f(\ )$ is continuous at the point z_0 if and only if $u(x\,y)$ and $v(x\,y)$ are continuous at $(x_0\,y_0)$ *See* REAL VARIABLE

Differentiation The derivative of a function $f(z)$ at a point z_0 is defined as $f'(z_0) = \lim_{z \to z_0} [f(z) - f(z_0)]/(z - z_0)$ provided this limit exists it is assumed that $f(\ )$ is defined throughout some neighborhood of z_0 and in taking the limit $\arg(z - z_0)$ shall not be restricted This definition of derivative is formally the same as for a real function of a real variable there follow the usual theorems for the existence of a derivative and for its value For instance if $f_1(z)$ and $f_2(z)$ possess derivatives $f_1'(z_0)$ and $f_2'(z_0)$ at the point z_0 so do their sum difference product and (if $f_2(z_0) \neq 0$) quotient the values of the respective derivatives are

$$f_1'(z_0) + f_2'(z_0) \quad f_1'(z_0) - f_2(z_0) \quad f_1(z_0)f_2'(z_0)$$
$$+ f_1'(z_0)f_2(z_0) \quad [f_2(z_0)f_1'(z_0) - f_1(z_0)f_2'(z_0)]/[f_2(z_0)]^2$$

A constant function has the derivative zero at every point Every polynomial possesses a derivative at every point and the derivative is continuous a rational function possesses a derivative necessarily continuous at every point where the denominator is different from zero

Analytic functions A function $f(z)$ is analytic (or holomorphic) at a point z_0 if it has a derivative at every point of some neighborhood of z_0 (that is in a disk whose center is z_0) and if the derivative is continuous there the function is analytic on a point set if analytic at each point of the set An analytic function $F[f(z)]$ of an analytic function $f(z)$ is likewise analytic The real elementary functions (rational trigonometric exponential logarithmic) can be extended in definition to complex values of the argument so as to be analytic the same is true of the solutions of many difference and differential equations Numerous properties even for real values of the argument are most easily proved by use of the general properties of analytic functions

By a region or domain is meant an open connected point set E the set E is open if when ever z_0 belongs to E so also do the points of some disk containing z_0 the set E is connected if when ever two points z_0 and z_1 belong to E so also does some broken line joining z_0 and z_1 A region E is simply connected if every closed curve in E with out multiple points can be continuously deformed into a point while remaining in E

Let $f(z) \equiv u(x\,y) + iv(x\,y)$ be analytic in a region E and let the point $z_0 = x_0 + iy_0$ belong to E If in the definition of $f'(z_0)$ one chooses successively $\Delta z = \Delta x$ $\Delta z = i\,\Delta y$

$$f'(z_0) = \frac{\partial u(x_0\,y_0)}{\partial x} + i\frac{\partial v(x_0\,y_0)}{\partial x}$$
$$= -i\frac{\partial u(x_0\,y_0)}{\partial y} + \frac{\partial v(x_0\,y_0)}{\partial y}$$

Consequently $u(x\,y)$ and $v(x\,y)$ satisfy throughout E the Cauchy Riemann equations

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} \qquad \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}$$

and the partial derivatives involved are continuous on E by the continuity of $f'(z)$ there Conversely if $u(x\,y)$ and $v(x\,y)$ are given with continuous partial derivatives in a region E satisfying there the Cauchy Riemann equations then $f(z) = u(x\,y) + iv(x\,y)$ is analytic in E With $z_0 = x_0 + iy$ and $z_0 + \Delta z = (x_0 + \Delta x) + i(y_0 + \Delta y)$ in E one can compute

$$\Delta w = \Delta u + i\,\Delta v$$
$$= \frac{\partial u\,(x_0\,y_0)}{\partial x}\Delta x + \frac{\partial u\,(x_0\,y_0)}{\partial y}\Delta y + \epsilon_1$$
$$+ i\frac{\partial v\,(x_0\,y_0)}{\partial x}\Delta x + i\frac{\partial v\,(x_0\,y_0)}{\partial y}\Delta y + \epsilon_2$$

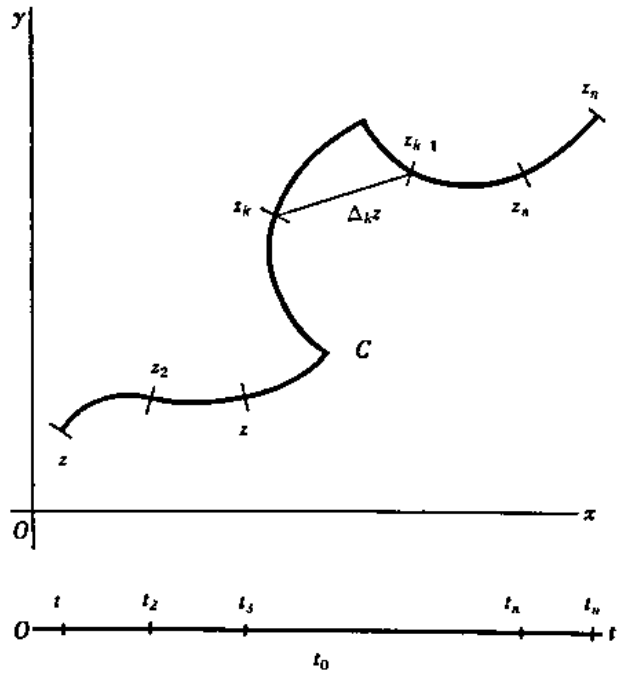


Fig 4

where $\epsilon_1/|\Delta z|$ and $\epsilon_2/|\Delta z|$ approach zero with Δz By use now of the Cauchy Riemann equations one may write

$$\frac{\Delta w}{\Delta z} = \frac{\partial u\,(x_0\,y_0)}{\partial x} + i\,\frac{\partial v\,(x_0,y_0)}{\partial x} + \frac{\epsilon_1 + \epsilon_2}{\Delta z}$$

whence $f'(z_0)$ exists and has the value $(\partial u/\partial x) + i(\partial v/\partial x)$

A pair of functions $u(x,y)$ and $v(x,y)$ which are continuous, have continuous first partial derivatives in a region E, and satisfy the Cauchy Riemann equations in E are said to be conjugate functions in E, this shows that $u(x,y)$ and $i\,(x,y)$ are conjugate functions in a region when and only when $f(z) \equiv u(x,y) + iv(x,y)$ is analytic there

If $f(z) = u(x\,y) + i\,(x,y)$ is analytic in a region so also are its successive derivatives $f'(z)$, $f''(z)$, If this result is used, it follows that $u(x,y)$ and $v(x,y)$ have continuous partial derivatives of all orders, differentiation of the Cauchy Riemann equations with respect to x and y respectively shows that $u(x,y)$ satisfies Laplace's equation

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0$$

and it similarly follows that $v(x,y)$ also satisfies this equation

Integration As for a function of a real variable, the inverse of differentiation of a function of a complex variable is integration but in the latter case integration is to be taken along a more or less arbitrary curve in the z plane Following W F Os good, a regular arc is defined as a point set E represented parametrically by $x = x(t)$, $y = y(t)$, $0 \leqq t \leqq 1$ where $x(t)$ and $y(t)$ are continuous and have continuous derivatives with $|x'(t)| + |y'(t) \neq 0$, and where $x(t_1) = x(t_2)$, $y(t_1) = y(t_2)$ implies $t_1 = t_2$ A regular curve is the union of a finite number of regular arcs placed end to end, it may also be expressed parametrically $x = x(t)$, $y = y(t)$, $0 \leqq t \leqq t_0$, a regular Jordan curve is the union of a finite number of regular arcs placed end to end without multiple points and where the terminal point of the last arc coincides with the initial point of the first arc Such a curve is known (Jordan's theorem) to bound two disjoint regions, its inside and its outside

If C is a regular curve on which the function $f(z)$ is continuous, the integral $\int_C f(z)\,dz$ is the limit of a sum

$$\sum_{k=1}^{n-1} f(z_k)\,\Delta_k z$$

Here (Fig 4) the parametric representation $x = x(t)$, $y = y(t)$, $0 \leqq t \leqq t_0$ is used, and n points t_k of subdivision of the interval $t_1 = 0 < t_2 < t_3 <$ $< t_n = t_0$ with $z_k = x(t_k) + iy(t_k)$, $\Delta_k z - z_{k+1} - z_k$ are

this limit is defined as the integral Indeed, if one sets $f(z) \equiv u + iv$, $\Delta_k z = \Delta_k x + i\,\Delta_k y$, $dz = dx + i\,dy$ the sum is precisely of the form

$$\sum_{k=1}^{n-1} [u(x_k,y_k)\,\Delta_k x - i\,(x_k,y_k)\,\Delta_k y] + i \sum_{k=1}^{n-1} [u(x_k,y_k)\,\Delta_k y + i\,(x_k\,y_k)\,\Delta_k x]$$

whose limit is known to exist and to be the sum of line integrals over C

$$\int_{[x(0)\ y(0)]}^{[x(t_0)\ y(t_0)]} [(u\,dx - v\,dy) + i(u\,dy + i\,dx)]$$

This definition of integral is applicable provided $f(z)$ is merely continuous on C An appraisal of the integral is of frequent use If L is the length of C and if $|f(z)| \leqq M$ on C,

$$\left|\sum_{k=1}^{n-1} f(z_k)\,\Delta_k z\right| \leqq M \sum_{k=1}^{n-1} |\Delta_k z| \leqq LM$$

whence $\left|\int_C f(z)\,dz\right| \leqq LM$, the desired inequality

If $f(z)$ is analytic, the integral has special properties

Cauchy's integral theorem. If a function $f(z)$ is analytic on and within a regular Jordan curve C, then $\int_C f(z)\,dz = 0$

If functions $P(x,y)$ and $Q(x,y)$ are continuous together with their first derivatives on C and throughout its interior D, the familiar theorem of Green asserts

$$\iint_D \left(\frac{\partial P}{\partial y} - \frac{\partial Q}{\partial x}\right) dS = -\int_C (P\,dx + Q\,dy)$$

where the line integral is taken over C in the positive or counterclockwise sense If $f(z) \equiv u + iv$ is analytic on $C + D$, the functions u and v together with their first partial derivatives are continuous on $C + D$ by the Cauchy Riemann equations and Green's theorem it follows that the real and pure imaginary parts of $\int_C f(z)\,dz$ both vanish, so Cauchy's integral theorem follows

From the definition it follows that the value of the integral over a regular curve C depends on the sense chosen, symbolically

$$\int_C f(z)\,dz = -\int_{-C} f(z)\,dz$$

If the Jordan curve C of Cauchy's integral theorem is divided into two arcs C_1 and C_2,

$$\int_{C_1} f(z)\,dz + \int_{C_2} f(z)\,dz = 0$$

or

$$\int_{C_1} f(z)\,dz = \int_{-C_2} f(z)\,dz$$

Thus if $f(z)$ is analytic in a simply connected region containing two regular curves having the same initial and terminal points, the integrals of $f(z)$ over the two curves are equal This result has been proved here only if the two curves have no common points other than the end points, but it can be extended easily A similar remark, similarly proved, is that the integrals $\int_{C_1} f(z)\,dz$ and $\int_{C_2} f(z)\,dz$ taken over two regular Jordan curves in the same sense are equal provided

deformation does not alter the integral

Cauchy s integral formula It is not to be supposed that all integrals of analytic functions are zero To evaluate the integral $\int_C d\ /$ taken over a regular Jordan curve C containing the origin O in its interior C may be chosen as the circle whose center is O and radius ρ namely $= \rho(\cos\theta + i \sin\theta)$ $0 \le \theta \le 2\pi$ By differentiation $d = \rho(-\sin\theta + i \cos\theta)\, d\theta - i z\, d\theta$ whence

$$\int_C d\ /z - i \int_C d\theta = 2\pi i$$

If now an arbitrary analytic function $f(z)$ divided by $z - z_0$ is integrated over a small circle whose center is z_0 it is reasonable to suppose that the value of the integral depends only on $f(z_0)$ and indeed that the integral may be taken over any Jordan curve containing z_0 in its interior on and within which $f(z)$ is analytic

If z_0 lies interior to the regular Jordan curve C on and within which the function $f(z)$ is analytic the result is Cauchy s integral formula

$$f(z_0) = \frac{1}{2\pi i} \int_C \frac{f(z)\, dz}{z - z_0}$$

where the integral is taken in the counterclockwise sense (Fig 5)

It is sufficient to prove this formula when C is a single circle γ If $\epsilon\ (> 0)$ is given there exists by the continuity of $f(z)$ at z_0 a number $\delta\ (> 0)$ such that for z on γ $|z - z_0| = \delta$ $|f(z) - f(z_0)| < \epsilon$ where $f(z)$ is analytic on and interior to γ Thus

$$\left| \frac{1}{2\pi i} \int_\gamma \frac{f(z)\, dz}{z - z_0} - f(z_0) \right| = \left| \frac{1}{2\pi i} \int_\gamma \frac{[f(z) - f(z_0)]\, dz}{z - z_0} \right| \le \frac{1}{2\pi} \cdot 2\pi\delta \cdot \frac{\epsilon}{\delta} = \epsilon$$

and the conclusion follows by the lack of dependence on γ of the integral

This formula is frequently written in the notation

$$f(z) = \frac{1}{2\pi i} \int_C \frac{f(t)\, dt}{t - z}$$

formal differentiation of which with respect to z yields the valid equation

$$f'(z) = \frac{1}{2\pi i} \int_C \frac{f(t)\, dt}{(t - z)^2}$$

and with repeated differentiation

$$f^{(n)}(z) = \frac{n!}{2\pi i} \int_C \frac{f(t)\, dt}{(t - z)^{n+1}}$$

Thus the $(n+1)$st derivative of $f(z)$ exists at $t = z$ the nth derivative is continuous there and $f^{(n)}(z)$ is analytic interior to C consequently the components of $f(z) \equiv u(x, y) + iv(x, y)$ possess continuous partial derivatives of all orders so (as

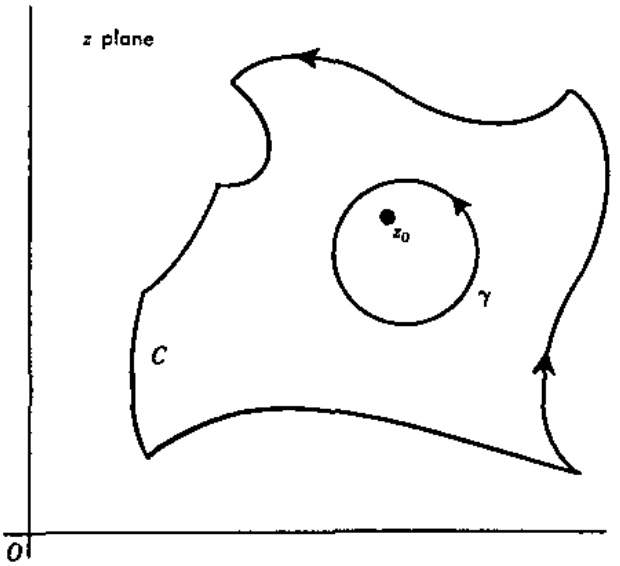


Fig 5

remarked above) u and v satisfy Laplace s equation

D Alembert s theorem is readily proved from Cauchy s integral formula If the polynomial $p(z) \equiv z^n + a_1 z^{n-1} + \cdots + a_n$ $(n > 0)$ has no zero the function $f(z) = 1/p(z)$ is analytic for all z Let z be arbitrary but fixed and let t lie on C a large circle whose center is z and radius R then $t - z = R(\cos\theta + i \sin\theta)$ $dt = i(t - z)\, d\theta$

$$f(z) = \frac{1}{2\pi i} \int_C \frac{f(t)\, dt}{t - z} = \frac{1}{2\pi} \int_C \frac{d\theta}{t^n \left(1 + \frac{a_1}{t} + \cdots + \frac{a_n}{t^n}\right)}$$

If $\epsilon\ (> 0)$ is given and R is chosen sufficiently large $|f(t)| < \epsilon$ on C $|f(z)| < \epsilon$ whence $f(z) = 0$ $f(z) \equiv 0$ which is absurd This contradiction proves that $p(z)$ has at least one zero

Morera s theorem If D is a region in which a function $f(z)$ is continuous and if for every z_0 and z_1 in D

$$\int_{z_0} f(t)\, dt$$

is independent of the particular path in D from z_0 to z_1 then $f(z)$ is analytic in D

Since the integral is independent of the path one may introduce the definition for in D

$$F(z) = \int_{z_0}^{z} f(t)\, dt$$

whence

$$F(z + \Delta z) = \int_{z_0}^{z+\Delta z} f(t)\, dt$$

$$F(z + \Delta z) - F(z) = \int_{z}^{z+\Delta z} f(t)\, dt$$

and choose the path of integration from z to $z + \Delta z$ a line segment If $\epsilon\ (> 0)$ is given for sufficiently small $|\Delta z|$ the values for t on this line segment satisfy $|f(z) - f(t)| < \epsilon$ whence

$$|F(z+\Delta z) - F(z) - f(z)\quad \Delta z)|$$
$$= \left| \int_z^{z+\Delta z} f(t)\,dt - \int_z^{z+\Delta z} f(z)\,dt \right|$$
$$= \left| \int_z^{z+\Delta z} [f(t) - f(z)]\,dt \right|$$
$$\leqq \epsilon|\Delta z|$$

Consequently $[F(z+\Delta z) - F(z)]/\Delta z \to f(z)$ as $\Delta z \to 0$ so $F'(z)$ exists and has the value $f(z)$ Thus $F(z)$ possesses a continuous derivative in D, and is analytic there together with its derivative $f(z)$ Morera's theorem is a converse of Cauchy's integral theorem By the use of Morera's theorem, it is possible to show that a function $f(z)$ which merely possesses a derivative $f'(z)$ at every point of a region possesses a continuous derivative there and hence is analytic

Taylor's theorem. In contrast to functions of a real variable every function of a complex variable possessing a continuous derivative can be expanded in a valid (infinite) Taylor development Let C be a regular Jordan curve (Fig 6) on and within which $f(z)$ is analytic Let $t = a$ be an arbitrary point interior to C, let the disk γ $|t-a| \leqq \rho$ lie interior to C and let z lie interior to γ Then

$$f(z) = \frac{1}{2\pi i}\int_C \frac{f(t)\,dt}{t-z} = \frac{1}{2\pi i}\int_C \frac{f(t)\,dt}{\left(1-\frac{z-a}{t-a}\right)(t-a)}$$
$$= \frac{1}{2\pi i}\int_C \frac{f(t)\,dt}{t-a}\left[1 + \frac{z-a}{t-a} + \left(\frac{z-a}{t-a}\right)^2 + \quad\right]$$
$$= f(a) + f'(a)(z-a) + \frac{f''(a)}{2!}(z-a)^2 +$$

the series in square brackets converges uniformly for t on C and for z on γ, hence the integrated (Taylor's) series is valid and converges uniformly for z on γ It can be shown that a valid series development $f(z) \equiv a_0 + a_1(z-a) + a_2(z-a)^2 +$ must converge uniformly in some disk whose center is a is unique and may be integrated or differentiated term by term, its sum is an analytic function interior to any region of convergence The series development just established may be valid throughout a much larger region than γ, indeed throughout a region containing points exterior to C, and thus may serve as a means of extending or prolonging the analytic function $f(z)$ beyond its given domain of definition

Further results Numerous further results can be established A function $f(z)$ analytic in a region D $0 < |z-a| < \delta$ can be expressed there as a unique two way power series

$$f(z) = \sum_{-\infty}^{\infty} a_k(z-a)^k$$

If no negative powers effectively occur, the additional or adjusted definition $f(a) = a_0$ yields a function $f(z)$ analytic also for $z = a$, if only a (positive) finite number of negative powers occur, the function $f(z)$ has a pole at $z = a$, to give $1/f(z) \to 0$ as $z \to a$, if an infinite number of negative powers occur, $f(z)$ has an essential singularity at $z = a$, and Picard's theorem asserts that $f(z)$ assumes all values w with at most one exception in every neighborhood of $z = a$ A singularity of an analytic function $f(z)$ is a point of nonanalyticity of $f(z)$ whose every neighborhood contains points of analyticity, the only isolated singularities (non limit points of other singularities) are those just discussed removable singularities, poles and essential singularities

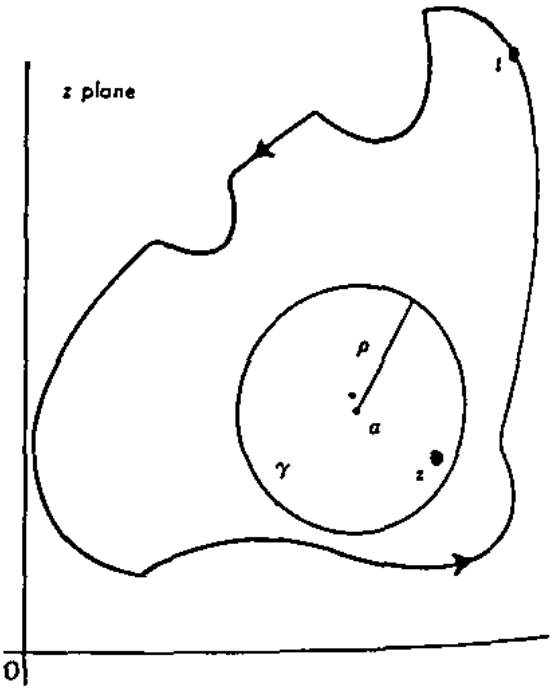


Fig 6

If $z = a$ is an isolated singularity of $f(z)$ the integral of $f(z)/2\pi i$ around a small circumference whose center is a is called the residue of $f(z)$ at a, the evaluation of line integrals and definite integrals is largely accomplished by the calculus of residues

The principle of maximum modulus expresses the fact that $|f(z)|$ cannot have a strong relative maximum at a point z_0 at which $f(z)$ is analytic and has a weak relative maximum at such a point z_0 only if $f(z)$ is identically constant in the neighborhood of z_0

The principle of argument asserts that if $f(z)$ is analytic and different from zero on a regular Jordan curve C, and analytic except perhaps for a finite number of poles interior to C, then

$$\frac{1}{2\pi}\arg f(z)\Big|_C = \frac{1}{2\pi i}\int_C \frac{f'(z)\,dz}{f(z)} = N - P$$

where N is the number of zeros of $f(z)$ and P the number of poles interior to C Here both zeros and poles are counted according to their multiplicities the functions

$$(z-a)^n[a_0 + a_1(z-a) + a_2(z-a)^2 + \quad]$$

and $(z-a)^{-n}[a_0 + a_1(z-a) + a_2(z-a)^2 + \quad]$

where the square brackets represent convergent power series with $a_0 \neq 0$ and where n is a positive integer, have respectively a zero of order n and a pole of order n at $z = a$ The first of these formulas shows that if $f(z)$ is analytic at $z = a$ with $f(a) = 0$, but $f(z) \not\equiv 0$, then some neighborhood of a contains no zero of $f(z)$ other than a

The inversion of a convergent power series

$$w = f(z) = \sum_0^\infty a_k(z-a)^k$$

means the expression of z as a convergent power series in (and therefore an analytic function of) w

$$z = f^{-1}(u) \equiv \sum_0^\infty b_k(w-b)^k$$

with $a_0 = b$, $b_0 = a$ Such inversion is always possible if $a_1 \neq 0$ Geometrically this procedure shows that the map or transformation defined by $w = f(z)$ sets up a correspondence between the points of a region containing a and the points of a region containing b which is one to one

For important applications of complex numbers *see* CONFORMAL MAPPING, LAPLACE'S DIFFERENTIAL EQUATION, SERIES [J L W]

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Composite beam

Composite beams are so called because they provide beam action of two materials joined together in such a way as to act as a unit In civil engineering the term is most commonly given to the beam action developed by a concrete slab resting on a steel beam usually an I or a wide flange shape the slab and the beam being made to act together by shear connectors

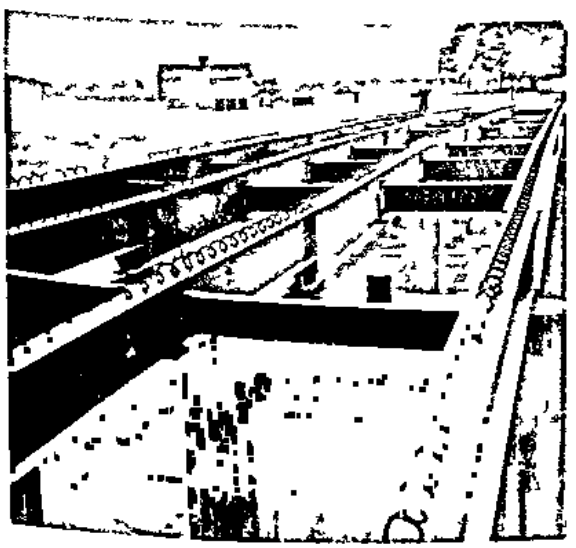


Fig 1 Steel portion of composite beam in place with spiral shear connectors welded to I beams (Porete Mfg Co)

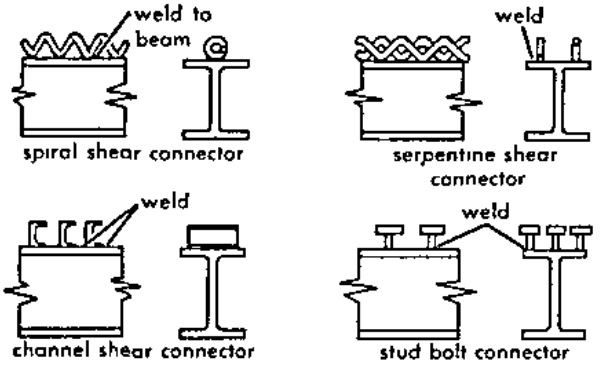


Fig 2 Typical shear connectors (*From L C Urquhart, C E O'Rourke and G Winter, Design of Concrete Structures 6th ed , McGraw Hill, 1958*)

In noncomposite design the structural function of the concrete slab is only to span transversely across a series of parallel steel beams In composite design the concrete slab performs its normal function and in addition increases to a considerable extent the capacity of the structure to resist bending in the direction of the steel beams The unit stresses in the concrete slab are not added algebraically from the dual function the slab performs, because the flexural stresses are in mutually perpendicular directions Consequently the concrete slab thickness and area of reinforcing steel are not necessarily greater for this type of design than for the noncomposite design

Shear connectors are devices that provide unified action between the concrete slab and the steel beam by resisting the horizontal shear developed in beam bending (Fig 1) They take the form of steel projections welded to the top flange of the steel beam and around which the concrete slab is poured The connectors perform a necessary function in the development of composite beam action, for without them the two elements, the concrete slab and the steel beam would act separately as two beams and the beam action would be analogous to two unconnected wooden planks placed one on top of the other and slipping on each other when bent under a transverse load There are many types of shear connectors but three commonly used types are (1) stud bolts (2) a helical coil of steel rod, and (3) short lengths of a standard channel shape

[illegible] several types of shear connectors

¾ in diameter and perhaps ⅛ in high All shear connectors must have some provision to prevent the concrete slab from lifting vertically from the steel beam when bent under load In the case of the stud bolt the head provides this restraint The bolts are welded to the beam flange several in a grouping, and spaced longitudinally along the beam in accordance with the design based on the intensity of the horizontal shearing stress at each position along the beam A short channel length welded across the beam flange provides the same shear

connection function as the stud bolts or a helical coil of rod with a 6 or 8 in pitch and a 4 or 5 in diameter can connect the two elements A typical rod diameter is ¾ in

Application Composite I eams are used both in building and highway bridge construction and can be used in any type of construction where it is appropriate to use a concrete slab resting on steel beams or stringers Definite and considerable economy is achieved in composite construction when the spans are of sufficient length to offset the increased cost of fabricating the shear connectors with the saving from the lesser I eam size required Composite construction is generally not considered economically feasible for spans under 35 or 40 ft but is used on simply supported spans up to 100–120 ft or longer with specially fabricated steel beams In the longer spans the size of the steel stringers can be reduced at least to the next lower standard rolled steel section In most size ranges the beams are listed in groupings of beam depths in 3 in multiples For example a I eam design for noncomposite action which required a 36 in depth could be expected to I e reduced to 30–33 in depth if composite action is provided [H L K]

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Composition (type)

The act of composing or combining type for printing either by machine or by hand Type may be set by hand from cases to a composing stick much as it was set in the days (about 1450) of Johann Gutenberg often credited with having been the inventor of printing from movable types (Fig 1) Each character or space is a separate piece of metal that may be combined with similar pieces in various styles and sizes *See* TYPE (PRINTING)

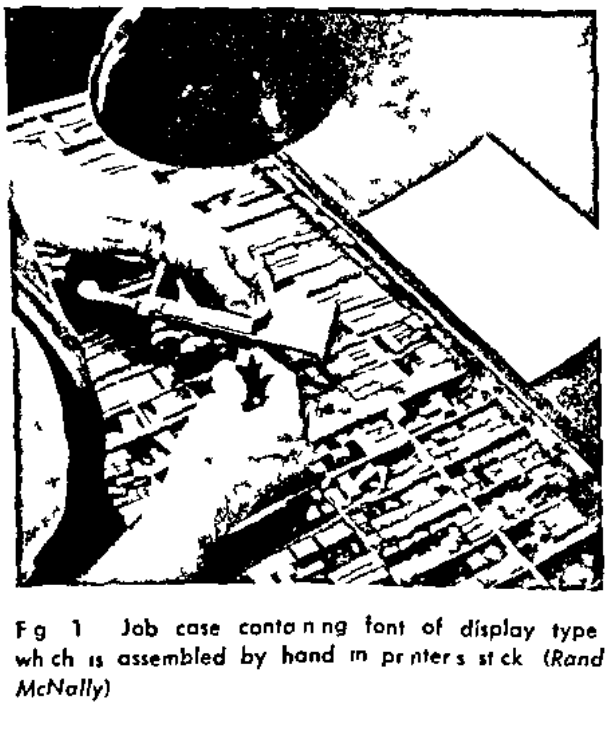


Fig 1 Job case containing font of display type which is assembled by hand in printer's stick (*Rand McNally*)

HAND COMPOSITION

Foundry types are cast of an alloy of lead tin, antimony and copper and are comparatively hard and long wearing They may be used over and over and are distributed after printing to their respective sections or boxes in the case Single types cast by machines such as the Monotype or the Thompson Type Caster and placed in the case for hand setting are ordinarily not as hard or as long wearing as foundry types because they contain no copper However, they do have a greater tin content and are harder than metal slugs of type cast on the Linotype or Intertype

Much of the type set by hand today is in the larger display sizes beginning with the 18 point and progressing to the 96 point size (A typographical point is equivalent to ½ in) This does not mean, however that smaller sizes even 6 point and larger sizes up to 288 point may not be set by hand

Composing rooms strive to set as much type as possible by machine either in slug form (Linotype Intertype or Ludlow) or in justified single type [illegible] However there are many de- es even imes.

Until recent years there were many companies in the United States in the business of casting foundry type The field has narrowed considerably and today there are only a few large companies still in the business There are others which operate on a smaller scale some regionally only supplying their customers with foundry type or single types with little or no copper content A number of European type foundries have outlets in the United States and distribute their type faces on a wide scale in direct competition with domestic foundries

MACHINE COMPOSITION

Much type in smaller sizes is set today by either the Linotype or the Intertype machines which assemble matrices or molds of the letters by means of a keyboard and deliver the line of type in slug form The slug has the advantage of being in one piece for rapid handling of the line without danger of the type becoming disassembled in such high speed work as daily newspaper production books and some commercial printing

Linotype Although preceded by a number of machines of varying practical value the Linotype was the first composing machine which would assemble the line mechanically by means of a keyboard cast the single solid line of type and then distribute the matrices to the magazine in such a manner that they could be used over again rapidly (Fig 2) The Linotype was invented by O Mergenthaler in 1878 but was not successfully demonstrated until July 3 1886 when it was used for the *New York Tribune* Mergenthaler had many difficulties to overcome and a great deal of field te ing

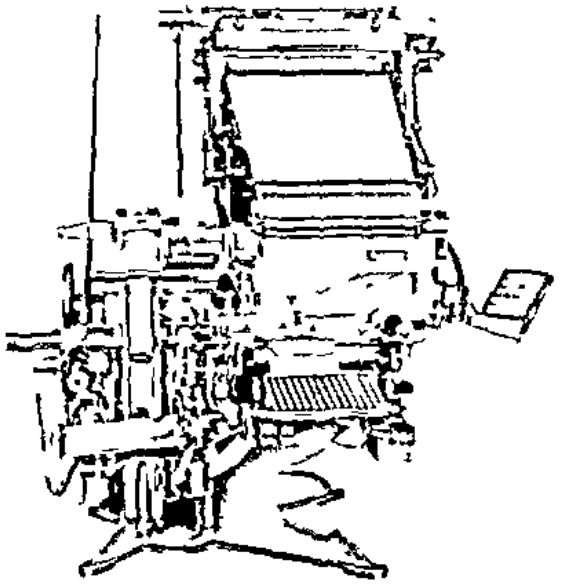


Fig 2 The Linotype (above) and Intertype machines are similar in basic mechanical principles Both produce type in the form of slugs or solid lines and may be equipped to cast large type for headlines and advertising display as well as small text sizes

to do before the printing trade would consent to try his machine There is now scarcely a printing plant or newspaper in the United States that does not own or have access to a line casting machine

Intertype. The Intertype machine first saw successful service about 1912 Its basic mechanical principles are essentially the same as those of the Linotype in that it assembles the matrices by means of a keyboard casts the line of type in slug form and then distributes the matrices automatically for repeated use

The Linotype and Intertype machines ordinarily will cast about 7 8 lines/min of average size body type for a newspaper column The manufacturers of both machines have succeeded in increasing the speeds of several models to 12–14 lines/min so that they are highly competitive Few Linotype or Intertype operators can actuate the keyboard rapidly enough to produce 12 14 lines/min and keep it up hour after hour, so the makers of the machines have through associated development with other manufacturers taken steps to provide automation Notable among these developments is the Teletype setter, an auxiliary device which will operate the keyboard of a Linotype or Intertype mechanically

Teletypesetter. The Fairchild Teletypesetter consists of two units one for perforating and one for actuating the keyboard The perforating unit punches holes in a special paper tape These holes represent a code which corresponds to the keyboard characters touched by the Linotype or Intertype operator The perforated tape is fed into the operating unit attached to the line casting machine This unit senses the code of the punched holes in the tape and operates the keyboard automatically By means of the Teletypesetter, the standard line casting machine will set about 400 lines/hour, high speed machines will set about 600 lines/hour The average operator will set manually from 200 to 300 lines/hour

The operator of the punch unit can do about 400 newspaper column lines per hour The tape may be punched well in advance of the typesetting and may be filed afterward

Electro-Typesetter. A line casting machine, an adaptation of the Linotype, developed for the various plants of the *Wall Street Journal*, is called the Electro Typesetter The Electro Typesetter has no keyboard assembly and the matrices are assembled automatically by tape controlled solenoids The system will set up to 540 characters/min, and its speed is limited only by the capability of the line casting machine It operates continuously at two to three times the speed of manually operated type setting machines

The Electro Typesetter unit is operated from a central control unit in the newspaper's news room where the tape is perforated A supervisor at a master control panel selects a line casting machine in the composing room sets the correct mold and plugs in a tape reader A light system indicates trouble when it occurs and the machine stops automatically for adjustment

Another automatic typesetting machine has been developed by the Intertype Company The Monarch model has no keyboard and is operated by perforated tape at a speed of 8 14 lines/min The Monarch is a conversion model of earlier high speed Intertypes

Ludlow. Slug casting by machine may also be accomplished by a device called a Ludlow or Ludlow Typograph The Ludlow differs from the Linotype and Intertype in that the brass matrices for the various characters and spaces are assembled by hand from cases to a special stick, which is inserted in the casting mechanism After the casting opera

will ordinarily accommodate is 96 point, alphabets and price figures up to 144 point and even larger can be supplied in special engraved matrices

Elrod A companion machine to the Ludlow is the Elrod which will cast material such as leads rules borders and spacing materials in continuous strips from 1 to 18 points in thickness Many rule designs and combinations are available

Monotype. The Lanston Monotype will cast type in single characters in justified lines of predetermined length The Monotype is really two machines a keyboard and a caster The keyboard punches holes in a strip of paper called a ribbon which looks something like an old fashioned player piano roll (Fig 3)

When the ribbon comes from the keyboa fed into the caster (Fig 4) Compressed

ing through the punched holes controls the action of a casting apparatus shifting the die case of 225 (or 255) characters in any of four directions—to either side, forward, and backward—whichever is needed to move the desired matrix to a position above the mouth of the mold Molten metal is then pumped in, casting the letter, and the mechanism moves on to another matrix The letters are assembled side by side When the line is finished it is ejected and positioned on a galley (Fig 5)

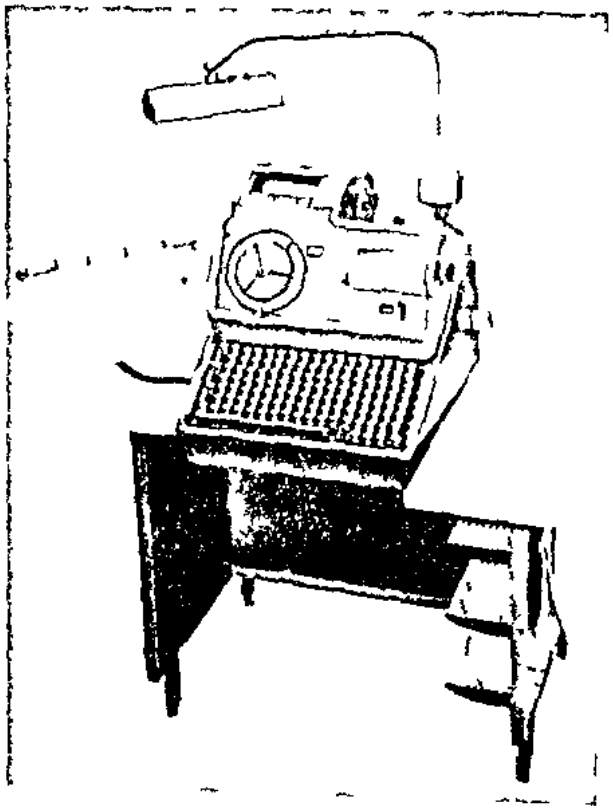


Fig 3 The Monotype keyboard punches a special paper ribbon much like the old fashioned player piano roll Keyboard illustrated is called Monomatic

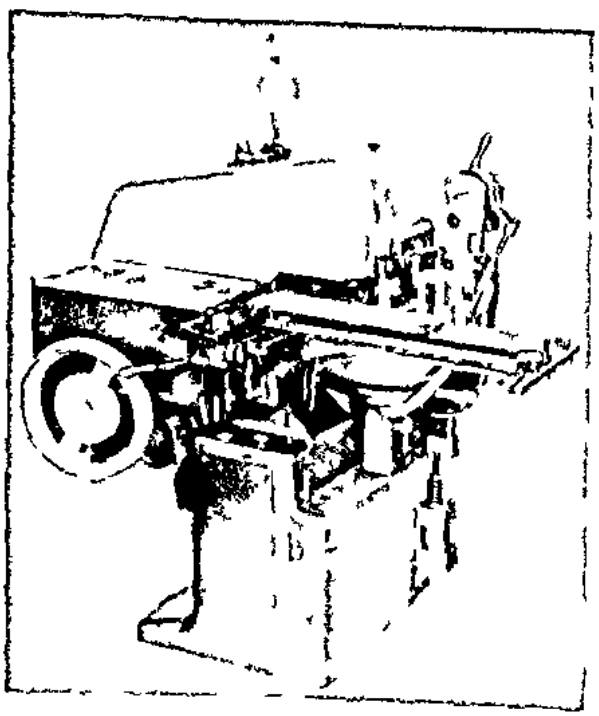


Fig 4 The Monotype Monomatic caster will cast type automatically from paper ribbon cut on keyboard and deliver it in single types in justified lines of predetermined length

The Monotype Caster will set type in all measures up to 60 picas (10 in) in all sizes from 4 to 18 point at the rate of 160–200 characters/min, depending upon the size of the matrices The machine may be equipped to cast display type up to 36 point leads, slugs and rules

Companion Monotype machines include the Giant Caster which will handle the 14- to 72-point range of single display types, and metal furniture from 14 to 72 point in continuous strips The Thompson Type Caster will cast type ornaments, borders, and quads and spaces in sizes from 14 to 48 point The material making machine will cast in strip form straight line rules, decorative borders, leads and slugs

PHOTOTYPESETTING

Although experiments with photographic composition of type matter have been conducted for many years it was not until 1949 that the first successful commercial photographic typesetting machine was made available to commercial printers and newspapers in the United States The Intertype Company announced its Fotosetter machine in that year

Fotosetter. Although the physical appearance of the Fotosetter has changed somewhat the original model resembled a hot metal line-casting machine The matrices of the Fotosetter contain photographic images rather than incised or punched characters By exposure to a turret type camera the images are photographed in rapid succession in a variety of sizes and the complete line appears on a film negative or positive

The Fotosetter will produce photographic composition in justified lines in galley form on film or photographic paper Type sizes range from 4 to 36 point inclusive, in lines up to 42 picas long Provision is also made for setting quadded tabular and rule form work as well as continuous script and other types of specialized composition

The resulting film product may be used for making albumin and deep etch plates for offset lithography, letterpress engravings gravure plates and cylinders plates for engraved stationery stencils for screen process work and others Enlargements of various small sizes to 144 point may be done on conventional enlargers

The Super Display Fotosetter will set type on film up to 72 point and up to 51 picas (8½ in) wide The machine will carry 6 8 12 and 18 point sizes and by combining them with 14 lenses it is possible to set more than 30 different type sizes ranging from 3 point through 72 point

Photon Totally different from the conventional circulating matrix machine is the Photon machine (Fig 6) The Photon incorporates a stroboscopic flashing light which selects desired characters to be

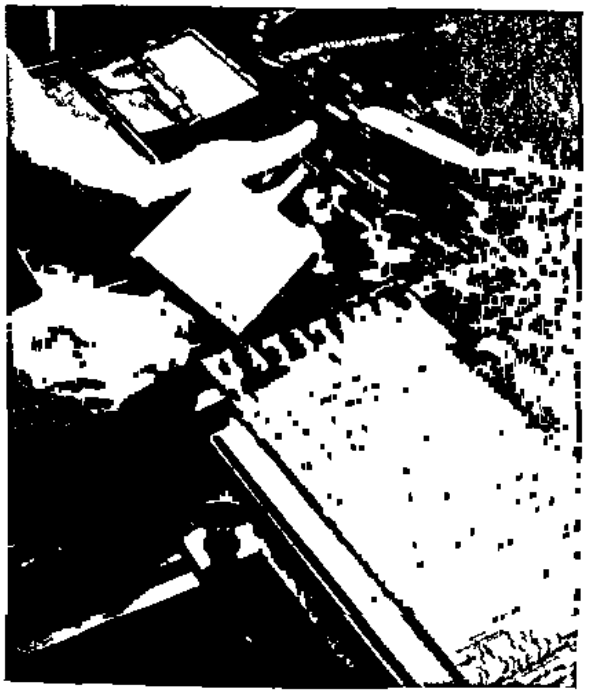


Fig 5 Monotype matrix case (in hands) and Monotype type Matrix case contains 225 mats, one for each character in the font, from which each piece of type is cast individually (*Rand McNally*)

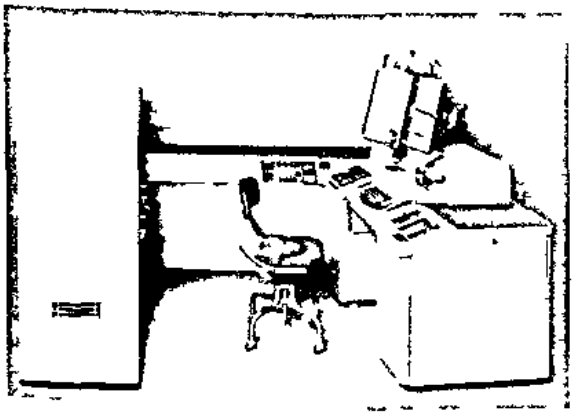


Fig 6 Photon sets type on film by means of a new principle, differing from the circulating-matrix principle of the hot metal Linotype or Intertype and the Intertype Fotosetter

reproduced on film from a rotating matrix disk and projects their images through appropriate lenses onto photographic film or paper

The Photon operator commands 17 280 characters from a single keyboard The matrix disk is lightweight, and composition speed is 8 10 characters/sec Line lengths may vary up to 54 picas and sizes range up to 72 point from keyboard operation The electric typewriter keyboard will bring into play any of 12 sizes in each type face up to 72 point

Monophoto A British contribution to setting type on film is the Monophoto This machine resembles the hot metal Monotype in many ways but delivers the product on film rather than in justified lines of single pieces of type

The Monophoto operates from a perforated paper ribbon prepared on existing Monotype keyboards The ribbon passes over air vents and brings the master negative into any one of the 255 positions, the photographic equivalent of a matrix case The ribbon provides remote control automatic operation (Fig 7)

The Monophoto will produce double or multiple column material on a single sheet of film Headings and other insertions not conforming to the body matter may be handled on the same film By using not more than three master negatives, type sizes can be varied from 6 to 24 point Desired leading in increments of ½ point can be determined after the keyboarding is completed before exposing the film

Linofilm. The Mergenthaler Linotype Company has developed a photographic typesetting machine which it calls Linofilm The system consists of four integrated components a keyboard, a photographic unit, a corrector, and a composer

The keyboard is a conventional typewriter keyboard with a small bank of control buttons for leading quadding and centering, justification, and other functions Eighteen fonts are available on the keyboard in a range of sizes from 6 point through 36 point The keyboard produces a perforated paper tape containing information necessary for automatic operation of the photographic unit

The photographic unit is capable of handling the tape output of several keyboards and will produce right reading positive type on film or on photographic paper It will change font, point size, leading and line length automatically in accordance with the signals from the tape The photographic unit operates at speeds equivalent to 16 newspaper text lines per minute Line lengths are through 42 picas

The Linofilm corrector makes corrections simply by welding corrected lines in position automatically

The composer unit combines the functions of make up and enlarging and produces a made up

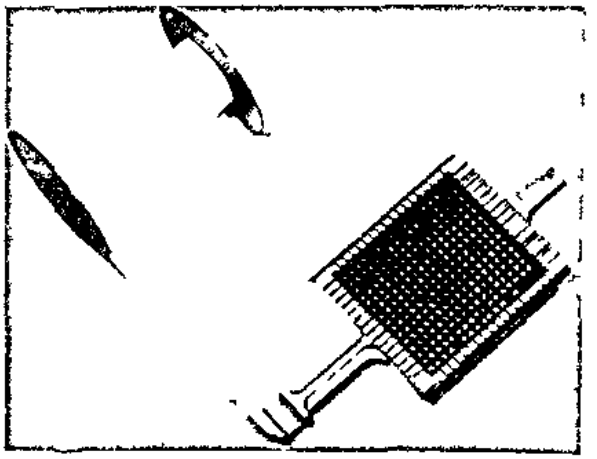


Fig 7 The negative master or matrix case of the Monophoto and the standard perforated paper ribbon which controls it are the heart of the Monophoto system

page with all the type in location and in proper size ready for insertion of halftones and art work It will enlarge through 180 point and will reduce to 4 point Widths through 102 picas are available

American Type Founders Typesetter The ATF typesetter a system for composing type on film consists of two portable desk top size machines the keyboard unit and the photographic unit The keyboard unit provides a typewritten proof and a common language perforated tape which is then used to operate the photographic unit automatically The system provides a range from 5 point to 14 point in measures up to 7½ in wide and is specifically designed for composition of text matter It will provide type on film for direct use in offset and gravure platemaking

Composition starts at the keyboard unit which is basically an electric typewriter In the same typing operation a justification code is automatically punched into a paper tape Justification is on a word space basis and letter spacing between letters is possible in single unit increments A standard typewriter ribbon is used on the keyboard unit and the bold or italic of a face is indicated on the typewritten proof in red color

The perforated tape is placed in the photographic unit where it automatically produces type on film composition which may be a right reading or wrong reading transparent positive on the emulsion side The tape controls the operation of the optical system and a plastic type disk which contains two fonts of type around the disk The photographic unit will operate automatically at a rate of 130 characters/min

American Type Founders Hadego Among the earlier devices which will put type faces on film by means of hand assembly methods is the ATF Hadego Photocompositor a Dutch invention marketed in the United States by the American Type Founders Co

Resembling a Ludlow hot metal machine in its basic principle of operation the ATF Hadego utilizes plastic matrices which have a white image against a black background The matrices are hand set in a special composing stick which is then placed in the machine The machine is set for the size of image desired and a button is pressed to make the exposure Using 48 point matrices the operator can make reproductions from 10 point to a maximum of 82 point The use of 20-point matrices will permit reductions or enlargements from 4 to 34 point The mach ne for

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rolls Among them are the Halber Typro Mergenthaler Linotype s Protype the Filmotype the Stri Printer the Vari Typer Corporation s Headliner the Rutherford lettering machine and the Optype

JUSTIFYING TYPEWRITERS

Various typewriters are available for producing composition in justified as well as unjustified lines for offset lithographic reproduction Those machines that produce justified type lines usually require two typings of the material because correct word spacing cannot be determined until the first typing has been accomplished

The Vari Typer Corporation manufactures a typewriter on which the type faces may be changed by inserting or withdrawing a small semicircular bar containing the font Typewriters made by International Business Machines and others have permanently affixed alphabets usually in one size and in one style The Justowriter system in which only one manual typing is necessary consists of two units On the first unit the material is typed simultaneously with the cutting of a perforated tape on which is indicated the proper word spacing The second unit automatically types with the tape a

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when the occasion requires with halftone and other line negatives made separately From these negatives are made plates suitable for printing by the letterpress offset lithography or gravure processes *See* PRINTING PRINTING PLATE [WVB]

Compressible flow

Flow in which the fluid density varies In aerodynamic phenomena when the flow velocity is large it is necessary to consider that the fluid is compressible rather than to carry over from classical aerodynamics the assumption that the fluid has a constant density Under this condition the speed of sound becomes an important factor At relatively low speeds the changes of temperature and density of a fluid caused by the motion of a body in the fluid are almost negligible However if the body moves at high speed through the fluid the motion can cause pronounced changes in density and temperature of the fluid Hence consideration of phenomena of this type involves not only classical fluid mechanics but thermodynamics as well *See* AERO-THERMODYNAMICS

The essential difference between an incompressible fluid and a compressible fluid is in the speed of sound In an incompressible fluid the propagation of pressure change is essentially instantaneous in a compressible fluid the propagation takes place with finite velocity For example if one strikes the surface of an incompressible fluid the effect observed at great distances is of course less than at a smaller distance but it reaches even infinite distance in essentially zero time In a compressible fluid the effect propagates at finite velocity A small disturbance propagates at the velocity of sound

In aerodynamic phenomena the effects of the compressibility of the fluid can be important if the variation of fluid volume caused by the variation of pressure occurring in the flow is of the same order of magnitude as the variation in velocity which corresponds to the variation in pressure The ratio of the fractional change in volume $\Delta v/v$ to the fractional change in velocity $\Delta u/u$ is equal to the ratio

of the square of the velocity to the square of the velocity of sound $(u/a)^2$ where a is sonic velocity Hence when the velocity of the flow is the same order of magnitude as the velocity of sound in the flow the variation of volume (or density) is the same order of magnitude as the variation in velocity The large velocity variations occurring in high speed flows therefore cause large changes in the fluid density

The ratio of the local fluid velocity to the local sound velocity is the local Mach number Mach number is an index of compressibility serving as a measure of the relative importance of density changes in a fluid flow field In aerodynamic forces the error which results from the assumption of incompressibility in *flow problems* amounts to roughly $M_0^2/2\%$ when M_0 is the flight Mach number *See* SUPERSONIC FLIGHT [J E SC]

Compression ratio

In a cylinder the piston displacement plus clearance volume divided by the clearance volume This is the nominal compression ratio determined by cylinder geometry alone In practice the actual compression ratio is appreciably less than the nominal value because the volumetric efficiency of an unsupercharged engine is always less than 100% due in part to late intake valve closing (*see* VOLUMETRIC EFFICIENCY) In spark ignition engines the allowable compression ratio is limited by incipient knock at wide open throttle Knock in turn depends on the molecular structure of the fuel and on such engine features as the temperature of the combustible mixture prior to ignition the geometry and size of the combustion space and the ignition timing For example isooctane benzene and alcohol can be burned at much higher compression ratios than *n* heptane In compression ignition engines critical compression ratio is that necessary to ignite the fuel and depends on fuel and cylinder geometry *See* COMBUSTION CHAMBER DIESEL ENGINE INTERNAL COMBUSTION ENGINE [N M]

Compressor

A machine that increases the pressure of a gas vapor or mixture of gases and vapors The pressure of the *fluid is* increased by reducing *the fluid* specific volume during passage of the fluid through *the compressor When compared with* centrifugal or axial flow fans on the basis of discharge pressure compressors are generally classed as high pressure machines fans as low pressure machines *See* FANS

Compressors are used to increase the pressure of a wide variety of gases and vapors for a multitude of purposes (Fig 1) A common application is the air compressor used to supply high pressure air for conveying paint spraying tire inflating cleaning pneumatic tools and rock drills Next is the refrigeration compressor used to compress the gas formed in the evaporator Other applications of compressors include chemical processing gas transmission gas turbines and construction *See* CHEMICAL PROCESS CONTROL GAS TURBINE REFRIGERATION

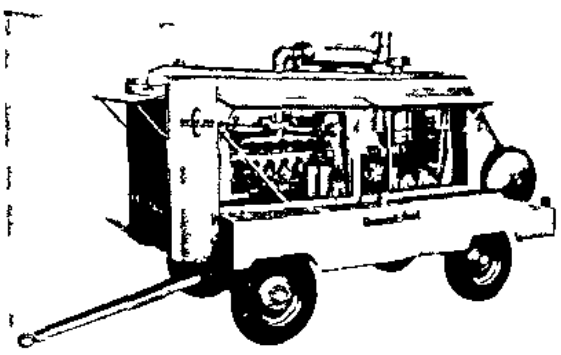


Fig 1 Mobile air compressor is driven by engine in forward compartment (*Ingersoll Rand*)

Compressor characteristics Compressor displacement is the volume displaced by the compressing element per unit of time and is usually expressed in cubic feet per minute (cfm) Where the fluid being compressed flows in series through more than one separate compressing element (as a cylinder) the displacement of the compressor equals that of the first element Compressor capacity is the actual quantity of fluid compressed and delivered expressed in cubic feet per minute at the conditions of total temperature total pressure and composition prevailing at the compressor inlet The capacity is always expressed in terms of air or gas at intake (ambient) conditions rather than in terms of arbitrarily selected standard conditions

Air compressors often have their displacement and capacity expressed in terms of free air Free air is air at atmospheric conditions at any specific location Since the altitude barometer and temperature may vary from one location to another this term does not mean air under uniform or standard conditions Standard air is at 68°F 14 7 psia and a relative humidity of 36% Gas industries usually consider 60°F air as standard

Compressor types Compressors can be classified as reciprocating rotary jet centrifugal or axial flow depending on the mechanical means used to produce compression of the fluid or as positive-*displacement or dynamic type depending on how* the mechanical elements act on the fluid to be compressed Positive displacement compressors confine successive volumes of fluid within a closed space in which the pressure of the fluid is increased as the volume of the closed space is decreased Dynamic type compressors use rotating vanes or impellers to impart velocity and pressure to the fluid

Reciprocating compressors are positive displacement have one or more cylinders each fitted with a piston driven by a crankshaft through a connecting rod Each cylinder also has intake and discharge valves and a means for cooling the mechanical parts (Fig 2) Fluid is drawn into the cylinder during the suction stroke At the end of the stroke motion of the piston reverses and the is compressed and expelled during the

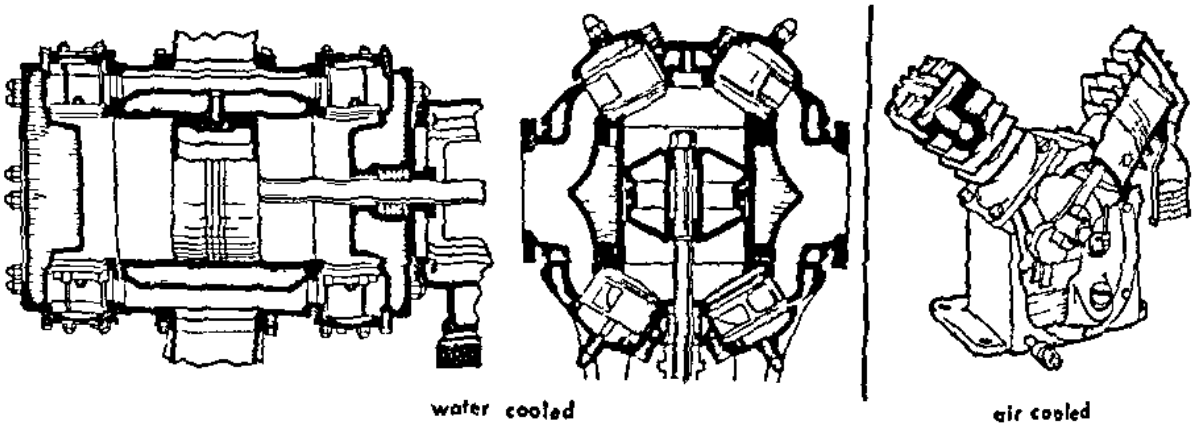


Fig 2 Compressor cylinders are water or air-cooled

stroke When only one end of the piston acts on the fluid the compressor is termed a single acting unit When both ends of the piston act on the fluid the compressor is double acting The double acting compressor discharges about twice as much fluid per cylinder per cycle as the single acting (Fig 3)

Single stage compressors raise the fluid pressure from inlet to discharge on each working stroke of the piston in each cylinder Two stage compressors use one cylinder to compress the fluid to an intermediate pressure and another cylinder to raise it to final discharge pressure When more than two stages are used the compressor is called a multi stage unit

Vertical and horizontal compressors may be single-cylinder or multicylinder units Angle type are multicylinder with one or more horizontal and vertical compressing elements (Fig 4) Single frame (*straight line*) units are horizontal or vertical double acting with one or more cylinders in line with a single frame having one crankthrow connecting rod and crosshead The V or Y type is a 2 cylinder vertical double acting machine with cylinders usually at a 45° angle with the vertical A single crank is used Semiradial compressors are similar to V or Y type but have horizontal double-acting cylinders on each side Duplex compressors have cylinders on two parallel frames connected through a common crankshaft In duplex tandem steam driven units steam cylinders are in line with air cylinders Duplex 4-cornered steam driven compressors have one or more compressing cylinders on each end of the frame and one or more steam cylinders on the opposite end In 4-cornered motor driven units the motor is on a shaft between compressor frames

Reciprocating compressors are built to handle fluid capacities ranging to 100 000 cfm pressures range to over 35 000 psi Special units can be built for larger capacities or higher pressures Water

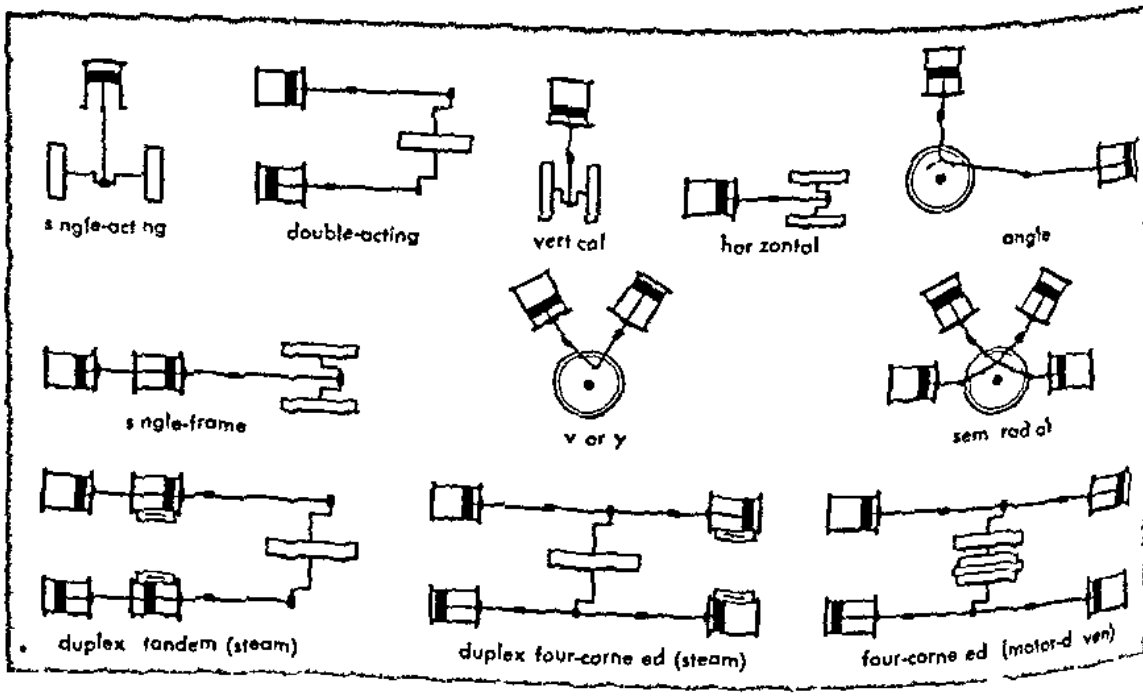
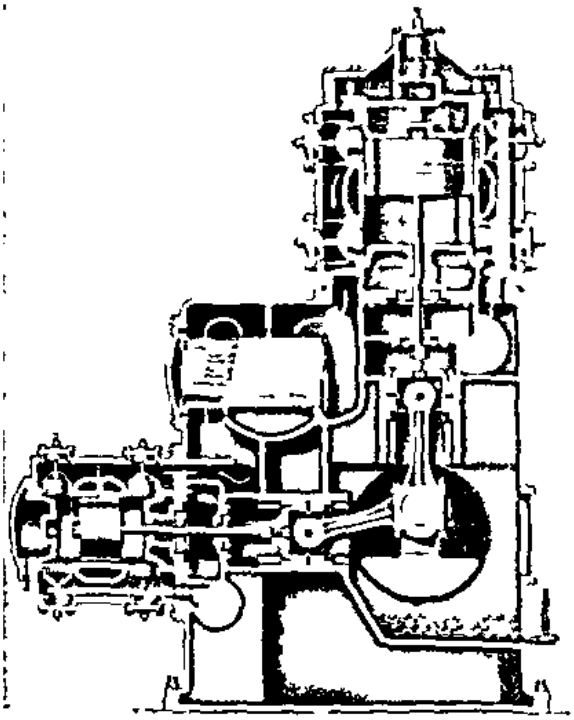


Fig 3 Frame arrangements of positive displacement piston compressors



ig 4 Cross section of stationary angle type com pressor with first stage vertical and second stage hori zontal

he usual coolant for cylinders, inter and after coolers, but other liquids, including refrigerants may also be used

Compressor thermodynamics. Compression ef ficiency in any compressor is compared against wo theoretical standards—isothermal and adia batic (*see* THERMODYNAMIC PROCESSES) Neither occurs in an actual compressor because of unavoid ible losses A plot of compression process on a pressure volume diagram shows that an actual unit works between these two standards (Fig 5) Iso thermal compression has perfect cooling—air re mains at inlet temperature while being com pressed Work input to compressor, measured by area ABCD, is least possible Adiabatic compres sion has no cooling, temperature rises steadily during compression Discharge pressure is reached sooner than with isothermal compression Since air pressure is higher during every part of the piston's stroke, more work input is needed as shown by area ABCE

If compression is divided into two or more steps or stages air can be cooled between stages This intercooling brings the actual compression line closer to the isothermal line Area BCDE shows the power saved

Water vapor in air entering the compressor leaves as superheated vapor because its temperature is in excess of that corresponding to its pressure It can be converted to water only by cooling to a tempera ture below the saturation temperature corre sponding to its pressure Immediate cooling of air after it leaves the compressor proves best, because this prevents vapor from reaching the distribution system Either air or water cooled heat exchangers, called aftercoolers, are used for this

The usual single stage reciprocating compressor is built for pressures to about 150 psi, two-stage types for up to about 500 psi, three stage for up to about 2500 psi, four and five stage for pressures to 15 000 psi, and higher

Rotary compressors. Other forms of positive displacement compressor are the various rotary types

Sliding vane type In the sliding vane rotary compressor, fluid is trapped between vanes as the rotor passes the inlet opening (Fig 6) Further ro tation of the rotor reduces the volume of the space in which the fluid is trapped Fluid pressure rises until the discharge port is reached when discharge occurs

Depending on design, the compressor may be cooled with atmospheric air oil, or water For low pressures one stage of compression is used two stages for higher pressures Capacities range to about 5000 cfm Some compressors of this type have rings around the vanes to keep them from bearing on cylinder walls Others have vanes bear ing against the cylinder

Lobe type In the lobed rotary compressor fluid is trapped between two or more rotors held in fixed relationship to each other (Fig 7) Rotation of the impellers reduces the volume in which the fluid is trapped producing a pressure rise Fluid is dis charged when the rotors pass the outlet port Ei ther two or three rotors are used Capacities range from about 5 to 50 000 cfm Pressures above about 15 psi are obtained by operating two or more lobe type compressors in series Rotors are straight, as shown or slightly twisted

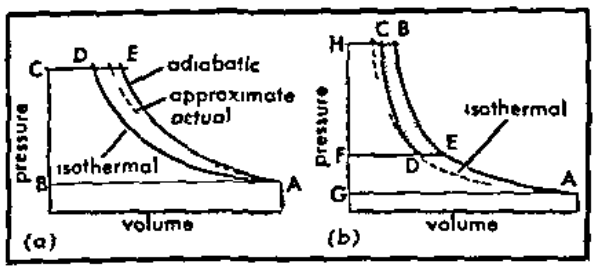


Fig 5 Compression curves for theoretical and actual units (a), and effect of intercooling (b)

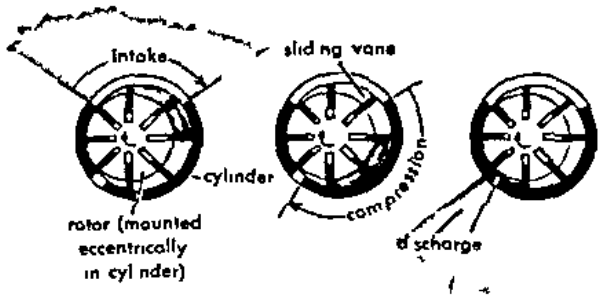


Fig 6 Operation of sliding vane rotary

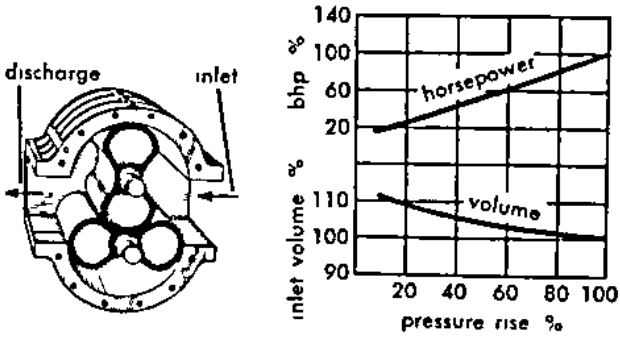


Fig 7 Two lobe compressor and its performance curves at constant speed

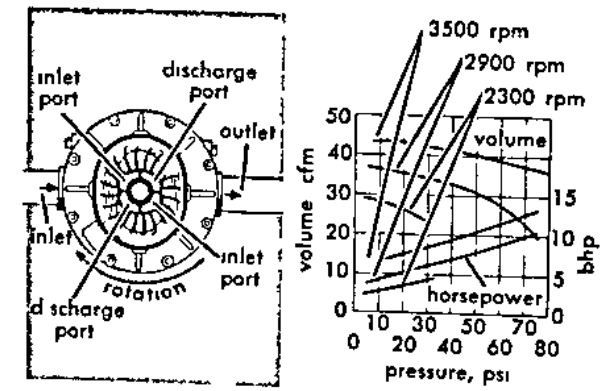


Fig 8 Liquid piston compressor and its constant speed performance curves

Liquid piston type In the liquid piston rotary compressor a round multiblade rotor revolves in an elliptical casing partly filled with liquid usually water When the rotor turns it carries liquid around with it the blades forming a series of buckets (Fig 8) Because the liquid follows the casing contours it alternately leaves and returns to the space between blades (twice each revolution) As the liquid leaves the bucket the fluid to be compressed is drawn in When the liquid returns it compresses the fluid to discharge pressure

Liquid piston compressors handle up to about 5000 cfm Single stage units can develop pressures to about 75 psi multistage designs are used for higher pressures Water or almost any other low viscosity liquid serves as the compressant For exacting services the compressor may be sealed with chilled water to prevent condensation in lines

Radial flow units Dynamic type centrifugal compressors use rotating elements to accelerate the fluid radially By diffusing action velocity is converted to static pressure (*see* BERNOULLI'S THEOREM, DIFFUSER) Thus the static pressure is higher in the enlarged section Centrifugal compressors usually take in fluid at the impeller eye (or central inlet of the circular impeller) and accelerate it radially outward (Fig 9) Some static pressure rise occurs in the impeller but most of the pressure rise occurs in the diffuser section of the casing where velocity is converted to static pressure Each impeller diffuser set is a stage of the compressor Centrifugal compressors are built with from 1 to 12 or more stages depending on final pressure desired and the volume of fluid to be handled The pressure ratio, or compression ratio of a compressor is the ratio of the absolute discharge pressure to the absolute inlet pressure

In the typical compressor (Fig 9), centrifugal action of the impeller A_1 produces pressure rise and a large increase in air velocity EF In the diffuser B_1, velocity energy is converted to static pressure Velocity falls from F to G, pressure rises from C to D

Pressure volume curves for a centrifugal compressor operating at different speeds show that, for example, at speed M the unit delivers volume V_M at pressure P_M (point A on the pressure volume diagram, Fig 9) Increasing speed to H raises volume to V_H at P_M or old volume V_M can be delivered at higher pressure P_H

Pressure delivered by a centrifugal compressor is practically constant over a relatively wide range of capacities

Pumping limit, also called surge point or pulsation point, is the lower limit of stable operation Percentage stability is 100 minus the pumping limit in per cent of design capacity

Multistage centrifugal compressors handle from to more than 150 000 cfm at pressures as high as 5000 psi but are limited to compression ratios of the order of 10

Axial flow units Compressors that accelerate the fluid in a direction generally parallel to the rotating shaft consist of pairs of moving and stationary blade-rows each pair forming a stage The pressure rise per stage is small, compared with

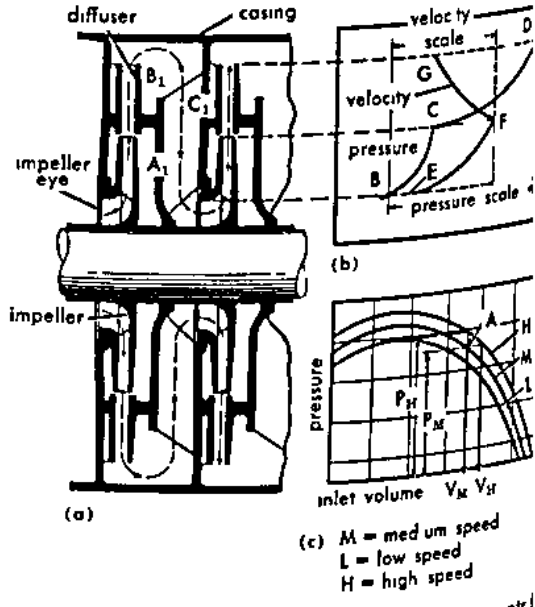
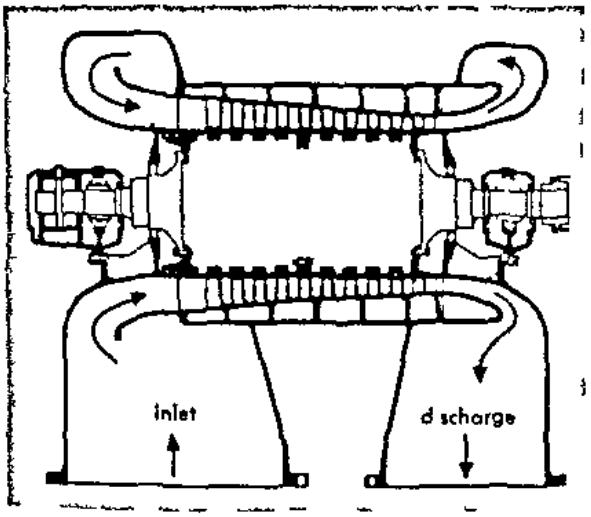


Fig 9 Performance curves for radial flow or centrifugal compressor (a) Air flow through centrifugal compressor follows paths shown by arrow (b) Pressure and velocity relationships of air in a typical centrifugal compressor (c) Volume and pressure relationships of a centrifugal compressor at various speeds



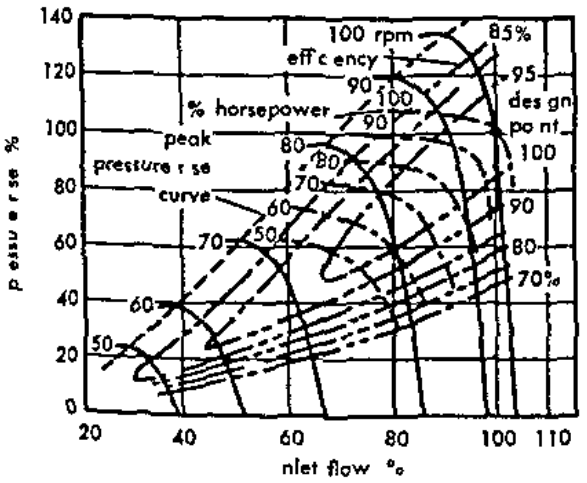


Fig 10 *Axial flow compressor and its constant speed character st c*

radial flow unit Hence the usual axial flow compressor has more stages than a centrifugal compressor working through the same pressure range Single stage axial compressors have capacities from a few to more than 100 000 cfm at pressures from less than 1 to several psi Multistage axials compress air to 150 psi or more Some special machines handle over two million cfm Pressure rise per stage is generally *relatively small so units for* higher pressures frequently have a considerable number of stages—20 or more (Fig 10)

While centrifugal machines deliver practically constant pressure over a considerable range of capacities axials have a substantially constant delivery at variable *pressures In general centrifugals* have a wider stable operating range than axials

Because of their more or less straight through flow axials tend to be smaller in diameter than centrifugals and are apt to be longer Efficiency of axials usually *runs slightly higher*

To prevent surging at extremely low loads large-capacity axials are sometimes fitted with a blowoff system that discharges excess air to the atmosphere With this hookup there is always enough air passing through the machine to keep it in its stable range

Because of difficulty in accurately predicting the performance curves of centrifugal and axial compressors only one capacity and one discharge pressure rating together with corresponding power input are normally guaranteed Shape of the curve may be indicated but is never guaranteed *See* FAN PUMPING MACHINERY [T G H]

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Compton effect

When a monochromatic beam of x rays of sufficiently short wavelength λ_1 is scattered by matter of low atomic number so that the scattered beam makes an angle ϕ with the original direction some of the scattered radiation is found to be of longer wavelength λ_2 The shift in wavelength is given approximately by the formula

$$\lambda_2 - \lambda_1 \cong (h/m_0c)(1 - \cos\phi) \qquad (1)$$

in 1922 was explained theoretically by Compton and independently and nearly simultaneously by P Debye It is known as the Compton effect or (in Europe) as the Compton Debye effect

The Compton effect constitutes one of the most fundamental manifestations of the interaction between matter (electrons) and radiation (photons) and thus lies close to the heart of quantum theory It led directly to W Heisenberg's formulation of his famous uncertainty principle The Compton effect together with the photoelectric effect pair production and the laws of atomic spectra have given the entire experimental basis on which modern quantum theory is founded For information on these related topics *see* ATOMIC STRUCTURE AND SPECTRA LIGHT PAIR PRODUCTION (ELECTRON POSITRON) PHOTOEMISSION QUANTUM MECHANICS QUANTUM THEORY NONRELATIVISTIC UNCERTAINTY PRINCIPLE

Thomson's theory About 1900 J J Thomson conceived a theory of x ray scattering by electrons in which a plane electromagnetic wave through its oscillating electric vector (*see* ELECTROMAGNETIC RADIATION) imparted to a free electron oscillating accelerations which in turn caused the electron to radiate with a definitely calculable intensity in various directions relative to that of the incident wave

In Fig 1 the electron situated at O receives an oscillating acceleration from the electric vector E of the radiation with components E_y and E_z the latter normal to the plane of the paper The acceleration of the electron results in propagation (in all directions) of a wave from O which r/c sec later gives rise to an electric vector at P with

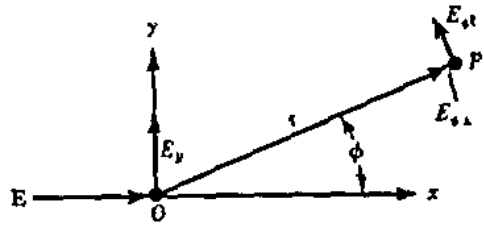


Fig 1 Diagram relating to Thomson s derivation of the scattering cross section of the electron

components $E_{\phi\parallel}$ and $E_{\phi\perp}$ parallel and perpendicular to the plane of the scattering angle ϕ The radiant intensity I_ϕ at P can readily be shown to be equal to $Ie^4(1+\cos^2\phi)\ 2r^2m_0^2c^4$ where I is the total primary intensity The electron s effective cross section for scattering in the direction ϕ is thus given by

$$\sigma_\phi = \frac{e^4}{m_0^2c^4}\,\frac{1+\cos^2\phi}{2} \qquad (2)$$

The quantity σ_ϕ is that cross section of the primary beam through which would flow the same energy as that which is scattered by the electron per steradian at the angle ϕ Integrating Eq (2) over all directions of scattering results in the fundamental natural constant known as the Thomson cross section σ_T

$$\sigma_T = (8/3)\pi e^4/(m_0^2c^4) \cong 6\,652 \times 10^{-25}\ \mathrm{cm}^2 \qquad (3)$$

Thomson s concept although greatly oversimplified contains elements of truth and gives results in rough agreement with observation for electrons of very light atoms in a limited range of x ray wavelengths or quantum energies For longer wavelengths matter exhibits a constructive interference effect known as excess scattering more intense than Thomson s formula predicts For shorter wavelengths the scattering behaves as though the electrons scattered in random phase the scattering per electron being independent of the atomic number Figure 2 illustrates these behaviors Below 0 1 A all curves coalesce but the scattering cross section per electron is markedly below the Thomson value for which $\sigma_a/\sigma_T \approx 1$ An infinite range of quantum energies is comprised in the wavelength interval from zero to 0 1 A The scattering per electron is substantially Thomsonian for the elements hydrogen up to carbon over a considerable wavelength range

The Thomson picture does not take into account the effect of the magnetic vector of the radiation The radiation pressure exerted on the electron because of the vector change in incident and scattered photon momenta $h\nu/c$ (ν is the photon frequency) is therefore ignored (*see* RADIATION PRESSURE) Thus the Thomson theory leads to the expectation that the scattered radiation will have identically the same wavelength or quantum energy as the original incident beam

That this is not the case for scattered radiation was clearly proved by J A Gray He showed that the scattered radiation from light elements although clearly related to the incident radiation rather than to the material of the scattering substance (hence not a secondary fluorescent emission), was nevertheless definitely more easily absorbed by absorbing screens than was the primary radiation A H Compton received the Nobel Prize for his explanation of this effect and for his experimental measurement of the wavelength shift

Compton's model Compton's (and Debye's ingenious but still oversimplified model pictures an initially free, stationary electron concerned [illegible] forces in the atom

ball The kinetic energy thus given to the e[illegible] and lost by the photon explains the shift in energy from $h\nu_1$ to $h\nu_2$ and the corresponding shift in wavelengths $\lambda_2 - \lambda_1$

In Fig 3 the recoil speed v of the electron is measured by $\beta = v/c$ Conservation of energy and conservation of momentum require the shift of wavelength to be

$$\lambda_2 - \lambda_1 = (h/m_0c)(1-\cos\phi)$$

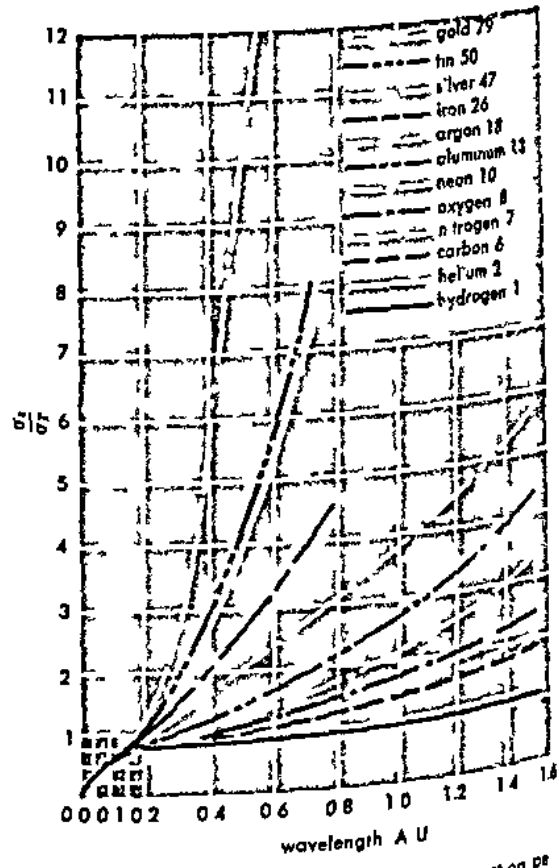


Fig 2 Behavior of σ_a the scattering cross section per electron for elements of various atomic number Z relative to Thomson s calculated value σ_T at different wavelengths (*From A H Compton and S K Allison X rays in Theory and Experiment 2d ed Van Nostrand 1935*)

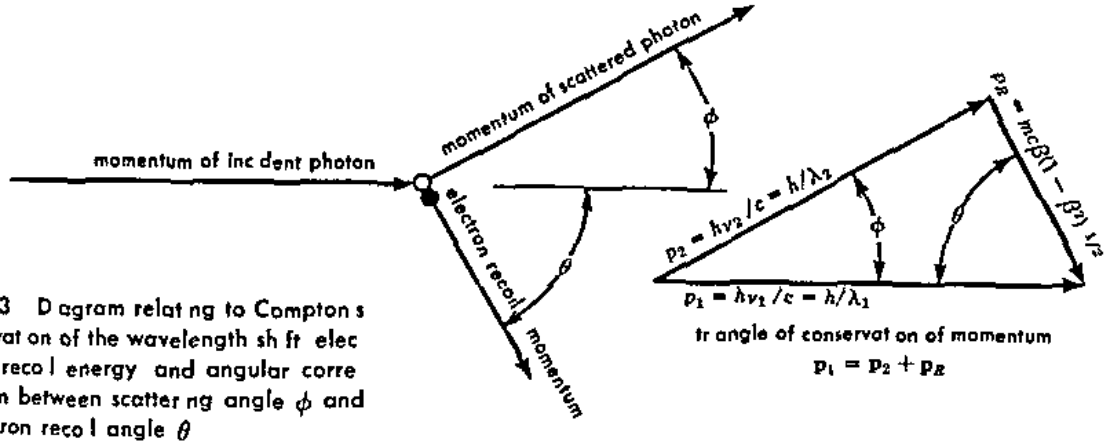


Fig 3 Diagram relating to Compton's derivation of the wavelength shift electron recoil energy and angular correlation between scattering angle ϕ and electron recoil angle θ

The recoil energy E_R in rest mass units is given by

$$E_R/m_0c^2 = r_1^2(1 - \cos\phi)/[1 + r_1(1 - \cos\phi)]$$

where $r_1 = \lambda_c/\lambda_1$

and $\lambda_c = h/m_0c \cong 24.26 \times 10^{-11}$ cm

Finally the relation

$$\cot\theta = -(1 + r_1)\tan(\phi/2)$$

is easily derived from the triangle

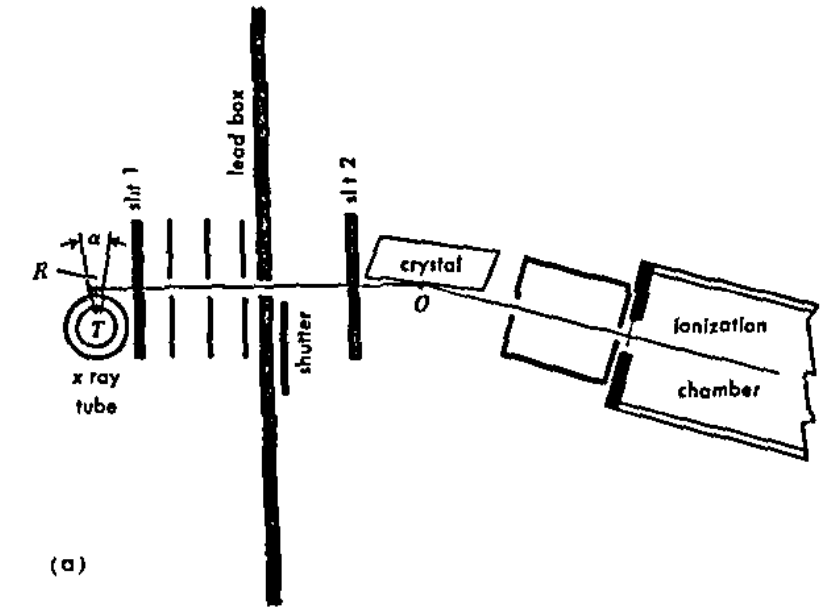
Figure 4*a* shows Compton's experimental set up in which the characteristic K line radiation from a molybdenum target x ray tube was scattered by a block of graphite then analyzed by means of a crystal spectrometer The scattered spectrum consisted of two components an unmodified line of the same wavelength as the primary radiation and a modified line of longer wavelength as given by Eq (1) Figure 4*b* shows the resulting spectra the topmost being the primary radiation without scattering and the others the scattered radiation for mean scattering angles of $\phi = 45°$ 90° and 135° Note the unmodified scattered line P and the increasing shift of the modified line M with increasing ϕ A severe experimental difficulty characteristic of these studies is the low intensity of the scattered spectrum In this initial work by Compton spectral resolution was sacrificed (for the sake of greater intensity) to such a degree that the Mo$K\alpha_1\alpha_2$ doublet (at P) was completely unresolved and had a breadth $\delta\lambda \cong 8.2 \times 10^{-11}$ cm For the same reason a large range α of inhomogeneity of the scattering angle ϕ was permitted (α about 0.31 radian at $\phi = 90°$ see Fig 4*a*) The dependence of shift on scattering angle ϕ is plotted in Fig 4*c* to show the spurious broadening $\Delta\lambda$ of the shifted line which results from a given range α of inhomogeneity of ϕ for the three different angles studied

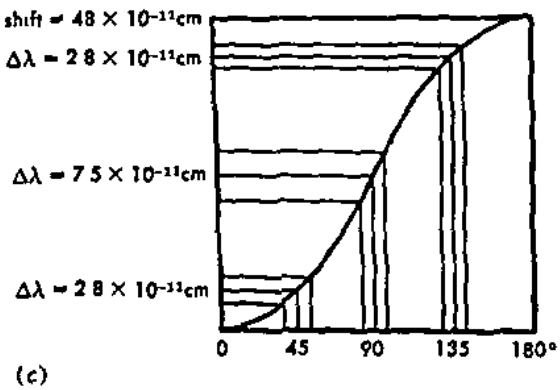
Numerous verifications of Compton's work soon appeared The recoil electrons were detected by C T R Wilson and by W Bothe with a Wilson cloud chamber Their momenta were measured by magnetic deflection and found to agree with Compton's theory by A A Bless while Bothe and H Geiger demonstrated the simultaneity of appearance of the scattered photon and recoil electron Then Compton and A W Simon using a cloud chamber provided with partitions were able to show that in individual Compton scattering processes the predicted correlation between the direction of the scattered photon and that of the recoil electron is satisfied The most startling feature in all of this was the seemingly unavoidable inference that the radiation scattered by the electron instead of spreading out in all directions around the scattering center as one expects waves to do instead takes a definite direction in each individual process as a particle would

Wave particle duality Through the ideas of L de Broglie and E Schrodinger and their experimental verification by C Davisson and L Germer it was established that electrons under appropriate circumstances behave as though they are waves of wavelength λ_D as given in the case of a free electron by the formula $\lambda_D = h/p$ where p is the electron momentum (*see* DE BROGLIE WAVELENGTH ELECTRON DIFFRACTION) With this background Schrodinger in 1927 gave his alternate wave explanation of the Compton effect According to Schrodinger interference occurs between the two wave trains of the electron corresponding to its initial and final (recoil) states These are conceived as being simultaneously present (an absurd idea for a particle but completely rational for trains of waves) and depending on the system of reference the interference forms a system of standing or traveling plane waves of matter density or probability density The x ray photon waves are diffracted by these waves in a well defined direction of constructive interference analogous to the diffraction of x rays by the periodically stacked planes of atoms in a crystal to form a Laue spot *See* X RAY DIFFRACTION

No preferred choice has been found between the particle and wave models of the Compton effect Indeed a similar duality characterizes all phenomena involving matter and energy

In the Schrodinger wave model the so called grating of matter waves (that is the electron) recedes with just such recoil velocity as to explain quantitatively the Compton shift of the photon





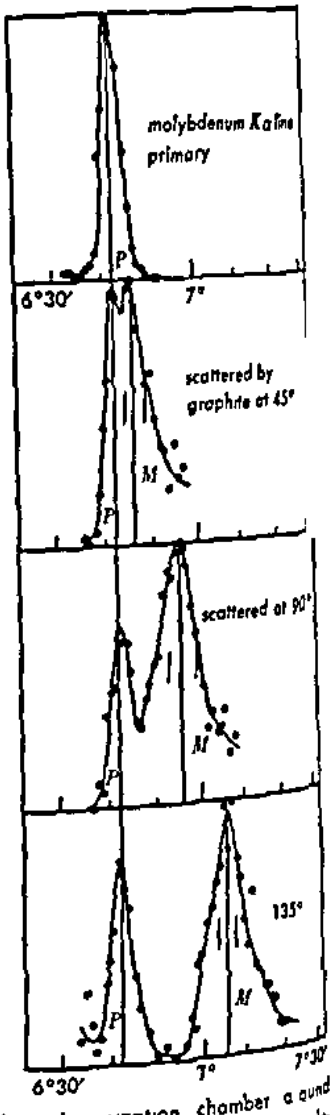


Fig 4 Compton s experiment (*a*) The characteristic *K* lines from the molybdenum target *T* of the x ray tube (shown in cross section) fall on the graphite scatterer *R* The scattered radiation is passed through slits 1 and 2 and analyzed spectrally by slow rotation of the calcite crystal and ionization chamber a round pivot *O* (*b*) Resulting spectra (*c*) Graph showing de pendence of the shift $\lambda_2 - \lambda_1$ on ϕ (*From A H Comp ton and S K Allison, X rays in Theory and Experiment, 2d ed , Van Nostrand, 1935*)

wavelength as a Doppler shift of the receding image of the source reflected in the moving grating of matter waves (*see* DOPPLER EFFECT) From this model the reduced scattering cross section at short wavelengths could be computed as a relativistic effect The ordinary Thomson cross section is thus decreased by a multiplying factor known as the Breit Dirac recoil factor R, given by

$$R = (\lambda_1/\lambda_2)^3 = [1 + \epsilon(1 - \cos\phi)]^{-3} \quad (4)$$

where ϵ is $h\nu_1/(m_0c^2)$, and λ_1 and λ_2 are the initial and final wavelengths

Klein Nishina formula. In addition to their charge and mass, electrons also have a quantized spin or angular momentum and an associated magnetic moment μ, (*see* ELECTRON SPIN) The interaction of these properties with the electromagnetic radiation introduces a further modifying factor into the Thomson cross section formula which together with the recoil factor R, yields the Klein Nishina scattering formula This takes into complete account by means of P A M Dirac's relativistic quantum mechanics the effects of the charge, mass, magnetic moment and associated spin of a free, initially stationary electron inter acting with the electric and magnetic radiation vectors (*see* QUANTUM THEORY, RELATIVISTIC) I thus involves three factors—the Thomson cros section (the principal one) and two correctio factors the Breit Dirac recoil factor and the sp magnetic moment interaction factor Equation (5 gives these three factors in the order named e pressing the Klein Nishina cross section per ster dian σ_ϕ as a function of the scattering angle ϕ

$$\sigma_\phi = \left[\frac{e^4}{m^2c^4}\left(\frac{1+\cos^2\phi}{2}\right)\right][1+\epsilon(1-\cos\phi)]^{-3} \left\{1 + \frac{\epsilon^2(1-\cos\phi)^2}{(1+\cos^2\phi)[1+\epsilon(1-\cos\phi)]}\right\} \quad (5)$$

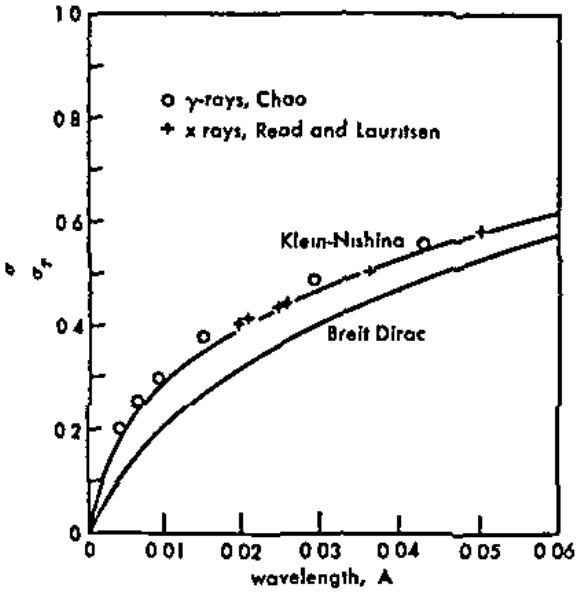


Fig 5 Plot of Klein Nishina scattering cross section (From A H Compton and S K Allison, X rays in Theory and Experiment, 2d ed, Van Nostrand, 1935)

Equation (6) gives the Klein Nishina global cross section σ, resulting when σ_θ is integrated over all directions:

$$\sigma = \left[\frac{8\pi e^4}{3m^2c^4}\right]\frac{3}{4}\left[\frac{1+\epsilon}{\epsilon^3}\left\{\frac{2\epsilon(1+\epsilon)}{1+2\epsilon} - \ln(1+2\epsilon)\right\} + \frac{1}{2\epsilon}\ln(1+2\epsilon) - \frac{1+3\epsilon}{(1+2\epsilon)^2}\right] \quad (6)$$

Equation (6) has been tested by C Y Chao and by J Read and C C Lauritsen over the wavelength range 0 004–0 05 A The excellent experimental verification found is shown in Fig 5 The curve marked Breit Dirac, which does not include the spin magnetic moment interaction factor, gives too

stationary free electrons interacting in two body processes with photons This postulate fails to explain the unmodified scattered line and other important phenomena It is technically impossible by many orders of magnitude to achieve a sufficient

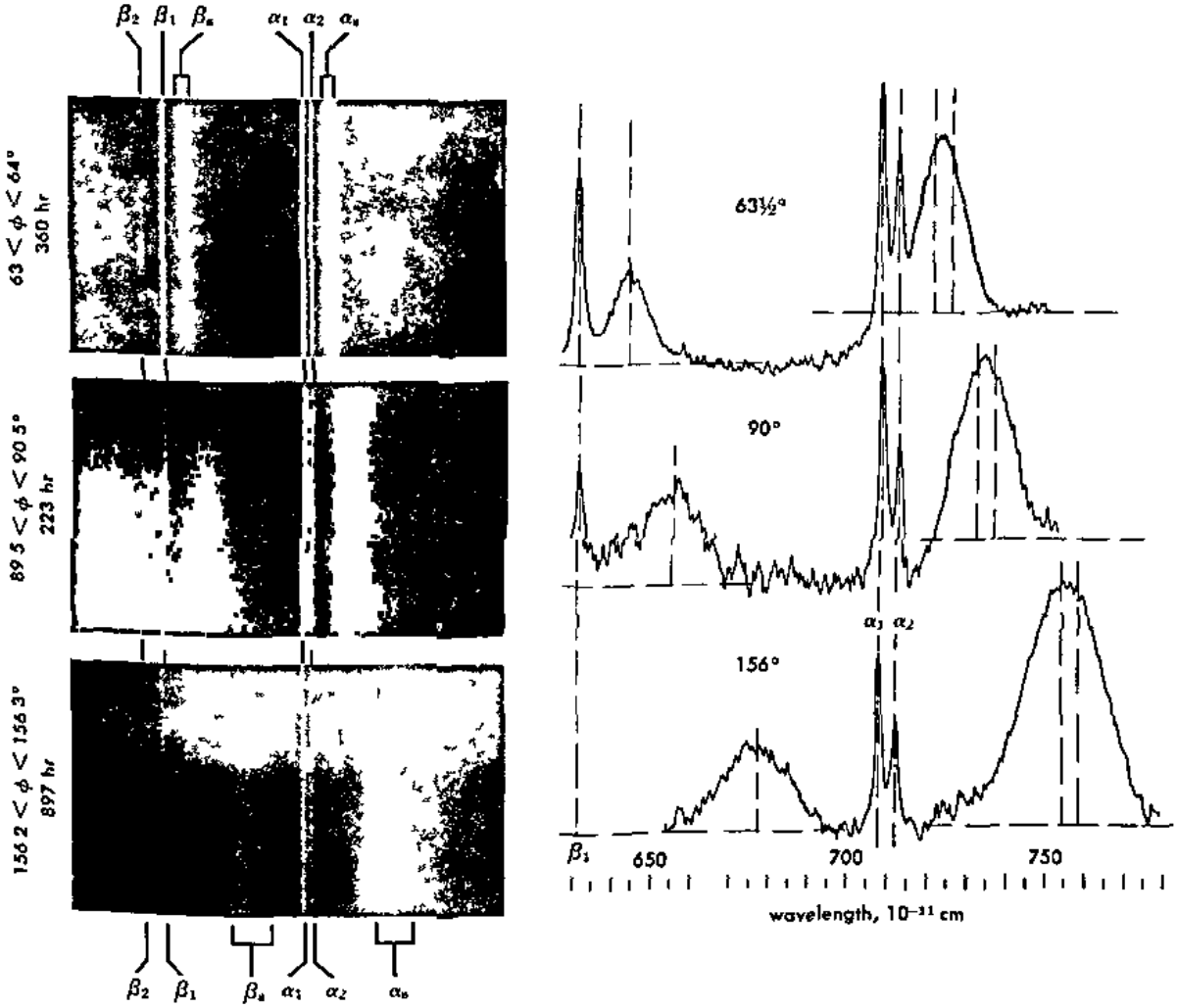


Fig 6 Spectra of molybdenum K x radiation, taken with the mult crystal spectrograph Graphs on the right are plots of the intensities of the lines on the photographic plates

concentration of free electrons (let alone stationary ones) for the study of the Compton effect One must always deal with electrons in rapid motion which are either bound to individual atoms or molecules or, in the case of the conduction electrons in a metallic solid at least bound in the crystal lattice

Reformulating the photon electron interaction process in accordance as before with energy momentum conservation but postulating an electron with specified initial momentum (in amount and direction relative to the primary and scattered photon directions) J DuMond and P Kirkpatrick have shown that there is superposed upon the Compton shift a second shift This shift can be regarded as a Doppler shift and can either decrease or increase the Compton shift depending on the direction of the electron s initial momentum For an isotropic distribution of electron momenta there must result a broadening of the shifted line which is descriptive of the distribution of the initial momenta in momentum space This broadening shows clearly in the spectra of Fig 6 taken by DuMond and Kirkpatrick with a multicrystal spectrograph This instrument first provided the greatly improved resolution and homogeneity of the scattering angle requisite to establish the effect and its interpretation The behavior of this broadening with change of scattering angle and of primary wavelength is in quantitative accord with the theory and establishes proof of its interpretation as a Doppler effect of initial electron motion or momentum Thus here one has direct experimental evidence that electrons actually move in free atoms and in solid bodies Similar evidence has confirmed the Fermi Sommerfeld degenerate gas theory for the conduction of electrons in metals *See* FREE ELECTRON THEORY OF METALS *See also* DOPPLER EFFECT

Figure 7 shows the apparatus employed by DuMond and Kirkpatrick for the study of Mo K x radiation scattered at large angles from hydrogen and helium gas together with the resulting spectra A bent quartz crystal spectrograph was used to resolve the scattered spectrum The pressure chamber containing the gaseous scatterer was a long lead lined steel cylinder provided with a celluloid window through which the primary beam entered and the scattered beam emerged The effective scattering volume was subdivided as shown into regions by the curved loci of constant ϕ corresponding to uniform increments of $(1-\cos\phi)$ whose exact values are shown on the figure The spurious broadening from inhomogeneity of the scattering angle ϕ was thus kept negligible The purpose here was to test whether the observed

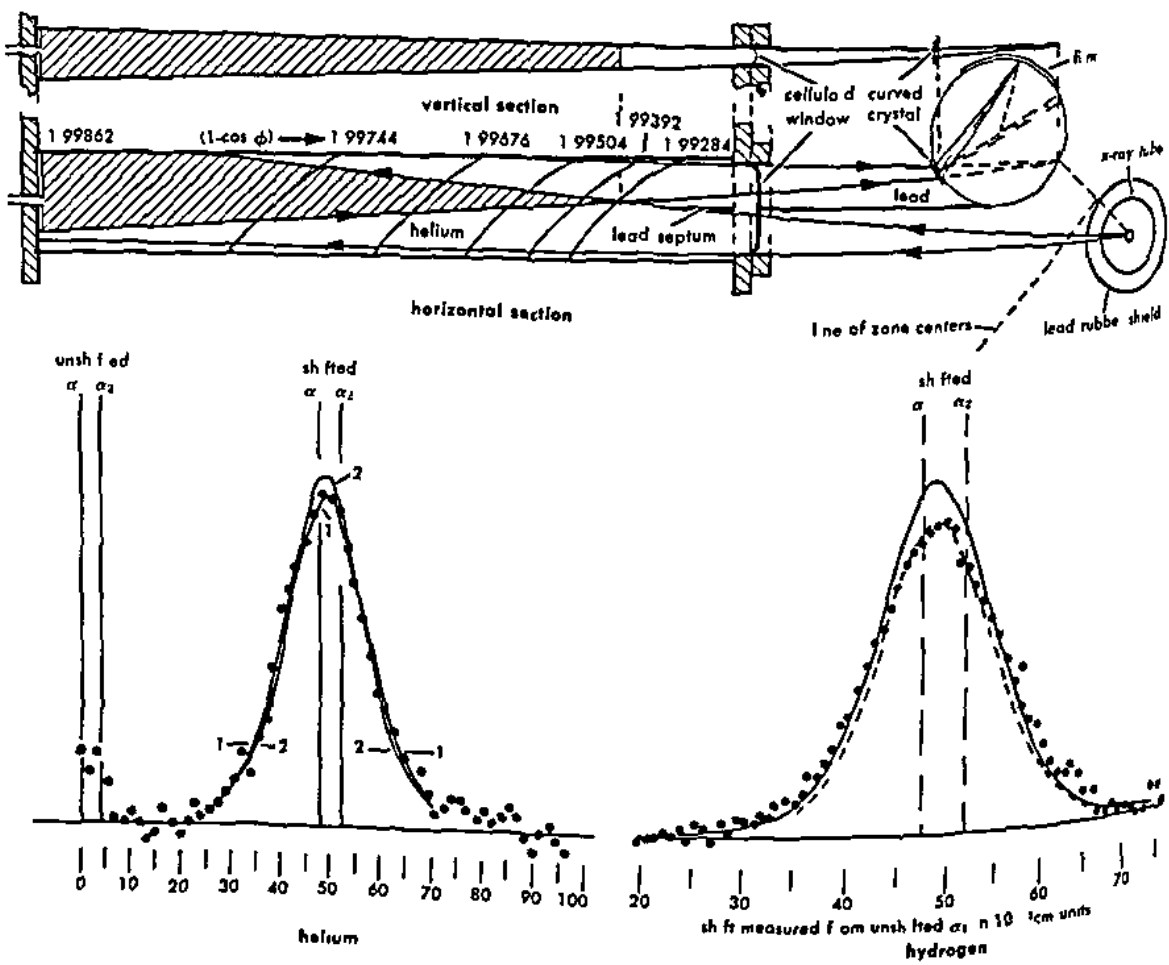


Fig 7 Apparatus for study of the molybdenum K x rad at on scattered from hydrogen and hel um

broadened Compton shifted line profile agrees with the theoretically calculated profile for cases of scattering by single atoms (not disturbed by proximity of neighbors as in the solid state) of sufficiently simple character to permit computing their electron momentum distributions on the basis of quantum mechanical theory The computed profiles (solid lines) agree excellently with the observed line profiles

The unmodified scattering clearly evident from the sharp unshifted lines of Fig 6 is ascribed to those photon electron interactions for which momentum energy conservation would require a free electron recoil energy comparable to or smaller than the electron binding energy The electron's energy state in the atom (indeed the energy state of the atom as a whole) may for such cases be undisturbed by the interaction The momentum change accompanying scattering is therefore communicated to the much more massive atom as a whole and involves a negligible energy loss by the photon Were it not for such unshifted scattering no study of crystal structure by x ray diffraction would be possible for in shifted scattering the indispensable condition for interference effects a coherent phase relationship between primary and scattered radiation is absent The theory giving the ratio of intensities of modified and unmodified scattering has been given by I Waller and D R Hartree When the electrons are bound this diminishes slightly the amount of the Compton shift as was demonstrated experimentally by P A Ross and Kirkpatrick

In Compton's modified scattering picture the atomic electrons are in bound energy states before the scattering process and the total energy of the initially approximately stationary atom is a quite well defined quantity whereas after the Compton modified scattering process one of the atomic electrons is free and possesses a recoil momentum and energy given to it by the radiation so that the system may then have a total energy varying over a continuous range of values In 1959 K Das Gupta succeeded in demonstrating for the first time the reality of a long predicted process of modified scattering in which both the initial and the final states of the atom scattering the radiation are bound states of well defined but different energies the final state being one in which the atom is excited above its ground state but not ionized In this case a sharp shifted scattered line of longer wavelength is to be expected and Das Gupta has found it The difference between the quantum energy of the primary x ray line and that of the shifted x ray line in this case is expended to cause the excitation The momentum imparted in the scattering process is given to the atom as a whole (because no electron is set free) and as in the case of unmodified scattering the mass of the atom is so much greater than that of the electron that any recoil effect contributes no perceptible loss of photon energy This verification of Das Gupta's very satisfactorily rounds out the entire picture of the possible processes predicted by A Smekal to which the Compton effect properly belongs [J W M D]

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Computer

Any of a large variety of devices capable of performing mathematical calculations on numbers or magnitudes

Computers are broadly classified as either analog when they represent numbers by continuously varying quantities such as lengths voltages and rotating shafts or as digital when they represent numbers by devices capable of assuming discrete countable states such as relays cog wheels electronic tubes (biased to conducting or nonconducting states) and bead positions on wires This classification applies to simple devices such as the analog slide rule and polar planimeter and the digital abacus and desk adding machine as well as to large mechanical and electronic computers

Some analog computers make measurements on quantities that are analogous to the numbers they represent For example logarithms are represented on a slide rule by proportional distances The discrete states of digital computer registers however are symbols which are not necessarily iconic or analogous to the entities represented For instance a relay contact configuration representing the number 1 in a 3 bit register would be of the same multiplicity as one representing 10 or 100 *See* Bit

Analog computers are faster than digital computers but are not so precise A precision of three decimal places is typical for analog computers whereas the precision of a digital computer is limited only by the number of digital positions or orders built into its registers A special analog computer for solving 10 simultaneous linear equations would produce a solution almost instantaneously while a digital computer properly pro-

grammed would take several seconds or minutes depending upon its operational rate and type of built in circuitry

Analog computers are usually for special purposes Many kinds of equation solvers network analyzers harmonic analyzers and synthesizers differential analyzers integrators differentiators together with flexible combinations thereof have been made For details *see* ANALOG COMPUTER

Digital computers are usually for general purposes They may be programmed to solve any problems that can be reduced to a sequence of arithmetical and simple logical operations Digital computers however are also used in special purpose equipment including air borne computers digital control computers digital differential analyzers information retrieval systems and reservation systems (*see* DATA PROCESSING SYSTEM DIGITAL COMPUTER) For further descriptions of both digital and analog equipment *see* ANALOG TO DIGITAL CONVERTER DIGITAL TO ANALOG CONVERTER SIMULATOR

By extension digital computers are devices for manipulation of symbols according to specified rules A simple mathematical concept of a computer in this general sense was stated by A M Turing in 1936

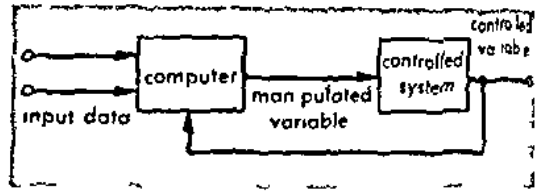
A Turing machine consists of the machine proper which is capable of assuming a finite number of states and theoretically infinite tape marked off in cells which may hold symbols from a given finite alphabet The machine scans and prints symbols and moves one cell at a time to the right or left relative to the scanned tape The machine being in a state q and scanning a symbol s is determined uniquely to perform one of the operations of printing or moving left or right and then to jump to another or the same state A list of such situations completely defines the machine Arithmetical functions fo
can be four
capable o
functions are termed universal Large scale computers if supplied with unlimited bulk storage can be shown to be equivalent to universal Turing machines

By generalization of the Turing machine operations digital computing circuits may be studied as finite Turing machines or automata [R J N]

Computer control system

A special form of feedback control system which employs a computer both to process input data and to implement the functions of a controller The essential characterizing feature is that the controller is an active computer device which is programmed to produce desirable system performance For a discussion of system performance *see* CONTROL SYSTEMS

In some control systems the input data are in a form which is not directly usable to generate a control error For example the position and velocity data of a vehicle in a navigation control system



Block diagram of simple computer control system

are given in terms that are convenient for measurement but not for control Therefore some computations must be carried out before a control error can be evaluated The computer used for this purpose can also be used to compute a manipulated variable which is applied to the controlled system to produce satisfactory performance The block diagram of such a system is shown in the figure

An advantage which is derived in a computer control system is that there is considerable freedom and range of adjustment The computer can implement a wide range of relationships between the input data controlled variable and manipulated variable Dynamical performance of the control system can be adjusted better and can be made more flexible in the presence of changing conditions

The computer may take various forms and dimensions depending on the complexity of the computation If the unprocessed data are in continuous analog form the computer is usually analog and may have electronic electromechanical mechanical or pneumatic components If the unprocessed data are discrete in form that is as a sequence of samples or numbers the computer is usually digital in form and the resultant control system is classified as a sampled data system *See* SAMPLED DATA CONTROL SYSTEM

Whether the computer is analog digital or mixed in form it must operate in real time (that is no significant slowdown or delay is permissible in the computation of the manipulated variable) This is in contrast with the computers used only for calculations where high computing speeds are desirable only from the point of view of time saving In control systems the computer is an active element in the control loop so that delays in computation can lead to instability or poor performance The same basic limitations and rules for design apply to computer control systems as to the more conventional types [J R R]

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Concentration scales

Concentration is a very important property of mixtures because it defines the quantitative relation of the components In solutions the concentration

is expressed as the mass, volume, or number of moles of solute present in proportion to the amount of solvent or of total solution Each scale of concentration has significant features of experimental simplicity or of theoretically significant relationship

Percentage. The simplest scale to measure is percentage hence it is often used for medicinal or household solutions Weight per cent is the number of parts by weight of solute per hundred parts of solution (total) For example, a 10% saline solution contains 10 g of salt in 90 g of water that is, 100 g total weight Gaseous mixtures being difficult to weigh are often expressed as volume per cent Thus air is said to contain 78% nitrogen by volume Solutions of liquids in liquids (for example alcohol in water) may also be expressed in volume %

Molarity. To the chemist, the number of moles of solute is of more significance than the number of grams The molarity (abbreviated M) is the number of moles of solute per liter of total solution Thus 12 M HCl means that the solution contains 12 formula weights (12×36.5) or 438 g of HCl/liter Concentration is an intensive, rather than an extensive property of solutions Thus 0.5 liter of the acid just mentioned is still 12 M although it contains only 6 moles of solute

Molality. Certain solution properties for example the lowering of the freezing point of water by addition of salt requires the use of a concentration scale which relates the number of moles of solute to the weight of solvent rather than to the volume of solution This scale called molality (abbreviated m) indicates the number of moles of solute/1000 g of solvent Thus 34.2 g of sucrose ($C_{12}H_{22}O_{11}$ mol wt 342), if dissolved in 200 g of water, has the concentration of 0.5 mole of sucrose/1000 g of water and hence is 0.5 m For dilute aqueous solutions the molality is essentially identical with the molarity In solutions with densities other than unity the two scales differ Molality may be computed from molarity by first subtracting from the weight of 1 liter ($1000 \times$ density) the weight of solute and then scaling the result by proportion to the number of moles/1000 g

$$m = M\left(\frac{1000}{1000d - M \times \text{mol wt}}\right)$$

where the molecular weight is that of the solute

Normality. Solutes which possess more than one a[illegible] ion molarity Thus one volume of 0.1 M sulfuric acid will neutralize twice its volume of 0.1 M sodium hydroxide The normality scale represents concentration based upon chemical equivalents Normality equals the molarity multiplied by the number of units of reaction per molecule (for example 3 for H_3PO_4 with its 3 hydrogen ions in acidimetry, or 5 for $KMnO_4$ when it accepts 5 electrons in oxidation reduction reactions) Thus 0.3 M $Ba(OH)_2$ is 0.6 N

Formality. In recent years many chemists have sought to avoid the molarity scale lest it imply that electrolyte solutes exist as molecules rather than ions The formality scale (abbreviated F) represents formula weights per liter Its values are identical with the molarities of unionized solutes

Mole per cent (mole fraction) Many properties of solutions (for example vapor pressure of one component) are dependent on the ratio of the number of moles of solute to the number of moles of solvent instead of on the ratios using the volume or mass of solvent The mole fraction (abbreviated N_A or Y_A for component A) is the ratio of the number of moles of solute to the total number of moles of all components Thus for 16 g of methanol (0.5 mole) dissolved in 18 g of water (1 mole), the mole fraction of methanol is 0.5/1.5 or 2/3, the mole % is 66.7 For gases, the mole % is identical with the volume % *See* GRAM EQUIVALENT WEIGHT, GRAM MOLECULAR WEIGHT, SOLUTION, STOICHIOMETRY TITRATION [A L H]

Conch

Any member of the family Strombidae class Gastropoda phylum Mollusca The conchs are among the more familiar of the marine invertebrates, their large shells are frequently used as door props dinner horns and rock garden decorations

Conchs have some commercial importance as the shells are used for lime and in the cutting of cameos and the manufacture of porcelain Sometimes the animal is used for food

Conchs are typically reef dwellers and are found in tropical seas throughout the world The species in the West Indies are the largest and most beautiful Nearly every child has at one time listened to "the roar of the sea" in a conch shell The heavy, porcelaneous shell is polished inside and has an elongate aperture There is a clawlike operculum The foot is narrow in front arched and broad behind The front of the foot extends a thumblike process in traveling

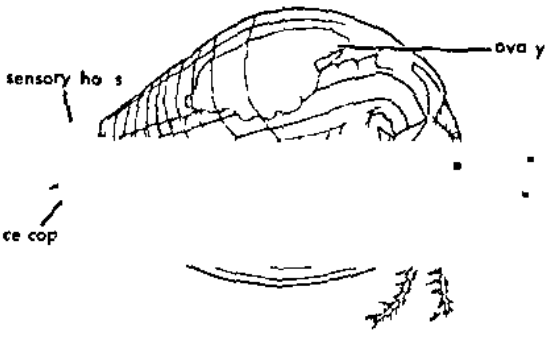
The queen conch, *Strombus gigas*, of the coast of Florida and the West Indies is the largest gastropod in the western hemisphere growing to 1 ft in length and weighing 5 lb It is also one of the most intelligent and active mollusks Employing the claw and the thumblike extension of the foot, it flops rapidly from side to side and can actually leap and turn with agility when pursued

Quantities of shells of this species are shipped to Liverpool and elsewhere for the porcelain trade

The fighting conch or fighting stromb, *Strombus pugilis* is a somewhat smaller species, 3–4 in long common along the coast of Florida Like other conchs it is quite active and has been known to jump from a boat after being captured This ani[illegible] of smell They congregate in numbers around dead fish or other animal refuse on the beach *See* GASTROPODA, SNAIL [J D B]

Conchostraca

An order of mussel like crustaceans of moderate size belonging to the subclass Branchiopoda The multisegmented laterally compressed trunk termi nates in a telson with two clawlike cercopods A bivalved shell covers the entire animal The anten nae are powerful swimming organs The legs are foliaceous of almost uniform structure and as



Limnad a lent cular s female lateral aspect

numerous as the trunk segments Genital openings *occur mostly* on the eleventh pair of legs The legs form filter chambers similar to those of the An *ostraca further* similarities to this group are found in feeding habits development and distribution Among the many genera are *Limnadia, Leptesthe ria* and the aberrent *Limnetis* The group is allied to the Cladocera *See* BRANCHIOPODA [F L]

Concrete

A versatile engineering material consisting of a hydraulic cementing substance aggregate water and often controlled amounts of entrained *air*

Concrete is initially a plastic workable mixture which can be molded into a wide variety of shapes Strength is developed in the hydration *reaction be* tween the cement and water The products mainly calcium silicates calcium aluminate and *calcium* hydroxide are relatively insoluble and bind the ag gregate in a hardened matrix

Concrete is considerably stronger in compres sion than in tension For structures required to carry only compressive loads such as massive grav ity dams and heavy foundations no reinforcement

crete which is then called reinforced concrete (*see* REINFORCED CONCRETE) An extension of the rein forcement principle is prestressing in which *high* tensile strength steel wires or wire strand em bedded while in tension induces a precompression in the concrete so as to increase its resistance *to* tensile stress *See* PRESTRESSED CONCRETE

Concrete has a wide variety of applications In buildings it is used in footings foundations *col* umns beams girders wall slabs roof units—in short all important building elements Concrete not only meets structural demands but also lends itself readily to architectural treatment

Other important applications of concrete are in road pavements airport runways and bridges Nor mally concrete for these structures is pla n con crete containing embedded steel only in order to resist the small volume changes caused by changes in temperature and moisture content

Concrete is widely used in conservation project such as dams irrigation canals water d ver on structures sewage treatment plants and water d s tribution pipe lines

A considerable amount of concrete is used in the form of masonry units manufactured in equ pment utilizing vibration and pressure to achieve com paction Examples are building blocks and brick

Cementing material Portland cement is the usual cementing substance Portland cement with finely ground blast furnace slag added is be ng used in increasing amounts Natural pozzolan, or portland pozzolan cements are used in concrete for particular applications Pozzolans are sil ceous ma terials which in themselves are not cement t ous but when finely divided will react with l me in the presence of water to form compounds po es ng cementitious properties Pozzolanic admixtures are discussed in more detail in a later section See CE MENT PORTLAND CEMENT

Aggregate Aggregate is derived from igneous sedimentary and metamorphic rock or manufac tured from clays shales slates and slags Natural sands and gravels are generally *widely* available and therefore constitute the major source of aggre gate Crushed stone is the next most w dely u ed class of concrete aggregate (Fig 1) Lightwe ght aggregate manufactured from clays *shales slates* and slags is assuming increasing importance Such aggregate can bring economies because of is lighter weight and also improve *the concrete s* ther mal and acoustical insulating properties But the concrete is not as strong as when stone aggregate is used

Aggregate is often washed to remove impur ie which may retard cement hydration or prove *other* wise deleterious particularly for naturally occur ring sands and gravels All aggregate is screened



Fig 1 Cross sect on of hardened concre e Ceme paste completely surrounds each agg ega e part cle

to insure proper gradation of sizes Fine aggregate commonly called sand is composed of particles smaller than ¾ in nominal Coarse aggregate is composed of particles larger than the clear opening of a No 4 sieve (0 185 in)

The physical and chemical properties of the aggregate influence the properties of the resulting concrete The size shape and grading of the particles influence the amount of water required Surface texture influences the bond between aggregate and paste The elastic properties of the aggregate influence the elastic properties of the concrete and the amount of resistance to shrinkage of the paste Reactions at the interface of the cement matrix and the aggregate may improve bonding between the two and consequently the quality of the concrete Certain reactions may be deleterious however for instance, the reaction between certain silica constituents present in some aggregate and alkalies in cements may cause abnormal expansion and cracking of the concrete

Water Water used for making concrete should be free of acids alkalies and oil unless tests or experience indicates that a particular source is satisfactory Organic impurities may interfere with the setting and hardening process

Proportioning The proportions of the ingredients in concrete can be altered to produce specific changes in its properties particularly in strength and durability But first the following facts must be known the desired strength at a particular age the type of exposure anticipated the maximum size of coarse aggregate which can be used and the consistency and workability necessary for proper placement in construction forms (Fig 2) Because cement is generally the most expensive ingredient of concrete the proportions finally selected are those that use the least cement and still fulfill all of the above requirements

The most widely used and the most logical basis for proportioning concrete mixtures was introduced in 1918 by Duff Abrams It was the first practical method to recognize the great importance of the amount of water in the mixture (exclusive of water absorbed by the aggregate) in relation to the amount of cement The water cement ratio law was stated by Abrams as follows With given concrete materials and conditions of test the quantity of mixing water used per bag of cement determines the strength of the concrete so long as the mix is of workable plasticity The relationship is expressed by a hyperbolic curve with the concrete strength decreasing as the water cement ratio increases This relationship fits all combinations of different cements and aggregates in a qualitative manner Quantitatively the relationships are influenced by the specific properties of the cement and aggregate and by age temperature moisture availability and other factors

For any given set of materials the first step is to find the water cement ratio that will produce the strength desired using any gradation of aggregate giving adequate workability Concretes with a range of water cement ratios are fabricated cured



Fig 2 Three concrete mixtures. (a) Insufficient cement sand mortar to fill all the spaces between the coarse aggregate particles This mixture would be difficult to handle and place and would result in rough honeycombed surfaces and porous concrete (b) An excess of cement-sand mortar The yield would be low and therefore the mixture is uneconomical (c) Correct amount of cement sand mortar Mixture is workable and will give maximum yield

and tested for strength The intersection on the plot of water cement ratio and desired strength indicates the proper water cement ratio Different proportions of fine and coarse aggregate are then used in trial mixes to determine which produce concrete of desired consistency and workability but with the minimum amount of cement paste at the required water cement ratio On projects using a large amount of concrete such as dams paste content may be further reduced by varying the gradation of the aggregates particularly the fine aggregate

Durability requirements are satisfied by (1) limiting the water cement ratio to some maximum value based on exposure conditions and field experience and (2) providing entrained air The American Concrete Institute and other agencies provide information on maximum water cement ratios for certain structures under different exposure conditions They also provide data useful in calculating the proper amount of entrained air

Admixtures In the strict sense an admixture is a material added to the concrete at the time of mixing to impart special properties Some admixtures such as air entraining agents can be interground with the cement clinker during production of cement In this case the material is called an addition or an additive Only a few materials are approved by the American Society for Testing Materials and Federal specifications as additions Approval is granted only after exhaustive study by ASTM Committee C 1 on Cement

Admixtures are normally classified as follows accelerators retarders air entraining agents workability agents damp proofing and permeability reducing agents pozzolans color pigments and other miscellaneous materials Many materials fall in more than one classification

Accelerators Admixtures that increase the rate of hydration of the cementing material are called accelerators The result is usually a shorter setting time for the concrete and higher early strengths are achieved Although the early strengths are increased ultimate strengths may be lower than for a similar concrete without the accelerator Materials that function as accelerators include calcium chloride sodium chloride sodium sulfate sodium hydroxide sodium sulfite potassium sulfate and potassium hydroxide Of these only calcium chloride is in common use as an accelerator principally because of its relatively low cost and its generally predictable effect when used with different cements Calcium chloride may be used in amounts of 1–2% by weight of cementing material when higher early strength is desired for example when concreting during cold weather

Retarders Retarders are materials that decrease the cement s rate of hydration thereby increasing setting time and decreasing the strengthening rate during the early ages Gypsum (calcium sulfate) an approved addition to portland cement is used to prevent rapid or flash setting Other examples of retarders are sugars (effective even at 0 1–0 2% by weight of cement), caseins sodium bicarbonate sodium hexametaphosphate various forms of starch salts of carboxymethyl cellulose and calcium or sodium salts of lignin sulfonic acid

Air entraining agents These are materials that help to incorporate a greater volume of air in the concrete during mixing than is normally entrained Air entraining agents include natural wood resins fats such as tallow fatty acids such as oleic acid and various sulfonated compounds These materials are used in small quantities 0 005–0 05% by weight of cement The entrained air produces concrete highly resistant to freezing and thawing eliminates scaling resulting from the use of deicing chemicals on pavements reduces the water requirement for a particular level of consistency and maintains the homogeneity of the mix by reducing bleeding or settlement of solids (Fig 3) *See* AIR ENTRAINING PORTLAND CEMENT

Workability agents Materials that increase plasticity of freshly mixed concrete are called workability agents Bentonite clay and diatomaceous earth in amounts not exceeding 3–5% by weight of cement have been used Fly ash finely divided silica fine sand hydrated lime talc and pulverized stone have been used in larger amounts Air entraining agents also increase workability

Damp proofing and permeability agents These materials are said to reduce concrete s permeability to and absorption of, water Materials that reduce absorption are called water repellents Masonry cements normally contain a material of this type However water repellents provide no barrier to water under pressure Typical examples of chemically inactive water repellents are metallic stearates resins vegetable oil fats waxes and bituminous materials Most proprietary material

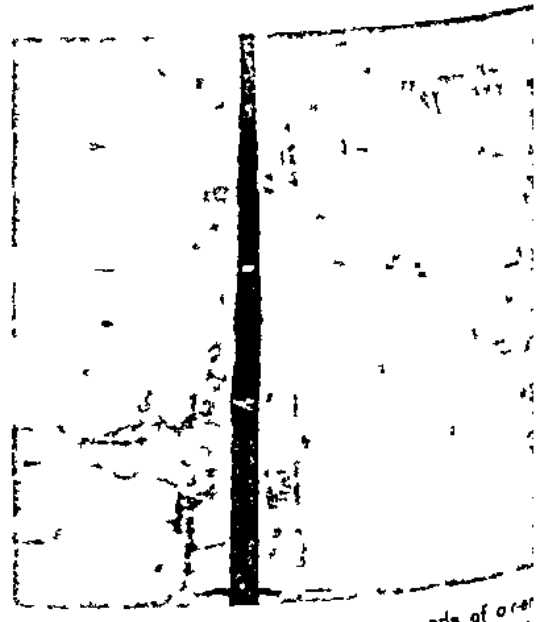


Fig 3 Pavement on the right was made of air-entrained concrete The highly scaled pavement on the left is in the same lane of traffic but air-entrained concrete was not used

this class contain the stearate of calcium or aluminum Finely subdivided materials are also claimed to decrease the permeability of concrete to water

Pozzolans Naturally occurring pozzolans are diatomaceous earth opaline chert tuffs and pumicite Artificial pozzolans are ground blast furnace slag fly ash and calcined clays and shales Their chief value lies in the possible economy of replacing a portion of the cement provided the resultant concrete is at least equal in quality to one without pozzolan Pozzolans are also used to reduce setting of heavier particles improve the workability of lean concrete mixtures reduce permeability increase resistance to sulfate attack and reduce heat evolution in massive structures by replacing a portion of the cement Their use will generally result in lower concrete strengths at early ages but equal or greater strengths at about 3 months Many pozzolans function as partial inhibitors of the alkali aggregate reaction mentioned earlier

Color pigments These are mineral oxides used to impart color to concrete No more than 10% pigment by weight of cement can be used without appreciably decreasing concrete strength Typical color pigments are brown oxide of iron for brown carbon black and black iron oxide preferably the latter for different shades of black red iron oxide for red chromium oxide for green cobalt oxide for blue and synthetic yellow oxide for buffs The full coloring value of pigments can be obtained only with white portland cement In addition hue can be considerably increased by casting the surface to be exposed against a smooth plastic form liner sheet

Mixing concrete Care is exercised to insure that the materials are maintained in a uniform condition during the progress of the job since variations will cause variability in the resulting concrete Mechanical mixers are mostly batch type in which a definite quantity is mixed and discharged at the completion of mixing The mixing is done by a series of revolving blades or baffles inside the mixer

Portable batch mixers suitable for building construction have capacities of 3½–14 ft^3 of concrete Paving mixers generally have a drum capacity of 27 34 ft^3 and are usually self propelled Stationary batch mixers having capacities of 1–10 yd^3 are generally used for large projects such as dams or as mixers for central plants supplying concrete for delivery to specific sites by truck mixers Truck mixers supply what is referred to as ready mixed concrete They either mix or merely agitate a batch mixed at the plant

The mixing time required increases with the capacity of the mixer usually 1 minute for the first cubic yard plus ¼ minute for each additional cubic yard

Conveying and placing concrete Conveyances may be wheelbarrows carts trucks chutes conveyor belts buckets or pipe lines Where chutes or belts are used the flow of material is maintained as continuous as possible On l

crete may be delivered to the formwork in dump buckets by cableways or by cranes In many instances direct pumping through pipe lines is used to convey concrete from the mixer or hopper to the point of placement

At times concrete must be placed under water The conveyance used called a tremie consists of a large metal tube with a hopper at the top end of the tube and a valve arrangement at the bottom submerged end of the tube While the tremie method is not as satisfactory as working in the dry good results can be achieved

The concrete is placed and consolidated in the formwork by hand tamping or puddling around reinforcing steel or by spading at or near vertical surfaces Another technique vibration or mechanical puddling is the most satisfactory one for achieving proper consolidation Vibrators are of three general types internal surface and form Internal vibrators are drawn vertically through concrete (Fig 4) Surface vibrators are used in pavement and flat slab work and are capable of consolidating the layer to its full depth Vibrators are placed against the form when the exposed concrete section is too thin or deep to permit the use of internal or surface vibrators Concrete of relatively dry consistency can be placed with vibration effecting economy in both labor and cement

Consolidation is sometimes achieved by means of vacuum pads incorporated in the forms for vertical surfaces or applied to the surface of a flat slab The vacuum removes water from the concrete and the result is consolidation of the mass and a reduction in the water cement ratio

In another process Gunite consolidation is achieved by blowing a mixture of cement sand and water through a nozzle onto a formed surface or a prepared concrete surface Depth is built up in a series of passes over the surface This technique is particularly useful for repairing portions of existing structures lining reservoirs and encasing steel for fireproofing *See* GUNITE

In the Prepakt process consolidation is accomplished by packing the form with the aggregate and then filling the voids with grout pumped into the mass under pressure The grout usually consists of cement water a workability admixture and a retarder to insure that the grout remains fluid until filling is completed

Finishing Finishes for exposed concrete surfaces are obtained in a number of ways Surfaces cast against forms can be given textures by using patterned form liners or by treating the surface after forms are removed for instance by brushing scrubbing floating rubbing or plastering (Fig 5) After the surface is thoroughly hardened other textures can be achieved by grinding chipping bush hammering or sandblasting

Unformed surfaces such as the top of pavement slabs or floor slabs may be either broomed or smoothed with a trowel Brooming or dragging burlap over the surface produces scoring which re



Fig 4 An inte v brator (a) The concrete has just been placed (b) The v brator has consol dated the concrete

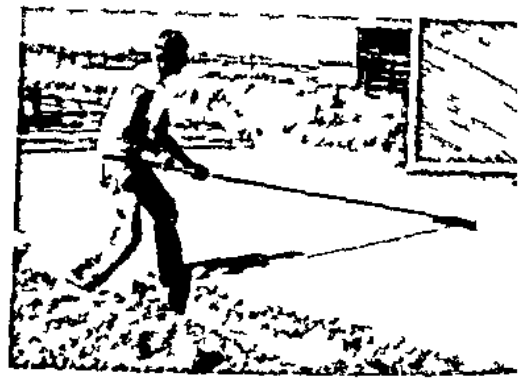


Fig 5 Fin shing a pavement by broom ng le shows grooved texture produced by broom ng

Curing of concrete Adequate curing is essential to l ring the concrete to required strength and quality The aim of curing is to promote the hydration of the cementing material This is accomplished by preventing moisture loss and whe necessary controlling temperature The rate of r action is increased by high temperatures and d creased by low temperatures

Moisture is a necessary ingredient in the cur n process since hydration is a chemical react on be tween the water and the cementing material Un formed surfaces are protected again t mo tur loss immediately after final finishing by means o wet burlap soaked cotton mats wet earth or sand sprayed on sealing compounds waterproof paper or waterproof plastic sheets Formed surfa es particularly vertical surfaces may be protected against moisture loss by leaving the forms on as long as possible covering with wet canvas or bur lap spraying a small stream of water over the sur face or applying sprayed on sealing compound

The length of the curing period depends upon the properties desired and upon atmospher c con ditions such as temperature humid ty and w nd ve locity during this period In general concre e should be kept moist for at least five days af er casting Shorter periods may be sufficient where temperatures are higher than normal But longer periods may be necessary in for example hot dry weather when moisture would be lost too rapid y

Short curing periods are used in fabricating con crete products such as block or precast structural elements Curing time is shortened by the u e of elevated temperatures The trend in the masonry block industry is to use high pressure steam auto claves in which temperature reaches 350°F at a sat urated steam pressure of about 125 psi A curing period of about 8 hours is adequate For relati ely large structural elements such as concrete p pe or prestressed bridge girders saturated steam at at mospheric pressure is used to attain temperatures of 140–160°F or higher Sufficient strength is gen erally attained in 16 18 hours of curing In bo h methods precautions are taken to insure a sa u rated atmosphere during the curing cycle [P K]

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Concrete beam

A structural member of reinforced concrete placed horizontally to carry loads over openings

As both bending and shear in such beams induce tensile stresses steel reinforcing increases beam strength tremendously Usually the beams are designed under the assumption that tensile stresses have cracked the concrete and the steel reinforcing is carrying all the tension

Two design theories are currently used elastic design and ultimate load design

Elastic design The following assumptions are made

1 Plane sections remain plane after bending and perpendicular to the longitudinal fibers

2 The stress strain curve is a straight line

3 The ratio of the modulus of elasticity of steel to that of concrete is a constant $E_s/E = n$

4 The concrete does not carry tensile stress

Transformed section One approach to elastic design of reinforced concrete beams is to convert the steel to concrete Because the steel and concrete are assumed to be firmly bonded and thus strained the same amount the stress in the steel is n times the concrete stress where n is the ratio of the modulus of elasticity of steel to that of concrete Hence the steel area may be replaced by an equivalent concrete area n times as large (Fig 1)

If the equivalent area is placed at the same level as the steel and the moment of inertia I computed for the transformed section the bending stresses can be computed from the simple flexural formula $f = Mc/I$ where M is the bending moment and c the distance from the neutral axis to the level at which stresses are to be computed

Rectangular beams The following formulas can be derived from the basic assumptions of the elastic theory

$$\frac{nf_c}{f_s} = \frac{k}{1-k}$$

where n is the ratio of the modulus of elasticity of steel to that of concrete f the stress in the extreme fiber of the concrete f_s the stress in the steel and

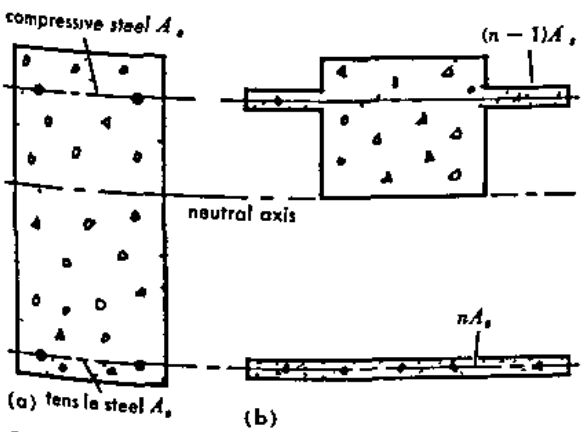


Fig 1 Sketch of (a) an actual beam section and (b) the same section transformed

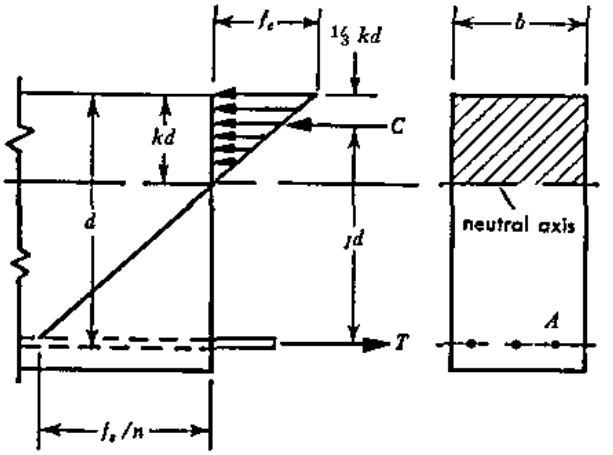


Fig 2 Stress distribution in a rectangular beam designed according to the elastic theory C is the total compressive force in concrete T the total tensile stress in longitudinal reinforcement

k the ratio of the distance between the top of the beam and the neutral axis to the distance between the top of the beam and the steel (Fig 2)

The design equation for equal moment resistance of concrete and steel (balanced design) is

$$k = \frac{1}{1 + f_s/nf_c}$$

Review equations

$$k = \sqrt{2np + (np)^2} - np$$

where p is the ratio of effective area of tension reinforcement to effective area of concrete in beams

$$j = 1 - k/3$$

where j is the ratio of lever arm of resisting couple to depth d

$$M = \tfrac{1}{2} f_c kjbd^2$$

where M is the moment resistance of the concrete b is the width of the rectangular beam or width of flange of the T beam and d is the depth from the compressive surface of beam or slab to center of longitudinal tension reinforcement

$$M_s = f_s A_s jd$$

where M_s is the moment resistance of the steel and A_s the steel area

When M_s is less than M the capacity of the steel determines the maximum moment the beam will carry The beam is called underreinforced If the beam is loaded to failure the steel rather than the concrete determines the maximum load that is sustained

When M is less than M_s the concrete determines the maximum moment the beam will carry The beam is said to be overreinforced Usually overreinforced beams are avoided because they are not considered economical and failure may occur without warning

To design a rectangular beam by the elastic theory, (1) determine k from the formula for balanced design, (2) compute j and select allowable unit stresses, (3) assuming the resisting moment of the concrete equal to the bending moment on the section calculate bd^2 and select values for b and d, and (4) determine the steel area by equating the resisting moment of the steel to the bending moment on the section This equation indicates that the amount of steel required can be reduced by increasing the depth If the depth is fixed and an overreinforced beam results it may be economical to use compression steel

Compression reinforced rectangular beams Reinforcement may be added in the compression zone of concrete beams when the resisting moment of the concrete is less than the bending moment on the section or to avoid an overreinforced design The compression steel is assumed to act as in plastic design, the Building Code Requirements of the American Concrete Institute allow the steel to take twice the stress given by elastic theory formulas provided the allowable tensile stress of the steel is not exceeded

Formulas for design of beams with both tension and compression reinforcement can be derived from the elastic theory in the same manner as for beams with tension reinforcement only but they are too complicated for ordinary use The following formulas are either exact or a close approximation

$$k = \frac{1}{1 + f_s/nf_c}$$

$$f'_s = nf_c \frac{kd - d'}{d - kd}$$

$$A_s = M/f_s jd$$

$$M_c = \tfrac{1}{2} f_c bkd\left(d - \frac{kd}{3}\right)$$

$$M'_s = M - M_c$$

$$A'_s = \frac{M'_s}{2f'_s(d - d')}$$

where k = ratio of distance between top of beam and neutral axis to the distance between top of beam and tension steel
f_s = allowable steel stress
f_c = allowable concrete stress
n = ratio of modulus of elasticity of steel to that of concrete
f'_s = stress in compression steel computed from elastic theory formula
d' = distance from top of beam to compression steel
A_s = area of tension steel
M = bending moment on the section
jd = moment arm of the tensile reinforcement (assumed)
M_c = resisting moment of the concrete
b = width of beam
d = distance from top of beam to tension steel
M'_s = resisting moment of the compression steel
A'_s = area of compression steel

Concrete T beams A slab cast integrally with a rectangular concrete beam usually is assumed to assist the beam in carrying loads In regions of positive bending moment, the two act together as a T beam In regions of negative moment, the beam is designed as a rectangular section because the slab is in tension and is assumed not to be able to resist such stresses, which must be taken by the reinforcing

If the neutral axis of a T beam is within the slab, it is designed as a rectangular beam with width b the same as that of the flange, to resist bending moments For shear, however, only the width of stem b' can be assumed to be effective

If the neutral axis falls within the stem the section can be designed as a T beam However the compression in the stem is negligible and can be ignored to simplify computations

The American Concrete Institute's code recommends the following limits for the part of the slab that can be considered effective as the flange (1) b shall be less than one-fourth the span length, (2) the overhanging width of flange shall not exceed eight times the slab thickness and (3) the overhanging width shall not exceed one half the clear distance between beams

If t is the flange thickness and the remaining symbols are the same as for elastic theory design of rectangular beams the following formulas can be used for T beams when stem compression is neglected

$$k = \frac{1}{1 + f_s/nf_c}$$

$$\frac{f_s}{f_c} = \frac{bt(2kd - t)}{2A_s kd}$$

$$kd = \frac{2ndA_s + bt^2}{2nA_s + 2bt}$$

$$z = \frac{t(3kd - 2t)}{3(2kd - t)}$$

$$jd = d - z$$

$$M_s = A_s f_s jd$$

$$M_c = \frac{f_c btjd}{2kd}(2kd - t)$$

$$f_c = \frac{f_s}{n}\left(\frac{kd}{d - kd}\right)$$

The shear unit stress in T beams is computed from

$$v = \frac{V}{b'jd}$$

where V is the shear on the section and j is customarily assumed to be $\frac{7}{8}$

Ultimate load design This theory is also known as ultimate strength design limit load design and the plastic theory Design assumptions differ from those of the elastic theory principally in that the stress strain curve is not a straight line Instead of being designed to carry allowable unit stresses as in the elastic theory beams are proportioned to

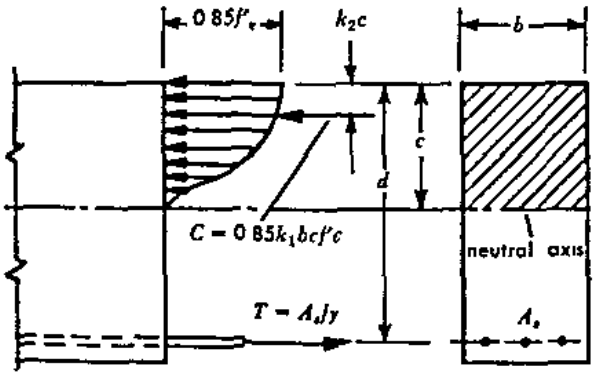


Fig 3 Stress distribution in a rectangular beam under ultimate load T and C are as in Fig 2

carry at ultimate capacity the design load multiplied by a safety factor

Among the reasons for using ultimate load design are the following

1 The elastic theory is not corroborated with sufficiently great accuracy by beam tests

2 It is logical to use different safety factors for live and dead loads This can easily be done with ultimate load design but not with elastic design

3 Column design is based on a modified ultimate load theory To avoid inconsistency, structural members subjected to both bending and compressive stress should also be designed by ultimate load theory

4 The ultimate strength of beams carrying both bending and axial compression determined in tests conforms closely with ultimate load theory

Rectangular beams The compressive stress distribution may be assumed to be a rectangle parabola trapezoid or any other shape that conforms to test data Maximum concrete stress is assumed to be $0\,85f'_c$, where f'_c is the compressive strength of a standard test concrete cylinder at 28 days (Fig 3)

When the moment resistance of the steel is less than that of the concrete, the bending moment that a rectangular beam can sustain under ultimate load is

$$M_u = A_s f_y d\left(1 - \frac{k_2}{k_1}\frac{pf_y}{0\,85f'_c}\right)$$

where A_s = area of tension reinforcement
f_y = yield point stress of steel, or 60,000 psi (whichever is lower)
k_2 = ratio of distance between extreme fiber and resultant of compressive stresses to the distance between extreme fiber and neutral axis
k_1 = ratio of average compressive stress to $0\,85f'_c$
b = width of beam
d = distance from top of beam to the steel
$p = A_s/bd$

The ratio k_2/k_1 depends on the assumed stress strain relation When the shape of the stress diagram is rectangular, the ratio is equal to ½, it is ⅔ for a triangle M_u cannot exceed either

$$M_u \leqq A_s f_y d\left(1 - \frac{0\,59pf_y}{f'_c}\right)$$

or

$$M_u \leqq f'_c bd^2 q(1 - 0\,59q)$$

where $q = pf_y/f'_c$ In the last equation the maximum values of p and q that can be used are

$$p_o = \frac{0\,40f'_c}{f_y} \qquad q_o = 0\,40$$

Compression reinforced rectangular beams Based on a nonlinear stress strain relation, the bending moment that a rectangular beam with both compression and tension reinforcement can sustain under ultimate load is

$$M_u = (A_s - A'_s)f_y d\left[1 - \frac{0\,59(p - p')f_y}{f'_c}\right] + A'_s f_y(d - d')$$

where A_s = area of tension steel
A'_s = area of compression steel
f_y = yield point stress of the steel
d = distance from top of beam to tension steel
b = width of beam
$p = A_s/bd$
$p' = A'_s/bd$
d' = distance from top of beam to compression steel
f'_c = compressive strength of standard test concrete cylinder at 28 days

In this formula, $p - p'$ should not exceed $0\,40f'_c/f_y$

Concrete T beams Two cases should be considered one with a relatively thick slab and one with a thin slab

If the flange thickness exceeds $1\,30qd$, where $q = pf_y/f'_c$ the bending moment under ultimate load may be taken as

$$M_u = f'_c bd\ q(1 - 0\,59q)$$

where the value of p used in computing q is A_s/bd with b the width of the flange

For thinner flanges use

$$M_u = (A_s - A_{sf})f_y d\left[1 - \frac{0\,59(p_w - p_f)f_y}{f'_c}\right] + A_{sf} f_y(d - 0\,5t)$$

where $A_{sf} = 0\,85f'_c(b - b')t/f_y$
f_y = yield point stress of steel
t = flange thickness
b = width of flange
b' = width of stem
$p_w = A_s/bd$
$p_f = A_{sf}/b'd$

In this formula $p_w - p_f$ should not exceed $0\,40f'_c/f_y$

Shear and bond. The maximum unit shear stress v acting on a section of a beam subjected to total shear V is given by

$$v = \frac{V}{bjd}$$

where b is the beam width d the depth from top of beam to the tensile steel and j approximately $\frac{7}{8}$

The bond stress can be computed from

$$u = \frac{V}{\Sigma_o jd}$$

where Σ_o is the sum of the bar perimeters This formula applies only to tension steel Bond stresses will be at a maximum where shear is a maximum and the steel is in the tension side of the concrete

To develop a given bar stress through bond a bar should be embedded a length L at least equal to

$$L = \frac{f_s a}{4u}$$

where a is the side of a square bar or the diameter of a round bar This length of embedment is called anchorage Usually bars are extended 10 diameters past the section where they are no longer required for bending stress

Shear in itself is not as important in the design of a concrete beam as the tensile stresses that accompany it on a diagonal plane To resist these stresses concrete beams should be reinforced with bent up bars or with stirrups The latter are bars placed vertically or on an incline in a beam They may be the legs of a single bar bent into a U shape or the sides of a rectangle

The shear V taken by stirrups is assumed to be the total shear on the section at which the stirrups are to be placed less the shear taken by the concrete $vbjd$ The cross sectional area of the stirrups needed at a section is given by

$$A_v = \frac{V's}{f_s jd}$$

where f_s is the allowable tensile stress of the steel and s is the stirrup spacing

If the stirrups instead of being vertical are laid at an angle α with the horizontal greater steel area is required

$$A_v = \frac{V s}{jd(\sin \alpha + \cos \alpha) f_s}$$

Every potential 45° crack should be crossed by at least one line of reinforcement

If the area of the stirrups is given the spacing can be computed from the two formulas above The first stirrup is usually placed as close to the support as practical generally 2 in Stirrups should be placed throughout a beam even if theoretically they are not needed They serve also as supports for the longitudinal steel When not required for diagonal tension stirrups should be spaced at most 18 in apart

It is common practice to cut off bars or bend them up when they are no longer needed to resist tension at the bottom of the beam The bent bars serve as diagonal tension reinforcement and tensile reinforcement at the top of the beam over the support [F S M]

Bibliography American Concrete Institute *Building Code Requirements for Reinforced Concrete* 1956, C W Dunham *Theory and Practice of Reinforced Concrete*, 3d ed 1953 P M Ferguson *Reinforced Concrete Fundamentals* 1958 L C Urquhart, C E O Rourke and G Winter *Design of Concrete Structures* 6th ed 1958

Concrete column

A structural member subjected principally to compressive stresses Concrete columns may be unreinforced or they may be reinforced with longitudinal bars and ties (tied columns) or with longitudinal bars and spiral steel (spiral reinforced columns) Sometimes the columns may be a composite of structural steel or cast iron and concrete

Plain concrete columns Unreinforced concrete columns are seldom used because of the existence of transverse tensile stresses and the possibility of longitudinal tensile stresses being induced by buckling or unanticipated bending Because concrete is weak in tension such stresses are generally avoided

When plain concrete columns are used they usually are limited in height to five or six times the least thickness Under axial loading the load divided by the cross sectional area of the concrete should not exceed the allowable unit compressive stress for the concrete

Axially loaded reinforced columns Reinforced concrete columns are designed by ultimate load theory (*see* CONCRETE BEAM) Two types of columns are considered short and long. Those whose length is three to ten times their least lateral dimension are called short columns

For spiral reinforced short columns the American Concrete Institute code gives the following formula for the allowable load in pounds

$$P = 0.225 f'_c A_g + f_s A_s$$

where f'_c is the 28 day compressive strength of a standard concrete test cylinder in pounds per square inch (psi) A_g the gross area of section in in^2 f_s the allowable unit stress for steel in psi and A_s the area of reinforcing steel in in^2

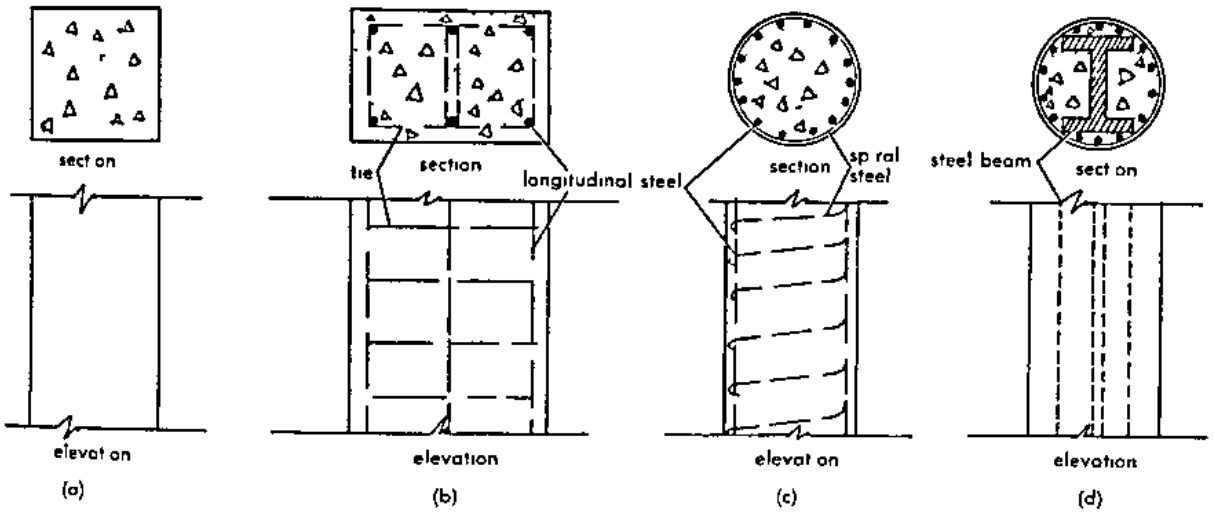
For a tied column the allowable load is 80% of that for a spiral reinforced column Spiral reinforced columns are stronger because column tend to fail by a lateral bursting of the concrete as the longitudinal bars bend outward and spiral reinforcing is more effective than ties in restraining the concrete If spirals are used the longitudinal bars should be arranged in a circle

For long columns the allowable load is reduced from that permitted for short columns because of the possibility of buckling When h/d the ratio of unsupported length of column to least lateral dimension is equal to or greater than 10 the allowable load for a long column is

$$P' = P(1.3 - 0.03h/d)$$

where P is the safe load on a column of the same cross section but with h/d less than 10

Spiral reinforced columns should be designed for a minimum eccentricity of 5% of the depth of the section and tied columns for 10% of the depth



Types of concrete column (a) Plain concrete (b) Tied column (c) Spiral reinforced column (d) Composite column

Spiral reinforcement is determined from the formula

$$p' \geq 0.45(R-1)f'_c/f'_s$$

where p' is the ratio of the volume of spiral reinforcement to the volume of the spiral core (out to out of the spiral), R is the ratio of gross area to core area, and f'_s is the yield point stress of spiral steel, with a maximum of 60 000 psi

Composite columns. A concrete compression member having a structural steel or cast iron core with a cross sectional area not exceeding 20% of the gross area of the column is called a composite column Spiral and longitudinal reinforcing also may be incorporated in the concrete

The allowable load in pounds on a composite column is given by

$$P = 0.225A_c f'_c + f_r A_r + f_s A_s$$

where A_c is the net area of the concrete section $(A_g - A_r - A_s)$, A_s is the area of longitudinal reinforcement other than the metal core A_r is the cross sectional area of the structural steel or cast iron core, f_r is the allowable unit stress for the core and f_s is the allowable unit stress for the longitudinal reinforcement

If the core area is 20% or more of the gross area and the concrete is at least 2 in thick over all metal except rivet heads, the member is called a combination column If the concrete is to be allowed to share the load with the core, the concrete must be reinforced, usually wire fabric is wrapped completely around the core

Combined bending and axial load. Because columns are designed by ultimate load theory and this theory has also been developed for beams, it is logical to design columns subjected to both bending and axial loads by ultimate load theory The ultimate load is given by

$$P_u = 0.85f'_c bdk_u k_1 + A'_s f_y - A_s f_s$$
$$P_u e = 0.85f'_c bd^2 k_u k_1(1 - k_2 k_u) + A'_s f_y d(1 - d'/d)$$

The ratio k_2/k_1 should not be less than 0.5, nor should k_1 be greater than 0.85 In these formulas P_u is the axial load e the eccentricity of the load f_s the stress in the tensile reinforcement (f_y, the yield point if tensile reinforcement governs), $k_u d$ the distance between the extreme fiber and the neutral axis A_s the area of tensile steel, A'_s the area of compressive steel, k_2 the ratio of distance between extreme fiber and resultant of compressive stresses to the distance between extreme fiber and neutral axis compressive stress to $0.85f'_c$

When the unsupported length L of the column is greater than fifteen times the least lateral dimension d the ultimate load should be reduced to

$$P'_u = P_u(1.6 - 0.4L/d)$$

See CONCRETE SLAB, REINFORCED CONCRETE

[F S M]

Concrete slab

A shallow reinforced concrete structural member that is relatively wide Spanning between beams girders or columns slabs are used for floors, roofs, and bridge decks If they are cast integrally with beams or girders they may be considered the top flange of those members and act with them as a T beam *See* CONCRETE BEAM

One way slab. A slab supported on four sides but with a much larger span in one direction than in the other may be assumed to be supported only along its long sides It may be designed as a beam spanning in the short direction For this purpose a 1 ft width can be chosen and the depth of slab and reinforcing determined for this unit

Some steel also is placed in the long direction to resist temperature stresses and distribute concentrated loads The area of the steel generally is at least 0.25% of the concrete area

Two way slab A slab supported on four sides and with reinforcing steel perpendicular to all

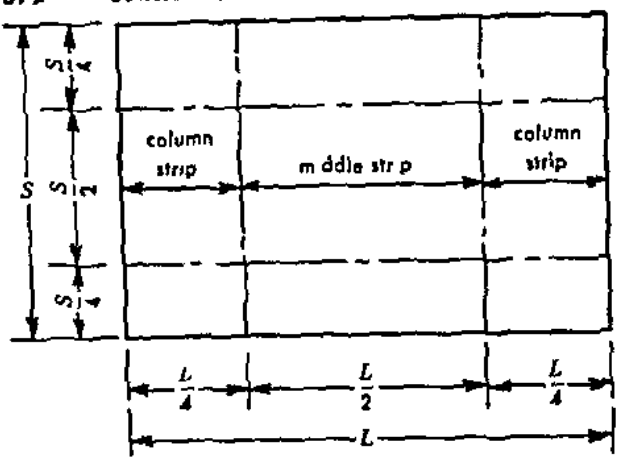


Fig 1 A two way slab divided into strips for design purposes

The American Concrete Institute (ACI) code recommends the following design method divide the slab in both directions into a column strip and middle strip (Fig 1) If the ratio S/L of the short span to the long span is equal to or greater than 0 5 the width of the middle strip in the short direction equals $L/2$ as shown If S/L is less than 0 5 the width of the middle strip in the short direction is $L - S$ the remaining width is divided equally between the two column strips However when S/L is less than 0 5 most of the load would be carried in the short direction and it would be desirable to design the slab as a one way slab

A table in the ACI code gives coefficients for calculation of the bending moments in the middle strip for different values of S/L and different types of panels The moment in the column strip is assumed to be two thirds that in the middle strip The reinforcing steel area is determined from $A_s = M/f_s jd$ where M is the bending moment f_s the tensile unit stress in longitudinal reinforcement and j the ratio of lever arm of resisting couple to d the depth from compressive surface of beam or slab to center of longitudinal tension reinforcement

In the design of the beams that support a two way
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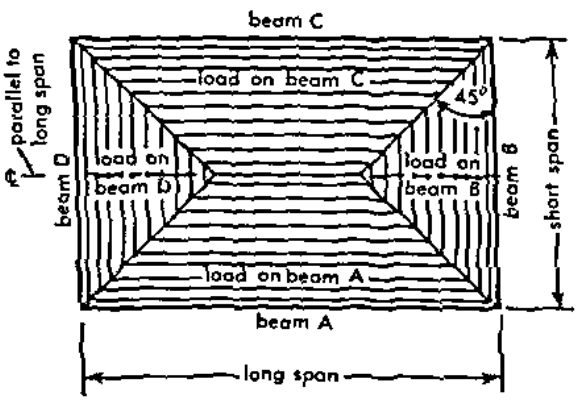


Fig 2 Load distribution assumed for beams supporting a uniformly loaded two-way slab

ments in the beams may be approximated by assuming the beams loaded with the following equivalent uniform loads for the short span $wS/3$ for the long span $wS(3 - S^2/L^2)/6$

Flat slabs When a slab is supported directly on

throughout Usually, the columns also have constant dimensions throughout the story height below the slab (excluding the portion forming capitals which are discussed later) In designing such construction it is necessary to investigate shear and diagonal tension in the vicinity of the columns frequently special reinforcement called shear head is embedded at the column tops

In flat slab construction it is customary to flare out the columns at the top to form capitals so as to give the slab column junction greater rigidity The capital is usually sloped at 45° For exterior columns, the capital is sometimes only a bracket that projects inward

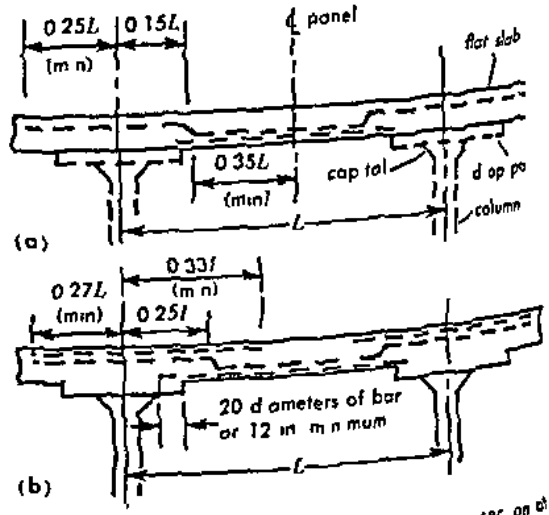


Fig 3 Details of a flat slab drawn in cross section at two points (a) Middle strip (b) Column strip L is the center to center distance between columns

Flat slabs generally are thickened in the region around the columns The thickened portion called a drop panel may be extended until it reaches hollow beams and

than slabs in beam and girder construction flat slabs are advantageous because they offer no obstruction to passage of light (as beam construction does), savings in story height and in the simpler formwork involved, less danger of collapse due to overload, and better fire protection with a sprinkler system because the spray is not obstructed by beams

Flat slabs may be reinforced in any of several different ways

1 Two way system When the columns are arranged to form rectangular bays the reinforcing

steel may be placed in two directions perpendicular to the column lines Design is based on column strips and middle strips similar to that for a two way slab

2 Four way system Column strip steel is similar to that for a two way slab But middle strip reinforcing consists of diagonal bands of steel extending over the columns

3 Circumferential system Bars are placed in the top of the slab in concentric rings around the columns also radially Similar radial and circular bars are placed in the bottom of the slab in the central portion

4 Three-way system When columns are arranged so that lines joining them would form triangles the reinforcing steel may be laid parallel to the column lines

Design of flat slabs and flat plates is based on empirical formulas The ACI code presents design rules that are widely used *See* CONCRETE COLUMN REINFORCED CONCRETE [F S M]

Bibliography *See* CONCRETE BEAM

Concretion

A loosely defined term used for a sedimentary mineral segregation that may range in size from inches to many feet Concretions are usually distinguished from the sedimentary matrix enclosing them by a difference in mineralogy color hardness and weathering characteristics Some concretions show definite sharp boundaries with the matrix while others have gradational boundaries Most concretions are composed dominantly of calcium carbonate with or without an admixture of various amounts of silt clay or organic material Less common are the clay ironstone concretions characteristic of the Carboniferous coal measures in many parts of the world The latter are mixtures of iron carbonate minerals and iron silicate minerals Coal balls are calcareous concretions found in or immediately above coal beds in which there may be a high percentage of original plant organic matter showing wonderfully preserved plant fossils in a noncompressed condition Concretions are normally spherical or ellipsoidal some are flattened to disklike shapes Frequently a concretion is dumbbell shaped indicating that two separate concretionary centers have grown together *See* COAL BALLS SEDIMENTARY ROCKS [R S]



Calcareous concretions from clay beds (*From W H Emmons G A Thiel C R Stauffer I S Allison Geology Principles and Processes McGraw Hill 1955*)

Concussion

A state following injury in which there is temporary functional impairment without physical evidence of damage to the impaired tissues The term usually refers to cerebral concussion produced by any type of trauma

From a clinical point of view cerebral concussion is produced by a head injury which causes temporary unconsciousness but with complete recovery within 24 hours This temporary alteration may affect reflexes and other nervous system components and is believed to result from one of several mechanisms In all of these a sudden acceleration or deceleration appears to be a prerequisite The sudden movement is thought to cause an unequal shifting of tissues of different specific gravities within the skull between skull and brain or between different brain tissues Because no permanent detectable lesion is produced the exact mechanisms remain speculative

There are increasing orders of damage which pass beyond concussion states Clinically it is difficult to judge whether a brief period of unconsciousness is the result of concussion or is an early sign of laceration contusion or hemorrhage of brain tissues and related structures Therefore a guarded prognosis is made and careful watch is maintained often for many weeks after a head injury has been sustained *See* BRAIN [E G ST]

Condensation polymerization

The formation of high molecular weight polymers from monomers by chemical reactions of the condensation type *See* CONDENSATION REACTION POLYAMIDE RESIN POLYMERIZATION

Condensation reaction

One of a class of chemical reactions involving a combination between molecules or between parts of the same molecule A relatively small molecule such as water or alcohol is often eliminated in the process The conversion of oxygen to ozone and of diethyl pimelate to 2 carbethoxycyclohexanone are examples

$$3O_2 \rightarrow 2O_3$$

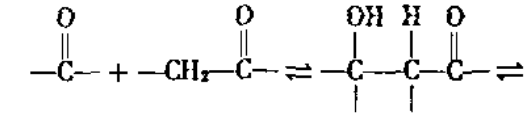
$$C_2H_5O_2C(CH_2)_5CO_2C_2H_5 \rightarrow \begin{matrix} CH_2CH_2C{=}O \\ | \quad\quad | \\ CH_2CH_2CHCO_2C_2H_5 \end{matrix} + C_2H_5OH$$

The term condensation reaction is used very loosely by chemists Some authors define the term to include all reactions which result in formation of carbon carbon bonds General usage however does not classify all reactions resulting in formation of carbon carbon bonds as condensation reactions Furthermore the reaction commonly re-

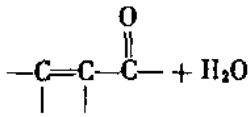
ferred to as condensation polymerization involves formation of carbon oxygen or carbon nitrogen bonds *See* POLYMERIZATION

The following reactions of organic compounds are usually described as condensation reactions

Aldol condensations These reactions involve a carbonyl component and an α hydrogen component



Carbonyl component — α Hydrogen component



The carbonyl component is most often an aldehyde (RCHO) but may also be a ketone ($R_2C{=}O$) The α hydrogen component may be an aldehyde ketone simple ester (RCH_2CO_2R) succinate es ter $RO_2CCH_2CH_2CO_2R$ (the Stobbe condensa tion) carboxylic acid anhydride $(RCH_2CO)_2O$ (the Perkin reaction) or compounds containing an activated methylene of the type Y—CH_2—Z where Y and Z may be groups such as —CO_2H —CO_2R —CO—R —CN —$CONH_2$ —NO_2 (the Knoeve nagel reaction)

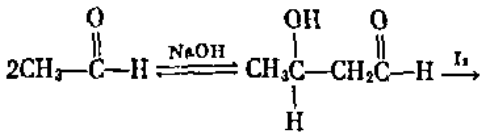
Aldol condensations are catalyzed by bases such as sodium hydroxide sodium ethoxide or amines Catalysis by acids is feasible in certain cases

The α hydroxycarbonyl compounds initially formed in aldol condensations can sometimes be isolated but they often eliminate water under the experimental conditions and form $\alpha\,\beta$ unsaturated carbonyl compounds

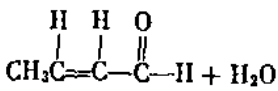
At least two α hydrogen atoms are present in the α hydrogen component of most aldol condensa tions but the first stage of the reaction sometimes involves a single α hydrogen atom

The Darzens condensation of aldehydes and ke tones with α haloesters to produce glycidic esters is also an aldol type condensation

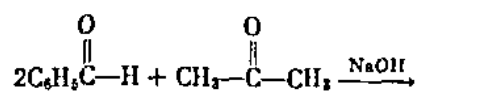
Simple aldol



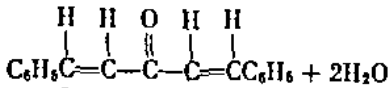
Acetaldehyde — Aldol



Crotonaldehyde

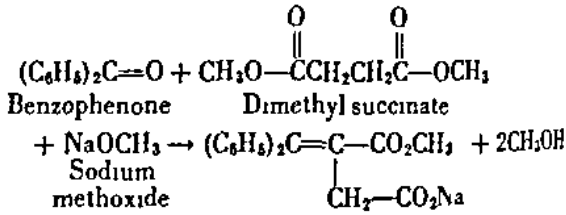


Benzaldehyde — Acetone



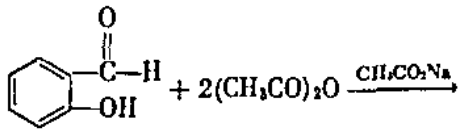
Dibenzalacetone

Stobbe

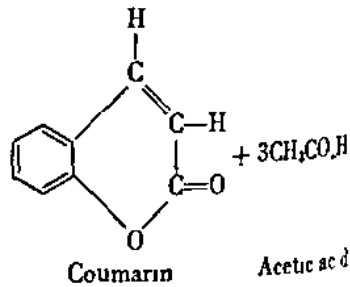


Benzophenone — Dimethyl succinate — Sodium methoxide

Perkin

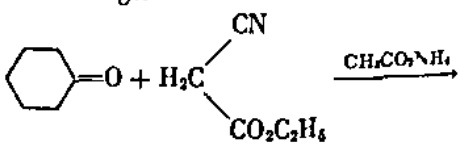


Salicyl aldehyde — Acetic anhydride

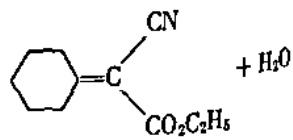


Coumarin — Acetic acid

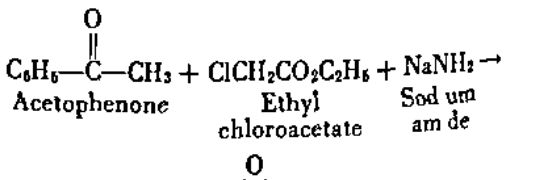
Knoevenagel



Cyclo hexanone — Ethyl cyanoacetate

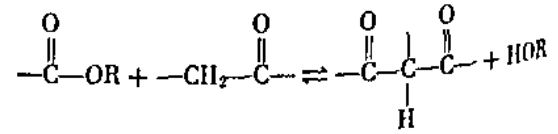


Darzens



Acetophenone — Ethyl chloroacetate — Sodium amide

Claisen condensations The carbonyl component in a Claisen condensation is an ester Esters of



Carbonyl component — α Hydrogen component

oxalic acid (RO_2CCO_2R) are particularly reactive

as carbonyl components The α hydrogen component may be an ester or ketone

Claisen condensations involving esters as both components are known as acetoacetic ester condensations and have as products β ketoesters ($RCO{-}CHRCO_2R$)

$$2CH_3CO_2C_2H_5 + NaOC_2H_5 \rightarrow$$

Ethyl acetate — Sodium ethoxide

$$Na(CH_3COCHCO_2C_2H_5) + C_2H_5OH$$

$$\xrightarrow{HCl} CH_3{-}C(=O){-}CH_2{-}C(=O){-}OC_2H_5 + NaCl$$

Simple esters react with ketones to produce β-diketones ($RCO{-}CHR{-}CO{-}R$) and oxalic esters react with ketones to give oxalyl esters ($R{-}CO{-}CHR{-}CO{-}CO_2R$) as products

$$C_6H_5CO_2C_2H_5 + C_6H_5{-}C(=O){-}CH_3 \xrightarrow[(2)\ HCl]{(1)\ NaOC_2H_5}$$

$$C_6H_5{-}C(=O){-}CH_2{-}C(=O){-}C_6H_5$$

$$\text{cyclohexanone} + (C_2H_5CO_2)_2 \xrightarrow[(2)\ HCl]{(1)\ NaOC_2H_5}$$

$$\text{cyclohexanone-}C(=O){-}C(=O){-}OC_2H_5$$

Condensations of esters of dicarboxylic acids which produce cyclic β ketoesters are known as Dieckman condensations

Claisen condensations are brought about by strong bases such as sodium alkoxides sodium amide and sodium hydride At least 1 mole of base for each mole of α hydrogen component is required

α Hydrogen components with only one α hydrogen atom may be utilized in Claisen condensations if very strong bases such as sodium triphenyl methyl are employed

Michael condensations Compounds containing an active methylene group often add to the carbon

$${-}C{=}C{-}C{=}O + X{-}CH_2{-}Y \rightleftharpoons$$

$$X{-}CH(Y){-}C(H){-}C{-}C{=}O$$

carbon double bond of α β unsaturated carbonyl compounds in the presence of basic catalysts

$$H_2C{=}CHCO_2C_2H_5 + H_2C(CO_2C_2H_5)_2 \xrightarrow{NaOC_2H_5}$$

Ethyl acrylate — Diethyl malonate

$$CH_2{-}CH_2{-}CO_2C_2H_5$$
$$|$$
$$CH(CO_2C_2H_5)_2$$

Benzoin condensations. Aromatic aldehydes in the presence of catalytic amounts of potassium cyanide are converted to hydroxy ketones of the type $ArCHOH{-}CO{-}Ar$ called benzoins

$$2C_6H_5C(=O){-}H \xrightarrow{KCN} C_6H_5{-}CH(OH){-}C(=O){-}C_6H_5$$

Acyloin condensations Aliphatic esters react with metallic sodium to produce intermediates which are converted by hydrolysis into aliphatic α-hydroxyketones called acyloins

$$2C_3H_7CO_2C_2H_5 \xrightarrow[2\ H_2O]{(1)\ Na}$$

$$C_3H_7{-}CH(OH){-}C(=O){-}C_3H_7 + 2C_2H_5OH + 4NaOH$$

Mannich reaction The most common application involves a ketone formaldehyde and dimethylamine The reaction results in replacement of α hydrogen atoms with one or more dimethyl aminomethyl groups Other secondary amines may be used

$$CH_3{-}C(=O){-}CH_3 + CH_2O + (CH_3)_2NH_2 \rightarrow$$

$$CH_3{-}C(=O){-}CH_2CH_2N(CH_3)_2 + H_2O$$

Cyanoethylation Acrylonitrile adds a variety of weakly acidic compounds The reaction is catalyzed by strong bases such as potassium hydroxide *See* CYANOETHYLATION

$$CH_3COCH_3 + 3CH_2{=}CHCN \rightarrow$$

$$CH_3{-}COC(CH_2CH_2CN)_3$$

$$(CH_3)_2CHC(H){=}O + CH_2{=}CHCN \rightarrow$$

$$NCCH_2CH_2C(CH_3)_2{-}C(H){=}O$$

$$CH_3CH_2OH + CH_2{=}CHCN \rightarrow$$

$$CH_3CH(OCH_2CH_2CN)$$

$$CH_3CH_2NH_2 + 2CH_2{=}CHCN \rightarrow$$

$$CH_3CH_2N(CH_2CH_2CN)_2$$

Pinacol formation Ketones are converted to tetrasubstituted ethylene glycols (called pinacols) by certain reducing agents

$$2CH_3COCH_3 + Mg \rightarrow$$

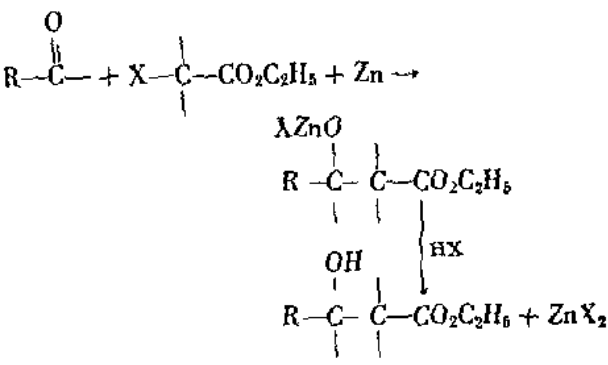
$$(CH_3)_2C(O{-})$$
$$|\quad Mg \xrightarrow{HCl}$$
$$(CH_3)_2C(O{-})$$

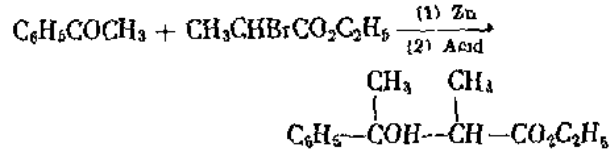
$$(CH_3)_2C(OH)$$
$$|\quad + MgCl_2$$
$$(CH_3)_2C(OH)$$

$$2(C_6H_5)_2CO + (CH_3)_2CHOH \xrightarrow{Light}$$

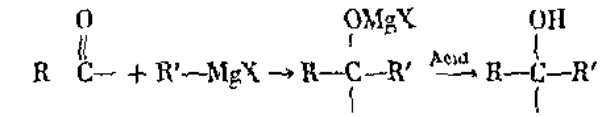
$$(C_6H_5)_2C(OH)$$
$$|\quad + CH$$
$$(C_6H_5)_2C(OH)$$

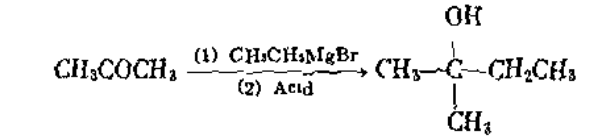
Reformatsky reaction. Aldehydes and ketones react with α haloesters in the presence of zinc Treatment of the reaction mixture with a dilute acid produces β hydroxy esters *See* REFORMATSKY REACTION

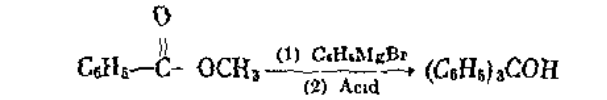


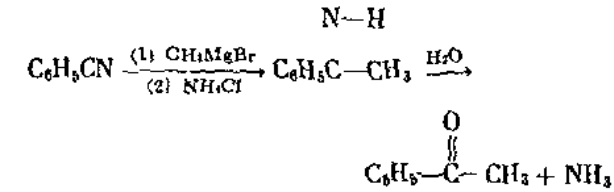


Additions of Grignard reagents. Grignard reagents (RMgX) add to carbonyl groups and to nitriles Alcohols, imines, and ketones may be prepared by this method









Organolithium compounds (RLi) and organo zinc compounds (R_2Zn) add to carbonyl groups in the same way that Grignard reagents react *See* GRIGNARD REACTION

Friedel Crafts alkylations and acylations. Alkyl and acyl groups may be substituted for hydrogen atoms in aromatic compounds Aluminum chloride is the usual catalyst for the reaction, but other strong acids may be used Alkyl and acyl halides are often the substituting reagents, but alcohols, olefins, anhydrides organic acids, aldehydes, ketones, ethers, and esters may be employed *See* FRIEDEL CRAFTS REACTION.

Alkylations of organometallic compounds Compounds of the type RMe, where Me represents a metal such as Na, K, Li, or MgX, react with many alkyl halides to eliminate MeX and replace the metal with an alkyl group

$$RMe + R'X \rightarrow R{-}R' + MeX$$

The availability of the compounds RMe and the reactivity of the halides R'X are the limiting factors

Grignard reagents are readily available from halides and magnesium metal These reagents are alkylated by reactive halides such as allyl bromide

$$CH_3CH_2MgBr + BrCH_2CH{=}CH_2 \rightarrow CH_3(CH_2)_2CH{=}CH_2 + MgBr_2$$

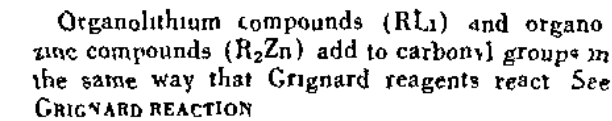
Compounds of the type Y—CH_2—Z where Y and Z are activating groups are converted to metallocompounds by treatment with sodium or potassium alkoxides, and may then be alkylated by allyl primary, or secondary halides

$$H_2CYZ + MeOR \rightarrow MeHCYZ + HOR$$
$$MeHCYZ + R'X \rightarrow R'HCYZ + MeX$$

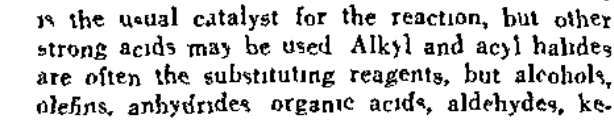
A second alkyl group may be introduced by repeating the process

$$R'HCYZ \xrightarrow[(2)\ R''X]{(1)\ MeOR} R'R''CYZ$$

Alkylations of acetoacetic and malonic esters are classical examples of this procedure



Ketones with at least one α hydrogen atom may usually be metallated with sodium amide and subsequently alkylated



See ETHYL ACETOACETATE. ETHYL MALONATE. On

GANIC REACTION MECHANISM, ORGANOMETALLIC COMPOUND [W B R]

Bibliography R Adams (ed), *Organic Reactions* vols 1 2 3 4 5 6 8 1942–1949

Condenser, electrical

A device for introducing capacitance into a circuit In modern usage the word capacitor is replacing the word condenser since nothing is really condensed in this device Hence for a discussion of this electric circuit component see CAPACITOR see *also* CAPACITANCE [R P WI]

Condenser, vapor

A heat transfer device which reduces a thermodynamic fluid from its vapor phase to its liquid phase The condenser extracts the latent heat of vaporization from the vapor as the higher temperature heat source by absorption in a heat receiving fluid of lower temperature The vapor to be condensed may be wet saturated or superheated The heat receiver is usually water but may be a fluid such as air a process liquid or a gas

Classification Condensers may be divided into two major classes according to use those used as part of a processing system and those used for serving engines or turbines in a steam power plant cycle Process condensers selectively recover liquid from a mixed vapor recover pure liquid from the vapor of an impure liquid recover noncondensables from a mixture of gas and vapor or extract heat from heat pump and refrigeration cycles Steam condensers are used as part of the steam power plant cycle and serve as an efficient heat sink in the cycle by reducing the back pressure on the turbine or engine so that a maximum of heat energy becomes available as useful work (see THERMODYNAMIC CYCLE) Another important function of a condenser in the steam power plant cycle is the recovery of condensate as the major source of pure boiler feed water for the boilers *See* BOILER FEED WATER

Condensers may be further classified according to type as surface condensers or as contact condensers In the surface condenser the condensing vapor and the cooling fluid remain separated from each other by a dividing wall which forms the heat transfer surface (see SURFACE CONDENSER) This heat transfer surface is most often tubes but may also be plates or partitions of various geometries Condensate cooling fluid and noncondensable gases are usually removed separately although in particular designs the condensate and noncondensable gases are withdrawn from the condenser as a mixture

In the contact condenser the vapor and cooling liquid come into direct contact with each other and are mixed in the condensing process (see CONTACT CONDENSER) The [illegible] mid comb together withdraw [illegible] although in some contact condensers the noncondensable gases are entrained in the mixed condensate and cooling liquid and removed through a common outlet

Removal of noncondensables Condensers are required almost without exception to condense impure vapors that is vapors which contain air or other noncondensable gases Because most condensers operate at subatmospheric pressures air leaking into the apparatus or system becomes a common source of vapor contamination Many process condensers are used to condense vapors whose impurities are independent of air which may leak into a vacuum system Because the vapor present in a condenser is continuously reduced to liquid the noncondensable gases collect and concentrate Their accumulation seriously affects heat transfer and a means must be provided to direct them to a suitable outlet Most surface and contact condensers are arranged with a separate zone of heat transfer surface within the condenser and located at the outlet end of the vapor flow path for the efficient removal of noncondensable gases by dehumidification (Fig 1)

Separate external coolers arranged in series with the vapor flow path of the condenser are used when the ratio of noncondensable gases to condensing vapor is high or when it is necessary to reduce the vapor content of the noncondensable gases to low values

The removal of noncondensables from condensers operating at subatmospheric pressures requires vacuum pumps The noncondensables are removed from condensers operating above atmospheric pressure by venting to atmosphere or venting to after condensers to reduce further the moisture content of the removed gases before discharging them to atmosphere or to a recovery process

Heat sink fluid Water is the most commonly used liquid for absorbing heat from condensing vapors Liquid hydrocarbons and other chemical compounds in liquid state are used primarily as heat receivers for condensers which are used as part of a petroleum or chemical manufacturing process Because of natural evaporation surface waters are normally at a lower temperature than ambient air when air temperatures exceed 32°F and thus provide the lowest temperature heat sink readily available High heat capacity ease in pumping and good heat transfer properties characterize water as an excellent medium for use as a heat receiver in a condensing system The tendency of water to corrode metal surfaces is not a serious disadvantage Thin walled heat transfer surfaces of the less costly corrosion resistant alloys are generally satisfactory Ferritic materials used for the water containing parts of condensers can be made suitable for the corrosive environment by increasing thickness as a corrosion allowance or by the use of corrosion resistant coatings

Air is the gas most commonly used for absorbing heat from a condensing process However its low heat capacity low density and poor heat transfer properties preclude it from being an ideal fluid for this purpose Its availability and the fact that air

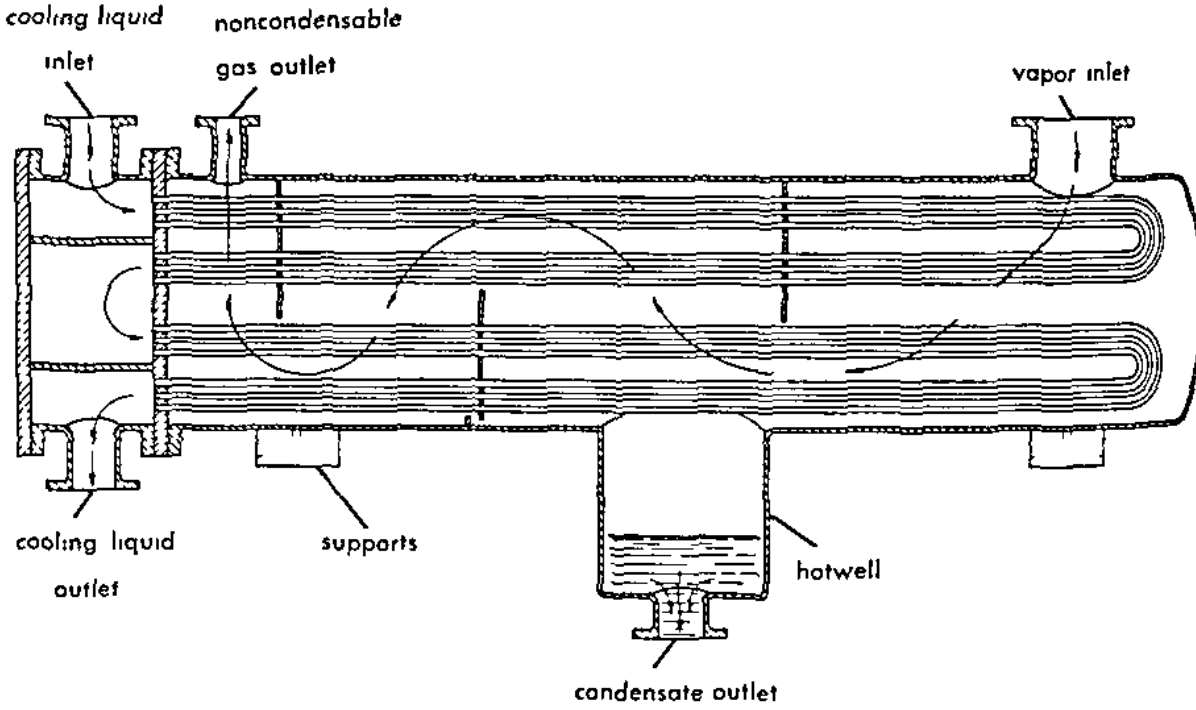


Fig 1 Horizontal process condenser with one baffled shell pass of condensing vapor and four tube passes of cooling liquid

does not readily corrode or foul heat transfer surfaces offer certain advantages in its use

The cooling of heat transfer surfaces by evaporation involves the use of both water and air The heat transfer surfaces are continuously wetted by water Air is blown over the wetted surfaces and absorbs the vapor as it is released from the evaporating cooling water, thereby removing the heat released in the condenser

Condensate reheating Modern steam surface condensers for turbines are provided with means for condensate reheating (Fig 2) Condensate falling from tube to tube becomes cooled below the temperature corresponding to condenser operating pressure and unless provision is made for reheating this condensate before it is removed from the condenser, a measurable amount of heat energy is lost from the cycle, and its efficiency is reduced In addition, subcooled condensate absorbs air from the condensing vapor and if allowed to remain in the boiler feed water may cause serious corrosion of the feed system and boilers

The condensate is reheated by directing a suitable portion of the incoming steam to the condenser hotwell in such a manner that its velocity energy is converted to pressure (Fig 3) As a result, the local static pressure and corresponding temperature become equal to or greater than the static pressure and the corresponding temperature at the condenser steam inlet Provision is made for the condensate, after falling from the tube bundle, to spread out in thin films over trays, plates, or baffles so that it may be reheated in this zone of higher pressure and temperature Adequate venting of the hotwell area of both air and vapor effects a high degree of condensate deaeration, as well as condensate reheating Under favorable conditions the condensate may reach temperatures as much as 5°F above the temperature corresponding to static pressure at the condenser steam inlet, and the dissolved oxygen content of the condensate may be consistently less than 0 01 cubic centimeter per liter

Condenser capacity. The quantity of cooling fluid required to condense a given quantity of vapor may be obtained by applying the general heat balance equation For a condensing vapor which may be superheated, saturated or wet, with its condensate subcooled or reheated and with the noncondensable gases cooled, the equation is

$$W_v(h_a - h_c) + W_n(h_{na} - h_{nb}) = W_f(h_{fb} - h_{fa}) \quad (1)$$

where W_v = quantity of vapor
h_a = enthalpy of entering vapor
h_c = enthalpy of leaving condensate
W_n = quantity of noncondensable gases
h_{na} = enthalpy of entering noncondensables
h_{nb} = enthalpy of leaving noncondensables
W_f = quantity of cooling fluid
h_{fa} = enthalpy of entering cooling fluid
h_{fb} = enthalpy of leaving cooling fluid

(Engineering practice is to express quantities in lb/hr and enthalpies in Btu/lb)

The temperature of the leaving cooling fluid is usually selected to be 5–10°F less than the condensing temperature of the saturated vapor Ordinarily, low temperature differences are associated with contact condensers, larger temperature differences are characteristic of economic design for surface condensers Very small temperature differ

ences require enormous amounts of condensing surface and are seldom a practical design consid eration

For both contact and surface condensers the con ditions for determining the hourly heat transferred can be expressed by the equation for undirectional steady state heat flow

$$Q = UA\,\Delta t_m \qquad (2)$$

where Q = hourly heat, Btu/hr
U = over all heat transfer coefficient, Btu/(hr)(ft²)(°F)
A = area of heat transfer surface, ft²
Δt_m = logarithmic mean temperature difference °F

Logarithmic mean temperature difference Δt_m is based on the assumption of constant specific heat and substantially constant condensing temperature with the cooling fluid temperature increasing from inlet to outlet in its flow path Over all heat trans fer coefficient U and surface A are generally appli cable to surface condensers only

For direct contact condensers where surface is not readily determined, it is usual to consider heat transferred per unit volume of condensing space rather than per unit area In this case the heat flow equation becomes

$$Q = KV\,\Delta t_m \qquad (3)$$

where K = volumetric heat transfer coefficient, Btu/(hr)(ft³)(°F)
V = volume of direct contact condensing space, ft³

and the other symbols are as previously defined

The magnitude of K depends on the physical properties of the condensing vapor and heat receiv ing fluid the type of direct contact surface (spray, tray, or packing) and the operating temperature It is ordinarily determined experimentally for each type contact condenser

The magnitude of U, for use in Eq (2), can be obtained from the summation of the individual re sistances in the heat transfer system

$$U = \frac{1}{r_v + r_i + r_w + r_f}$$

where $1/r$ = conductance across any boundary, Btu/(hr)(ft²)(°F)
r_v = condensing boundary resistance
r_i = cooling fluid boundary resistance
r_f = fouling, dirt, or scale resistance
r_w = separating wall, resistance

resistances being expressed in (hr)(ft²)(°F)/Btu

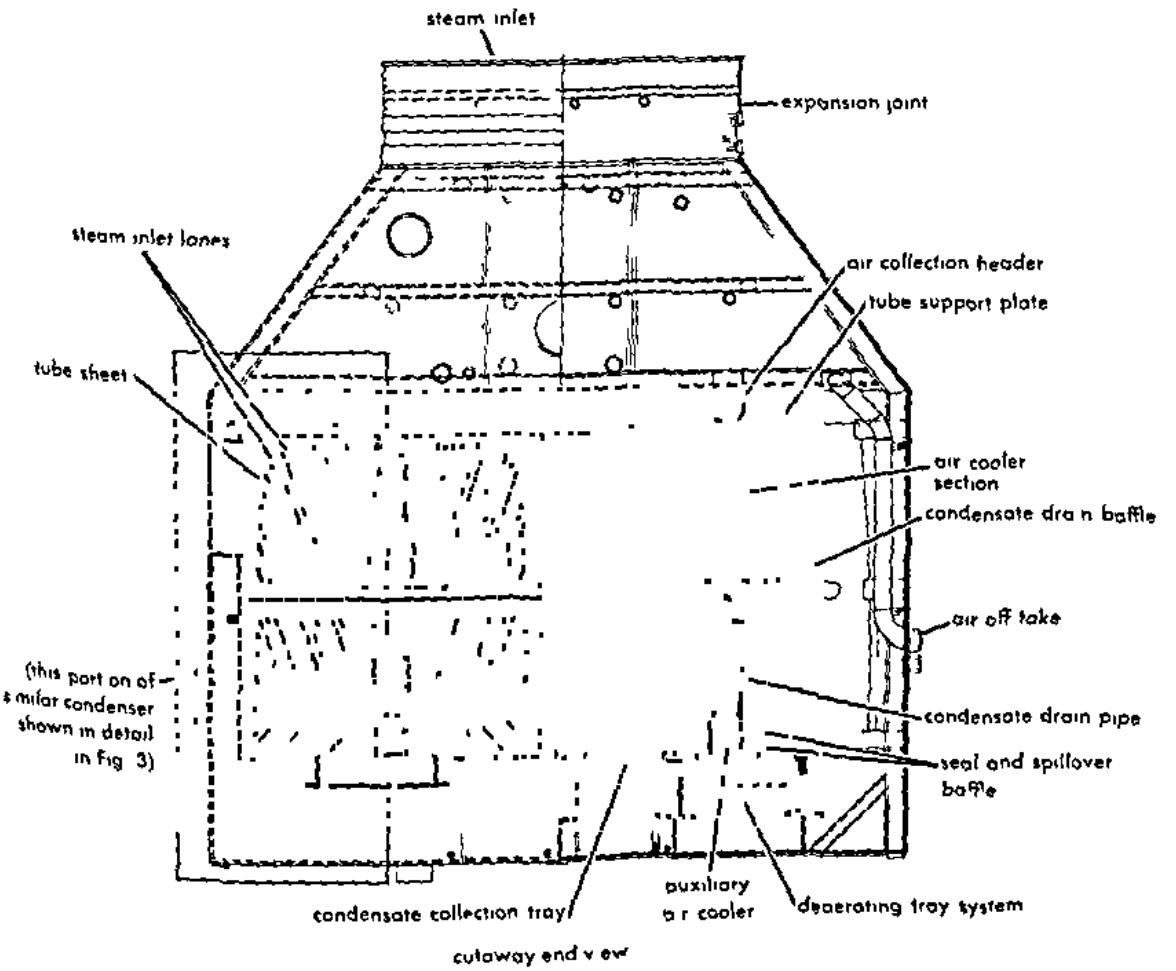


Fig 2 Typical section of steam surface

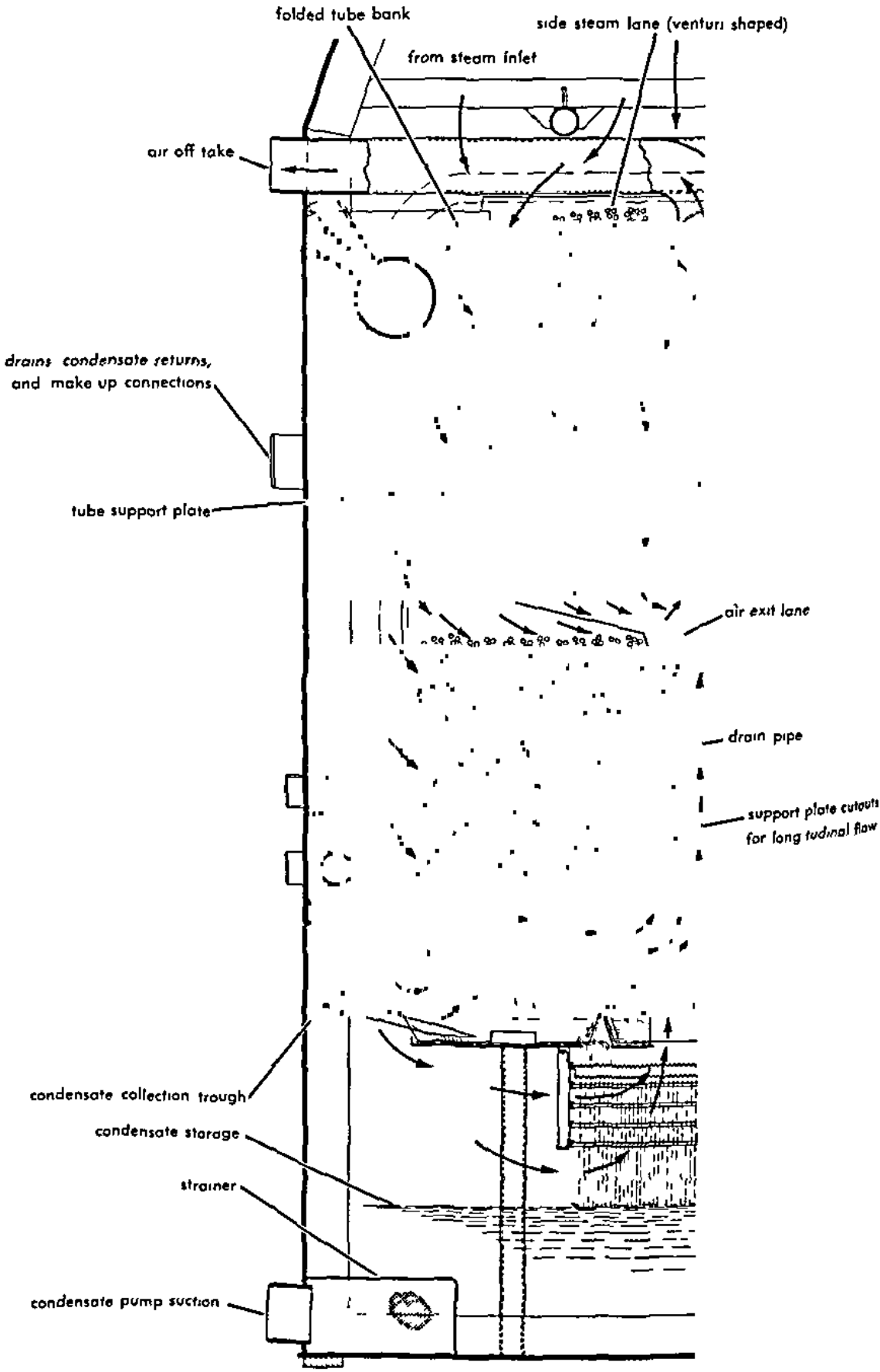


Fig 3 Detail of portion of condenser similar to that of Fig 2 (*Worthington Corp*)

The conductance of the condensing boundary $1/r_c$ may be determined analytically for pure vapors For steam on the outside of tubes $1/r_c$ may be 2000–2500 in well designed multitube condensers The conductance of the cooling fluid boundary $1/r$ for fluids flowing inside of tubes may be determined from the relation of the Nusselt number to the product of the Reynolds and Prandtl numbers with the use of empirical constants as suggested by W H McAdams Excellent agreement between computed values and test values results from the use of these equations For water inside of tubes $1/r$ may be 1000–1400 for normal water velocities The conductance for fouling or dirt films $1/r_f$ is dependent on the characteristics of the cooling fluid and condensing vapor as well as on the corrosion resistance of the separating wall The magnitude of $1/r_f$ is usually based on experience with a specific process in similar environments For large steam condensers a value of 2000 is reasonable for copper base alloy tubes after mechanical cleaning The conductance of the separating wall $1/r_w$ may be computed from the thickness of the wall and the thermal conductivity of the material from which it is made The over all heat transfer coefficient varies with the physical properties and flow rates of the fluids and the geometry of the heat transfer surface For steam condensers U may be 350–800 Btu/(hr) (ft²) (°F) generally heat transfer is lower with condensing vapors other than steam

Condenser components The components of a representative contact condenser are shown in Fig 4 The cooling liquid distribution system shown consists of impingement surfaces it may also be comprised of nozzles or spray valves In the illustrated condenser the cooling section for noncondensable gases coincides with the coolant distribution system and uses counterflow In jet condensers noncondensables are entrained in the cooling liquid The barometric leg provides the liquid seal as well low level condensers have a pump or diffuser

Components of a typical surface condenser are shown in Fig 5 The condensing surface consists usually of tubes of 0 5–1 in outside diameter made of copper base alloys less frequently of aluminum nickel alloys or chromium nickel steels The cooling surface for noncondensables is ordinarily the same material as the main condensing surface although more corrosion resistant alloys may be used The tube sheets into which tubes are welded expanded or packed are generally of Muntz metal naval brass copper silicon alloy or other corrosion resistant alloy In nuclear plants tube sheets may be double to reduce cooling water leakage to the condenser steam space the inner tube sheets usually being of carbon steel and the outer sheets of copper alloy The circulating system for the cooling fluid consists of chambers attached to the tube sheets and arranged with inlets and outlets for the cooling fluid When this fluid is water the chambers distribute the water over the face of the sheets and into the tubes with little or no cavitation

Condensers may have one or more passes according to the number of times the coolant travels through the length of the vapor space Steam surface condensers used in large steam power plants are of single pass design except where cooling water supply is limited Large installations which

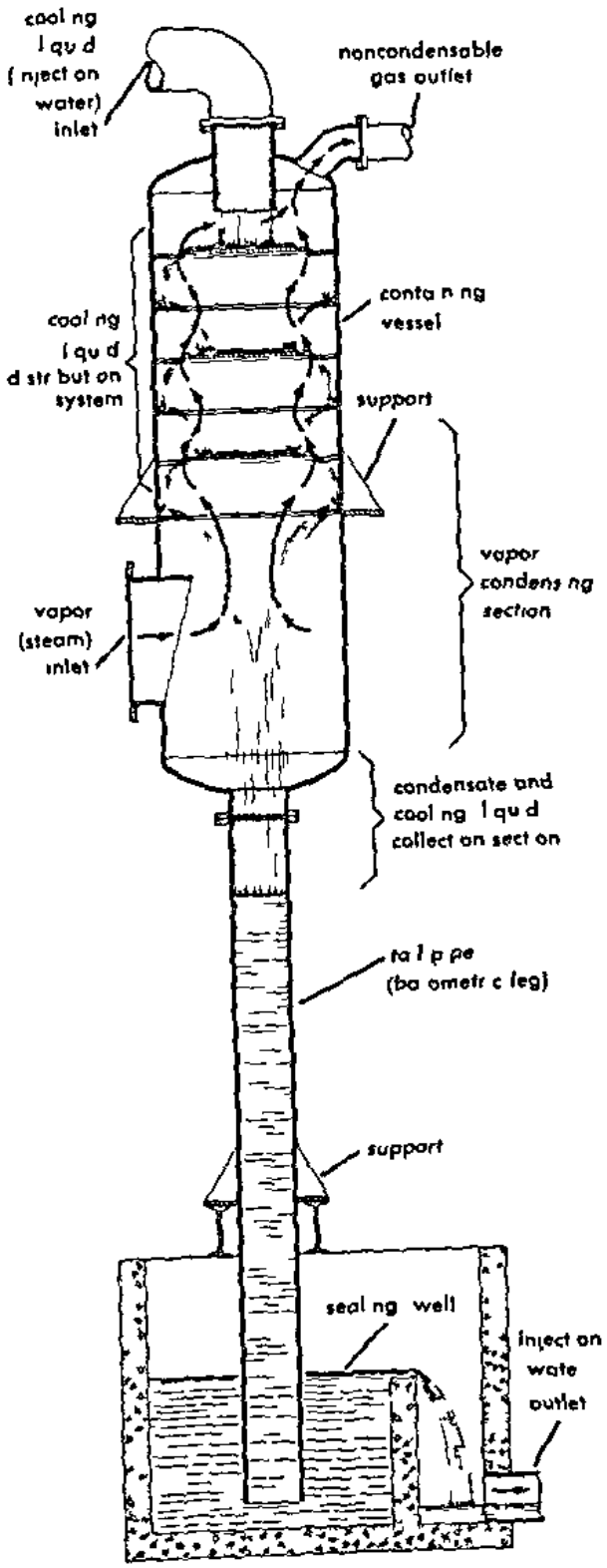


Fig 4 Counter flow barometric type contact condenser

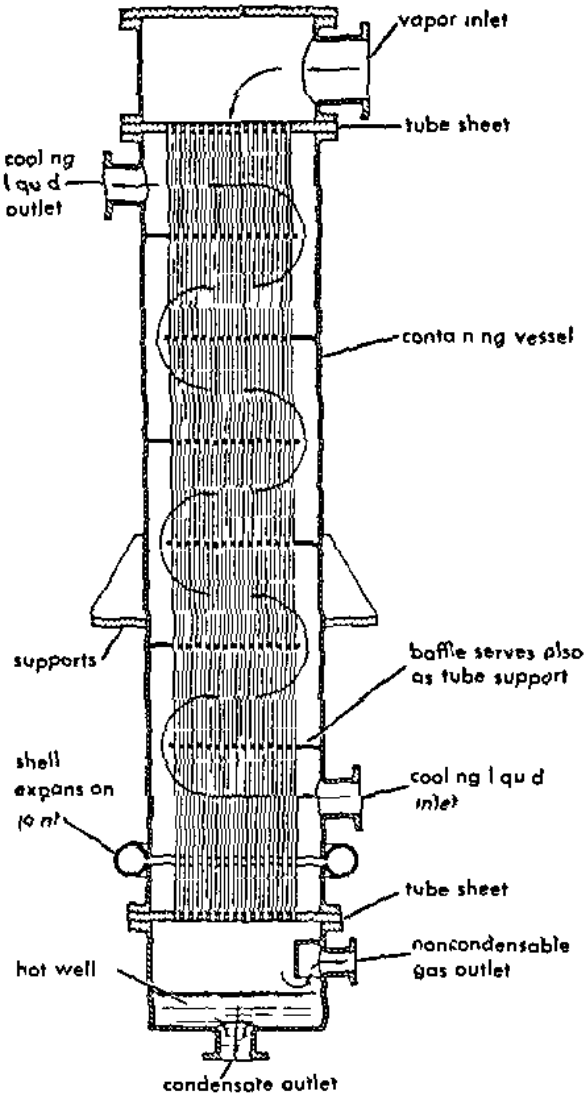


Fig 5 *Vertical-process surface condenser with condensing vapor inside tubes and cooling liquid outside tubes (inside shell)*

require cooling towers spray or *evaporation* ponds as a means for controlling cooling water temperature ordinarily *require two pass* condensers Condensers *with* three or more passes seldom prove economical for servicing engines or turbines *Process* condensers are frequently designed with two or *more cooling* fluid passes

Auxiliary equipment Operation of condensers *requires* pumps (*1*) for injecting or circulating the cooling fluid (2) for removing *condensate* or mixed condensate and injection *water, and* (3) for removing noncondensables

Centrifugal pumps are usually used for injecting or circulating *cooling water Conventional* volute pumps are used for circulating *cooling water for* small surface condensers and as *injection water* pumps for contact condensers *Mixed flow* volute pumps and axial flow pumps of vertical design *are* best suited to large surface condensers

Centrifugal pumps of the *horizontal volute* type are ideally suited for removing *condensate* There is a tendency to use vertical multistage *condensate* pumps for economy in large installations. Positive displacement pumps are used for withdrawing condensate from small condensers Tail pumps of the conventional centrifugal type are used for removing *mixed* condensate and injection water from low level jet (contact) condensers

Pumps for removing noncondensable gases are classified as displacement and ejector types The displacement machine is built either as a reciprocating vacuum pump similar to a piston type air compressor or as a rotary machine similar to a gear pump or sliding vane rotary compressor The displacement type vacuum pump is widely used on condensers of all sizes It is not suitable for use at high vacuum with high noncondensable gas loads because it must be disproportionately large for such conditions It is suitable for use with extremely large surface condensers serving turbines, *because* of the low noncondensable gas loads characteristic of these installations *See* VACUUM PUMP

Steam jet ejectors are widely used as vacuum pumps Having no moving parts they require little or no operating attention and are simple to install They have excellent capacity characteristics at high vacuum and are especially suited to applications where the noncondensable gas load is high. When used with surface condensers serving turbines steam jet ejectors are equipped with surface inter and after condensers The exhaust steam is condensed and returned to the feed system and the heat from the exhaust is also recovered in the feed water Thus they become highly efficient machines for removing noncondensable gases from condensers used in the generation of power *See* CENTRIFUGAL PUMP, COOLING TOWER, DISPLACEMENT PUMP [J F S]

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Conductance

For a series circuit the real or in phase part of the complex representation for the admittance Y of a circuit

$$Y = G \pm jB$$

where B is the imaginary part called the susceptance Since $Y = 1/Z = 1/(R + jX)$ where R is the resistance and X is the total reactance $X_L - X_C$ then

$$Y = \frac{R}{R^2 + X^2} - j\frac{X}{R^2 + X^2}$$

and conductance $G = R/(R^2 + X^2)$ This is the general expression for conductance and shows that conductance is a function involving both resistance and reactance

If reactance is negligible then $G = R/R^2 = 1/R$ or conductance is the reciprocal of resistance This is called simple conductance and is strictly correct only where the impedance contains no reactance Thus in a dc circuit conductance is the reciprocal of resistance These functions find ap-

plication chiefly in computations of parallel circuits

The total admittance of a number of parallel admittances, if expressed in complex quantities, is equal to the sum of the individual admittances *See* ADMITTANCE, ALTERNATING-CURRENT CIRCUIT THEORY

Conduction (electricity)

Electrical conduction may be defined as the passage of electric charge This can occur by a variety of processes

In metals the electric current is carried by free electrons These are not bound to any particular atom and can wander throughout the metal In general, *the conductivity of metals is higher than that* of other materials At very low temperatures certain metals become superconductors possessing infinite conductivity The free electrons are able to move through the crystal lattice without any resistance whatsoever *See* SUPERCONDUCTIVITY, *see also* ELECTRICAL CONDUCTIVITY OF METALS, FREE ELECTRON THEORY OF METALS, RESISTANCE, ELECTRICAL RESISTIVITY, ELECTRICAL.

In semiconductors (germanium silicon and so on), there are a limited number of free electrons and also "holes," which act as positive charges, available to carry current The conductivity of semiconductors is *much smaller than that of metals* and in contrast to most metals increases with rising temperature *See* SEMICONDUCTOR, *see also* HOLES IN SOLIDS

Aqueous solutions of *ionic crystals* readily conduct electricity by means of the positive and negative ions present, for example, Na^+ and Cl^- in an ordinary solution of sodium chloride (*see* ELECTRO

to migrate through the crystal under the influence of an applied electric field *See* IONIC CRYSTALS

A strong electric field ionizes gas molecules and thereby permits a flow of current through the gas in which the ions are the charge carriers If sufficient ions are formed, there may be a spark *See* ELECTRICAL CONDUCTION IN GASES, SPARK ELECTRIC

Electric current can flow across a vacuum for example in a vacuum tube The charge carriers are electrons emitted by the filament The effective conductivity is low because of low available current densities at the normal temperatures of electron emitting filaments *See* ELECTRON EMISSION, ELECTRON MOTION IN VACUUM

[J W ST]

Conduction (heat)

The flow of thermal energy through a substance from a higher to a lower temperature region Heat conduction occurs by atomic or molecular interactions Conduction is one of the three basic methods of heat transfer, the other two being convection and radiation *See* CONVECTION (HEAT), HEAT RADIATION, HEAT TRANSFER

Steady state conduction is said to exist when the temperature at all locations in a substance is constant with time, *as in the case of heat flow through* a uniform wall Examples of essentially pure transient or periodic heat conduction and simple or complex combinations of the two are encountered in the heat treating of metals air conditioning, food processing and the pouring and curing of large concrete structures. Also the daily and yearly temperature variations near the surface of the earth can be predicted reasonably well by assuming a simple sinusoidal temperature variation at the surface and treating the earth as a semi infinite solid The widespread importance of transient heat flow in particular has stimulated the development of a *large variety of analytical solutions to many problems* The use of many of these has been facilitated by presentation in graphical form

For an example of the conduction process, consider a gas such as nitrogen which normally consists of diatomic molecules The temperature at any location can be interpreted as a quantitative specification of the mean kinetic and potential energy stored in the molecules or atoms at this location This stored energy will be partly kinetic because of the random translational and rotational velocities of the molecules partly potential because of internal vibrations and partly ionic if the temperature (energy) level is high enough to cause dissociation The flow of energy results from the random travel of high temperature molecules into low temperature regions and vice versa In colliding with molecules in the low temperature region, the high temperature molecules give up some of their energy The reverse occurs in the high temperature region These processes take place almost instantaneously in infinitesimal distances *the result being a quasi* equilibrium state with energy transfer The mechanism for energy flow in liquids and solids is similar to that in gases in principle but different in detail



Fig 1 Heat flow by conduction

Fourier equation The mathematical theory as well as the practical calculation of heat conduction is based on a macroscopic interpretation as contrasted to the basic microscopic mechanism just described From a physical point of view it is reasoned that the steady heat flow from a surface (Fig 1) at temperature t_1 to a parallel surface at t_2 is directly proportional to $(t_1 - t_2)$ the area A normal to the direction of flow and the time of flow τ and inversely proportional to the distance l between the two planes These factors are modified by a coefficient κ accounting for the heat conducting nature of the particular substance between the two planes Thus the heat flow Q (in British thermal units for example) is

$$Q = \kappa A \frac{(t_1 - t_2)}{l} \tau \qquad (1)$$

In terms of the time rate of flow $q = Q/\tau$ through an infinitesimally thin layer dx in which the temperature change is dt this becomes

$$q = -\kappa A \left(\frac{dt}{dx}\right) \qquad (2)$$

The minus sign is conventionally included to make dt/dx positive when heat flows in the increasing direction of x since dt/dx is then negative Although this equation was first proposed by J Biot it is named after J Fourier in honor of Fourier s extensive contributions to the theory of heat conduction

Thermal conductivity The coefficient κ in Eqs (1) and (2) called the thermal conductivity is an important property of matter It accounts for the heat conducting ability of a substance and depends not only on the particular substance involved but also on the state of that substance The Fourier equation is essentially a definition of κ which (see Fig 1) can be interpreted as the rate of heat flow per unit of area normal to the direction of flow when a unit temperature difference exists in unit length Thus from Eq (2)

$$\kappa = \frac{-q/A}{(dt/dx)} = \frac{q/A}{(t_1 - t_2)/l} \qquad (3)$$

Thus κ is seen to have the dimensions of a heat rate per unit area and per unit of temperature gradient In the cgs system it can be expressed in cal/(sec) (cm²) (°C/cm) which is equivalent to cal/(sec) (cm) (°C) In engineering the units most frequently used are Btu/(hr) (ft) (°F)

Considerable progress has been made in the interpretation of thermal properties from theories of matter This is particularly true for gases where theory involving intermolecular forces has yielded very accurate results (*see* INTERMOLECULAR FORCES KINETIC THEORY OF MATTER) The process of heat conduction in liquids is believed to be similar to that of sound transmission In dielectric solids energy is transmitted primarily by means of waves traveling through the atomic lattice in metals the electrons behave like an electron gas and provide for energy transfer as well as electrical conduction. This is the basis of the Wiedemann Franz law which states that $\kappa/\sigma T$ = constant (σ is the electrical conductivity and T the absolute temperature)

For materials occurring as crystalline or amorphous solids the general trend of κ at atmospheric pressure throughout the three physical states is as shown in Fig 2 The numerical value at the maximum which occurs near absolute zero in crystalline substances is comparatively high For example the κ of a copper crystal at 20°K has been found to be 7050 Btu/(hr) (ft) (°F) which is more

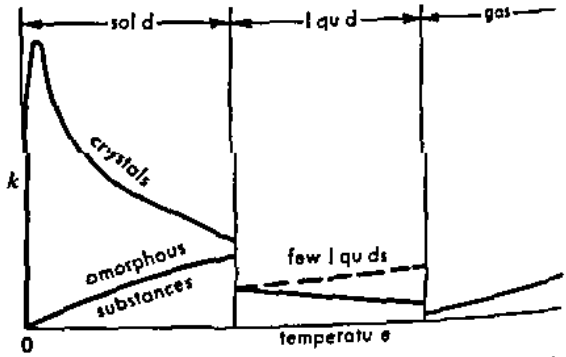


Fig 2 General variation of thermal conductivity with temperature throughout the three physical states (*After L S Kowalczyk Trans ASME 77 1021–1035 1955*)

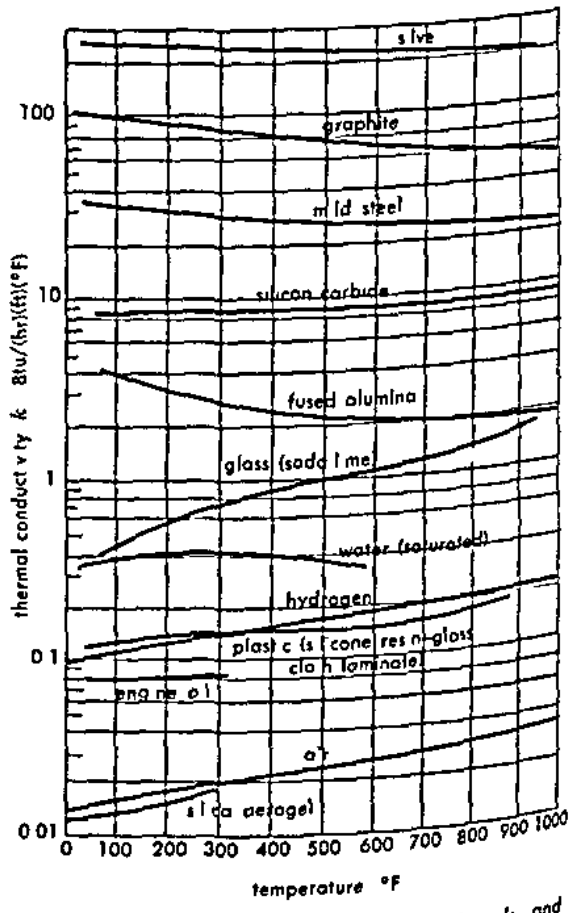


Fig 3 Thermal conductivities of gases liquids and solids

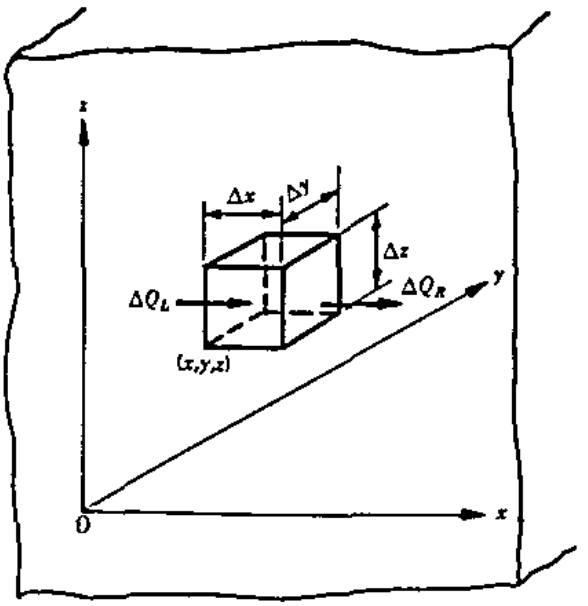


Fig 4 Heat flow through an elemental volume in a homogeneous medium

than thirty times its value at room temperature Thermal conductivity of solids is discussed in detail in a later section

Because of the complexity and incomplete understanding of the mechanisms responsible for heat conduction, values of κ are usually determined experimentally Results for typical gases, liquids, and solids throughout appropriate temperature ranges are shown in Fig 3 The effect of pressure is significant primarily in gases

Differential equation of conduction. The evidence of heat flow by conduction through a substance is the variation of the temperature with location and time If the temperature as a function of the space coordinates and time is known or can be determined the heat flow at any location and in any direction can be specified by appropriate differentiation A given problem is normally attacked by solving the differential equation governing the temperature distribution in a homogeneous substance and making this solution fit the prescribed initial or boundary conditions This differential equation is essentially an expression of the first law of thermodynamics applied to the heat flow, and is derived by making a heat balance on an elemental volume in a medium, as shown in Fig 4

Considering first the x direction the net heat flow into the element in time $\Delta\tau$ is the difference between that flowing in on the left minus that flowing out on the right, or, applying Eq (1)

$$\Delta Q_x = -\kappa\,\Delta y\,\Delta z\left(\frac{\partial t}{\partial x}\right)_x \Delta\tau - \left[-\kappa\,\Delta y\,\Delta z\left(\frac{\partial t}{\partial x}\right)_{x+\Delta x}\Delta\tau\right] \quad (4)$$

Accounting for the variation of κ with temperature is extremely difficult and may make the analytical solution of a problem impossible Because of this it is customary to use an appropriate average value which is regarded as constant Equation (4) can then be rearranged to read

$$\Delta Q_x = \kappa\,\Delta y\,\Delta z\,\Delta x\,\frac{\left(\frac{\partial t}{\partial x}\right)_{x+\Delta x} - \left(\frac{\partial t}{\partial x}\right)_x}{\Delta x}\Delta\tau$$

which as $\Delta x \to 0$, becomes

$$\Delta Q_x = \kappa\,\Delta x\,\Delta y\,\Delta z\,\Delta\tau\,\frac{\partial^2 t}{\partial x^2} \quad (5)$$

Similar expressions apply for the y and z directions Heat generated within the element at a uniform rate G per unit volume and time would add an amount $G\,\Delta x\,\Delta y\,\Delta z\,\Delta\tau$

The net heat flow into the element would be manifest as stored energy and would be equal to

$$\Delta x\,\Delta y\,\Delta z\,wc\,\Delta t \quad (6)$$

where w is the specific weight (weight per unit volume) of the medium, c its specific heat, and Δt the temperature rise in the time increment $\Delta\tau$ Equating the net flow into the element to that stored and letting Δx, Δy, Δz and $\Delta\tau \to 0$ leads to

$$\kappa\left[\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right] + G = wc\,\frac{\partial t}{\partial\tau} \quad (7)$$

When no heat source is present Eq (7) becomes

$$\left[\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right] = \frac{1}{\kappa/uc}\frac{\partial t}{\partial\tau} = \frac{1}{\alpha}\frac{\partial t}{\partial\tau} \quad (8)$$

The ratio $\kappa/uc = \alpha$ is defined as the thermal diffusivity, and is the significant thermal property of a material for transient heat flow (see Fig 5) Equation (8) will be recognized as the equation governing a potential field written in terms of tem

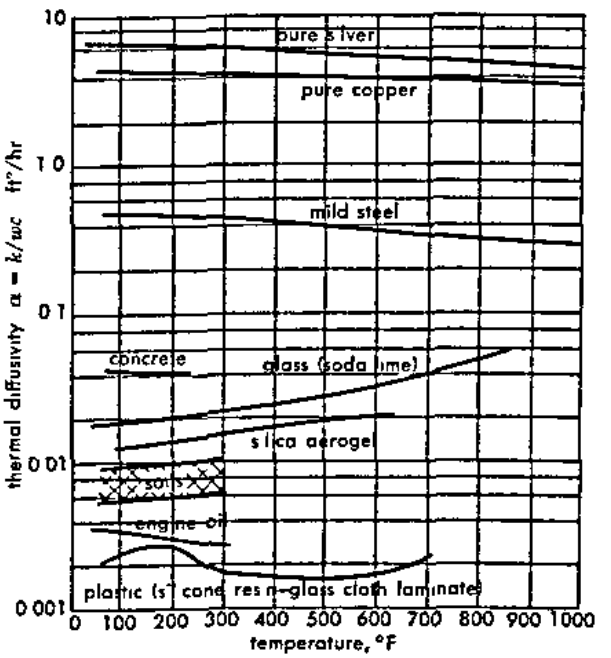


Fig 5 Thermal diffusivities of materials

perature Similar equations are satisfied by other potential field phenomena such as electricity magnetism diffusion and ideal fluid flow Because of this solutions to problems in one field are applicable to analogous systems in the others Also an experimental solution of a problem in one field may be obtained from an analogous system in another *See* POTENTIALS (PHYSICS)

Steady state conduction When the temperature at all locations is constant with time or mathematically when $\partial t/\partial \tau = 0$ steady state conduction exists Many important practical problems fall in this category the most familiar being heat flow through a wall and a hollow cylinder Referring to Fig 1 and assuming no heat generation within the wall Eq (8) reduces to

$$\frac{\partial^2 t}{\partial x^2} = 0 \tag{9}$$

The terms $\partial^2 t/\partial y^2$ and $\partial t/\partial z^2$ are eliminated since t is considered to vary only with x The desired temperature distribution is obtained by integrating Eq (9) twice and evaluating the two constants from the known temperatures at $x = 0$ and $x = l$ This leads to

$$t = t_1 - (t_1 - t_2)\frac{x}{l} \tag{10}$$

Application of Eq (2) to obtain q yields

$$q = \kappa A \frac{(t_1 - t_2)}{l} \tag{11}$$

In the case of steady radial heat flow through a cylindrical wall (Fig 6) Eq (2) is applicable to any imaginary thin annular ring in the wall thus

$$q = -\kappa A \frac{dt}{dr} = -\kappa 2\pi r l \frac{dt}{dr} \tag{12}$$

Integration from $t = t_1$ to t and r_1 to r leads to

$$t = t_1 - q\frac{\ln (r/r_1)}{2\pi\kappa l} \tag{13}$$

which indicates that the effect of the increasing area for heat flow is to produce a logarithmic variation in the temperature as shown by the curve in the left part of Fig 6

Heat flow through a cylindrical wall is usually expressed in the same form as Eq (11) by writing

$$q = \kappa A_m \frac{t_1 - t_2}{r_2 - r_1} \tag{14}$$

Solving Eq (13) for q and substituting in Eq (14) shows that the appropriate value for A_m must be

$$A_m = \frac{A_2 - A_1}{\ln (A_2/A_1)} \tag{15}$$

which is called the logarithmic mean area

If the rate of heat flow and the inner and outer temperatures of a plane wall or hollow cylinder are measured during steady heat conduction values of κ can be determined from Eq (11) or (14) Because of the simplicity of the equations and the physical systems most devices for measuring thermal conductivity are based on these types of heat flow

When heat flows from one material to a second with which it is intimately in contact distributions in each are as shown in Fig 7*a* For steady state conditions to exist

$$\kappa_1 \left(\frac{dt}{dx}\right)_1 \quad \kappa_2 \left(\frac{dt}{dx}\right)_2 \tag{16}$$

which implies that at the interface there is a discontinuity in the temperature gradient although the temperature distribution itself is continuous In actuality this picture is never quite correct because even extremely smooth surfaces when placed together touch only at projecting spots the aggregate of which is frequently only a small percentage of the nominal contact area The impairment to the heat flow path caused by this imperfect contact is referred to as contact resistance Since the distance through which this operates is very small an ap

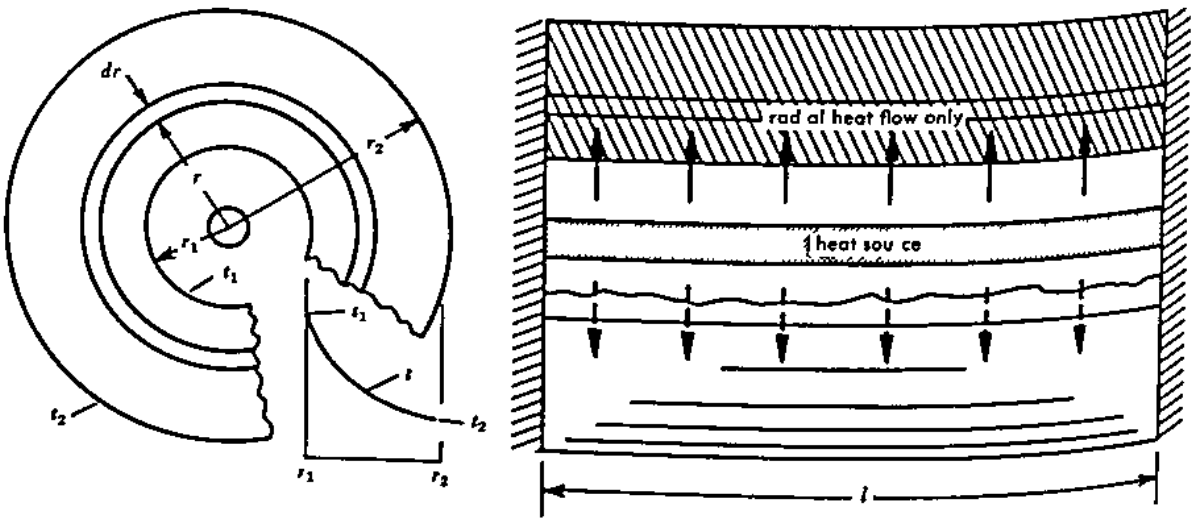


Fig 6 Temperature distribution for radial heat flow through a circular cylinder wall

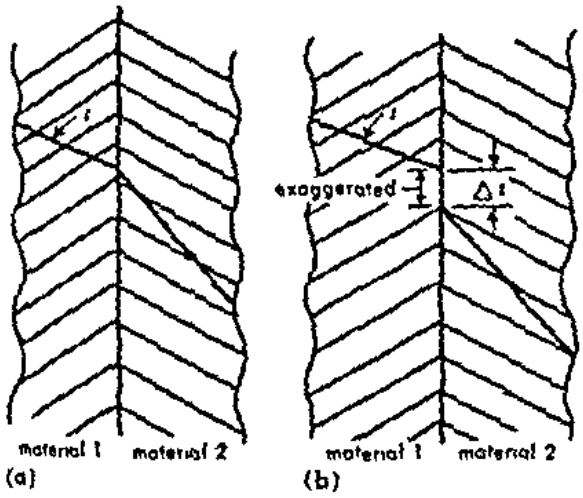


Fig 7 Temperature distributions at a solid solid interface (a) No contact resistance (b) Contact resistance present

parent temperature discontinuity exists as shown in *Fig 7b* This is usually negligible

Internally generated heat Conduction of heat generated internally occurs, for example, in the fuel elements used in nuclear reactors Many of these elements are essentially long flat plates over which a coolant flows It is usually necessary to clad the fissionable material to prevent corrosion and keep [illegible] from entering the coolant [illegible] heat [illegible] ible [illegible] rial [illegible] it is usually [illegible]

To illustrate the effect of the heat generation, assume that it is uniform with space and time in the radioactive material of Fig 8 [that is, G in *Eq* (7) is constant] Heat flow from the ends of the elements and parallel to the flow direction of the coolant is negligible

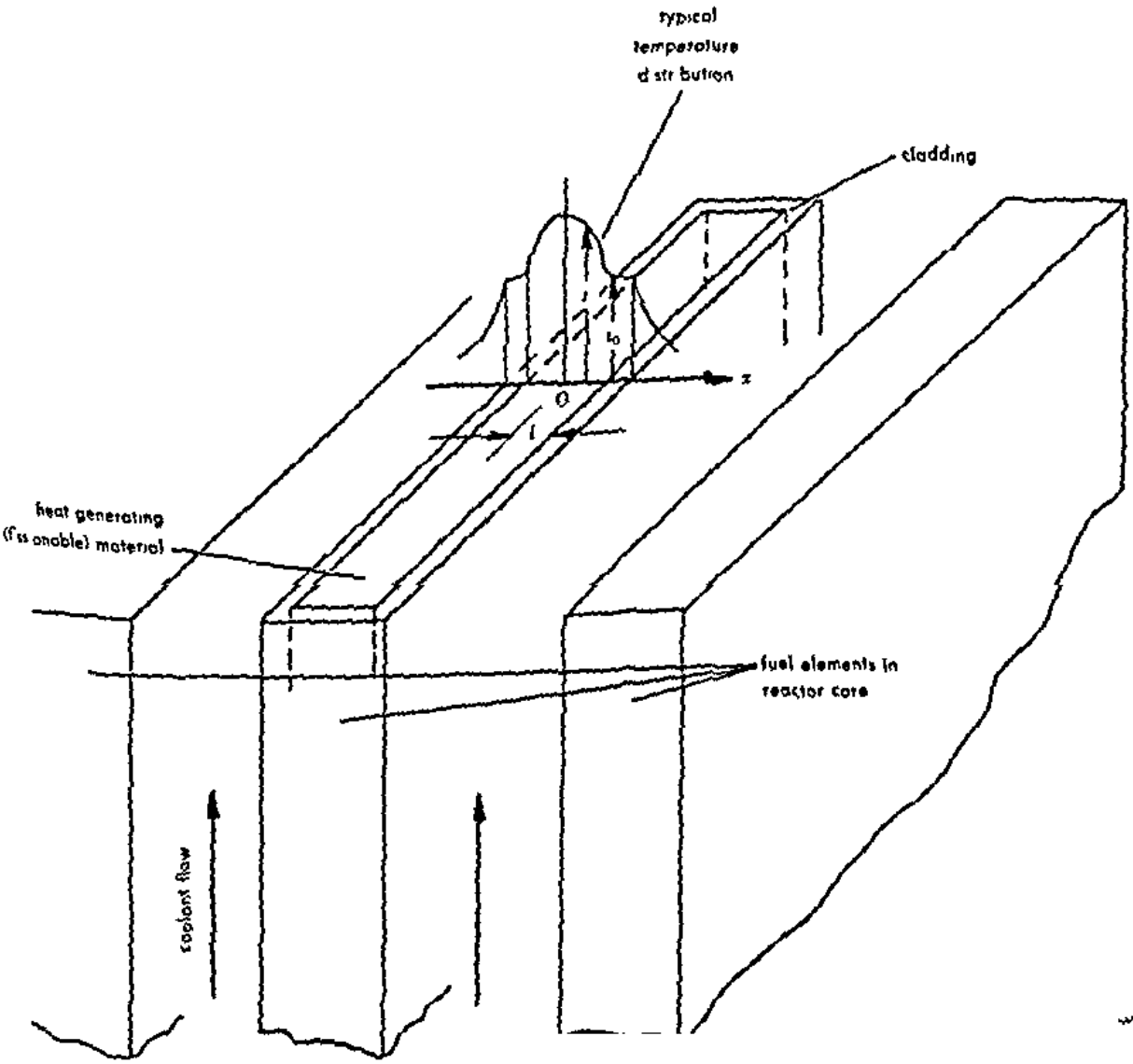


Fig 8 Temperature distribution in reactor fuel ele

Therefore, Eq (7) reduces to

$$\frac{d^2t}{ax^2} + \frac{G}{\kappa} = 0 \qquad (17)$$

A solution for t is obtained by integrating twice and applying the boundary conditions (considering cooling to be the same on each side) $dt/dx = 0$ at $x = 0$ and $t = t_0$ at $x = l$ The result shows the temperature distribution to be parabolic, that is

$$t = t_0 + \frac{G}{2\kappa}(l^2 - x^2) \qquad (18)$$

The rate of heat transfer to the coolant is obtained by differentiating Eq (18) with respect to x, evaluating at $x = l$ and substituting in Eq (2)

Since the heat generation rate is frequently dependent on the temperature, G will be more complex, possibly making an analytical solution impossible Numerical methods of solution are then employed

Non steady state conduction. Transient and periodic heat conduction are the two types of non steady state heat flow A transient state occurs when the temperature or heat flow at one or more locations in a body is momentarily or permanently changed The resulting variation in the temperature distribution throughout the body involves energy storage or removal so that the period of adjustment is influenced by the thermal capacity uc of the material, as well as its conductivity κ and the nature of the imposed change The $\partial t/\partial \tau$ term in the governing differential equation [Eq (7) or (8)] is not zero, and an analytical solution for the temperature distribution will be a function of the time τ and the space coordinates A periodic state is actually a continual transient state in which the temperature and heat flow at all locations vary continuously with time, but pass through the same series of values in each period of time τ_0 A periodic variation may be superimposed on a transient change

The general nature of the transient and periodic states is well illustrated by the response of a temperature measuring device such as a thermometer or thermocouple when suddenly placed in a fluid stream, the temperature of which is fluctuating above and below some mean value t_m (see Fig 9) The relatively small sizes and high thermal conductivities of temperature measuring elements permit the simplifying assumption of a uniform temperature throughout them at any instant of time even

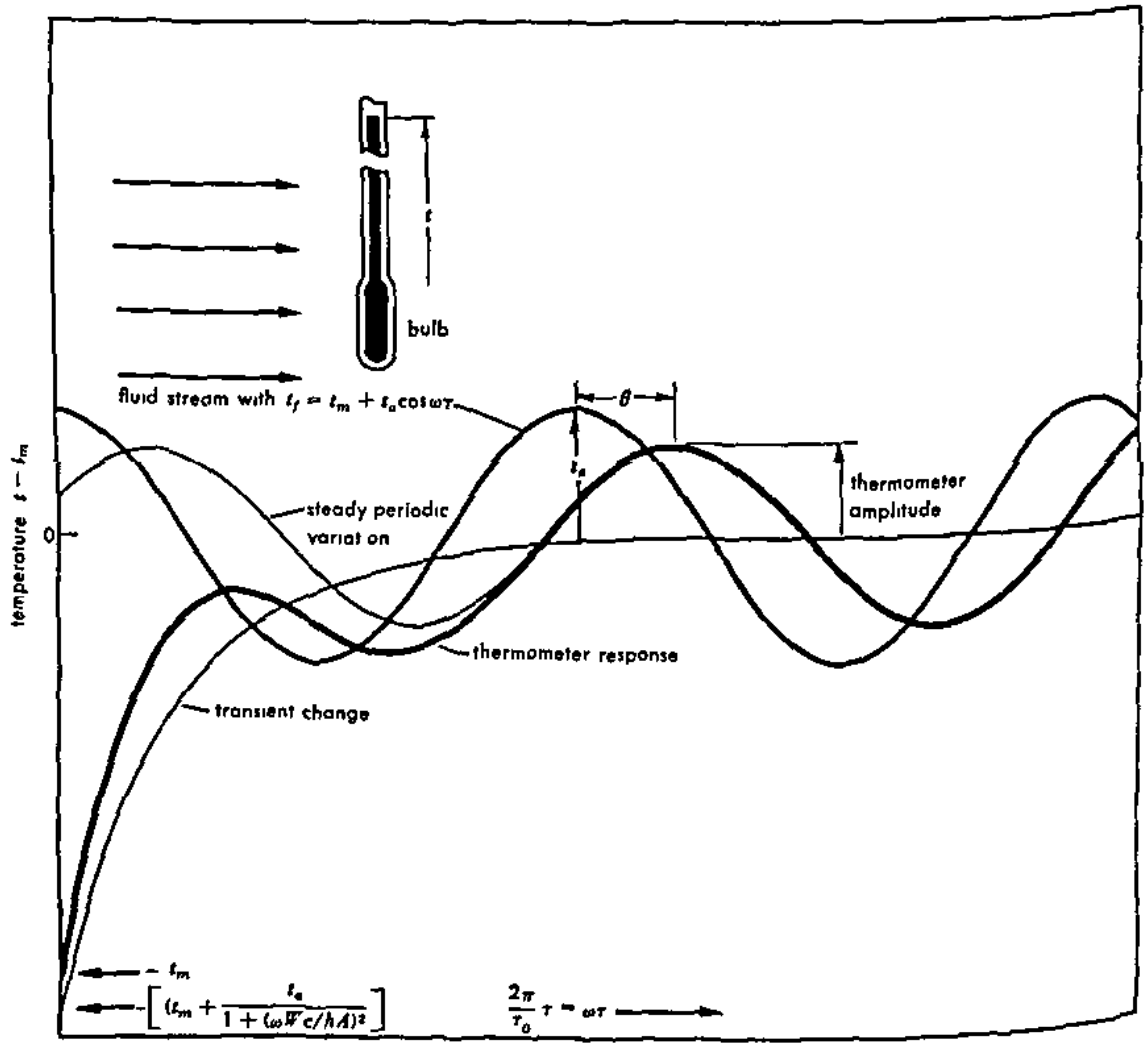


Fig 9 Response of a thermometer placed in a fluid stream with periodic temperature variation

though this temperature is changing rapidly Equating the rate of heat transfer by convection to the rate of energy storage in the thermometer then yields the following ordinary differential equation

$$hA(t_f - t) = hA\{(t_m + t_a \cos \omega\tau) - t\} = Wc\frac{dt}{d\tau} \tag{19}$$

where h is the convective heat transfer coefficient c is the average specific heat of bulb and fluid and W is the weight of bulb and fluid When the thermometer is initially at zero temperature the solution to Eq (19) can be written as

$$t - t_m = -Ae^{-(hA/Wc)\tau} + B\cos(\omega\tau - \theta) \tag{20}$$

where $$A = t_m + \frac{t_a}{1 + (\omega Wc/hA)^2}$$

$$B = t_a/\sqrt{1 + (\omega Wc/hA)^2}$$

and $$\theta = \tan^{-1}(\omega Wc/hA)$$

The first term of Eq (20) describes the transient change and if this change only were involved t would approach t_m as τ becomes large The second term represents the steady periodic temperature variation which is less in amplitude than the fluid temperature variation and lags (reaches its maximum) the fraction of the period $\theta/2\pi$ after the fluid temperature The duration of the transient is determined by the quantity Wc/hA (the thermometer time constant) the amplitude of the temperature variation B and the phase angle θ are determined by the quantity Wc/hA multiplied by the angular frequency ω The actual thermometer temperature is the sum of the transient and periodic effects and gradually approaches the steady periodic variation [W H C]

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THERMAL CONDUCTIVITY OF SOLIDS

Thermal conductivity varies widely among different types of solids It depends markedly on temperature and at low temperatures it depends also on the purity and the physical state of the solid

The principal processes of heat conduction in solids are conduction by the lattice vibrations and in the case of good electrical conductors by the conduction electrons The electronic thermal conductivity is related to the electrical conductivity In pure metals the lattice component is usually negligible but in alloys and semimetals (metals which are relatively poor conductors of electricity) the electronic conductivity is reduced and the two components may be comparable In nonmetallic solids the lattice waves are the only carriers of heat In metals the electrons not only carry heat but cause a reduction in the lattice thermal conductivity Both components of the conductivity are sensitive to crystal imperfections particularly at low temperatures All these factors contribute to the great diversity found in the magnitude and temperature variation of the thermal conductivity of solids. Measurements of the thermal conductivity can yield fundamental information about the properties of solids and about their lattice imperfections See CRYSTAL DEFECTS ELECTRICAL CONDUCTIVITY OF METALS LATTICE VIBRATIONS SPECIFIC HEAT OF SOLIDS

Conductivity of metals As in the case of electrical conductivity the electronic thermal conductivity of metals is limited by the scattering of the conduction electrons In the periodic potential of a perfect lattice electrons move without being scattered but in actual crystals they undergo scattering because the periodicity is disturbed by the thermal vibrations of the lattice and by static imperfections (impurities point defects dislocations grain boundaries and the like) hence the electrons have a limited mean free path ℓ

According to the free electron theory of metals the conduction electrons form a gas obeying Fermi Dirac statistics (*see* FREE ELECTRON THEORY OF METALS) The energy state of each electron is specified by a momentum p and the occupation probability f of each state cannot exceed unity All conduction properties arise from the behavior of

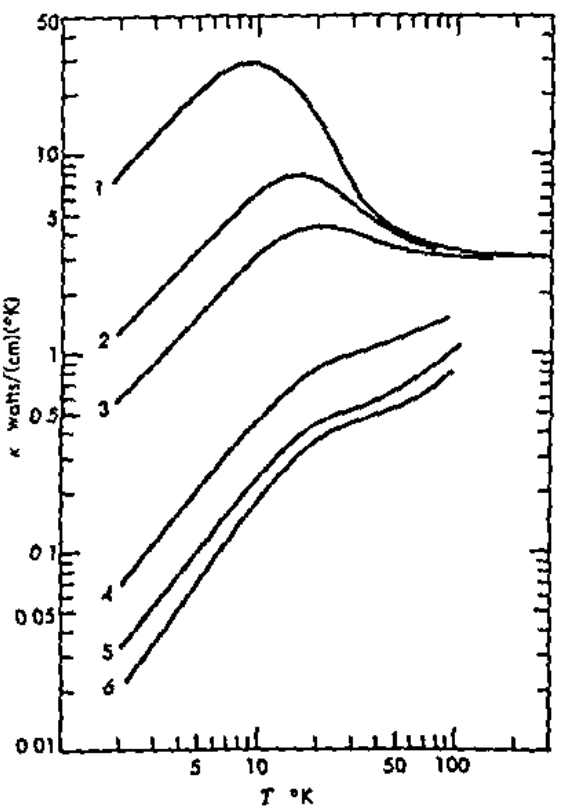


Fig 10 Thermal conductivity of gold and some alloys Curve 1 99 999% gold annealed Curve 2 cold-drawn Curve 3 99 9% gold cold 4 gold with 0 7% plat 5 plat num Curve 6 gol % measurements made at Sydney Australia)

electrons on the Fermi surface, where f varies rapidly with electron energy E. At equilibrium f is a function of E only. If an electric field F or a temperature gradient grad T is applied f will be disturbed, but the scattering processes will tend to restore equilibrium. A steady state ensues, such that f is an unsymmetrical function of p (*see* BOLTZMANN TRANSPORT EQUATION), this results in an electric current and a heat current. These two currents are proportional to l, and consist of a term proportional to F and to grad T, respectively.

In the case of thermal conduction, there is no net electric current. This results from the fact that there is an electric field opposing the temperature gradient which is the cause of the thermoelectric effects (*see* THERMOELECTRICITY). The heat current does not vanish even if the electric current vanishes; the resulting thermal conductivity κ is proportional to l. The isothermal electrical conductivity σ is also proportional to l, and if the mean free path is the same for thermal and electrical conduction, the two conductivities are related by the Wiedemann-Franz law

$$\frac{\kappa}{\sigma T} = L = \frac{\pi^2}{3}\left(\frac{K}{e}\right)^2 \tag{21}$$

where K is the Boltzmann constant and e the electronic charge. Thus $L = 2.45 \times 10^{-8}$ (watt) (ohm) ($^\circ$K^{-2}).

Because there are two scattering mechanisms (lattice vibrations and static imperfections) contributing additively to the scattering probability and thus to $1/l$, each mechanism contributes to the resistivity. Thus the electrical resistivity is

$$\frac{1}{\sigma} = \rho = \rho_0 + \rho_i(T) \tag{22}$$

where the residual resistivity ρ_0 arises from the elastic scattering of electrons by imperfections and the ideal resistivity $\rho_i(T)$ from the scattering by the lattice vibrations. It is known that $\rho_i(T) \to 0$ as $T \to 0$ (*see* MATTHIESSEN'S RULE, RESISTIVITY ELECTRICAL). An additivity of the thermal resistivity holds in an analogous manner

$$\frac{1}{\kappa} = W = W_0 + W_i(T) \tag{23}$$

where W_0 is due to imperfections, and $W_i(T)$ is due to lattice vibrations.

Curves 1, 2 and 3 of Fig. 10 show the thermal conductivity of three samples of gold, differing in their values of ρ_0 and W_0. Hence, the conductivities differ in the low temperature region where $\kappa = 1/W_0 \propto T$. At higher temperatures $W_i > W_0$ and the curves converge. The best information about the ideal resistivity is obtainable from the purest specimen, at low temperatures (from 10 to 30°K), $W_i \propto T^2$. This behavior is observed for all metals that are good conductors. However, if ρ_0 (and thus W_0) are further increased by alloying κ is no longer proportional to T at lowest temperatures, and it exceeds the calculated value, this is because the lattice component of thermal conductivity is no longer negligible. Semimetals have an appreciable lattice component even when pure.

Conductivity of insulators. In insulators heat is transported by the lattice vibrations. The vibrations of the crystal lattice can be resolved into traveling elastic waves (lattice waves). There is a slow interchange of energy among the waves due to anharmonicity of the lattice forces and due to static imperfections. The energy content of each wave attains an equilibrium value appropriate to the temperature. At a temperature T, the energy of the lattice vibrations resides mainly in waves whose frequency ν is of the order KT/h, where h is Planck's constant.

Each lattice wave (wavelength λ) is specified by a wave vector k (equal to $2\pi/\lambda$ in the direction of propagation) and by its mode of polarization (longitudinal or transverse), the wave velocity is $v = \nu\lambda = 2\pi\nu/k$. The energy content of each wave consists of an integral number of phonons (quanta of energy $h\nu$), and the lattice waves can be regarded as a gas of phonons each of energy $h\nu$ and momentum $hk/2\pi$. *See* PHONON.

At equilibrium, the phonons are distributed isotropically in momentum space, but a temperature gradient tends to set up an asymmetry in the phonon distribution. On the other hand, the interchange of energy among the lattice waves tends to restore equilibrium, a balance ensues between these two processes to produce an asymmetrical distribution which has an associated heat current. The energy interchange among the waves implies a finite mean free path l of the phonons, and the thermal conductivity can be shown to be

$$\kappa = \tfrac{1}{3}Svl \tag{24}$$

where S is the specific heat per unit volume.

At low temperatures, the variation of κ with T depends on the variation of l with phonon frequency so that it is possible to draw some conclusions about the principal imperfections from observations of the thermal conductivity.

Figure 11 illustrates the conductivity of some dielectric materials. Curves 2 and 2a show the effect of damage due to neutron irradiation, curves 3 and 3a show the difference in the conductivity between a single crystal and a polycrystalline aggregate, and curves 4 and 4a show the effect of a change in the external dimensions of a single crystal.

Conductivity of glass. Because the lattice structure of glass is highly disordered, the mean free path of phonons is short, and the conductivity is small, for example, the curve for fused quartz lies about a decade below curve 2a in Fig. 11. Above liquid oxygen temperatures values of l derived from Eq. (24) are only of the order of 10^{-7} cm, that is of the dimensions of the structural units of glass. At lower temperatures where the important waves have longer wavelengths l increases because the microscopic disorder is less important the longer the waves. From the temperature variation of κ, the frequency variation of l may be deduced

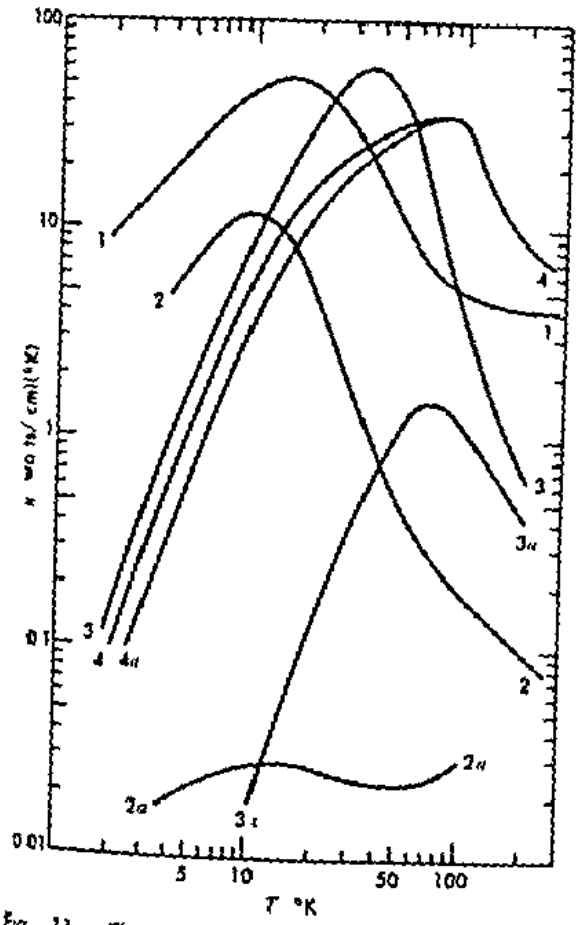


Fig 11 Thermal conductivity of some insulators Curve 1 pure copper (for comparison) Curve 2 quartz crystal Curve 2a same after intense neutron irradiation Curve 3 aluminum oxide (single-crystal sapphire) Curve 3a aluminum oxide (sintered alumina) Curve 4 diamond Curve 4a same reduced diameter (Measurements made by R Berman and coworkers at Clarendon Laboratory Oxford England)

this throws some light on the correlation in orientation of neighboring structural units that is on the order over the range of the phonon wavelength Similar considerations apply to all amorphous solids The thermal conductivity at low temperatures is a good indicator of crystallinity in such materials

Conductivity of alloys In the case of alloys the thermal conductivity is additively composed of an electronic component κ_e and a lattice component κ_g

$$\kappa = \kappa_e + \kappa_g \qquad (25)$$

where κ_e is identical to κ of Eq (23) except that now W_0 is much larger than in pure metals The lattice thermal conductivity is given by the same considerations as the conductivity of insulators except that the scattering of phonons by electrons acts as an additional scattering mechanism producing a resistance W_E and decreasing κ_g considerably While the lattice conductivity of insulators is comparable to the electronic thermal conductivity of metals (see Fig 11) in metals $\kappa_g \ll \kappa_e$ because of this additional resistance

Curves of κ_g versus T have been obtained for a number of alloys by measuring κ and ρ, calculating W_0 from ρ_0 and hence calculating κ_e and obtaining κ_g by subtraction It is found that in well annealed alloys $\kappa_g \propto T^2$ at lowest temperatures as might be expected from theoretical considerations At higher temperatures κ_g decreases with T This is due partly to an intrinsic thermal resistivity which is proportional to T and partly to the scattering of phonons by the solute atoms In plastically deformed metals, κ_g still varies as T^2 but is reduced the extra resistivity varies as T^2 and is the result of the dislocations In some cases there is also evidence of additional point defects or other imperfections By studying simultaneous changes in κ_g ρ_0 and other quantities one can obtain information about the imperfections in deformed materials

Conductivity of superconductors In the superconducting state κ_e is reduced and κ_g is increased because W_E is reduced The overall conductivity is thus either increased or decreased depending on the importance of the various factors determining κ_g and κ Well below the transition temperature both κ and W_E vanish and the thermal conductivity (due entirely to lattice waves) is similar in character to the thermal conductivity of a dielectric crystal *See* SUPERCONDUCTIVITY [P G K]

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Conduction band

The electronic energy band of a crystalline solid which is partially occupied by electrons The electrons in this energy band can increase their energies by going to higher energy levels within the band when an electric field is applied to accelerate them or when the temperature of the crystal is raised These electrons are called conduction electrons as distinct from the electrons in filled energy bands which as a whole do not contribute to electrical and thermal conduction In metallic conductors the conduction electrons correspond to the valence electrons (or a portion of the valence electrons) of the constituent atoms In semiconductors and insulators at sufficiently low temperatures the conduction band is empty of electrons Conduction electrons come from thermal excitation of electrons from a lower energy band or from impurity atoms in the crystal *See* VALENCE BAND *see also* BAND THEORY OF SOLIDS ELECTRICAL CONDUCTIVITY OF METALS INSULATOR ELECTRIC SEMICONDUCTOR [H Y F]

Conductivity

A measure of the ability of a material to conduct electric current It is the reciprocal of resistivity Conductivity is commonly expressed as mhos per

meter since the unit of resistivity is the ohm meter The conductivity of metallic elements varies inversely with absolute temperature over the normal range of temperatures but at temperatures approaching absolute zero the imperfections and impurities in the lattice structure of a material make the relationship more complicated *See* ELECTRICAL CONDUCTIVITY OF METALS For thermal conductivity *see* CONDUCTION (HEAT)

The conductivity associated with conduction electrons in a semiconductor is known as *n* type conductivity that associated with the holes in an impurity semiconductor (equivalent to positive charges) is known as *p* type conductivity *See* SEMICONDUCTOR [J MR]

Conductor, electric

Metal wires cables rods tubes and bus bars used for the purpose of carrying electric current While any metal assembly or structure can conduct electricity the term conductor in practical use refers particularly to the component parts of the current carrying circuit or system

Types of conductor The most common forms of electrical conductors are *wires cables and bus bars*

Wires Wires employed as electrical conductors are slender rods or filaments *of metal usually soft* and flexible They may be bare or covered by some form of flexible insulating material They are usually circular in cross section but for special purposes they may be drawn in square *rectangular* ribbon or other shapes Conductors may be solid or stranded that is built up by a *helical lay or* assembly of smaller solid conductors (Fig 1)

Cables Stranded single conductors in the larger sizes are called cables Small flexible insulated cables are called cords Assemblies of two or more insulated wires or cables within a common jacket or sheath are called multiconductor cables

Bus bars Bus bars are rigid solid conductors usually rectangular in cross section but also employed in other shapes such as rods tubes and hollow squares Bus-bars may be applied as single conductors one bus bar per phase or as multiple conductors two or more bus bars per phase The individual conductors of a multiple conductor installation are identical

Materials Most wires cables and bus bars are made from electrolytically pure copper Copper of all the metals except silver offers the *least* resistance to the flow of electric current It may be bent and formed readily and has good *flexibility* in small sizes and in stranded constructions It is also low in cost

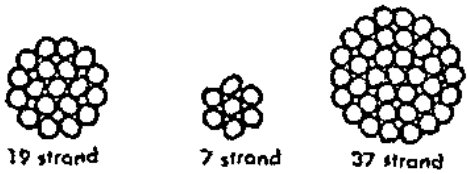


Fig 1 End views of stranded round conductors

Aluminum because of its higher resistance has less current carrying capacity than copper for a given cross sectional area However its low cost and light weight (only 30% that of the same volume of copper) permit wide use of aluminum for bus bars transmission lines and large insulated cable installations

In outdoor overhead installations where superior physical strength is required special wires or composite constructions are used Typical of these are copper covered steel a steel core to which is fused an outer shell of copper aluminum conductor steel reinforced a composite construction of aluminum strands built up around a stranded steel core (Fig 2), and self supporting aerial cables an assembly of insulated conductors suspended from a steel messenger cable

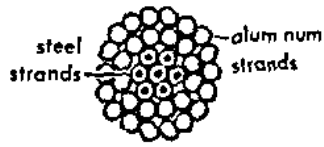


Fig 2 End view of alum num conductor steel-reinforced (ACSR)

Bare conductors Bare wires and cables are used extensively in outdoor power transmission and distribution lines Conductors are supported on or from insulators usually porcelain of various designs and constructions depending upon the voltage of the line and the mechanical considerations involved

Bare bus bars are used extensively in outdoor substation construction in switchboards and for feeders and connections to electrolytic and electroplating processes Where dangerously high voltages are carried the use of bare bus bars is *usually* restricted to areas accessible only to authorized personnel Bare bus bars are supported on insulators of a design suitable for the voltage

Insulated conductors Insulated electric conductors are provided with a continuous covering of flexible insulating material A great variety of insulating materials and constructions has been developed to serve particular needs and applications The selection of an appropriate insulation depends upon the voltage of the circuit the operating temperature the handling and abrasion likely to be encountered in installation and operation and environmental considerations such as exposure to moisture oils or chemicals and applicable codes and standards *See* INSULATION ELECTRIC

Magnet wires used in the windings of motors solenoids transformers and other electromagnetic devices have relatively thin insulations usually of enamel or cotton or both Enamel or cotton enamel insulated magnet wire is designated Class *A* suitable for operation up to 105°C Heavy enamel with a serving of glass fiber yarn is designated Class B suitable for operation up to 130°C Glass fiber yarn bonded with silicone varnish is des g

nated Class H capable of withstanding a temperature of 180°C. *See* MAGNET WIRE

Conductors in buildings Building wires and cables are used in electrical systems in buildings to convey electric power from the point of electric service (where the system is connected to the utility lines) to the various outlets fixtures and utilization devices Building wires are approved for 600-volt operation but are commonly used at utilization voltages substantially below that value typically 120 240 or 480 volts Insulations commonly used include thermoplastic natural rubber synthetic rubber and rubberlike compounds Rubber insulations are usually covered with an additional jacket such as a fibrous braid to resist abrasion Building wires are grouped by type in several application classifications in the National Electrical Code For example rubber or rubberlike insulations for general service are designated Type R if moisture resistant and suitable for use in wet locations Type RW, if heat resistant Type RH Other types of insulating materials used on electrical conductors for the wiring of buildings include varnished cambric and asbestos

Building wires and cables are also available in duplex and multiple conductor assemblies the individual insulated conductors are covered by a common jacket For installation in wet locations wires and cables are often provided with a lead sheath (Fig 3)

For residential wiring the common constructions used are nonmetallic sheath cables, twin and multiconductor assemblies in a tough abrasion resistant jacket, and armored cable with twin and multiconductor assemblies encased in a helical flexible steel armor as in Fig 4

Power cables Power cables are a class of electric conductors used by utility systems for the distribution of electricity They are usually installed in underground ducts and conduits Power cables are also used in the electric power systems of industrial plants and large buildings

Power cable insulations in common use include rubber paper varnished cambric asbestos and thermoplastic Rubber insulated cables (Fig 5) are suitable for voltages up to 15 000 volts varnished cambric (Fig 6) to 28 kv and impregnated paper to 75 kv The type and thickness of the insulation for various voltages and applications are specified by the Insulated Power Cable Engineer Association

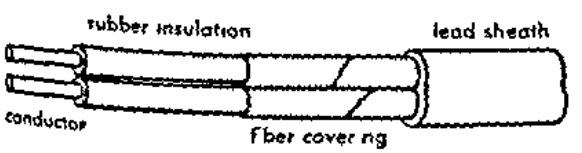


Fig 3 Rubber insulated fiber covered lead sheathed cable

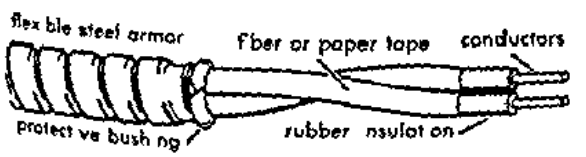


Fig 4 Two-conductor armored cable

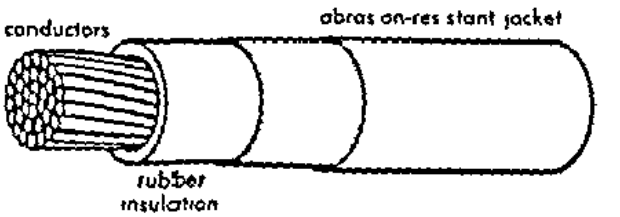


Fig 5 Rubber insulated power cable

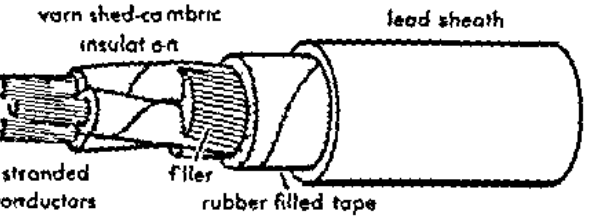


Fig 6 Varn shed-cambric insulated lead sheathed cable

Enclosed bus bar assemblies or busways are extensively used for service conductors and feeders in the electrical distribution systems of industrial plants and commercial buildings They consist of prefabricated assemblies in standard lengths of bus bars rigidly supported by solid insulation and enclosed in a sheet metal housing

Busways are made in two general types feeder bus duct and plug in bus duct Feeder busways have no provision for taps or connections between the ends of the assembly Low reactance feeder busways are so constructed that the conductors of different phases are in close proximity to minimize inductive reactance Plug in busways have provisions at intervals along the length of the assembly for the insertion of bus plugs

Voltage drop in conductors In electric circuits the resistance and (in ac circuits) the reactance of the circuit conductors result in a reduction in the voltage available at the load (except for capacitive loads) Since the line and load resistances are in series the source voltage is divided proportionally The difference between the source voltage and the voltage at the load is called voltage drop

Electrical utilization devices of all kinds are designed to operate at a particular voltage or within a narrow range of voltages around a design center The performance and efficiency of these devices are adversely affected if they are operated at a significantly lower voltage Incandescent lamp light output is lowered fluorescent lamp light output is lowered and starting becomes slow and erratic the starting and pull out torque of motors is seriously reduced

Voltage drop in electric circuits caused by line resistance also represents a loss in power which appears as heat in the conductors In excessive cases, the heat may rapidly age or destroy the insulation The power loss also appears as a

ponent of total energy use and cost *See* COPPER LOSS

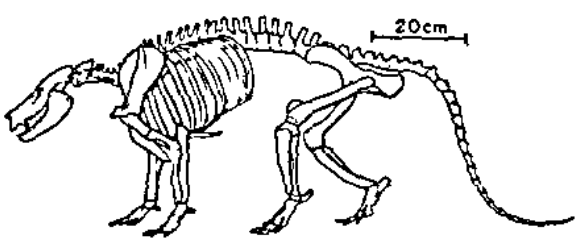
Consequently the conductors of electric power systems must be large enough to keep voltage drop at an acceptable value A typical maximum for a building wiring system for light and power is 3% voltage drop from the utility connection to any outlet under full load condition *See* WIRING (ELECTRIC) [W T S]

Condylarthra

An extinct order of primitive hoofed herbivores with 5 toed platigrade to semidigitigrade feet The astragalus is carnivorelike Known skulls are also carnivorelike in outline but the dentition has been modified for an herbivorous diet Inflated auditory bullae are not present The teeth are usually low crowned and superficially piglike but one group possesses selenodont teeth Condylarths are best represented in the early Cenozoic deposits of North and South America The order is near the ancestry of all living hoofed mammals *See* DENTITION

The order Condylarthra is subdivided into five families Hyopsodontidae (*Mioclaenus Oxyacodon Protoselene Hyopsodus*) represented abundantly in the Paleocene and Eocene of North America are seldom larger than rabbits They are possible descendants of early insectivores and may be ancestral to artiodactyls Phenacodontidae (*Tetraclaenodon Ectocion Phenacodus*) abundantly represented in the early Paleocene to early Eocene of North America and in the early and middle Eocene of Europe are large herbivores similar in body proportions to carnivores Their teeth are similar to those of certain creodont carnivores but are lower crowned They show affinity with South American didolodontids and with the creodonts and may be near the ancestry of the Proboscidea Desmostylia Tubulidentata Sirenia and Perissodactyla Didolodon

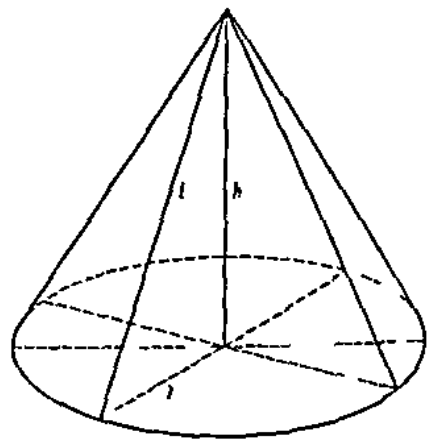
gadolodus) are generally large herbivores They show possible relationships to the earliest notoungulates and astrapotheres and gave rise to the litopterns Periptychidae (*Anisonchus Ectoconus Periptychus*) Paleocene of North America were a short lived but highly successful group of herbivores with specialized fluted teeth They are related to hyopsodontids and phenacodontids Meniscotheriidae (*Meniscotherium Orthaspidotherium Pleuraspidotherium*), late Paleocene of France and late Paleocene and early Eocene of North America, possess selenodont teeth and molarized premolars. They are not closely related to other condylarths but may be related to the Hyracoidea [M C MC.]



Skeleton of *Ectoconus* an early Paleocene phenacodont condylarth (*After G G Simpson*)

Cone

The solid of revolution obtained by revolving a right triangle about one of its two shorter sides is called a cone, or more precisely a right circular cone (see illustration) More generally the word



Right circular cone

cone is used in solid geometry to describe a solid bounded by a plane and a portion of one nappe of a conical surface In analytic geometry however the word cone refers not to a solid but to a conical surface This is a surface generated by a straight line which moves so that it always intersects a given plane curve called the directrix and passes through a point called the vertex not in the plane of the directrix The generating line in each of its positions is called an element of the cone The vertex divides the surface into two parts called nappes that are congruent to each other in the extended sense (under rotation and reflection combined) but may not be superposable by a rigid motion in three dimensional space

If the elements of a cone make equal angles with a line through the vertex the cone is called a cone of revolution the line is called the axis of revolution and the angle is called the semivertical angle ϵ Plane sections of a cone of revolution are called conic sections

If the plane makes an angle θ with the axis and does not contain the vertex the resulting conic section is called nondegenerate and is a circle if $\theta = 90°$, an ellipse if $\epsilon < \theta < 90°$ a parabola if $\theta = \epsilon$ or a hyperbola if $\theta < \epsilon$ In the latter case the plane cuts both nappes of the cone and the conic section consists of two separate congruent arcs called the branches of the hyperbola

If the cutting plane contains the vertex of the cone the conic section is degenerate and consists of a point, a line or a pair of intersecting lines Cones whose directrices are conic sections are called quadric cones

The volume of a solid cone is $V = Bh/3$, where B is the base area included within the directrix and h is the altitude (or height) measured from the vertex to the plane of the base The volume V and surface area S of a right circular cone are $V = \pi r^2 h/3$ and $S = 2\pi l + 2\pi r$, where r denotes the radius of the base and $l = \sqrt{r^2 + h^2}$ denotes the slant height measured from vertex to base along an element of the cone

A frustum of a cone is a solid bounded by two parallel planes and a portion of a conical surface The plane boundaries are called bases If the bases are circles of radii r and R, the volume of the frustum is $V = (\pi/3)(r^2 + rR + R^2)$ *See* CONIC SECTION GEOMETRY, EUCLIDEAN, SURFACE AND SOLID OF REVOLUTION [J S F]

Conformal mapping

A special operation in mathematics in which a point set in one coordinate system is mapped or transformed into a corresponding point set in another coordinate system

A mapping or transformation of a point set E in the xy plane is merely a correspondence $u = u(x,y), v = v(x,y)$ which makes correspond to each point of E some point $(u\,v)$ of the uv plane If distinct points (x,y) are transformed into distinct points $(u\,v)$ the mapping is one to one A mapping is conformal if it is one to one and if small triangles are transformed into small triangles approximately similar to the original triangles the approximation to similarity approaching perfection as the size of the triangles diminishes indefinitely It follows that any small figure since it can be cut up into triangles can be transformed into an approximately similar figure

The following fact is decisive the transformation defined by an analytic function whose derivative is different from zero is conformal Let the transformation be $w = f(z)$, $z = x + iy$ $w = u + iv$, which is one to one in suitable neighborhoods of $z = z_0$ and $w = u_0 = f(z_0)$, for example (*See* COMPLEX NUMBERS AND COMPLEX VARIABLES) Let its their If z_1 nages z_1 and w_2 lie on C'_1 and C'_2 The angles of the rectilinear triangles $z_0z_1z_2$ and $w_0w_1w_2$ at z_0 and u_0 are respectively (arg signifies the argument or amplitude of the complex number)

$$\arg \frac{z_2 - z_0}{z_1 - z_0} \quad \text{and} \quad \arg \frac{w_2 - u_0}{u_1 - u_0}$$

and the ratios of the sides of the triangles adjoining z_0 and u_0 are

$$\left|\frac{z_2 - z_0}{z_1 - z_0}\right| \quad \text{and} \quad \left|\frac{u_2 - w_0}{z_1 - z_0}\right|$$

The assumed existence of $f'(z_0)$ asserts

$$\lim_{z_1 \to z_0} \frac{w_1 - u_0}{z_1 - z_0} = \lim_{z_2 \to z_0} \frac{u_2 - w_0}{z_2 - z_0} = f'(z_0) \neq 0$$

whence one has

$$\arg \frac{u_2 - u_0}{u_1 - u_0} - \arg \frac{z_2 - z_0}{z_1 - z_0} \to 0$$

$$\left|\frac{w_2 - u_0}{u_1 - u_0}\right| \Big/ \left|\frac{z_2 - z_0}{z_1 - z_0}\right| \to 1$$

Thus when the triangles are small they are nearly similar in the sense that the angles at z_0 and w_0 are nearly equal and the ratio of the adjacent sides of the one triangle is approximately equal to the corresponding ratio for the other triangle, these approximations approach perfection as the lengths of the sides of the triangles approach zero

In the discussion just given it follows that the angle between chords of C_1 and C_2 and the angle between chords of C'_1 and C'_2 approach equal limits these limits are by definition the angles between the curves so in a conformal transformation angles between curves are preserved Indeed, such angles are preserved algebraically as well as in magnitude

It can also be shown that conversely, a conformal map must be defined by an analytic function with nonvanishing derivative This article deals only with the transformation of one plane region onto another the term conformal applies also to the transformation of any surface onto another, such as the mapping of a portion of the earth's surface onto a portion of a plane The Mercator and stereographic projections are conformal in this same sense Small regions are essentially unchanged in shape but not in relative size *See* MAP PROJECTIONS

On the other hand a map defined by an analytic function whose derivative is zero cannot be conformal For instance the transformation $w = z^2$ in the neighborhoods of $z = 0$ and $w = 0$ can be written $\Delta w = (\Delta z)^2$ so $\arg(\Delta w) = 2 \arg(\Delta z)$, $\arg(\Delta_1 w) = 2 \arg(\Delta_1 z)$, angles at $z = 0$ are doubled in transformation to the z plane

Linear transformations The transformation $w = \alpha z + \beta$, $\alpha \neq 0$ transforms every figure into a similar figure whose size is changed in the ratio $1 : |\alpha|$ for with $w_1 = \alpha z_1 + \beta$ $w_2 = \alpha z_2 + \beta$ one has $w_2 - w_1 = \alpha(z_2 - z_1)$ whence $|w_2 - w_1| = |\alpha|\,|z_2 - z_1|$, also $\arg(w_2 - w_1) = \arg\alpha + \arg(z_2 - z_1)$, every line segment being rotated through the angle $\arg\alpha$

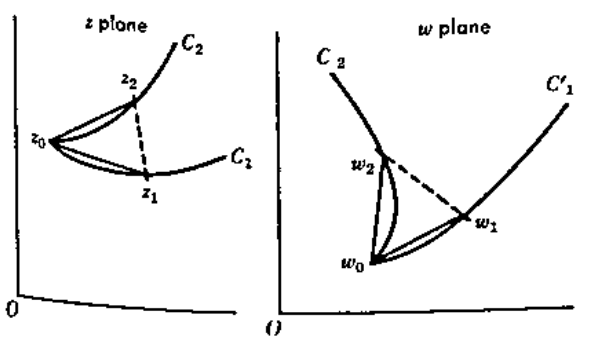


Fig 1 Transformation of curves from z plane to w plane

The transformation $w = 1/\bar{z}$, where z indicates the conjugate of z, asserts essentially that $\arg w = \arg z$, $|w| = 1/|z|$ (Fig 2) This transformation is not defined by an analytic function of z, and hence is not conformal But the transformation is equivalent to the succession of transformations $z' = z$, $w = 1/z'$ The first is merely a 180° rotation of the plane about the x axis and leaves all angles unchanged in magnitude but reversed in direction, and thus is inversely conformal, the second is conformal Thus $w = 1/\bar{z}$ (called inversion in the unit circle) is also inversely conformal, it is one-to-one in the entire z plane and w plane except that $z = 0$

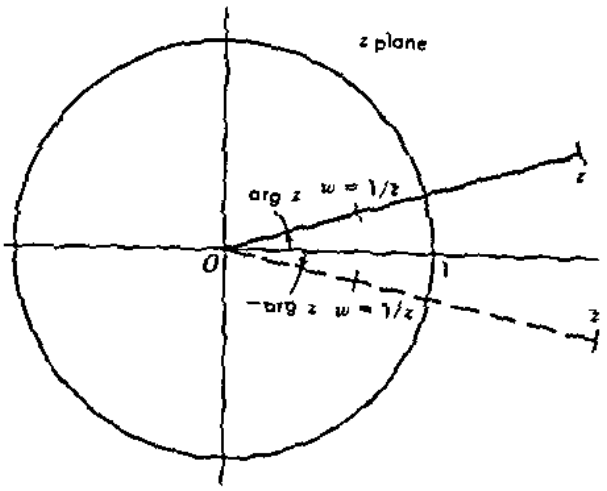


Fig 2 An inversely conformal transformation

and $w = 0$ have no images To avoid these exceptions, one may introduce ideal (or fictitious) points "at infinity" $z = \infty$, $w = \infty$ When z is near 0 w is remote from $w = 0$, so $w = \infty$ can be considered the image of $z = 0$, and $w = 0$ the image of $z = \infty$ With this convention, the transformation is one to one in the extended plane Angles between curves at infinity can be introduced either by studying limits of chords as one point of intersection recedes indefinitely or by projecting the plane stereographically onto a sphere by using a point of the sphere as center of projection (here the point at infinity in the plane projects into the center of projection) In either case it is also true that angles even at infinity are unchanged in magnitude by the transformations $w = 1/z$, $w = 1/z$

The general linear transformation of the complex variable is defined by

$$w = \frac{\alpha z + \beta}{\gamma z + \delta} \qquad \alpha\delta - \beta\gamma \neq 0$$

where α β, γ, δ are constants, the purpose of the restriction on their values is merely to assure that the fraction does not reduce identically to a constant This transformation is readily shown to be one-to-one in the extended plane One of the important properties of such a transformation is that it leaves invariant the cross ratio of any four distinct points If the points are z_1, z_2 z_3 z_4, one defines the cross ratio as

$$(z_1,z_2,z_3,z_4) = \frac{(z_1 - z_2)(z_3 - z_4)}{(z_2 - z_3)(z_4 - z_1)}$$

with a suitable convention when a point is at infinity, and if the image points are u_1, u_2 u_3 u_4 (any one of which may be at infinity), it is a matter of direct verification to prove $(u_1 u_2 u_3 u_4) = (z_1,z_2,z_3,z_4)$

If four points lie on a circle, their cross ratio is real, as is expressed by the equation

$$\arg \frac{z_2 - z_1}{z_2 - z_3} - \arg \frac{z_4 - z_1}{z_4 - z_3} = 0 \text{ or } \pi$$

and is proved by the euclidean properties of angles inscribed in a circle, conversely, if the cross ratio is real, the four points are either concyclic or collinear For simplicity one enlarges the concept of circle to include straight line If three distinct points z_1, z_2, z_3 are given the point z is concyclic with them when and only when the cross ratio (z_1,z_2,z_3,z) is real, here is included the case that z may coincide with a z_k Under a linear transformation the points z_1, z_2, z_3 go over into distinct points w_1, w_2, w_3, and z goes into w with preservation of the cross ratio The latter is real when and only when z_1, z_2, z_3, z are concyclic, which occurs when and only when (w_1,w_2,w_3,w) is real namely when and only when w_1, w_2, w_3 w are concyclic Thus a linear transformation carries every "circle" into a "circle"

There exists a linear transformation which carries the unit disk into itself and any given point α of the disk into the origin namely

$$w = \lambda \frac{z - \alpha}{1 - \bar{\alpha}z} \qquad |\lambda| = 1$$

With $zz = 1$, one has

$$w\bar{w} = \frac{z - \alpha}{1 - \bar{\alpha}z}\frac{\bar{z} - \bar{\alpha}}{1 - \alpha\bar{z}} = \frac{z - \alpha}{1 - \bar{\alpha}z}\frac{1 - \bar{\alpha}z}{z - \alpha} = 1$$

the point α with $|\alpha| < 1$ is carried into $w = 0$ so by the continuity of the transformation $|z| < 1$ is carried into $|w| < 1$ It can be shown that no other linear transformation has the property required

Riemann's theorem. Trivial simply connected regions of the plane are the plane of finite points and the extended plane, neither of these can be mapped one-to-one and conformally onto the unit disk G F B Riemann asserted (the fact was first proved by W F Osgood) that essentially any other simply connected region D (one having at least two boundary points) can be so mapped The proof depends on extremal properties of univalent functions, namely analytic functions assuming no value more than once in D The most general of such maps is given by combination with the linear transformations just discussed If in particular D is a Jordan region, the map may be defined so as to be one to one and continuous in the closed regions

Multiply connected regions. If a region D is bounded by a finite number $p(>1)$ of mutually disjoint Jordan curves, it cannot be mapped one-to-one onto a circular disk Various canonical re-

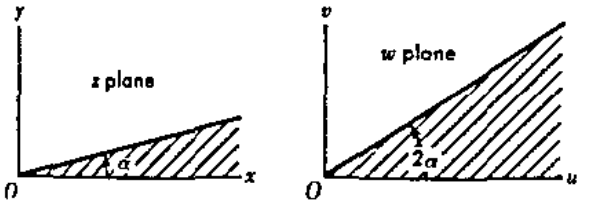


Fig 3 Formation of a Riemann surface

gions have been proposed for the study of such regions and comparison of two such regions which may or may not be mappable onto each other Such *canonical* regions may be bounded by p circles by p parallel rectilinear slits, by slits of arcs of circles whose center is the origin, by a circle whose center is the origin plus such slits, by two circles whose common center is the origin plus such slits, by loci

$$\left|\frac{A(z-a_1)^{m_1}(z-a_2)^{m_2}\quad(z-a_\mu)^{m_\mu}}{(z-b_1)^{n_1}(z-b_1)^{n_2}\quad(z-b_\nu)^{n_\nu}}\right| = 1 \text{ and } B$$

by regions bounded by arcs of logarithmic spirals by numerous other kinds of prescribed boundaries

Riemann surfaces If one studies the map of a sector $0 < \arg z < \alpha$ under the transformation $w = z^2$, it is seen that for small α the image is the sector $0 < \arg w < 2\alpha$ and that as α increases the image sector also increases (Fig 3) When α passes through the value π the boundary of the image sector passes through the value 2π and continues to increase beyond 2π, say in a new sheet over the w plane in the sense that as new points z occur it is natural to continue to adjoin new points w But when the sector in the z plane reaches the angle 2π it abuts on values of z already considered so it is natural to 'heal' the boundaries of the sector of angle 4π in the w plane by passing one sheet through another (say, along the positive half of Ox) and joining the edges There is thus formed a Riemann surface over the u plane which is useful for studying the behavior of $z = \sqrt{w}$ as a function of w with reference to the two branches of the function their continuity and their passing (along various w curves) continuously from one into the other

There exists more generally a Riemann surface of n sheets for the inverse of any irreducible polynomial function $w = a_0z^n + a_1z^{n-1} + \quad + a_n$ Moreover, the exponential function $w = e^z = e^{x+iy}$ can be defined as $e^x(\cos y + i \sin y)$ for complex z whose analyticity for all z can be verified by the Cauchy Riemann equations The inverse function

$$z = \log w = \log [r(\cos \theta + i \sin \theta)] = \log r + i\theta$$

is infinitely many valued, its Riemann surface consists of infinitely many sheets over the u plane each connected (for instance) along the positive half of Ox to its predecessor along one edge and to its successor along the other

Riemann surfaces may be defined abstractly also, their classification and properties have occupied mathematicians for more than a century, and unsolved problems remain abundant *See* TOPOLOGY [J L W]

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Conformational analysis

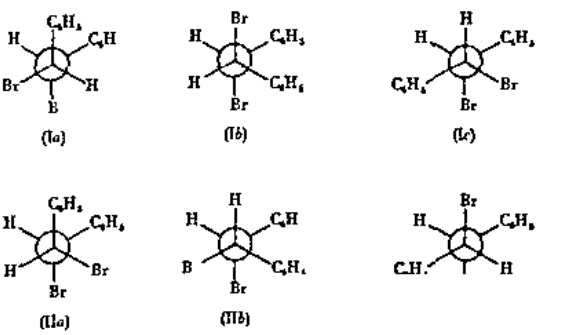
The determination of the arrangement in space of the constituent atoms of a molecule that may rotate about a single bond These rotations produce changes in conformation Conformational analysis also includes the study of the chemical and physical differences between the conformations of a molecule A particular conformation is chemically significant only when capable of finite existence

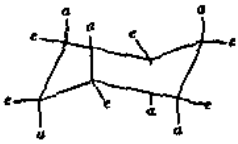
Conformations may be treated in a manner analogous to the treatment of geometrical isomers which are differentiated by the large energy barrier to rotation imposed by the carbon carbon double bond However the barrier to rotation about a carbon carbon single bond is usually considerably lower and consequently different conformations are more readily interconvertible

Ethane theoretically possesses an infinite number of conformations but, if the hydrogen atoms are not differentiated there are but two significant conformations Viewed along the axis of the carbon carbon bond one of these has the hydrogen atoms of one methyl group exactly lined up behind those of the other methyl group and the other has the hydrogens of one methyl group falling midway (60° from the former position) between those of the other methyl group The former is an eclipsed (hydrogens opposed to each other) conformation and *the latter a staggered conformation* The eclipsed conformation represents a free energy maximum and the staggered conformation a free energy minimum presumably due to repulsions, or lack thereof between the electrons of the carbon hydrogen bonds

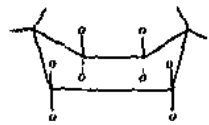
If the ethane carbons each carry two substituents other than hydrogen three staggered conformations are possible and the most stable one is determined by the relative magnitudes of steric repulsions between the substituent groups on the central carbons

configura
configurat
dibromide are shown in (I) and (II) with reference to the phenyl groups the conformations shown in (Ic) and (IIc) are called trans whereas the remaining are called skew or gauche In general the





(IIIa)



(IIIb)

energetically most favorable (and therefore most populous) conformation will resemble (Ic) and (IIc) the largest groups (phenyl) being trans

The conversion of either isomer to a stilbene by loss of the bromines requires the bromines to be trans (Ib) or (IIc) initially The molecules must also be in the conformations with respect to the hydrogens and phenyl groups resembling the resultant stilbene cis for (I) phenyls opposed to each other and trans for (II) phenyls opposed to hydrogens and therefore more energetically favorable Since energy must be expended to convert (Ic) to (Ib) and since more energy will be required to convert (Ib) to its transition state than to convert
of (I)
conver
ments may be advanced to predict both the course and relative rates of other reactions and in turn such data can be used to assign a particular conformation to a molecule

In cyclic systems containing more than five ring members the normal bond angles (carbon = 109°28) produce a nonplanar arrangement and two significant conformations are possible chair (IIIa) and boat (IIIb) Conformational analysis reveals a greater stability for the chair form in which the hydrogens are completely staggered whereas the boat form contains four pairs of opposed hydrogens o in (IIIb) In the chair form the hydrogens are directed perpendicularly to the mean plane of the carbons—axial conformation a in (IIIa)—or equatorially to the center of the mean plane—equatorial conformation e in (IIIa)

An examination of models suggests that there is less steric interaction if the bonds of a cyclohexane system are rotated to place a single substituent equatorially When several substituents are present in a given isomer the most stable conformation is that in which the maximum number of groups are equatorial When not all groups can be so placed preference for equatorial placement is given to the largest group

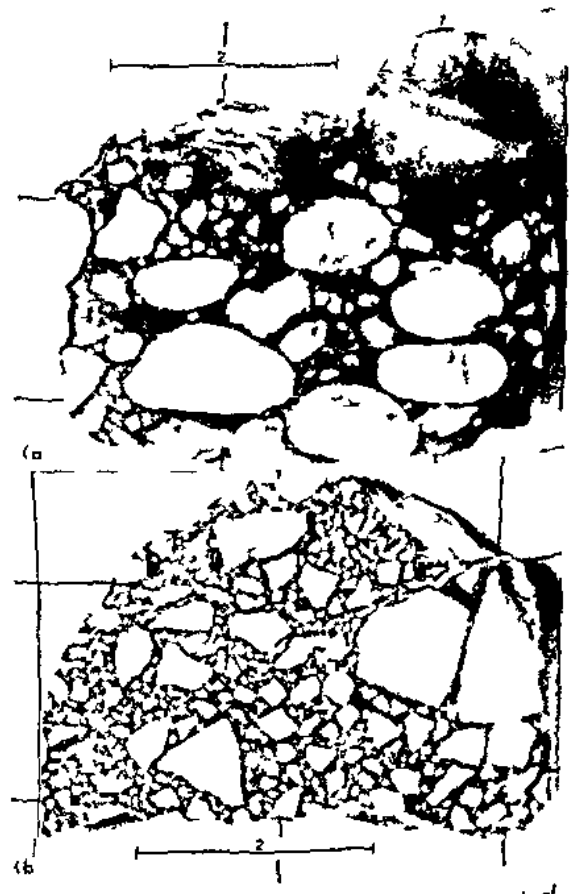
Similarly the relative thermodynamic stability of a pair of cis trans disubstituted cyclohexanes can be predicted by conformational analysis a 1 2 trans isomer can have both substituents equatorial whereas the cis isomer can have only one substituent equatorial thereby having greater energy content or lower thermodynamic stability On the other hand in the 1 3 isomers both substituents can be equatorial in the cis isomer but not in the trans isomer and so the cis isomer is thermodynamically more stable

The extension of conformational analysis to polycyclic systems leads to many useful conclusions concerning the structure configuration and mode of reaction of such important natural products as the steroids terpenes and alkaloids *See* STEREOCHEMISTRY [WRV]

Conglomerate

The consolidated equivalent of gravel Conglomerates are aggregates of more or less rounded particles greater than 2 mm in diameter Frequently they are subdivided on the basis of size of particles into pebble (fine) cobble (medium) and boulder
(
s
d
erates (50% or more pebbles) sandy conglomerates (25–50% pebbles) and pebbly or conglomeratic sandstones (less than 25% pebbles) The pebbles of conglomerates are always somewhat rounded giving evidence of abrasion during transportation this distinguishes them from some tillites and from breccias whose particles are sharp and angular

Conglomerates fall into two general classes based on the range of lithologic types represented by the pebbles and on the degree of sorting and amount of matrix present The well sorted, matrix poor conglomerates with homogeneous pebble l



(a

(b

(a) Conglomerate a lithified gravel composed of rounded pebbles (b) Breccia a lithified gravel containing many angular fragments (Specimen from Princeton University Museum of Natural History Photo by Willard Starks)

thology are one type and the poorly sorted matrix rich conglomerates with heterogeneous pebble li thology are the other The well sorted class includes quartz pebble chert pebble and limestone pebble conglomerates The quartz pebbles were derived from long continued erosion of the source rock ter rain that resulted in the disappearance of all un stable minerals such as feldspars and ferromagne sian minerals that make up most igneous and metamorphic rocks Typically the quartz pebble conglomerates are thin sheets that overlie an un conformity and are basal to a series of overlapping marine beds Chert pebble conglomerates are de rived from weathered limestone terrains Limestone pebble conglomerates seemingly are the result of special conditions involving rapid mechanical ero sion and short transport distances otherwise the limestone would quickly become degraded to finer sizes and dissolve The well sorted conglomerates tend to be distributed in thin widespread sheets normally interbedded with well sorted quartzose sand tones *See* UNCONFORMITY

The poorly sorted lithologically heterogeneous conglomerates include many different types all re lated in having very large amounts of sandy or clayey matrix and pebbles of many different rock classes The graywacke conglomerates are the outstanding representatives They are composed of pebbles many times only slightly rounded of many different kinds of igneous and metamorphic rock as well as sedimentary rocks bound together by a matrix that is a mixture of sand silt and clay They seem to have been formed from the products of rigorous mechanical erosion of highlands and transported in large part by turbidity or density currents (*see* TURBIDITY CURRENT) Another rep resentative of the poorly sorted class is fanglom erate a conglomerate formed on an alluvial fan Fanglomerates in many cases are much better sorted than the graywacke conglomerates but have heterogeneous pebble composition A tillite is an other representative of this class of conglomerate All of these poorly sorted conglomerates tend to occur in fairly thick sequences and some of them typically the fanglomerates are wedge-shaped ac cumulations *See* SEDIMENTARY ROCKS

Special types of conglomerates such as volcanic conglomerates and agglomerates and some intra formational conglomerates composed of shale peb bles or deformed limestone pebbles do not seem to fall easily into either class Some of the shale and limestone intraformational conglomerates have formed from the tearing up of previously deposited beds at the sea bottom while they were still rela tively soft and only partially consolidated Because of the angularity of some of these pebbles they have often been called breccias *See* BRECCIA GRAVEL GRAYWACKE TILL [R S]

Conglutination

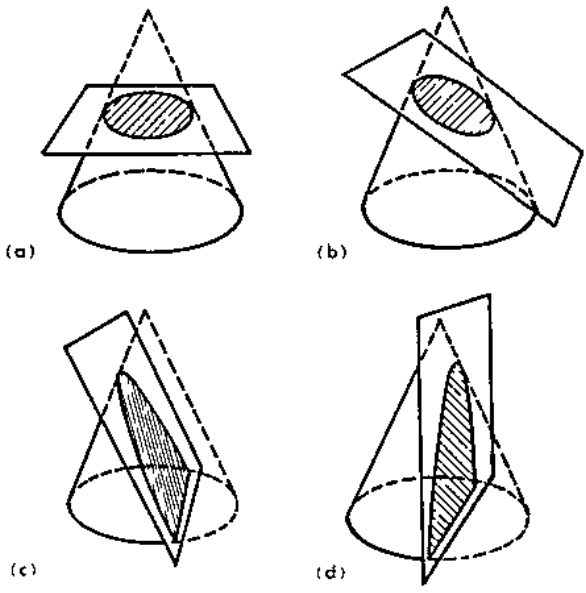
A term used in serology to describe the completion or enhancement of an incomplete agglutinating system by the addition of certain s[illegible] bacteria or erythrocyte suspensions do not exhibit the visible agglutination ordinarily expected after they have been coated with their specific antibodies and complement Further addition of a conglutinat ing agent—normal bovine serum—however initi ates visible agglutination Complement is an essen tial component of the system The conglutination reagent is itself without effect in the absence of antibody and complement Similar over all actions such as agglutination of Rh^+ cells occur when hu man serum gelatin or bovine serum albumin are added to the incomplete Rh antibodies found in some sera but since this enhancing effect occurs also in the absence of complement these reactions probably are to be distinguished in mechanism from that of the traditional conglutination *See* AG GLUTINATION REACTION BACTERIA BLOOD GROUPS COMPLEMENT (SERUM) [H P T]

Conic section

One of the class of curves in which a plane may cut a cone (surface) of revolution They were ex tensively studied by the ancient Greeks The sec tion is a parabola if the plane is parallel to an ele ment of the cone an ellipse or circle if the plane cuts all elements of one nappe (but does not go through the apex) and a hyperbola if the plane cuts elements of both nappes (for example the plane parallel to the cone's axis of revolution) and does not go through the apex If a line g in tersects the cone's axis perpendicularly at a point distinct from the apex a plane π that revolves about g will cut all three kinds of conics from the cone If a plane contains the cone's axis it inter sects the cone in a pair of lines (a degenerate hy perbola) if it goes through the apex but does not contain the axis it has in common with the cone either the apex alone (degenerate ellipse) or an element of the cone (degenerate parabola)

Algebraic definitions After the advent of ana lytic geometry the synthetic method used by the Greeks to develop the properties of conics gave way to algebraic procedures which using other definitions divorced these curves from their origi nal relationship to cones and regarded them as graphs of second degree equations in cartesian co ordinates x y (*see* ANALYTIC GEOMETRY) Let plane π cut all the elements of one nappe of a cone C (π not perpendicular to the cone's axis and not passing through the apex) and let E denote the curve of intersection of π and C To show that E is an ellipse consider the spheres S_1 and S_2 inside C that are tangent to π and to all the elements of C and that lie on the opposite sides of π The contact points of S_1 and S_2 with C form circles whose planes π_1 and π_2 are perpendicular to the axis of C Let F_1 and F_2 denote the contact points of S_1 and S_2 respectively with π If P is any point of E then

$$\text{dist } (P F_1) = \text{dist } (P Q_1)$$
$$\text{dist } (P F_2) = \text{dist } (P Q_2)$$



Conic sections (a) Circle (b) Ellipse (c) Parabola (d) Hyperbola

where Q_1 Q_2 are those contact points of S_1, S_2, respectively that lie on the element of C through P Since dist (P,Q_1) + dist (P,Q_2) is the (constant) distance between the parallel planes π_1, π_2, then

$$\text{dist } (P,F_1) + \text{dist } (P F_2) = \text{constant}$$

and so E is an ellipse The directrices of E are the lines in which τ_1 π_2 intersect π

Conics are basic in astronomy, where it is shown that the Newtonian inverse square law of gravitation implies that the orbits of the planets are ellipses with the sun at one focus Other heavenly bodies certain comets for example have parabolic and hyperbolic paths

Conic sections in projective geometry. The third phase in the study of conic sections began with the development of projective geometry (*see* PROJECTIVE GEOMETRY) In that subject, it is shown that the locus of the points of intersection of two projective (nonperspective), coplanar (nonconcentric) pencils of lines is a nondegenerate (point) conic All nondegenerate conics are projectively equivalent, that is if C_1, C_2 are any two such conics there is a projective transformation of their plane into itself that transforms C_1 into C_2 Conics may be classified into types by their behavior with respect to an arbitrarily selected line g say the ideal line of the plane In the geometry (affine) obtained by considering only those projective transformations that transform g into itself, a conic is a hyperbola a parabola or an ellipse according as the number of points that the conic has in common with g is two, one, or none, respectively Dual to point conics are line conics, the locus of all lines joining corresponding points of two projective (not perspective), coplanar (not collinear) point ranges The tangents to a point conic form a line conic, and the contact points of a line conic form a point conic One of the most famous theorems concerning conics was proved by the French philosopher mathematician Blaise Pascal, in 1640 when only 16 years old The theorem asserts that if six points A_i, with $i = 1, 2$, 6 are on a conic, then the intersections P,Q,R of the lines (A_1,A_2) and (A_4,A_5), (A_2,A_3) and (A_5,A_6) (A_3,A_4) and (A_6,A_1), respectively, lie on a line This theorem, together with its converse (which is also valid) has numerous interesting consequences The Brianchon theorem, proved 166 years later, is its dual It states that if a hexagon circumscribes a conic, the three lines joining the three pairs of opposite vertices are concurrent *See* CONE, ELLIPSE, HYPERBOLA; PARABOLA [L M BL]

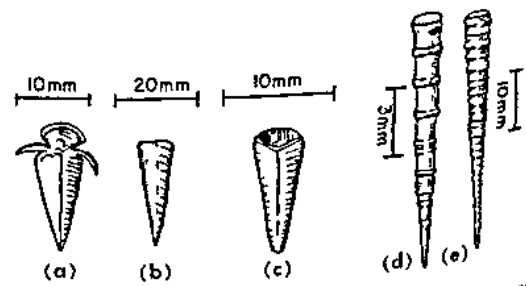
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Coniconchia

The class name Coniconchia has been proposed for extinct organisms thought to have been mollusks These fossils are distinguished by a calcareous univalve shell, open at one end and lacking an internal siphon Thirty two genera are included in [illegible] two com se and during Paleozoic time, have never been satisfactorily classified They have been considered as allied to the gastropods, the coelenterates, and to the tube secreting worms *See* MOLLUSCA

Tentaculites is a small fossil having a bulbous embryonic shell from which a narrow tube expands slowly Transverse thickenings or rings are common on the tube The aperture is circular and simple *Hyolithes* is somewhat larger and is triangular in section The tip is simple and the shell expands at a slightly greater angle than in *Tentaculites* The base is flattened and extends forward forming a shelf in front of the aperture The shell is slightly curved when viewed from the side Some species, perhaps all have a triangular operculum attached to the upper part of the aperture

Tentaculites is common in rocks of Silurian and Devonian age The circular cross section, small size



Early Paleozoic *Hyolithes* and *Tentaculites* (a) *H connatus* Matthew, Middle Cambrian (b) *H baconi* Whitfield, Middle Ordovician (c) *H neapolis* Clarke Upper Devonian (d) *T gyracanthus* (Eaton), Upper Silurian (e) *T scalariformis* Hall, Middle Devonian (*Adapted from R C Moore, C G Lalicker, and A G Fischer Invertebrate Fossils, McGraw Hill, 1952*)

and bulbous early chamber is suggestive of a swimming animal *Hyolithes* ranges from Cambrian through Permian but is increasingly rare above the Cambrian The flattened base suggests a bottom living animal Both genera are world wide in distribution and specimens are present in all types of sedimentary rocks They are uncommon fossils but may be abundant locally [ELY]

Coniferales

An order of the plant class Gymnospermae with more than 50 genera and over 540 species—the dominant forest makers of the world Here belong the pine spruce hemlock cedar fir larch juniper cypress yew redwood big tree, kauri podocarpus and many others All are woody, being either shrubs or trees The largest plants are conifers with the big tree of California (*sequoia gigantea*) heading the list The giants of this species are 300 ft tall have a diameter of 34 ft and are over 3500 years old With only a few exceptions such as *Agathis* (kauri) and podocarpus which have leaf blades the leaves are needlelike or scalelike In most species the trees retain green foliage throughout the year therefore, they are called evergreens

Distribution The conifers appeared in the Carboniferous attained their zenith and widest distribution in the Jurassic and then began to wane (*see* GEOLOGY) However the persistent species form some of the most extensive forests of modern times Characteristically they are mountain dwellers ranging from the Arctic to the Antarctic circles with the greatest display in the temperate zones and a good representation in the tropics

Reproduction The cones are unisexual In some species both male and female cones are borne on the same plant (monoecious) in others on separate plants (dioecious) The sperms are nonciliate and nonmotile In the pine the mature pollen grains (microspores) fall from the microsporangia of the staminate (male) cones and are carried by the wind Some microspores sift down between the scales of the pistillate (female) cones settling on the megasporangia At the end of each megasporangium is a tiny pore (micropyle) through which the microspore moves to the nucellus the central body of the megasporangium Here the microspore germinates Each megasporangium contains a megaspore which also germinates producing a female gametophyte with two or three archegonia the egg producing organs The microspore produces the pollen tube (male gametophyte) with two sperms The tube grows at the expense of the nucellus carrying the sperms to the archegonia each containing one egg Here a sperm unites with an egg (fertilization) forming a zygote which will produce several embryos Only one embryo survives to produce a new plant Usually a year intervenes between pollination and fertilization and another year between fertilization and embryo formation

Economic importance The conifers supply much material used in landscaping and they are the source of valuable lumber and such by products as turpentine tar resin and oils of various kinds See separate articles describing most of the major conifers by common names *see also* PLANT KINGDOM [PDS]

Bibliography See EMBRYOPHYTA

Coniferophytae

A subclass of the plant class Gymnospermae With some exceptions these are large plants and all have much branched stems simple leaves and cones Distributed principally in the temperate zones the group includes four orders Cordaitales Ginkgoales Coniferales and Gnetales See separate articles describing each of these orders *see also* EMBRYOPHYTA PALEOBOTANY PLANT KINGDOM [PDS]

Conjunctivitis

Inflammation of the conjunctiva the mucous membrane which lines the eyelids and continues over the anterior portion of the eyeball to join the transparent circular window or cornea through which light passes into the eye

Because of its exposed location the conjunctiva is a common site for inflammations due to trauma infection allergy and other causes Trauma may be imposed by ultraviolet radiation chemical irritations and burns and foreign bodies The conjunctivitis produces congestion edema and direct damage to the epithelial tissue *See* ULTRAVIOLET RADIATION (BIOLOGY)

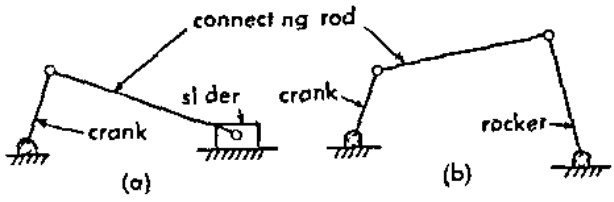
In certain allergic disorders such as hay fever and food sensitivities severe itching swelling and proliferation of the epithelium are seen Often a characteristic ropy secretion is present *See* HYPERSENSITIVITY

Infectious agents that may cause conjunctivitis are bacteria viruses and other microorganisms In many cases the exact agent cannot be determined but the clinical picture of acute infectious conjunctivitis is typical It is marked by intense congestion pain edema and some form of abnormal secretion Pus forming organisms like staphylococci pneumococci and gonococci cause a thick purulent exudate Less virulent organisms may cause catarrhal conjunctivitis in which a mucous or watery secretion is formed Scanty secretion in the presence of acute inflammation usually suggests a virus infection *See* BACTERIA VIRUS

Distinctive or nonspecific types of conjunctivitis may be present in tularemia diphtheria trachoma epidemic keratoconjunctivitis trichinosis ophthalmic goiter tuberculosis syphilis and many other local or systemic diseases [EGST]

Connecting rod

A link in several kinds of mechanisms Usually one end of a connecting rod is intended to follow a circular path while the other end follows a path along a straight line or a curve of large radius The term is sometimes applied however to any straight link that transmits motion from one link



Connecting rod in (a) slider crank mechanism and (b) crank and rocker mechanism

to another within a mechanism The illustration shows conventional arrangements of connecting rods in typical mechanisms In some applications (for example the connecting rod between the crank and an overhead oscillating or walking beam in a well drilling rig or between the steering column and cross links in an automobile) the connecting rod is called a pitman [E S F]

Connective tissue

One of the four primary tissues of the body It differs from the other three tissues in that the extracellular components (fibers and intercellular substances) are abundant It cannot be sharply delimited from the blood whose cells may give rise to connective tissue cells and whose plasma components continually interchange with and augment the ground substance of connective tissue Bone and cartilage are special kinds of connective tissue

The functions of connective tissues are varied They are largely responsible for the cohesion of the body as an organism of organs as functioning units and of tissues as structural systems This cohesive function is achieved through their permeation of other tissues of the body The connective tissues are essential for the protection of the body both in the elaborate defense mechanisms against infection and in repair from chemical or physical injuries Nutrition of nearly all cells of the body and the removal of their waste products are both mediated through the connective tissues Connective tissues are important in the development and growth of many structures Constituting the major environment of most cells they are probably the major contributor to the homeostatic mechanisms of the body so far as salts and water are concerned They act as the great storehouse for the body of salts and minerals as well as of fat Finally the connective tissues determine in most cases the pigmentation of the body

Cellular components The connective tissues consist of cells and extracellular or intercellular substance (see illustration) The cells include many varieties of which the following are the most important (1) fibroblasts—variable in shape frequently outstretched to form many fine processes some as small as 200–300 A (2) macrophages (histiocytes)—variable in shape strongly motile or outstretched frequently with numerous minute cell processes highly phagocytic (the ability to take particulate material into the cytoplasm) (3) mast cells—frequently large ameboid nucleus centrally located cytoplasm very often packed with granules about 0 4 μ in diameter (4) plasma cells—generally ovoid weakly ameboid nucleus eccentric granular cytoplasm staining strongly with basic dyes (toluidin blue methylene blue hematoxylin) (5) melanocytes—cytoplasm of highly branched cells filled with minute granules which appear yellow or brown because of the melanin they contain and (6) fat cells of two kind (*a*) yellow fat cells—very large (80 μ or more) generally spherical with a thin shell of protoplasm (3 0–0 1 μ or less) enclosing a single enlarged fat droplet which appears yellowish and (*b*) brown fat cells—moderately large generally spherical with small droplets of variable size (about 2 μ or less) scattered in the cytoplasm In addition connective tissues may contain especially in the vicinity of small blood vessels undifferentiated mesenchymal cells which may be considered as potentially embryonic and blood cells which have wandered through the walls of blood vessels including lymphocytes and polymorphonuclear granular leukocytes It is especially important to realize that most of the cells of the connective tissue are developmentally related even in the adult for example fibroblasts may be developed from histiocytes or from undifferentiated mesenchymal cells

Extracellular components The extracellular components of connective tissues may be fibrillar or nonfibrillar The fibrillar components are (1) reticular fibers which may be stained differentially with certain silver stains (2) collagenous fibers which have a longitudinally striated appearance with the light microscope and are readily stainable with the acid dyes eosin and aniline blue and (3) elastic fibers which are highly refractile appear slightly yellowish and may be stained differentially by certain dyes like orcein With the higher resolution achieved with the electron microscope both reticular and collagenous fibers are

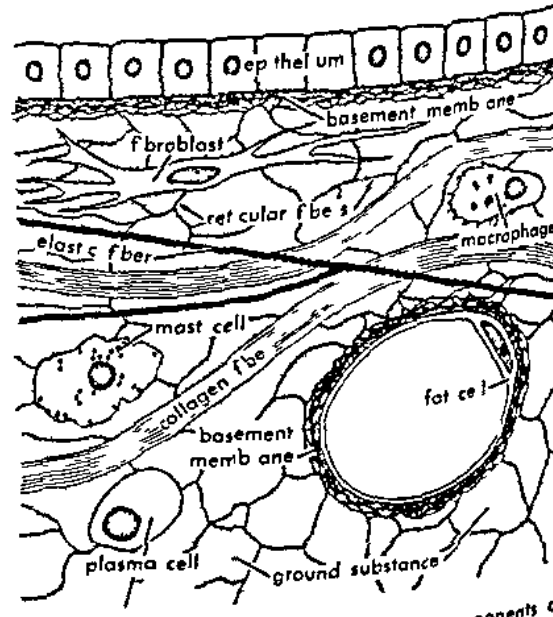


Diagram of cellular and intercellular components of connective tissue

seen to be made up of smaller fibrils of about 200–1000 A in diameter each with an internal cross banded structure which is repeated on an average of every 640 A The elastic fibers are also resolvable into finer fibrils which may be 80 A or larger in diameter All fibers visible with the light microscope are thus composed of bundles of submicroscopic fibrils visible only with the electron microscope

The nonfibrillar component of connective tissues appears amorphous with the light microscope and is the matrix in which cells and fibers are embedded It consists of two groups of substances (1) those probably derived from secretory activity of connective tissue cells including mucoproteins mucopolysaccharides tropocollagen and antibodies and (2) those probably derived from the blood plasma including albumen globulins inorganic and organic anions and cations and water In addition the ground substance contains metabolites derived from cells hormones and nutrients derived from the blood The ground substance of local origin and the tissue fluid of hematogenous origin are not only coextensive but are dynamically related in a two phase system The two phases of this thermodynamic system are probably recognizable in the electron microscope as a series of small watery vacuoles (about 600 A in diameter) embedded in a denser matrix The basement membrane is a specially differentiated sheetlike part of the ground substance (100–500 A thick) which underlies directly many epithelia and encloses muscle fibers and fat cells It is denser than the adjacent ground substance with which it is continuous and may contain fibrils

Classification of connective tissues All the manifold varieties of connective tissue (except cartilage) may contain all the cells and fibers discussed above in addition to ground substance They differ from each other in the relative occurrence of one or another cell type in the relative proportions of cells and fibers in the preponderance and arrangement of one or another fiber and in the relative amount and chemical composition of ground substance In the classification which follows some of these differences are pointed out

1 Irregularly arranged connective tissue—which may be loose (subcutaneous connective tissue) or dense (dermis) The dominant fiber type is collagen though others may be present The fibers are irregularly interwoven and the cells irregularly distributed The looser type has more ground substance than the denser type

2 Regularly arranged connective tissue—primarily collagenous—with the fibers arranged in certain patterns depending on whether they occur in tendons or as membranes (dura mater capsules fasciae aponeuroses or ligaments)

3 Mucous connective tissue—ground substance especially prominent (umbilical cord)

4 Elastic connective tissue—predominance of elastic fibers or bands (ligamentum nuchae) or lamellae (aorta)

5 Reticular connective tissue—fibers mostly reticular moderately rich in ground substance frequently numerous undifferentiated mesenchymal cells

6 Adipose connective tissue—yellow or brown fat cells constitute chief cell type reticular fibers most numerous

7 Pigment tissue—melanocytes numerous

See BLOOD BONE CARTILAGE HISTOLOGY *See also* ANGSTROM CELL (BIOLOGICAL) CHROMATOPHORE HOMEOSTASIS PHAGOCYTOSIS [I C]

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Connector, electric

A device that joins electric conductors mechanically and electrically to other conductors and to the terminals of apparatus and equipment The term covers a wide range of devices designed for example to connect small conductors employed in communication circuits or at the other extreme large cables and bus-bars

Electric connectors are applied to conductors in a variety of ways Soldered connectors have a tube or hole of approximately the same diameter as the conductor The conductor and connector are heated the conductor inserted and solder flowed into the joint until it is filled Solderless connectors are applied by clamping the conductor or conductors in a bolted assembly or by staking or crimping under great mechanical force usually by means of special tools designed for the purpose

Industrial and power connectors Connectors for electric power systems are commonly cast and assembled with bolts The material most commonly used is copper alloy which may vary in composition and properties depending upon the intended use of the connector Where heavy currents flow through the body of the connector an alloy of relatively high conductivity is used Where the connector serves principally to clamp conductors together an alloy of higher strength and lower conductivity may be used An important consideration governing the choice of alloy is that it must have a coefficient of thermal expansion very close to that of pure copper so that the connection will remain secure through wide temperature changes

Connectors designed for severe outdoor service and heavy current and mechanical loading are called power connectors and are widely used in power substations for cable-to-stud connections at equipment cable-to-bus bus-to-bus and bus-to-line connections

For industrial application more compact constructions and greater versatility may be required and connectors with such features are called industrial connectors In practice both classes are employed in power systems and industrial plants the choice depending upon the actual service con-

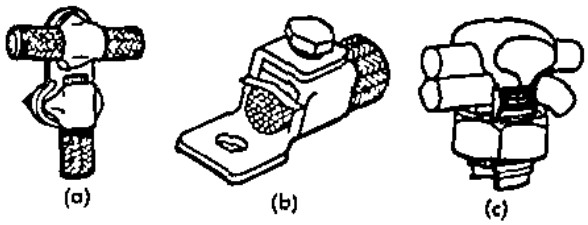


Fig 1 Types of connector (a) T connector (b) Terminal (c) Split bolt connector

Typical connector types are couplers T connectors terminals and stud connectors Couplers join conductors end to end T connectors join a through conductor to another conductor at right angles to it (Fig 1*a*) Terminals join the conductor to a drilled tongue for bolting to the terminals of equipment (Fig 1*b*) Stud connectors join the conductor to equipment studs the stud clamp is threaded or smooth to match the stud Many variations of these types are made

Split bolt connectors are a compact construction widely used for splices and taps in building wiring The bolt shape casting has a wide and deep slot lengthwise The conductors are inserted in the slot and the nut is drawn up clamping the conductors together inside the bolt (Fig 1*c*)

Expansion connectors or flexible connectors allow some limited motion between the connected conductors The clamp portions of the connector are joined by short lengths of flexible copper braid and may also be held in alignment by a telescoping guide

Heavily tinned copper alloy bolted connectors may be used to connect aluminum conductors They are applied with an oxide inhibiting compound Where copper and aluminum conductors are to be clamped together they are separated by bimetal or tinned washers to prevent galvanic corrosion Connectors for aluminum conductors are also made of Duralumin

Separable electrical connectors These consist of matched plugs and receptacles which may be readily separated to disconnect a conductor or group of conductors from the circuit or system Separable connectors are commonly used for the connection of portable appliances and equipment to an electric wiring system In electronics and communication they are widely used for connecting various components so that a single component can be readily removed for servicing without disturbing the circuitry

For connections to an electric power supply separable connectors consist of receptacles usually fixed and permanently connected to the wiring system and attachment plugs usually connected to a cord or cable extending to the appliance or equipment served Other constructions provide cable-to-cable and cable to-appliance connections

Connectors for power systems are typically 2 wire 3-wire or 4-wire depending upon the circuit requirements They are made in a wide range of types and sizes for applications involving various voltage current mechanical and environmental requirements They are so constructed that a particular receptacle will accept only a matching plug of identical characteristics rating and circuit configuration Two wire connectors that can be coupled in only one position are said to be polarized Multiconductor connectors are designed by a nonuniform arrangement of contacts or by a key in the assembly housing so that they may be coupled in only one position

Locking connectors These are designed so that, when coupled they may not be separated by a strain or pull on the cord or cable In a typical construction the plug is inserted and twisted through a small arc locking it securely in place For hazardous areas where the spark caused by separating a connector under load may be dangerous connectors are designed so that the circuit is made or broken within the receptacle only in the fully engaged and locked position Receptacles may also be interlocked mechanically with a switch allowing insertion or removal of the plug only when the switch is in the open position

Multiwire connectors used in electronic communication and control circuits contain more connections of much smaller current capacity than power connectors Connector constructions are designed primarily for mechanical and electrical contact reliability

Coaxial connectors provide for connecting and disconnecting a coaxial cable from an equipment circuit They are so constructed as to maintain the conductor configuration through the separable connection and the characteristic impedance of the coaxial cable Coaxial connectors are made of copper or aluminum with contact and current carrying surfaces plated with silver or gold They are made in a variety of sizes adaptable to the cables with which they are used They are designed for cable to chassis and cable-to cable connections in plug jack receptacle feed through right angle and T adapter designs *See* COAXIAL CABLE

Common receptacles Plug receptacles sometimes called convenience outlets are a type of wiring device distributed throughout buildings for the attachment of portable lamps and appliances In residences at least one such outlet must be provided for every 12 linear feet or major fraction of wall perimeter The receptacle is conventionally 2 wire 120-volt 15 ampere and supplied by a 15- or 20 ampere branch circuit The slots which accept the attachment plug are parallel The device may



Fig 2 Grounding type 15-ampere receptacle

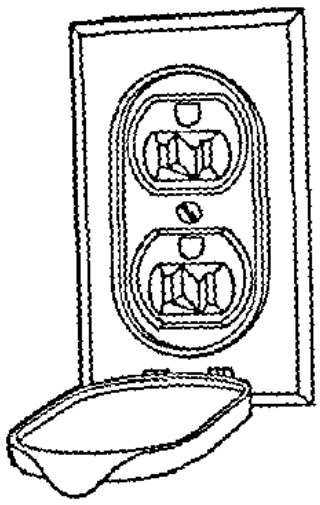


Fig 3 Weatherproof receptacle

consist of a single receptacle a duplex receptacle or a triplex receptacle (for one two or three attachments respectively) in a single outlet box More attachment plugs can be provided for by ganging two or more devices in a common outlet box under a common wall plate Receptacles may also be combined with other devices (as switches and pilot lights) In split-circuit duplex receptacles each half of the device is supplied independently through a separate terminal with typically one part connected directly to the branch circuit con ductors and the other connected through a switch Grounding receptacles have an additional contact that accepts the third round or U shaped prong of a grounding attachment plug (Fig 2) Grounding receptacles will accept either grounding or non grounding attachment plugs but grounding attach ment plugs can be used only in grounding recepta cles The grounding contact of the receptacles is connected internally to a supporting strap provid ing a ground both through the outlet box and the grounding conductor armor or raceway of the wir ing system

Multioutlet assemblies are a type of surface race way designed to hold conductors and plug recep tacles which are usually spaced uniformly along the length of assembly

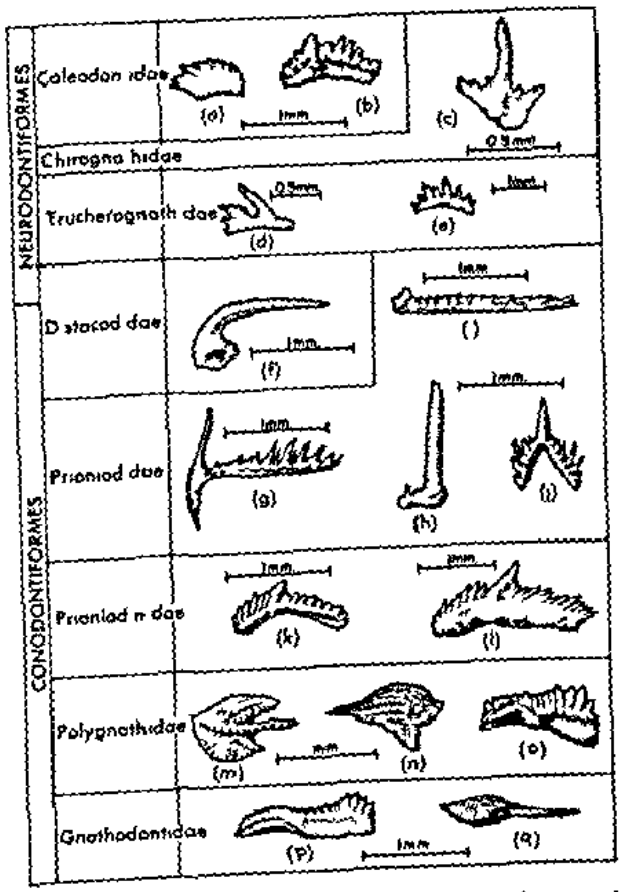
Weatherproof receptacles (Fig 3) are equipped with a weatherproof plate gasketed around the edges with a hinged or threaded cover over the de vice See WIRING (ELECTRIC) [W T S]

Conodont

A minute toothlike microfossil composed of trans lucent amber brown fibrous or lamellar calcium phosphate Conodonts have an uncertain and con troversial origin and are placed in the order Con odontophoridia Because conodonts have not been found in situ associated with a definitely classifia ble fossil a controversy has developed as to whether they are fish worms or mollusks There is even un certainty as to whether they represent teeth dermal plates gill rakers radula or copulatory structures Conodonts occur in rocks ranging from Cam brian to Cretaceous and are important geologically as guide fossils for subdivisions of the Paleozoic

The toothlike shapes ranging in length from a fraction of 1 mm up to 2 mm include single cones or cusps denticulated blades or bars and massive thickened platforms Each specimen possesses an attachment scar (escutcheon) which is interpreted as the place of connection between the conodont and bonelike phosphatic material possibly a jaw Conodonts are definitely paired (either upper and lower or right and left) and several pairs may oc cur in groups or assemblages suggesting a variety of forms in a single animal

For the purpose of describing conodonts each specimen is oriented so that the points of the den ticles are oral (up) and the escutcheon is aboral (down) Simple cone and bar or blade types have their denticles recurved toward the posterior Cur vature of blades or bars is always convex to the outside and the blade end of platforms is anterior



Classification of the Conodontophoridia with typical examples of each family (a) Coleodus a typical denticulate blade (b) Erismodus (c) Chirognathus (d) Polycaulodus (e) Curtognathus (f) Multioistodus a typical distacodid (g) Ligonodina (h) Hibbardella (i) Hindeodella a typical hindeodellid (j) Hibbardella (k) Bryantodus a typical bryantodid (l) Lewistownella, a so-called cavusgnath (m) Ancyrodella (n) Palmatolepis (o) Polygnathus a typical polygnathid (p q) Idiognathodus (After illustration in R R Shrock and W H Twenhofel Principles of Invertebrate Paleontology McGraw Hill 2d ed 1953)

Composition and occurrence Conodonts are composed of calcium phosphate in the form of dahllite one of the apatite minerals which is chemically identical to the enamel of vertebrate teeth and quite similar to the mineral matter of vertebrate bones All available evidence indicates that the dahllite is original it does not seem to have been replaced or altered during fossilization The conodont mineral matter is quite resistant to weathering and is insoluble in most common soil acids thus conodonts may accumulate in the residual soils on weathered limestones and shales They may also be extracted from limestone by dissolution of the calcareous rock in acetic acid leaving unaffected the conodonts as part of the insoluble residue Because the dahllite is heavier than quartz and calcite conodonts may be separated from quartz and calcite sands by means of appropriate mineral separation methods The tiny fossils will be included in the heavy mineral suites Conodonts were frequently reworked into younger sediments because of their superior resistance to weathering and above average specific gravity with the result that they are commonly found as components of complex admixtures of fossils that are not in the proper stratigraphic position

Conodonts occur in many different kinds of sedimentary rocks suggesting that they were buried in a wide variety of environments They are particularly abundant in black fissile shales commonly in spectacular numbers suggesting that they were buried in deep or stagnant marine waters *See* BLACK SHALE

Internal structure The fibrous and lamellar internal structures of conodonts are used as a basis of dividing conodonts into two groups The lamellar group has internal structure that may be interpreted as being made by the secretion of layers by external increments as if formed in a soft tissue invagination like the formation of dermal scales or teeth of fish All stages of development of an individual are preserved in a single specimen Thus conodonts are excellent fossils for ontogenetic studies Specimens may be broken and repaired by additional external layers There is little evidence of wear such as might be expected in grinding teeth

Problems of origin The assignment of conodonts to worms or mollusks may be rejected because (1) Recent and fossil worms and mollusks have no hard parts shaped like conodonts and composed of calcium phosphate (2) the internal structures of conodonts cannot be duplicated among the worms or mollusks (3) scolecodonts or fossil worm mandibles are silicochitinous and lack attachment scars and (4) paired assemblages suggestive of worms to some workers are equally applicable to other organisms *See* ANNELIDA FOSSILS

Conodonts differ from true fish teeth in that they have no true pulp cavity However the composition internal structure external shape assemblages geological occurrences and associated fossils are compatible with interpreting conodonts as primitive fish They may be dental or jaw armor skeletal elements of gill arches lingual teeth or scale clusters of fish closely related to the extinct cyclostomes. *See* CYCLOSTOMATA (CHORDATA)

Classification Based on internal structure external shape and structure of the escutcheon conodonts are classified as follows

Order Conodontophoridia
- Suborder Neurodontiformes fibrous internal structure Ordovician
  - Family Coleodontidae attachment scar clasps the length of the jaw ramus Middle Ordovician
  - Family Chirognathidae attachment scar clasps the tips of jaw ramus Lower and Middle Ordovician
  - Family Trucherognathidae attachment scar permits conodont to rest on the jaw ramus Middle and Upper Ordovician
- Suborder Conodontiformes lamellar internal structure Ordovician to Triassic
  - Family Distacodidae simple curved cone deeply excavated attachment scars Cambrian to Middle Silurian
  - Family Prioniodidae denticulated bars with a large denticle at one end Lower Ordovician to Permian
  - Family Prioniodinidae denticulated bars or blades with a large denticle in the middle third of the specimen Lower Ordovician to Cretaceous
  - Family Polygnathidae platforms with small pitlike attachment scars Middle Silurian to Cretaceous
  - Family Gnathodontidae platforms with large cup shaped attachment scars Upper Devonian to Permian

The fibrous conodonts are exclusively Ordovician in their stratigraphic occurrence The simple cones range through the Ordovician into Middle Silurian The blades and bars have an exceptionally long stratigraphic range and are not very valuable as guide fossils Various genera possessing platforms are excellent guide fossils because of their short stratigraphic range [SPE]

C. D. Ellison Jr. Conodonts as Paleozoic Petrol. Geol. Bibliography Catalogue Contr. Texas Univ. R. Shrock

Conservation of energy

The principle of conservation of energy states that energy cannot be created or destroyed although it can be changed from one form to another Thus in any isolated or closed system the sum of all forms of energy remains constant The energy of the system may be interconverted among many different forms—mechanical electrical, magnetic thermal

chemical nuclear and so on—and as time progresses it tends to become less and less available but within the limits of small experimental uncertainty no change in total amount of energy has been observed in any situation in which it has been possible to ensure that energy has not entered or left the system in the form of work or heat For a system that is both gaining and losing energy in the form of work and heat as is true of any machine in operation the energy principle asserts that the net gain of energy is equal to the total change of the system s internal energy *See* THERMODYNAMIC PRINCIPLES

Application to life processes The energy principle as applied to life processes has also been studied For instance the quantity of heat obtained by burning food equivalent to the daily food intake of an animal is found to be equal to the daily amount of energy released by the animal in the forms of heat work done and energy in the waste products Studies with similar results have also been made of photosynthesis the process upon which the existence of practically all plant and animal life ultimately depends

Conservation of mechanical energy There are many other ways in which the principle of conservation of energy may be stated depending on the intended application Examples are the various methods of stating the First Law of Thermodynamics the work kinetic energy theorem and the assertion that perpetual motion of the first kind is impossible (*see* ENERGY PERPETUAL MOTION) Of particular interest is the special form of the principle known as the principle of conservation of mechanical energy According to this principle the total mechanical energy (kinetic E_k plus potential E_p) of any system of bodies connected together in any way is conserved provided that the system is f o

servative forces are always present in any actual situation their effects in many cases are so small that the principle of conservation of mechanical energy is a very useful approximation Thus for a missile or satellite traveling high in space the dissipative effects arising from such sources as the residual air and meteoric dust are so exceedingly small that the loss of mechanical energy $E_k + E_p$ of the body ac

f

e

able as a theorem from Newton s laws of motion Also very old are the notions that the disappearance of mechanical energy in actual situations is always accompanied by the production of heat and that heat itself is to be ascribed to the random motions of the particles of which matter is composed But a really clear conception of heat as a form of energy came only near the middle of the nineteenth century when J P Joule and others demonstrated the equivalence of heat and work by showing experimentally that for every definite amount of work done against friction there always appears a definite quantity of heat The experiments usually were so arranged that the heat generated was absorbed by a given quantity of water and it was observed that a given expenditure of mechanical energy always produced the same rise of temperature in the water The resulting numerical relation between quantities of mechanical energy and heat is called the Joule equivalent or mechanical equivalent of heat The present accepted value is one 15° calorie 4.1855 ± 0.0004 joules

Conservation of mass energy In view of the principle of equivalence of mass and energy in the restricted theory of relativity the classical principle of conservation of energy must be regarded as a special case of the principle of conservation of mass energy However this more general principle

If the mass energy relation $F = mc$ where c is the speed of light is considered as providing an equivalence between energy E and mass m in the same sense as the Joule equivalent provides an equivalence between mechanical energy and heat there results the relation 1 kilogram = 9×10^{16} joules *See* INERTIA OF ENERGY

[DER]

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Conservation of mass

The notion that mass or matter can be neither created nor destroyed According to conservation of mass reactions and interactions which change the properties of substances leave unchanged their total mass for instance when charcoal burns the mass of all of the products of combustion such as ashes soot and gases equals the original mass of charcoal and the oxygen with which it reacted

The special theory of relativity of Albert Einstein which has been verified by experiment has shown however that the mass of a body changes as the energy possessed by the body changes Such changes in mass are too small to be detected except in subatomic phenomena Furthermore matter may be created for instance by the materialization of a photon (quantum of electromagnetic energy) into an electron positron pair or it may be destroyed by the annihilation of this pair of elementary particles to produce a pair of photons *See* LIGHT MASS PAIR PRODUCTION (ELECTRON POSITRON) RELATIVITY [LN]

Conservation of momentum

The principle of conservation of momentum states that when a system of masses is subject only to forces that masses of the system exert on one an

other the total vector momentum of the system is constant

Since vector momentum is conserved in problems involving more than one dimension the component of momentum in any direction will remain constant

The principle of conservation of momentum holds generally and is applicable in all fields of physics In particular momentum is conserved even if the particles of a system exert forces on one another such that the total mechanical energy is not conserved

Use of the principle of conservation of momentum is fundamental in the solution of collision problems (*see* COLLISION)

If a man standing on a well lubricated cart steps forward the cart moves backward One can explain this result by momentum conservation considering the system to consist of cart and man If both man and cart are originally at rest the momentum of the system is zero If the man then acquires forward momentum by stepping forward the cart must receive a backward momentum of equal magnitude in order for the system to retain a total momentum of zero

When the principle of conservation of momentum is applied care must be taken that the system under consideration is really isolated For example when a rough rock rolls down a hill the isolated system would have to consist of the rock plus the earth and not the rock alone since momentum exchanges between the rock and the earth cannot be neglected

Rocket propulsion The propulsion of a rocket through space can be explained in terms of momentum conservation Hot gases produced by the combustion of the fuel are expelled at high speed from the rear of the rocket Although the total mass of these hot gases may not be large the gases move with such a high velocity that the total momentum associated with them is appreciable The momentum of the gases is directed backward For momentum to be conserved the rocket must acquire an equal momentum in the forward direction If the rocket carries all the materials needed for the combustion of its fuel its propulsion does not require air and it can move through empty space

Exploding bomb An exploding bomb gives another application of the conservation of momentum The total resultant vector momentum of all the pieces of the bomb immediately after explosion must equal the momentum of the unexploded bomb just before the explosion

Proof of principle The principle of conservation of momentum follows directly from Newton s second and third laws While the principle will be proved here only for the straight line motion of a two particle system it can be generalized to systems containing any number of particles A particle is a mass with dimensions so small that rota

For the one-dimensional motion of an isolated two particle system Newton's third law states that the force F_{12} that particle 1 exerts on particle 2 is equal in magnitude and opposite in direction to the force F_{21} that particle 2 exerts on particle 1 Thus

$$F_{21} = -F_{12}$$

By use of Newton's second law this equation can be expressed in terms of the momenta m_1v_1 and m_2v_2 of particles 1 and 2 respectively where m_1 m_2 v_1 and v_2 are the masses and velocities of particles 1 and 2 respectively Then

$$m_1 \frac{dv_1}{dt} = -m_2 \frac{dv_2}{dt}$$

Integration gives

$$m_1v_1 + m_2v_2 = c$$

where c is a constant This equation expresses the conservation of momentum for two particles moving in the same straight line

Finally it should be mentioned that angular and linear momentum are independent quantities A complete description of a system must include both quantities The angular momentum of a system is conserved under quite general conditions *See* ANGULAR MOMENTUM, CONSERVATION OF ENERGY MOMENTUM [PWS]

Conservation of resources

Conservation is concerned with the utilization of resources—the rate purpose and efficiency of use The material in this article deals primarily with the conservation of human and recreational resources For additional information see the separate articles on conservation of fisheries forest, minerals range land soil water and wildlife and a conservation oriented article on land use planning

Nature of resources Universal natural resources are the land and soil water forests grassland and other vegetation fish and wildlife rocks and minerals and solar and other forms of energy Some natural resources such as metallic ores, coal petroleum and stone are called fund or stock resources They usually are referred to as nonrenewable natural resources because extraction from the stock depletes the usable quantity remaining and, even if some is being formed the rate of formation is too slow for practical meaning Other natural resources such as living organisms and their products and solar and atomic radiation are called flow resources They usually are referred to as renewable natural resources because they involve organic growth and reproduction or because they are relatively quickly recycled or renewed in nature as in the case of water in the hydrologic cycle and certain atmospheric phenomena (*see* HYDROLOGY) Some natural resources are difficult to fit into such a simple system Soil for example is commonly thought of as renewable as erosion and nutrient depletion can in some cases be rather quickly cor

rected but if the upper layers of the soil are removed or bedrock is exposed, renewal may take thousands of years Water is also commonly renewable but rapid extraction of water by wells from deep aquifers may be equivalent to mining minerals

Human resources are of two types the people themselves (their numbers qualities knowledge and skills) and their culture (the tools and institutions of society) The three broad classes of resources correspond to the economic factors of production land (natural resources) labor (personal human resources), and capital (cultural tools and institutions) The natural resources have meaning only as there is human ability to make use of them

Nature of conservation Conservation has received many definitions because it has many aspects concerns issues arising between individuals and groups and involves private and public enterprise Conservation receives impetus from the social conscience aware of obligation to future generations and is viewed differently according to one's social and economic philosophy To some extent the meaning of conservation changes with time and place It is understood differently when approached from the natural sciences and technologies than when it is approached from the social sciences Conservation for the petroleum engineer is largely the avoidance of waste from incomplete extraction for the forester it may be sustained yield of products and for the economist it is a change in the intertemporal distribution of use toward the future In all cases conservation deals with the judicious development and manner of use of natural resources of all kinds

No definition of conservation exists that is satisfactory to all elements of the public and applicable to all resources In its absence an operational or functional definition can be arrived at by considering a series of conservation measures

1 Preservation is the protection of nature from commercial exploitation to prolong its use for recreation watershed protection, and for scientific study It is familiar in the establishment and protection of parks and reserves of many kinds

2 Restoration another widely familiar conservation measure, is essentially the correction of past willful and inadvertent abuses that have impaired the productivity of the resources base This measure is familiar in modern soil and water conservation practices applied to agricultural land

3 Beneficiation is the upgrading of the usefulness or quality of something for instance the utilization of ores which were formerly of uneconomic grade Modern technology has provided many examples of this type of conservation

4 Maximization includes all measures to avoid waste and increase the quantity and quality of production from resources

5 Reutilization in industry commonly called recycling is the reuse of waste materials as in the use of scrap iron in steel manufacture or of industrial water after it has been cleaned and cooled

6 Substitution an important conservation measure has two aspects the use of a common resource instead of a rare one when it serves the same end, and the use of renewable rather than nonrenewable resources when conditions permit

7 Allocation concerns the strategy of use, the best use of a resource For many resources and products from them the market price as determined by supply and demand determines to what use a resource is put but under certain circumstances the general welfare may dictate usage and resources may be controlled by government through use of quotas rationing or outright ownership

8 Integration in resources management is a conservation measure because it maximizes over a period of time the sum of goods and services that can be had from a resource or a resource complex, such as a river valley this is preferable to maximizing certain benefits from a single resource at the expense of other benefits or other resources This is one of the meanings of multiple use and integration is a central objective of planning

A generalized definition that fits many but not all meanings of conservation is 'the maximization over time of the net social benefits in goods and services from resources Although it is technologically based conservation cannot escape socially determined values There is an ethic involved in all aspects of conservation Certain values are accepted in conservation but they are the creation of society not of conservation

Conservation trends There has been an important trend in conservation from an almost exclusive interest in production from individual natural resources to a balanced interest in that need and in the human resources and social goals for which resources are managed The conservation movement originated with the realization that the economic doctrine of laissez faire and quick profits—whether from forest farm or oil field—was resulting in tremendous waste that was socially harmful even if it seemed to be good business The beginnings of the conservation movement stemmed from revulsion against destructive and wasteful lumbering In time the movement spread to farm and grazing lands water wildlife and oil and gas It was gradually learned that conservation management was good business in the long run

The second trend in conservation was toward integrated management of resources Students and administrators of resources—in colleges business and government—were discovering that the way one resource was handled affected the usability of others Forestry broadened its interest to include forest influences on the watershed and the relations of the forest to wildlife and human uses for recreation For many industries working directly with natural resources or their products as in paper and chemical manufacturing and in coal mining it was discovered that waste products produced costly and dangerous pollution of streams and the air Engineering on great river systems moved on from problems of flood hazard abatement and hydropower development to the design of structures with regard to fisheries and recreational

values and it was slowly realized that the way the land of a valley was managed affected erosion sil tation water retention and flooding

Conservation in its third phase extends the eco logical or integrated approach to resources man agement to include a more complete acceptance of the force of societal factors (such as economics government and social conditions) in determining resource management There is also a closer exam ination of social costs and benefits and of human goals for which resources are employed

Conservation of human resources Many stu dents of conservation prefer for practical reasons to limit conservation to the management of natural resources and to leave problems of human re sources to other disciplines and fields of action However because of the inevitable interplay of natural resources and the resourcefulness of man in utilizing them others emphasize the role of man himself as a resource This leads to the application of conservation measures to man and his institu tions The many measures which tend to preserve rehabilitate renew maximize allocate and inte grate human abilities are coming to be referred to as conservation measures These measures tend to be organized and institutionalized so that the insti tutions themselves become means to an end within the society and are thus considered to be resources as truly as water petroleum or the labor force *See* ECOLOGY HUMAN

Conservation of recreation resources More than 30 000 000 acres of rural public land in the United States are managed for recreational use or to preserve scenic historical or scientific and nat ural history values and additional space is allo cated for more intensive recreational activities by units of local government There has been in recent decades a tremendous growth in use of such lands for all forms of recreation and the forecast is that outdoor recreation will increase more rapidly than population growth because of the increase in urban living and personal incomes more and better roads the shorter work week and paid vacations There are rapidly growing new trends in recreation that require special uses of space such as bow and ar row hunting skiing and motor boating With in creasing numbers of persons camping picnicking and swimming the provision of adequate facilities and physical maintenance of crowded sites have become problems

Except for the more intensive recreational uses rural and wildland areas serve multiple purposes

reational facilities Yet some land uses are in compatible municipal manufacturing and min ing pollution destroys water recreation values commercial developments destroy wilderness val ues

Many trends indicate that there are not enough acres dedicated to recreation especially smaller areas near strongly urbanized regions There is a growing need for research on trends in wildland usage by people and for better use of space in large parks and forests so as to avoid wearing out the sites by persistent concentration of people as at camp sites It is clear that certain human fa cilities must be provided where many people u e wildlands and that inappropriate ones such as amusement facilities must be kept separate from activities requiring special terrain Some grow ng recreational demands are being met by private en terprise such as in ski resorts and privately owned public hunting grounds Although game is owned by the public it lives and breeds largely on pr ate land In time more farm and ranch owners will be

improvement of management arising from it and from a better understanding by the sportsman of

pertaining to resources There could be a s gle national policy concerning a natural resource such as water only if the central government had com plete authority over all governmental agencies and private enterprises In the United States howe er many Federal and state departments bureaus agencies and commissions have some author ty over natural resources There usually are se eral policies concerning the use and management of soil water forests range lands fish and wildl fe minerals and space and they are not necessarily uniform as to objectives or program One excep tion is the Atomic Energy Commission which ha centralized authority in the creation and exe ut on of policy regarding radioactive resources This au thority stems from Congress and can be mod fied by it

Because each resource is capable of being ut lized for a variety of goods and services and be cause individuals enterprises and regions tend to value certain uses more than others conflicts ar e in the allocation of a resource among competing uses when the supply is inadequate for all de sirable uses The demand for water for example may be for rural domestic needs urban and industr al needs irrigation power development and recrea tion in its many aspects

Because situations such as this exist or are po tential with respect to every resource two outstand ing needs arise in the conservation of natural re sources Detailed information is needed concern ng the location quantity and quality of each resource and of the interrelations among the resources As a result each agency of government need to strengthen its own fact finding analysis and pro gramming machinery The second need is for co ordinating machinery that will improve the eff ciency of allocation of resources so as to max m ze the net private and public benefits from them Th is the goal of conservation policy and it must in a

democratic government be approached as far as possible through voluntary cooperation of government and private enterprise However, as pressures on society increase whether because of actual depletion of resources or because of an increase in critical demand as in war authority to allocate resources tends to be delegated by the citizenry to the central government

Federal conservation legislation National resources policy in the United States is framed by acts of Congress and in the states by acts of legislatures. The language of specific acts however usually permits some freedom for administrative decisions and also permits different interpretations which must be settled in the courts of law As the country has developed and conditions have changed a sequence of laws has been passed to deal with the exigencies of natural resource conditions Also there has occurred some evolution of political philosophy to meet the changing conditions In addition to legislative and court actions some natural resources are subject to treaties and other international agreements

Water In 1824 Congress assigned to the Army Corps of Engineers responsibility for improving rivers and harbors for navigation and this has become its principal civilian activity The Inland Waterways Commission in 1907 and the National Waterways Commission in 1909 were created by Congress with broad responsibilities for planning the development and conservation of water and related resources The Flood Control Act of 1927 provided for Federal surveys and that of 1936 provided for Federal construction of projects Subsequent amendments led to the 1954 Watershed Protection and Flood Prevention Act which clearly recognized the relation of upland management practices to erosion siltation stream flow and other water related resource problems Interest in irrigation has resulted in a series of acts from 1866 onward (the Desert Land Act of 1877 being significant) while water facilities drainage hydroelectric power and water pollution also have received repeated attention The Water Power Act of 1920 set up the Federal Power Commission and aimed to safeguard the rights of government and hydroelectric companies Water pollution control is largely state responsibility but the Federal Water Pollution Control Act of 1948 amended in 1956 enables financial and other assistance to the states

Soil Although soil surveys had been carried out for a century it was the Soil Conservation Act of 1935 which created the Soil Conservation Service and the autonomous Soil Conservation Districts Soil conservation payments were started under the Agricultural Adjustment Act of 1933 Research education cooperation and financial inducements have been stressed more than regulatory measures for soil and water conservation on the land

Minerals In 1866 Congress provided for sale of mineral lands but a general minerals policy did not exist until later The Minerals Leasing Act of 1920 provided that nonmetalliferous minerals on public lands could be utilized only under lease In 1953 Congress confirmed jurisdiction of the states over minerals under navigable inland waters and on the continental shelf to state boundaries

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Constellation

A name used in astronomy originally to designate

[illegible]

ings to resemble familiar objects animals and

values and it was slowly realized that the way the land of a valley was managed affected erosion sil tation water retention and flooding

Conservation in its third phase extends the ecological or integrated approach to resources man agement to include a more complete acceptance of the force of societal factors (such as economics government and social conditions) in determining resource management There is also a closer exam ination of social costs and benefits and of human goals for which resources are employed

Conservation of human resources Many stu dents of conservation prefer for practical reasons to limit conservation to the management of natural resources and to leave problems of human re sources to other disciplines and fields of action However because of the inevitable interplay of natural resources and the resourcefulness of man in utilizing them others emphasize the role of man himself as a resource This leads to the application of conservation measures to man and his institu tions The many measures which tend to preserve rehabilitate renew maximize allocate and inte grate human abilities are coming to be referred to as conservation measures These measures tend to be organized and institutionalized so that the insti tutions themselves become means to an end within the society and are thus considered to be resources as truly as water petroleum or the labor force *See* ECOLOGY HUMAN

Conservation of recreation resources More than 30 000 000 acres of rural public land in the United States are managed for recreational use or to preserve scenic historical or scientific and nat ural history values and additional space is allo cated for more intensive recreational activities by units of local government There has been in recent decades a tremendous growth in use of such lands for all forms of recreation and the forecast is that outdoor recreation will increase more rapidly than population growth because of the increase in urban living and personal incomes more and better roads the shorter work week and paid vacations There are rapidly growing new trends in recreation that require special uses of space such as bow and ar row hunting skiing and motor boating With in creasing numbers of persons camping picnicking and swimming the provision of adequate facilities and physical maintenance of crowded sites have become problems

Except for the more intensive recreational uses rural and wildland areas serve multiple purposes

poundments for multiple purposes create new rec reational facilities Yet some land uses are in compatible municipal manufacturing and min ing pollution destroys water recreation values commercial developments destroy wilderness val ues

Many trends indicate that there are not enough acres dedicated to recreation especially smaller areas near strongly urbanized regions There is a growing need for research on trends in wildland usage by people and for better use of space in large parks and forests so as to avoid wearing out the sites by persistent concentration of people a at camp sites It is clear that certain human fa cilities must be provided where many people use wildlands and that inappropriate ones such as amusement facilities must be kept separate from activities requiring special terrain Some grow ng recreational demands are being met by private en

land In time more farm and ranch owners will be

improvement of management arising from it and from a better understanding by the sportsman of the management problems

Conservation policies Individuals corporation and governmental entities at all levels have polic es pertaining to resources There could be a s ngle national policy concerning a natural resource such as water only if the central government had com plete authority over all governmental agencies and private enterprises In the United States howe er many Federal and state departments bureaus agencies and commissions have some author y over natural resources There usually are several policies concerning the use and management of soil, water forests range lands fish and wildl fe minerals and space and they are not necessarily uniform as to objectives or program One excep tion is the Atomic Energy Commission wh ch has centralized authority in the creation and execut on of policy regarding radioactive resources This au thority stems from Congress and can be mod fied by it

Because each resource is capable of being uti lized for a variety of goods and services and be cause individuals enterprises and regions tend to value certain uses more than others conflicts arise in the allocation of a resource among competing uses when the supply is inadequate for all desirable uses The demand for water for example may be for rural domestic needs urban and industrial needs irrigation power development and recrea tion in its many aspects

Because situations such as this exist or are po tential with respect to every resource two out stand ing needs arise in the conservation of natural re sources Detailed information is needed concern ng the location quantity and quality of each resource and of the interrelations among the resources As a result each agency of government needs to strengthen its own fact finding analysis and pro gramming machinery The second need is for co ordinating machinery that will improve the effi ciency of allocation of resources so as to maxim ze the net private and public benefits from them Th s is the goal of conservation policy and it must in a

democratic government be approached as far as possible through voluntary cooperation of government and private enterprise However, as pressures on society increase whether because of actual depletion of resources or because of an increase in critical demand as in war authority to allocate resources tends to be delegated by the citizenry to the central government

Federal conservation legislation National resources policy in the United States is framed by acts of Congress and in the states by acts of legislatures The language of specific acts however usually permits some freedom for administrative decisions and also permits different interpretations which must be settled in the courts of law As the country has developed and conditions have changed a sequence of laws has been passed to deal with the exigencies of natural resource conditions Also there has occurred some evolution of political philosophy to meet the changing conditions In addition to legislative and court actions some natural resources are subject to treaties and other international agreements

Water In 1824 Congress assigned to the Army Corps of Engineers responsibility for improving rivers and harbors for navigation and this has become its principal civilian activity The Inland Waterways Commission in 1907 and the National Waterways Commission in 1909 were created by Congress with broad responsibilities for planning the development and conservation of water and related resources The Flood Control Act of 1927 provided for Federal surveys and that of 1936 provided for Federal construction of projects Subsequent amendments led to the 1954 Watershed Protection and Flood Prevention Act which clearly recognized the relation of upland management practices to erosion siltation stream flow, and other water related resource problems Interest in irrigation has resulted in a series of acts from 1866 onward (the Desert Land Act of 1877 being significant) while water facilities drainage hydroelectric power and water pollution also have received repeated attention The Water Power Act of 1920 set up the Federal Power Commission and aimed to safeguard the rights of government and hydroelectric companies Water pollution control is largely state responsibility but the Federal Water Pollution Control Act of 1948 amended in 1956 enables financial and other assistance to the states

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Table 1 Traditional constellations

Ancient name	Modern name
Andromeda	Andromeda
Aquarius*	Water Bearer
Aquila	Eagle
Ara	Altar
Argo†	Ship
Aries*	Ram
Auriga	Charioteer
Bootes*	Bear Driver
Cancer*	Crab
Canis Major	Greater Dog
Canis Minor	Lesser Dog
Capricornus*	Sea goat
Cassiopeia*	Cassiopeia
Centaurus*	Centaur
Cepheus	Cepheus
Cetus	Whale
Corona Australis	Southern Crown
Corona Borealis	Northern Crown
Corvus	Crow
Crater	Cup
Cygnus*	Swan
Delphinus	Dolphin
Draco	Dragon
Equuleus	Little Horse
Eridanus	River Po
Gemini*	Twins
Hercules	Hercules
Hydra	Snake
Leo*	Lion
Lepus	Hare
Libra*	Balance
Lupus	Wolf
Lyra*	Lyre
Ophiuchus	Serpent Carrier
Orion*	Warrior
Pegasus*	Winged Horse
Perseus*	Perseus
Pisces*	Fishes
Pisces Austrinus	Southern Fish
Sagitta	Arrow
Sagittarius*	Archer
Scorpius*	Scorpion
Serpens	Serpent
Taurus*	Bull
Triangulum	Triangle
Ursa Major*	Great Bear
Ursa Minor*	Little Bear
Virgo*	Maiden

* Described further in a separate article of this title
† The large Ptolemy constellation Argo (Ship) is now divided into four smaller ones, namely Carina (Keel) Puppis (Stern) Pyxis (Compass) and Vela (Sail)

personages This was done to facilitate distinguish ing and recognizing the stars

Like cities on the surface of Earth which can be located by their coordinates (longitude and lati tude) stars on the celestial sphere also possess co-ordinates (right ascension and declination), which define their positions accurately in the sky How ever it is easier to find a city on the map by know ing its relationship to a coast line a river or a mountain Similarly a star is located faster by a recognition of the constellation in which it is situ ated The constellations are the landmarks and the bright stars the guide posts Constellations are use ful in helping astronomers navigators and survey ors to find the stars they need In this space age constellations are indispensable to moon watchers for tracking artificial satellites

The system of constellations in use today was begun thousands of years ago by Chaldean and Egyptian astronomers and was further developed by the Greeks and Romans Selecting conspicuous groups of stars, they fitted around them the im agined forms and figures from their mythology and wove about them legend and folklore Some con stellations vividly represent their designations, while others require a considerable stretch of the imagination to visualize any resemblance

People from different parts of the world natu rally arranged the stars differently Even prominent configurations were represented by different ob jects Thus the Oriental nations, such as China, Japan, Korea, and India, and the early American Indians have their own systems of sky maps which are, with few exceptions distinct from the Greco-Semitic patterns used today

The ancients gave us most of the constellations [illegible] the Alexan

The ancients living in northern latitudes were unable to see the southern sky, hence it was not mapped In 1603 J Bayer charted the southern re gions and named 13 new southern constellations as presented in Table 2 Finally in 1763 N L deLacaille completed the list by adding 14 names to new constellations given in Table 3

These constellations together with Coma Bere nices (Berenice's Hair) whose origin is uncertain although it is sometimes credited to Tycho Brahe make up a total of 88 groups, now recognized and universally accepted as illustrated

Of the constellations in the sky, those along the zodiac are of special significance The zodiac is an imaginary belt or zone of the sky, 18° wide and centered on the ecliptic (the path of the Sun) Within this zone move the Sun Moon and planets The stars in the zodiac were grouped into constel

Table 2 Bayer s constellations of the southern hemisphere

Latin name	English equivalent
Apus	Bird of Paradise
Camelopardalis	Giraffe
Canes Venatici	Hunting Dogs
Chamaeleon	Chameleon
Columba	Dove
Dorado	Sword Fish
Grus	Crane
Hydrus	Water Snake
Indus	Indian
Lacerta	Lizard
Leo Minor	Lesser Lion
Lynx	Lynx
Monoceros	Unicorn
Musca	Fly
Pavo	Peacock
Phoenix	Phoenix
Scutum	Shield
Sextans	Sextant
Triangulum Australe	Southern Triangle
Tucana	Toucan
Volan	Flying Fish
Vulpecula	Little Fox

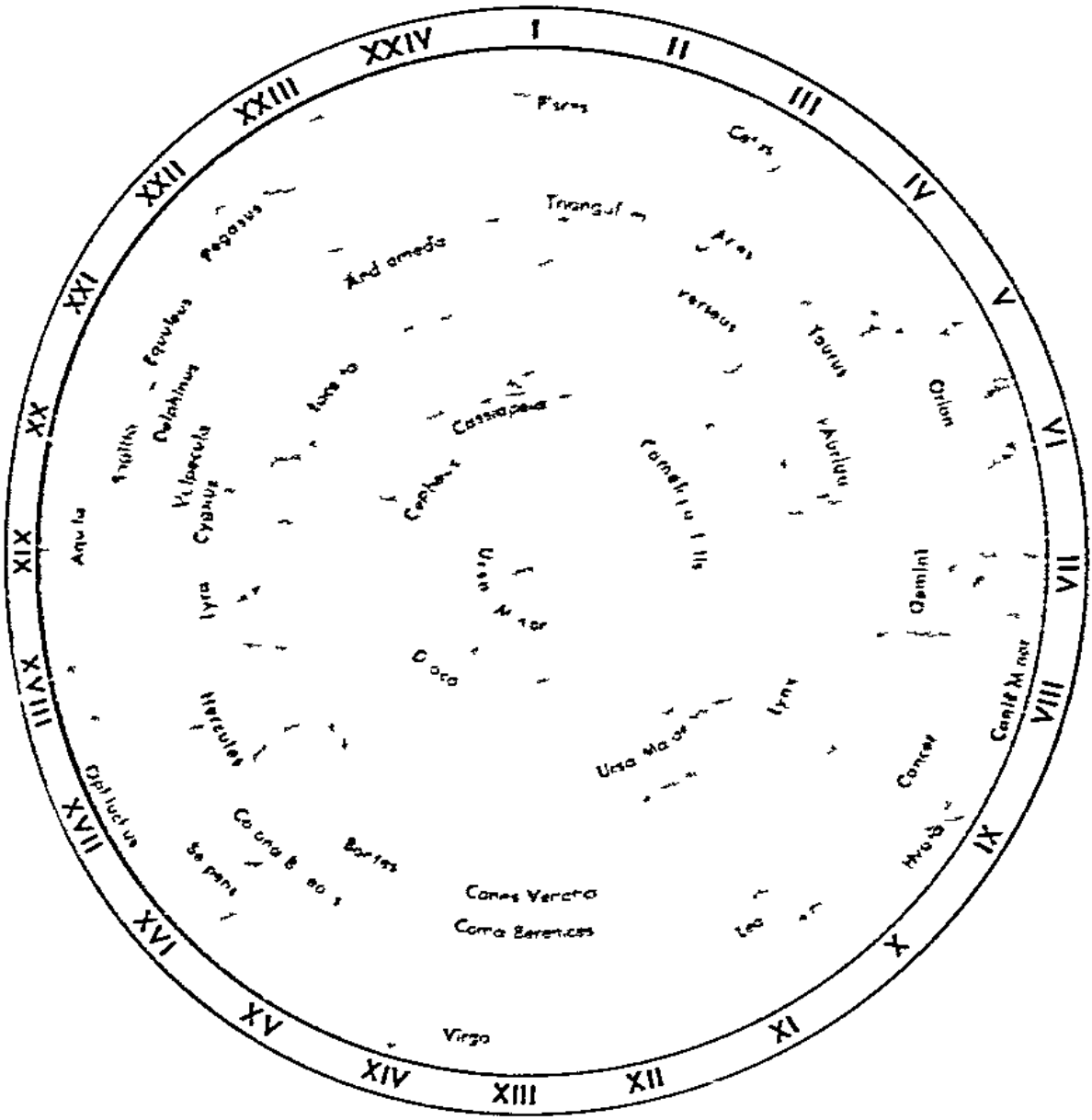


Fig 1 Northern hemisphere constellations, with brighter stars shown by larger dots.

Table 3. Lacaille's additional southern constellations

Latin name	English equivalent
Antlia	Air Pump
Caelum	Chisel
Circinus	Compasses
Crux*	Cross
Fornax	Furnace
Horologium	Clock
Mensa	Table
Microscopium	Microscope
Norma	Rule
Octans	Octant
Pictor	Easel
Reticulum	Net
Sculptor	Workshop
Telescopium	Telescope

* Described further in a separate article having this title

lations most of which have the figures of animals hence the name zodiac, or animal circle.

The zodiac is divided equally into 12 sections, called signs in each of which the Sun is situated for 1 month of the year. Each sign, 30° in length, is named from a constellation with which the sign originally coincided. These 12 zodiacal constellations are—beginning from the vernal equinox, the first point of Aries in order westward—Aries (Ram) Taurus (Bull) Gemini (Twins), Cancer (Crab) Leo (Lion) Virgo (Maiden) Libra (Balance) Scorpius (Scorpion) Sagittarius (Archer), Capricornus (Sea Goat) Aquarius (Water Bearer) and Pisces (Fishes)

When the zodiacal constellations first came into use over 2000 years ago the vernal equinox was at Aries. Because of the precession of the equinoxes, each of the zodiacal signs has since moved west

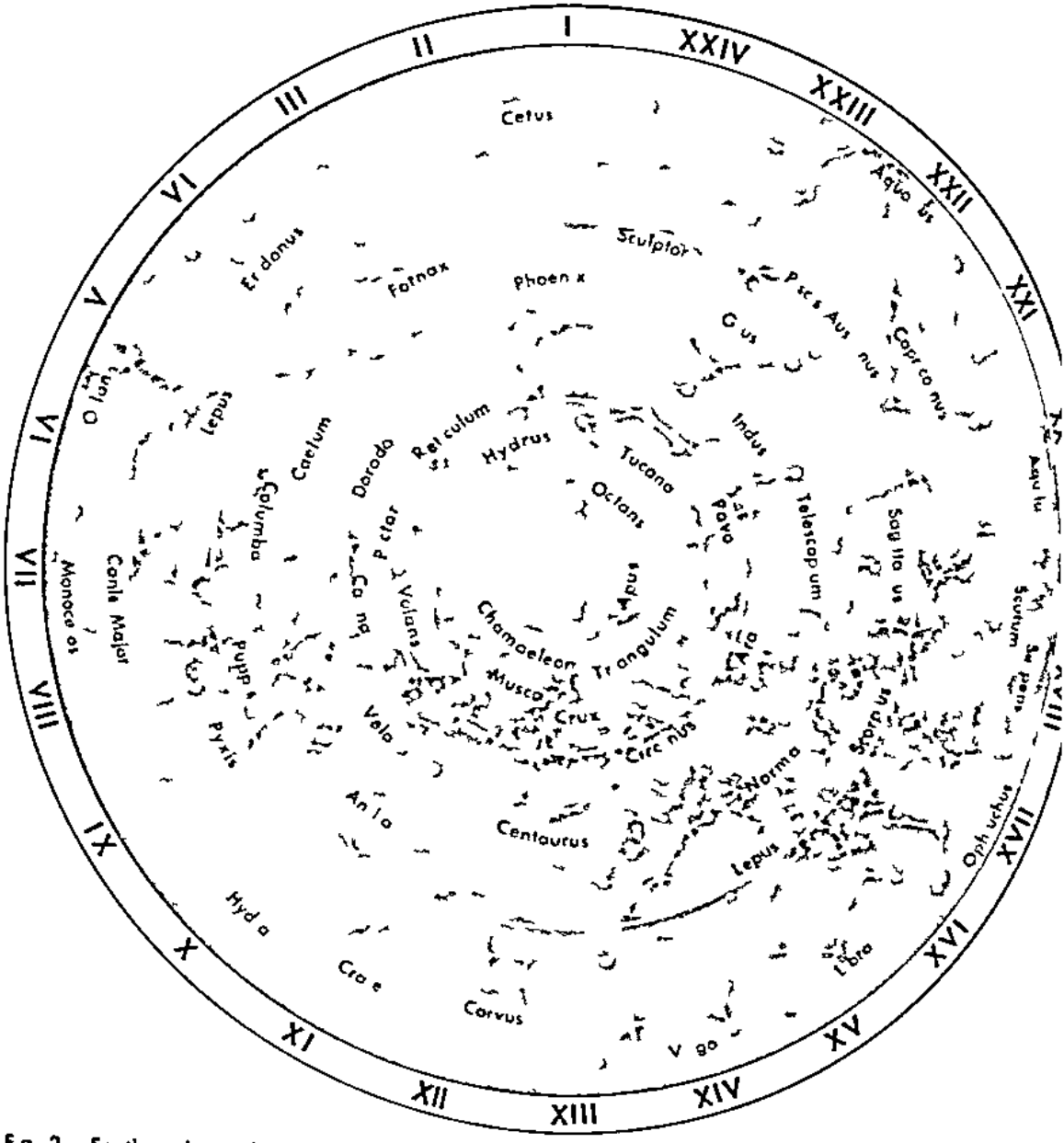


Fig 2 Southern hemisphere constellations with brighter stars shown by larger dots

ward 30° along the ecliptic Thus all the signs are now displaced into the neighboring constellation For instance the sign Aries is now in the constellation Pisces Unsuccessful attempts have been made to change the names of the constellations or to introduce new ones such as to replace the old pagan nomenclature with Christian names by substituting the names of the 12 Apostles for the 12 zodiacal constellations

Some of the old constellations have been given new significance For instance Cygnus today is better known as the Northern Cross The Big Dipper is the most familiar part of Ursa Major Delphinus is sometimes called Job's Coffin Also some familiar designations bear no relation to the constellations' names such as the Great Square in Pegasus the Sickle in Leo [illegible] Sa [illegible] W [illegible] was no ambiguity in locating them But when fainter and fainter stars were considered, and new and more constellations were added the sky areas became so crowded that uncertainty and confusion naturally resulted at the boundaries The situation became even more hopeless when different sky cartographers would draw the constellation figures and boundaries according to their own whims and fancies To remedy the confusion and to secure a general agreement on the boundaries, the International Astronomical Union in 1928 instituted a much needed reform by remapping all the constellations Replacing the irregular and uncertain outlines the new boundaries now run only from north to south and from east to west though they zigzag considerably to contain as many stars as possible in their former constellations [C S T]

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Constipation

The passage of hard dry stools The term has come to ind cate the irregularity or absence of bowel movements for any period of *time considered ab* normal by an individual However the character of the stool is generally of more significance than the interval between bowel movements or the quantity of feces evacuated

Bowel function has become a preoccupation of a large number of *persons and many misconceptions* misunderstandings and abuses have resulted There is no necessity for a fixed amount of fecal material to be moved at regular intervals in the healthy in d vidual although such characteristics are often present Some perfectly normal persons evacuate as often as two or three times a day whereas others may have a normal stool two or three *times a* week. Normal variations occur with changes in diet activity *state* of general health and a large num ber of other factors

Undigested residues normally enter the large *bowel* or colon as liquid material One of the many *functions* of the colon is to reabsorb water and other substances during the peristaltic passage of this ma *terial to* the rectum During this interval which nor mally takes 2 3 days the fecal matter loses most of its fluid *so that* it enters the rectum in a formed yet compressible state In the lower colon and rec tum the presence of the mass initiates the reflex acts that lead to defecation *See* DEFECATION

Constipation may result from one or more of *many* causes Atonic constipation is that form not accompanied by signs of abdominal griping or dis tress whereas hypertonic constipation is marked by spasms spasticity of the bowel and abnormal ac tivity of its movements

Common causes of constipation include faulty nutrition inadequate water intake poor general health and emotional stresses or tensions The use and abuse of laxatives is a common finding in cases of irregularity and bowel complaints Local disease of the colon such as inflammation fistulas tumors polyps and obstructions may produce constipation sometimes alternating with diarrhea Certain sys temic diseases such as hyperthyroidism circulatory d turbances stomach ailments and infections may be accompanied by constipation *See* CIRCULA TION DISORDERS INFECTION THYROID GLAND

Whatever the cause professional diagnosis and treatment should be solicited because self medica tion commonly leads to a vicious cycle of continued disturbances [E G ST]

Constraint

A restriction on the natural degrees of freedom of a system If n and m are the numbers of the natu ral and actual degrees of freedom the difference $n - m$ is the number of constraints In principle $n = 3N$ where N is the number of particles for example atoms In practice n is determined by the number of effectively rigid components

A holonomic system is one in which the n origi nal coord nates can be expressed in t dependent coordinates and possibly also the time It is characterized by frictionless contacts and in extensible linkages The new coordinates q_1 q_2 q_m are called generalized coordinates The equations of equilibrium and of motion may be ex pressed in terms of these coordinates *See* LA GRANGE S EQUATIONS

Nonholonomic systems cannot be reduced to in dependent coordinates because the constraints are not on the n coordinate values themselves but on their possible changes For example an ice skate may point in all directions but at each position it must point along its path This is a condition be tween changes $(dx\ dy)$ in the two position coordi nates $(x\ y)$ and the direction angle θ namely

$$dy = \tan \theta\ dx$$

This cannot be put in an integrated f rm

$$f(x\ y\ \theta) \quad 0$$

since a skater can pass in different directions re peatedly over a point

The static equilibrium conditions of a con strained system under impressed forces F_1 F_2 and so on are contained in a general statement the principle of virtual work or virtual displacement *See* STATICS IN SPACE VIRTUAL WORK PRINCI PLE OF

A moving constraint is one which changes with

do work For example a mass constrained to move on the floor of a rising elevator is carried also in the direction of the (vertical) force of constraint which does work on it [B G]

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Construction engineering

A specialized branch of civil engineering concerned with the planning execution and control of con struction operations for such projects as highways buildings dams airports and utility lines

Planning consists of scheduling the work to be done and selecting the most suitable construction methods and equipment for the project Execution requires the timely mobilization of all drawings layouts and materials on the job to prevent delays to the work Control consists of analyzing progress and costs to insure that the project will be done on schedule and within the estimated cost

Planning The planning phase starts with a de tailed study of construction plans and specifica tions From this study a list of all items of work is prepared and related items are then grouped to gether for listing on a master schedule A sequence

items are selected to satisfy the schedule and the character of the project at the lowest possible cost For a discussion of methods of operation *see* CONSTRUCTION METHODS For a discussion of various types of equipment *see* CONSTRUCTION EQUIPMENT

The amount of time allotted for a certain operation and the selection of methods of operation and equipment are generally determined by the equipment that is readily available to the contractor After the master or general construction schedule has been drawn up subsidiary detailed schedules or forecasts are prepared from the master schedule These include individual schedules for procurement of material equipment and labor as well as forecasts of cost and income

Execution The speedy execution of the project requires the ready supply of all materials equipment and labor when needed The construction engineer is generally responsible for initiating the purchase of most construction materials and expediting their delivery to the project Some materials such as structural steel and mechanical equipment require partial or complete fabrication by a supplier For these fabricated materials the engineer must prepare or check all fabrication drawings for accuracy and ease of assembly and often inspect the supplier's fabrication

Other construction engineering duties are the layout of the work by surveying methods the preparation of detail drawings to clarify the design engineer s drawings for the benefit of the construction crews and the inspection of the work to insure that it is in accordance with plans and specifications

On most large projects it is necessary to design and prepare construction drawings for temporary construction facilities such as drainage structures access roads office and storage buildings form work and cofferdams Other problems are the selection of electrical and mechanical equipment and the design of structural features for concrete material processing and mixing plants and for compressed air water and electrical distribution systems

Control Progress control is obtained by comparing actual performance on the work against the desired performance set up on the master or detailed schedules Since delay on one feature of the project could easily affect the entire job it is often necessary to add equipment or crews to speed up the work

Cost control is obtained by comparing actual unit costs for individual work items against estimated or budgeted unit costs which are set up at the beginning of the work A unit cost is obtained by dividing the total cost of an operation by the number of units in that operation

Typical units are cubic yards for excavation or concrete work and tons for structural steel The actual unit cost for any item at any time is obtained by dividing the accumulated costs charged to that item by the accumulated units of work performed

Individual work item costs are obtained by periodically distributing job costs such as payroll invoices to the various work item accounts Pay and equipment rental charges are distributed with the aid of time cards prepared by crew foremen The cards indicate the time spent by the job crew and equipment on the different elements of work The allocation of material costs is based the quantity of each type of material used for a specific item

When the comparison of actual and estimated unit costs indicates an overrun, an analysis is made to pinpoint the cause If the overrun is in equipment costs, it may be that the equipment has sufficient capacity or that it is not working properly If the overrun is in labor costs it may be that the crews have too many men lack proper supervision, or are being delayed for lack of materials layout In such cases time studies are invaluable analyzing productivity [W H

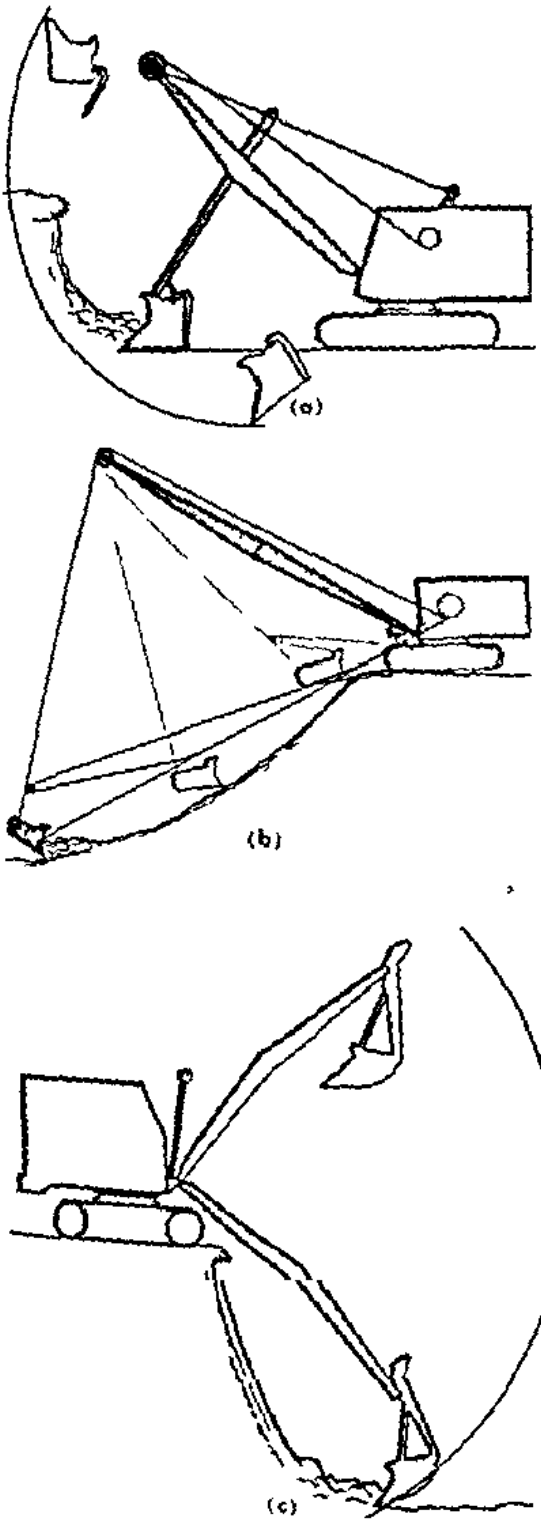
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Construction equipment

It is convenient to group construction equipment according to function such as equipment for excavation, for hauling for rock drilling and for pile driving The selection of a piece of equipment for a specific operation is usually based upon its ability to perform the work at the lowest possible cost This cost is determined by the equipment s productivity and the combined cost of owning and operating it

Excavating equipment This group of equipment includes machines which are purely excavators and those which combine excavating and hauling Another distinction may be made between land and marine excavators

Standard land excavators This classification includes the power shovel the dragline the crane with excavating buckets the backhoe the trenching machine the front end loader and the conveyor earth loader The power shovel is best adapted for digging into a bank It provides the greatest digging force and is widely used for difficult materials such as tough clays or blasted rock The dragline is best adapted for excavating material from the top of a bank as for a ditch or channel thus eliminating the need to go into a pit The crane with excavating bucket is used where the material is to be excavated from a shaft or from a stock pile of loose material such as sand or gravel There are two types of excavating buckets the *clam* shell bucket used for granular materials and the orange peel bucket used for blasted rock and sometimes for digging (see Fig 2) The backhoe is used for excavating trenches for pipelines and wall foundations Power shovels are made which can be rapidly converted into a dragline crane or backhoe by changing booms and modifying the rigging Special excavators include the trenching machine used for long runs in open areas the front end loader with the same application as the power shovel and the



g 1 Standard land excavators (a) Power shovel
) Dragline (c) Backhoe

onveyor earth loader which is best used in large
at areas

Combination excavators and haulers In this roup are the dozers and the carrying scrapers The ozer is a tractor with a front mounted movable lade which digs and pushes the material ahead ts economical hauling length is only a few hundred eet beyond which the scraper is more eco

The scraper consists of a crawler or rubber tired tractor pulling a specially designed wagon with a bladed bottom gate The blade excavates the ma terial and forces it into the wagon as the scraper moves ahead The gate is closed when the wagon is filled and remains closed as the scraper travels towards its destination At this point and with the scraper still traveling the gate is dropped and the excavated material discharged in an even layer

Marine excavators Marine excavators commonly known as dredges consist of excavating devices mounted on boats These devices may consist of a shovel or crane with clamshell bucket or a con tinuous bucket chain Suction dredges excavate by pumping the material out They are usually equipped with cutters to loosen the material prior to pumping

Hauling equipment Materials are hauled by special dump trucks dump wagons towed by rub ber tired tractors railroad cars conveyor belts or barges

The dump truck is the most common hauler be cause of its mobility and its adaptability to any job Dump wagon varieties are the rear or side dump version used for dumping rock and the bot tom dump version used for earth placement on large embankments

Drilling equipment Holes are drilled in rock for placing explosives for grouting for wells and for exploratory investigations Rock drills are gener ally classified according to the manner in which the bit or grinding tool disintegrates the rock Stand ard drill types are the percussion drill and the rotary drill The percussion drill grinds the rock by the impact from repeated blows It is the drill most commonly found in construction where the hole diameter varies from ¾ in to 6 in and the depth of the hole does not exceed 40 ft

Several types of percussion drills are the hand held jackhammer generally used for down holes the heavier drifter supported on a post or platform



Fig 2 Excavating buckets (a) Clamshell (b) Orange peel (c) Dragline

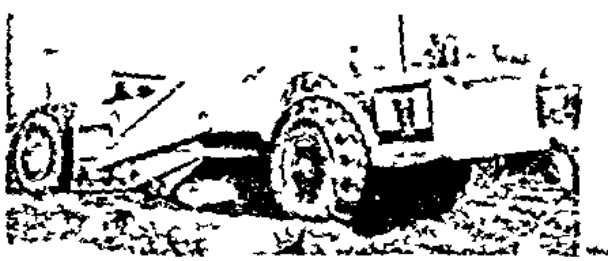


Fig 3 Motor scraper (General Motors)

so that it can drill horizontally or at an angle as required in tunnels and the wheel or crawler mounted drill commonly found in quarries

The rotary drill breaks up the rock through the grinding effect of a rotating bit One type of rotary drill is used for drilling quarry blast holes above 6 in in diameter Other types of rotary drills are the shot drill and the diamond drill which are mainly used for recovering rock cores for study

Pile driving equipment This equipment is used to drive bearing piles for foundations or sheet piles for cofferdams The basic piece of equipment is the pile hammer One type of hammer is the drop hammer which falls on the pile under its own weight and must be lifted by a rope

Hammers activated by steam or compressed air may be single acting where a pile driving ram is raised by air or steam pressure but drops by gravity or double acting where pressure is also applied to drive the ram The ram in a diesel hammer is raised and driven by an internal combustion explosion

Hoisting equipment Hoisting is a common operation during excavation concreting or steel erection The most common types of hoisting equipment are derricks cranes and cableways For a discussion of cableways *see* BULK HANDLING MACHINES

Derricks Derricks are of two types guy or stiff leg Guy derricks have the derrick mast tied to anchors by means of guy cables Stiff leg derricks use two structural steel sections to tie the mast back for support Guy derricks are stationary but stiff leg derricks can be made to move if counterweights are used for balance Derricks are used where hoisting will be done in a limited area as next to a shaft or

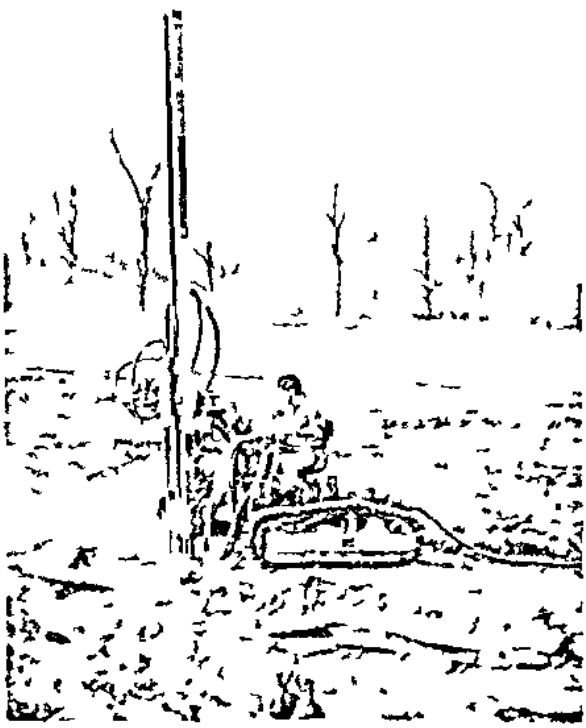


Fig 4 Crawler mounted drill (*Gardner Denver*)

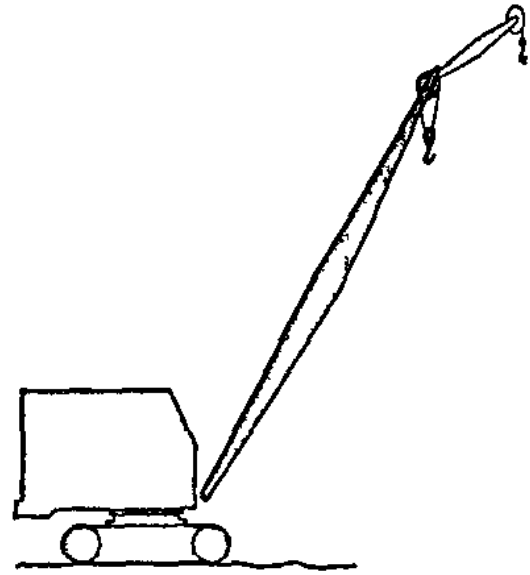


Fig 5 Crane

because the area or height of the work will prohibit the use of a crane

Cranes Cranes can swing around faster than derricks and have the ability to move They may be mounted on tire wheels crawler treads or railroad cars The wire rope used for hoisting cables consists of a number of individual wires wound into strands which are in turn twisted about a center made of hemp metal or wire rope The number of strands the direction of twist and the strength of the steel used for the wire rope can be varied according to specific use The hoisting machinery consists of a series of drums which can be driven by one engine or motor but can be separately controlled by individual clutches and brakes *See* HOISTING MACHINES

For other construction equipment *see* COMPRESSOR CONVEYING MACHINES PUMPING MACHINERY

Economic considerations Equipment cost is determined by adding depreciation investment maintenance and operation costs Depreciation is the decline in value over the economic life of the machine because of wear and tear and obsolescence The decline in value must be recovered by periodic depreciation payments into a fund to permit the owner to purchase an equivalent piece of equipment at the expiration of the machine s economic life Economic life always less than the possible operating life of a piece of equipment, is the time after which the increased cost of maintenance makes it uneconomical to keep the machine Investment costs consist of interest on investment, taxes and storage charges Maintenance costs cover necessary repairs overhaul and painting Operating costs cover operating labor fuel and lubrication. [W H]

See CONSTRUCTION ENGINEERING

Construction methods

The procedures and techniques utilized during construction Construction operations are generally classified according to specialized fields These include preparation of the project site earth moving

foundation treatment steel erection concrete placement asphalt paving and electrical and mechanical installations Procedures for each of these fields are generally the same even when applied to different projects such as buildings dams or airports. However the relative importance of each field is not the same in all cases For a description of tunnel construction which involves different procedures *see* TUNNEL.

Preparation of the site This consists of the removal and clearing of all surface structures and growth from the site of the proposed structure A bulldozer is used for small structures and trees Larger structures must be dismantled

Earth moving. This includes excavation and the placement of earth fill Excavation follows preparation of the site, and is performed when the existing grade must be brought down to a new elevation Excavation generally starts with the separate stripping of the organic topsoil which is later reused for landscaping around the new structure This also prevents the contamination of the nonorganic material which is below the topsoil and which may be required for fill Excavation may be done by any of several excavators such as shovels dragl nes clamshells cranes and scrapers For a discussion of their application *see* CONSTRUCTION EQUIPMENT

Efficient excavation on land requires a dry excavation area because many soils are unstable when wet and can not support excavating and hauling equipment Dewatering becomes a major operation when the excavation lies below the natural water table and intercepts the ground water flow When this occurs dewatering and stabilizing of the soil may be accomplished by trenches which conduct seepage to a sump from which the water is pumped out. Dewatering and stabilizing of the soil may in other cases be accomplished by wellpoints and electroosmosis For a discussion of these methods *see* ELECTROOSMOTIC DEWATERING WELLPOINT SYSTEMS

Some materials such as rock cemented gravels and hard clays require blasting to loosen or fragment the material Blast holes are drilled in the material explosives are then placed in the blast holes and detonated The quantity of explosives and the blast hole spacing are dependent upon the type and structure of the rock and the diameter and depth of the blast holes *See* BLASTING

After placement of the earth fill it is almost always compacted to prevent subsequent settlement Compaction is generally done by means of sheepsfoot grid and pneumatic tired rollers which are towed by tractors over the fill as it is being placed Hand held gasoline driven rammers are used for compaction close to structures where there is no room for rollers to operate

Foundation treatment When subsurface investigation reveals structural defects in the foundation area to be used for a structure the foundation must be strengthened Water passages cavities fissures faults and other defects are filled and strengthened by grouting Grouting consists of injection of fluid mixtures under pressure The fluids subsequently solidify in the voids of the strata Most grouting is done with cement and water mixtures but other mixture ingredients are asphalt cement and clay and precipitating chemicals

Steel erection The construction of a steel structure consists of the assembly at the site of mill rolled or shop fabricated steel sections The steel sections may consist of beams columns or small trusses which are joined together by riveting bolting or welding It is more economical to assemble sections of the structure at a fabricating shop rather than in the field but the size of preassembled units is limited by the capacity of transportation and erection equipment The crane is the most common type of erection equipment but when a structure is too high or extensive in area to be erected by a crane it is necessary to place one or more derricks on the structure to handle the steel In high structures the derrick must be constantly dismantled and reerected to successively higher levels to raise the structure For river bridges the steel may be handled by cranes on barges or if the bridge is too high by traveling derricks which ride on the bridge being erected Cables for long suspension bridges are assembled in place by special equipment that pulls the wire from a reel set up at one anchorage across to the opposite anchorage repeating the operation until the bundle of wires is of the required size

Concrete construction Concrete construction consists of several operations forming concrete

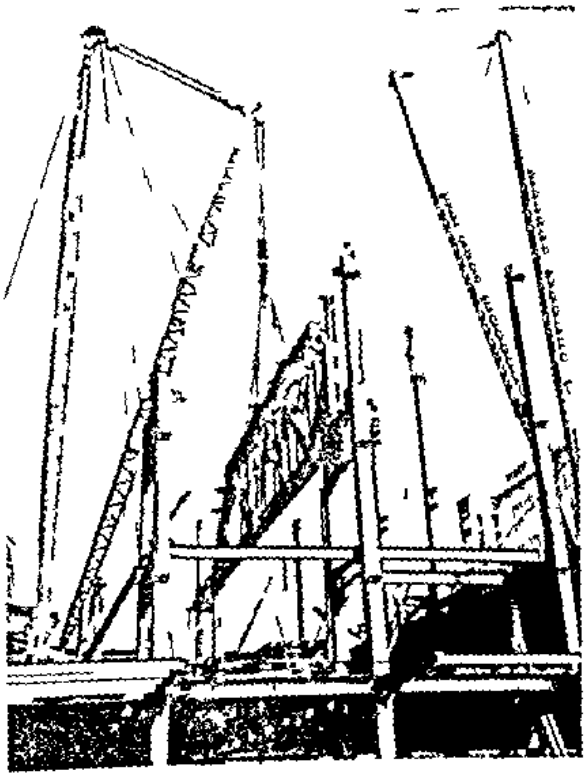


Fig 1 Steel erection with guy derricks (Bethlehem Steel Company)



Fig 2 Concrete form (*Superior Concrete Accessories*)

production placement and curing Forming is required to contain and support the fluid concrete within its desired final outline until it solidifies and can support itself The form is made of timber or steel sections or a combination of both, and is held together during the concrete placing by external bracing or internal ties The forms and ties are designed to withstand the temporary fluid pressure of the concrete

The usual practice for vertical walls is to leave the forms in position for a day after the concrete is placed They are removed when the concrete has solidified or set Slip forming is a method where the form is constantly in motion, just ahead of the level of fresh concrete The form is lifted upward by means of jacks which are mounted on vertical rods embedded in the concrete and are spaced along the perimeter of the structure Slip forms are used for high structures such as silos, tanks or chimneys

Concrete may be obtained from commercial batch plants which deliver it in mix trucks if the job is close to such a plant, or it may be produced at the job site Concrete production at the job site requires the erection of a mixing plant, and of cement and aggregate receiving and handling plants Aggregates are sometimes produced at or near the job site This requires opening a quarry and erecting processing equipment such as crushers and screens

Concrete is placed by chuting directly from the mix truck, where possible, or from buckets handled by means of cranes or cableways or it can be pumped into place by special concrete pumps

Curing of exposed surfaces is required to prevent evaporation of mix water or to replace moisture that does evaporate The proper balance of w and cement is required to develop full de strength *See* CONCRETE

Concrete paving for airports and highways fully mechanized operation Batches of conc are placed between the road forms from a truck or a movable paver, which is a combinat mixer and placer A series of specialized piece equipment, which ride on the forms follow spread and vibrate the concrete, smooth its surfa cut contraction joints, and apply a curing co pound

Asphalt paving. This is an amalgam of crush aggregate and a bituminous binder It may placed on the roadbed in separate operations mixed together in a mix plant and spread at o time on the roadbed Following placement, t pavement is compacted by rollers [W.J

Contact, electric

A conducting part which coacts with a similar pa to complete or interrupt an electric circuit Period intentional opening and closing is implied by th term contact in contrast with a joint between co ductors held together permanently Contacts are e sential elements of devices intended to make an break a metallic circuit in response to action of a operator or the apparatus of which the device is part For devices embodying contacts, *see* CIRCU BREAKER, RELAY, SWITCH ELECTRIC

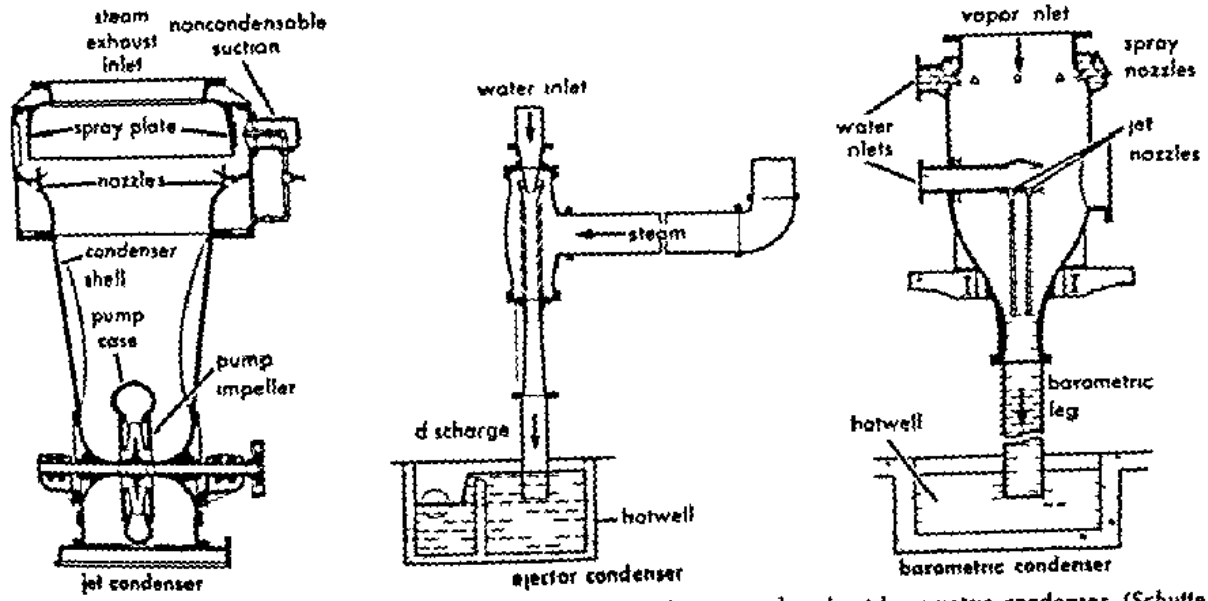
Contacts are classified according to function a (1) main which carry the full current of the cir cuit continuously, or (2) arcing, between whic an arc is struck when they open (arcing contact are connected in parallel with and arranged to par after the main contacts), the same contacts some times serve as both main and arcing

According to construction, contacts are classi fied as (1) butt, in which rigid coacting parts are held together by separate springs, (2) spring in which the resilience of the coacting members holds them together, and (3) wiping in which after touching, the members slide or roll with respect to each other so that the points of initial and final contact are different

Main contacts are often surfaced with metals such as silver, which maintain low electrical resist ance in the presence of air Arcing contact surfaces are usually made of refractory alloys which resist arc erosion [W.V.G.]

Contact condenser

A device in which a vapor is brought into direct contact with a cooling liquid and condensed by giv ing up its latent heat to the liquid In almost all cases the cooling liquid is water, and the condens ing vapor is steam Contact condensers are classi fied as jet barometric, and ejector condensers as illustrated In all three types the steam and cooling water are mixed in a condensing chamber and with drawn together Noncondensable gases are removed separately from the jet condenser, entrained in the cooling water of the ejector condenser and re-



Three basic types of contact condenser low level jet condenser (C H Wheeler Mfg Co) single jet ejector condenser and mult jet barometric condenser (*Schutte and Koert ng Co*)

moved either separately or entrained in the barometric condenser The jet condenser requires a pump to remove the mixture of condensate and cooling water and a vacuum breaker to avoid acci dental flooding The barometric condenser is self draining The ejector condenser converts the en ergy of high velocity injection water to pressure in order to discharge the water, condensate and non condensables at atmospheric pressure *See* Con DENSER, VAPOR [J F S]

Contact potential difference

The potential difference that exists across the space between two electrically connected metals it can also mean the potential difference between the bulk regions of a junction of two semiconduc tors In Fig 1*a* consider two metals M_1 and M_2 with work functions ϕ_1 and ϕ_2 respectively When the metals are brought in contact the Fermi levels that is the levels corresponding to the most ener getic electrons, must coincide as in Fig 1*b* Con sequently if $\phi_1 > \phi_2$, metal M_1 will acquire a neg ative and metal M_2 a positive surface charge at the contact area In the circuit indicated in Fig 2 here will thus exist a potential difference be tween the plates such that M_1 is negative with respect to M_2 the magnitude of the contact po tential is equal to $(\phi_1 - \phi_2)/e$ (of the order of a few volts or less) where $e \approx 1.6 \times 10^{-19}$ coulomb Note that the contact potential is independent of the number of different materials used in the cir cuit external to the plates in vacuum The contact potential difference may be measured by placing a variable electromotive force in the external circuit which can be balanced to make the potential dif ference between the plates equal to zero Contact potentials must be taken into account in analyzing physical electronics experiments *See* Work Func tion (Electronic) [A J DE]

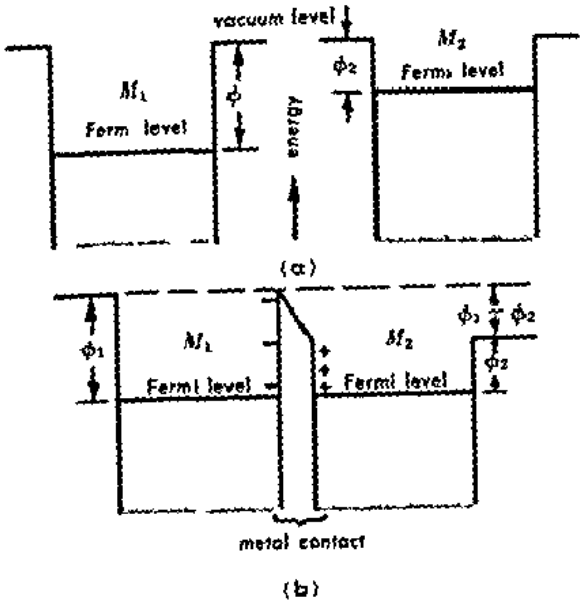


Fig 1 Energy-level d agram for the conduct on electrons of two metals (*a*) Before contact (*b*) After contact

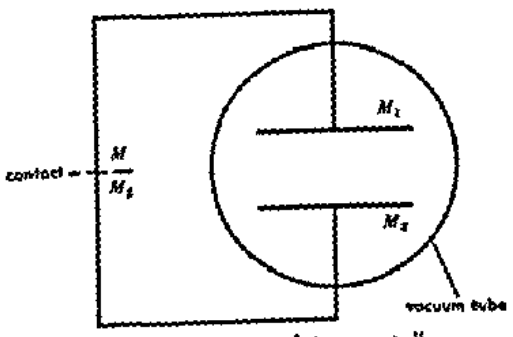


Fig 2 Schemat c diagram of two metall c vacuum between wh ch a contact potential o may be measured

Contact rectifier

A metal semiconductor rectifier which uses the electrical barrier at the contact between the metal and the semiconductor Common types are the copper oxide and selenium rectifiers also called dry plate or metallic rectifiers

Point contact rectifiers are usually called diodes More recently the techniques of jet etching and plating (*see* SURFACE BARRIER TRANSISTOR) have been applied to such rectifiers Most rectifier applications use semiconductor junction types rather than metal semiconductor contact types *See* SEMICONDUCTOR RECTIFIER [L P HU]

Continent

A protuberance of the earth's crustal shell with an area of several million square miles and with sufficient elevation above neighboring depressions (the ocean basins) so that much of it is above sea level

The term was originally applied to the most extensive continuous land areas of the globe The great majority of maps now in use imply that the boundaries of continents are their shorelines From the geological point of view however the line of demarcation between a continent and an adjacent ocean basin lies offshore at distances up to several hundred miles where the gentle slope of the continental shelf changes somewhat abruptly to a steeper declivity (*see* CONTINENTAL SHELF AND SLOPE) This change occurs at depths ranging from a few to several hundred fathoms at different places around the periphery of various continents

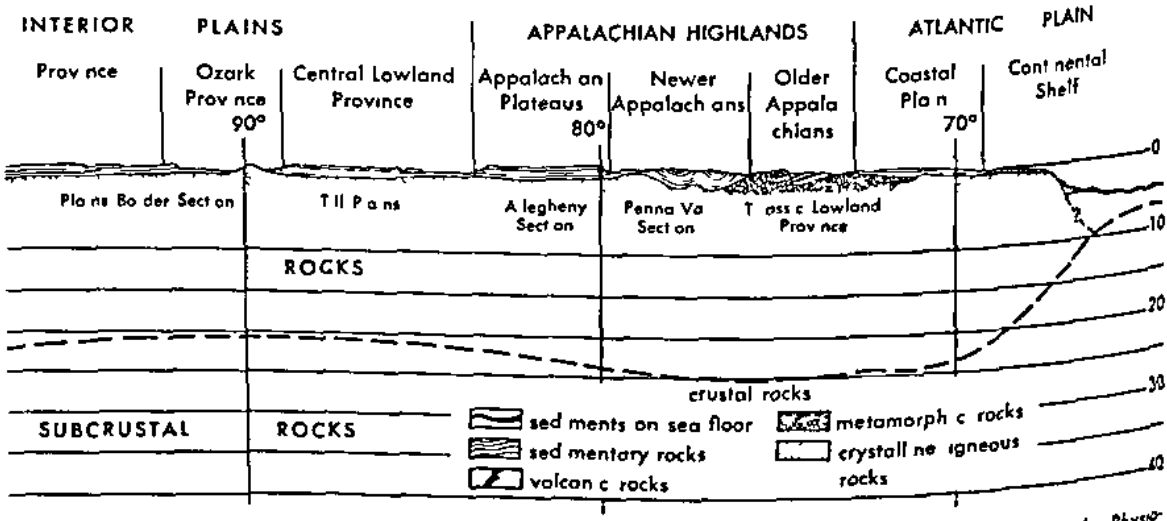
On such a basis numerous offshore islands the British Isles Greenland Ceylon and others are parts of the nearby continent Thus there are six continents Eurasia (Europe and India are parts of this largest continent), Africa North America South America Australasia (including Australia and New Zealand but not Indonesia) and Antarctica

All continents have similar structural features but display great variety in detail Each includes a basement complex of Precambrian age of metamorphosed sedimentary and volcanic rocks with associated igneous rocks mainly granite (*see* BASEMENT ROCK) Originally formed at considerable depths below the surface this was later exposed by extensive erosion then largely covered by sediments of Paleozoic and Mesozoic age chiefly marine limestones shales and sandstones In at least one area on each continent these basement rocks are now at the surface (an example is the Canadian Shield of North America) In some places they disappear beneath a sedimentary platform occupying a large fraction of the area of each continent, such as the area in the broad lowland drained by the Mississippi River in the United States In each continent there are long belts of mountains in which thick masses of sedimentary rocks are compressed into folds and broken by faults

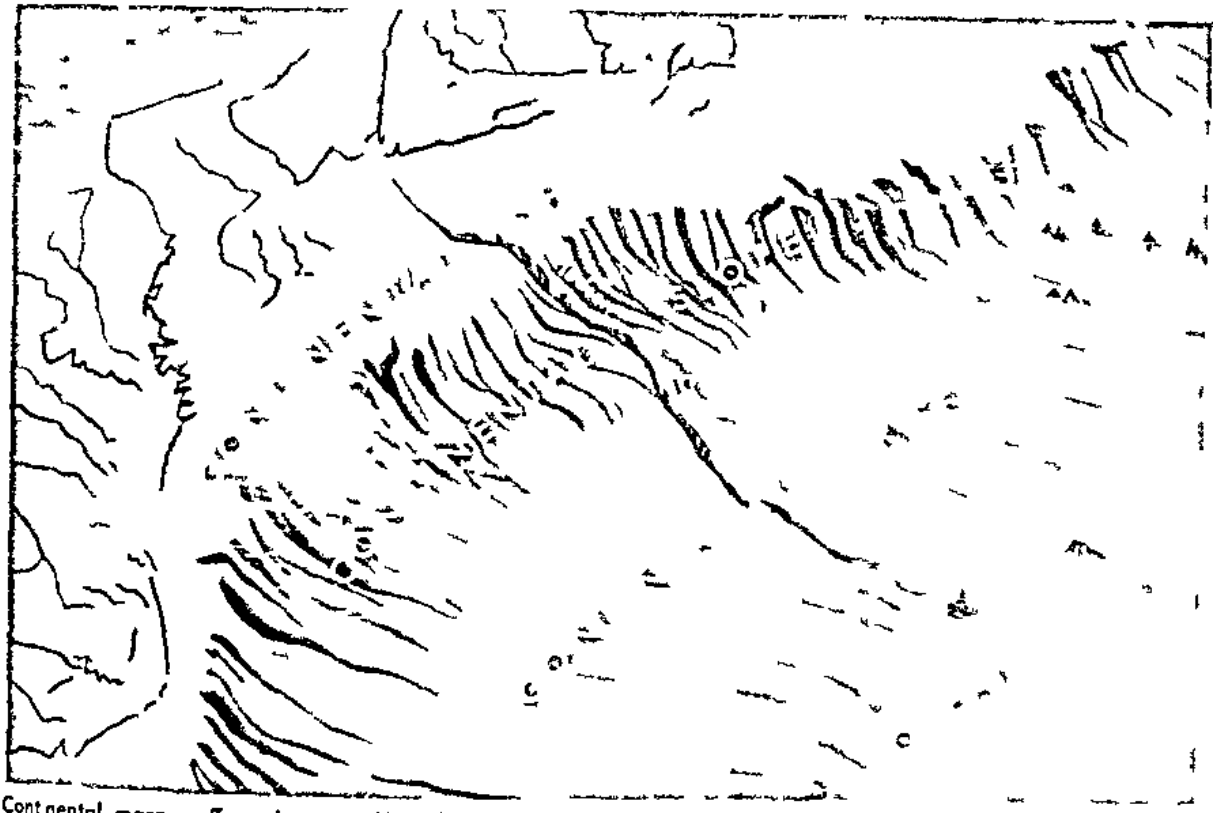
Presumably because of the large volume of granitic rocks beneath the surface of each continent the velocity of transmission of earthquake vibrations in continental segments of the earth's crust is slower than in oceanic segments in which basaltic rather than granitic rocks are the dominant type (*see* EARTHQUAKE, SEISMOLOGY) For the same reason the average density of the rocks composing continents is less than that of the rocks beneath the deep sea floors *See* ISOSTASY TERRESTRIAL GRAVITATION [K F M]

Continental shelf and slope

The continental shelf is the zone around the continent extending from the low water line to the depth at which there is a marked increase in slope to greater depth The continental slope is the declivity from the edge of the shelf extending down to great ocean depths Together the shelf and slope comprise the continental terrace which is the submerged fringe of the continent connecting the



A diagrammatic cross-sectional profile east-west across the North American continent at about 40°N (Geological section adapted from A K Lobeck *Physiographic Diagram of North America* Hammond 1948



Continental margin off northeastern United States

shoreline with the 2¼-mile deep abyssal ocean floor

Continental shelf This comparatively featureless plain with an average width of 45 miles slopes gently seaward at about 10 ft/mile At a depth of about 72 fathoms there generally is an abrupt increase in declivity called the shelf break or the shelf edge This break marks the limit of the shelf the top of the continental slope and the brink of the deep sea However some shelves are as deep as 200–300 fathoms especially in past or presently glaciated regions For some purposes especially legal the 100 fathom line or 200-meter line is conventionally taken as the limit of the shelf Characteristically the shelves are thinly veneered with clastic sands silts and silty muds which are patchily distributed but show a slight tendency to become finer offshore Geologically the shelf is in unity with the adjacent coastal plain in other words the position of the shoreline is geologically ephemeral being subject to constant prograding and regrading so that its precise position at any particular time is not important Genetically the origin of the shelf seems to be primarily related to shallow wave cutting (waves cut effectively as breakers and surf only down to about 5 fathoms the depth of vigorous abrasion) shoreline deposition and oscillations of sea level which have been especially

Although 5% of ably it

of the east coast of the United States the shelf is about 75 miles wide while off the west coast it is about 20 miles wide Especially broad shelves fringe northern Australia Argentina and the Arctic Ocean In the Barents Sea the shelf is 750 miles across

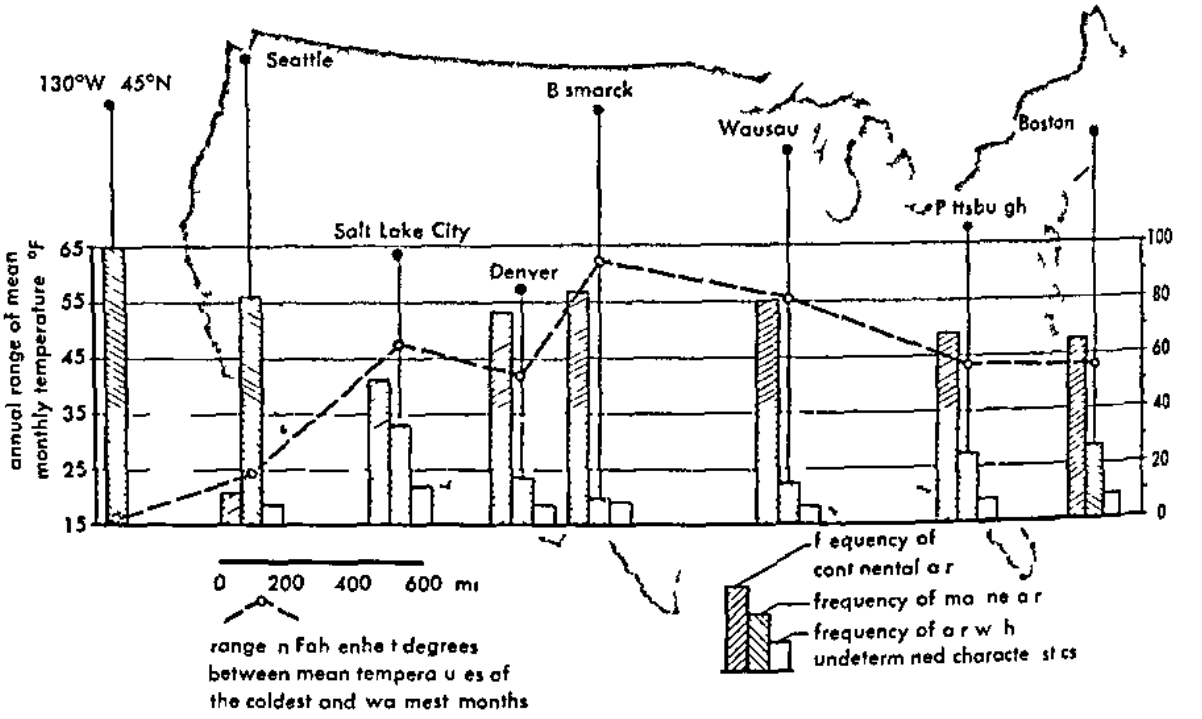
Continental slopes The drowned edges of the low density granitic or sialic continental masses are the continental slopes They are the walls of the deep sea basins Averaging 2½ miles high and in some places attaining 6 miles the continental slopes are the most imposing escarpments on the earth The slope is comparatively steep with an average declivity of 4 25° for the upper 1000 fathoms Most slopes resemble a straight mountain front which is highly irregular in detail in places it is deeply incised by submarine canyons some of which cut deeply into the shelf Usually the slope does not connect directly with the sea floor in

CANYON SUBMARINE TOPOGRAPHY [R S D]

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Continentality, weather and climate

The attributes of notably greater temperature ranges with associated weather characteristics that make inland and continental regions distinctly different from marine areas or areas bordering large bodies of water Unlike the latitudinal uniformity



Amplitude of the annual range in temperature in the United States related to continental location and to frequencies of maritime and continental air masses (Based on data compiled at *Headquarters Air Weather Service Climatic Center*)

of climate which might result from exposure of a uniform surface by the earth to the sun's rays some of the most outstanding differences are those between continental and oceanic areas—particularly in the middle latitudes These latitudes designated temperate zones by the Greeks of the classical period actually contain some of the least temperate weather and climate of the world over continental areas as well as truly temperate moderation in maritime provinces

The reasons are associated with the greatly different thermal behavior of water and land surfaces (*see* MARINE INFLUENCE ON WEATHER AND CLIMATE) The soil surfaces of the continents can be heated or cooled comparatively rapidly because the thermal effects are limited to a shallow surface layer The heat received at the ground is used to warm the top layers which consequently become hot in summer In winter by contrast the surface becomes notably cold since there is little conduction of heat from subsurface depths As a result of the responsiveness of the surface air temperature to the temperature of the underlying soil surface the air in contact with the ground undergoes temperature fluctuations of large amplitude lagging slightly behind the annual and diurnal periods of insolation

On the other hand the water surfaces which comprise the oceans are heated or cooled much less rapidly partly because the thermal effects extend to greater depths and partly because much of the solar energy absorbed at the sea surface is utilized for evaporation rather than heating As a result the upper layers of the ocean are not heated as strongly as the land surfaces in summer nor cooled as strongly by radiation in winter It follows that large annual and diurnal ranges in temperature with hot summers and cold winters are characteristic of the continental interiors of middle and high latitudes In contrast the summers over the oceans are cool and the winters relatively mild

Because the increase in the annual range in temperature inland over the continents is the most striking effect of the continental surface on climate climatologists have taken the annual range in temperature (ΔT) as a measure of the continentality The most frequently used formula is the one advanced by O V Johansson who defines the index of continentality K as

$$K = \frac{1.6\Delta T}{\sin \phi} - 14$$

where ΔT is annual range of monthly mean temperature in °C ϕ is latitude K is in % a pure oceanic climate presenting a value of 0% and completely continental climate one of 100% W Gorczynski and D Brunt have presented similar formulas although the one by Brunt while greater physical significance than the other two somewhat difficult to evaluate because it involves the use of solar radiation data as well as temperature data [W C]

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Continuous wave radar

A radar in which the transmitter output is uninterrupted in contrast to pulse radar where the output consists of short pulses The chief disadvantage of a continuous wave (CW) radar is that it is d

ficult to use a single antenna for both reception and transmission because both the transmitter and receiver are on all the time This difficulty has been overcome through the use of isolation circuitry which protects the receiver from a transmitter output up to 200 watts A continuous power of 200 watts permits the same long range performance as a peak pulse power of 200 kw in a conventional pulse radar having a duty cycle of 0 1% because the average power in each case is the same Separate antennas must be used for the transmitter and receiver if a higher power level is employed *See* RADAR

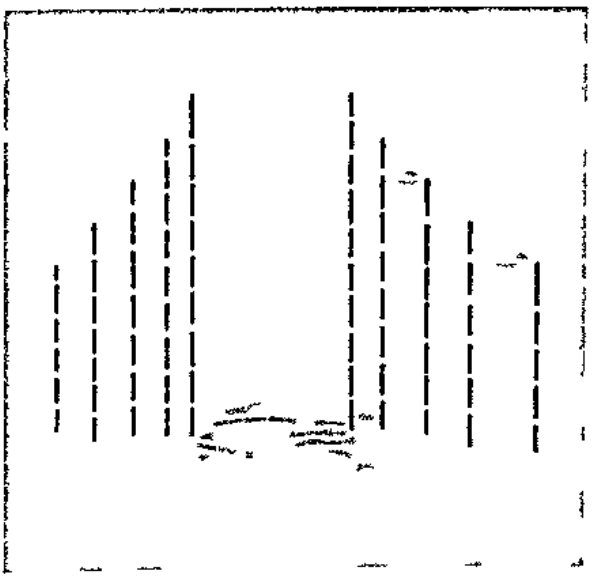
Among the advantages of CW radar is its ability to measure velocity with extreme accuracy by means of the Doppler shift in the frequency of the echo In general the frequency of a signal can be measured with a precision proportional to the time the signal is available for observation In CW radar the coherent observation time can be long whereas pulse radars do not permit comparable unambiguous Doppler measurements An additional CW advantage is that the total signal energy required for long range operation can be achieved with a comparatively low power level while pulse radars must employ relatively high peak power levels in short pulses to produce the necessary signal energy

In order to measure the range of targets some form of frequency modulation of the CW output must be used In one very effective form of modulation the carrier frequency of the transmitted signal is varied at a uniform rate Range is determined by comparing the frequency of the echo with that of the transmitter the difference being proportional to the range to the target that produced the echo Systems in which this is done are known as FM CW radars The range measuring precision is determined by the bandwidth of the frequency modulation The range measuring capabilities of FM CW and pulse radars can be compared on the basis of the spectral bandwidth of the signal transmitted in each case In pulse radars the spectral width is the reciprocal of the pulse width If an FM CW radar and a pulse radar transmit signals of the same spectral width they are capable of the same range resolution

A modified form of FM CW radar employs long but not continuous transmission This might be regarded as the same as transmitting extremely long pulses on a frequency modulated carrier Systems of this type are referred to as pulse compression radars The reason for the name is that the range resolution is determined by the frequency modulation rather than the pulse width and is of a quality corresponding to a pulse of much shorter duration or more compressed than the one employed The long pulse duration permits a long coherent observation of the Doppler shift leading to very good velocity accuracy Since the maximum effective range of the radar is determined by the total signal energy the use of a long pulse also permits the transmitter to operate at a lower power level than would be required in a conventional pulse radar [R I B]

Contour

The locus of points of equal elevation used in topographic mapping Contour lines represent a uniform series of elevations the difference in elevation between adjacent lines being the contour interval of the given map Thus contours represent the shape of terrain on the flat map surface Closely spaced contours indicate steep ground sparseness or absence of contours indicates gentle slope or flat ground Contours do not cross each other unless there is an overhang *See* TOPOGRAPHIC SURVEYING AND MAPPING



Contour representation

In ground survey procedures the horizontal positions and elevation of numerous points are observed Points on the elevations chosen for contouring are then located by interpolation and each contour is sketched by connecting the points found for its elevation *See* SURVEYING

In photogrammetric mapping with a stereoplotting instrument the operator sets his plotting table at the chosen contour elevation he hunts the elevation by shifting the table until a floating dot appears to touch the stereoscopic image he then lowers his plotting pencil and traces the contour by keeping the floating dot in apparent touch with the image *See* PHOTOGRAMMETRY [R H DO]

Control chart

Charts are an effective form in which to present quantities of data for rapid comprehension and interpretation Single events or isolated sets of data are presented in such forms as pie charts bar charts pictorial charts or line charts To compare recurrent events or sets of data from many supposedly identical situations control charts of several types may be used

Control charts are widely used in industry for quality control These statistical charts indicate the uniformity of a product such as the

SAMPLE NO.	Observations or Measurements				TOTAL	AVERAGE: $\bar{X}$	LARGEST VALUE	SMALLEST VALUE	RANGE: R
1	223	207	229	229	888	222	229	207	22
2	248	248	248	235	979	245	248	235	13
3	248	248	228	228	952	238	248	228	20
4	201	248	197	217	863	216	248	197	51
5	229	207	241	241	918	229	241	207	34
6	235	228	217	217	897	224	235	217	18
7	228	217	192	217	854	213	228	192	36
8	192	212	212	207	823	206	212	192	20
9	207	207	241	223	878	219	241	207	34
10	228	228	229	241	926	231	241	228	13

SECTION W-5

MACHINE Heat Treat #3

DATE March 10-14, 1958

DIMENSION
CONTROLLED Brinell Hardness

Fig 1 Typical work sheet for $\bar{X}$ and R chart

of an antibiotic or the octane rating of a gasoline The characteristic that is to be controlled is meas ured on several products or batches sampled from production and the results are recorded on the control chart As successive like samples are meas ured and the data recorded the statistical control chart indicates the degree of product uniformity If the production process can be modified changes can be made and their effects on the product ob served through the control chart In this way qual ity can be set and maintained at a desired level, and systematic changes in quality can be ant ci pated before the product becomes unmarketab Random variations inherent in the process a distinguished from unusual changes by the natu of the chart

The statistical theory on which control char are based stems from the normal frequency curv One characteristic of the normal curve is th 99 7% of all observations taken from a normal distributed universe lie within the limits $\bar{X} \pm 3$ Hence the limiting control lines of control char are located at what corresponds to $\bar{X} \pm 3\sigma$ Any ol servation plotted on a control chart that falls abo or below these control limits is presumed to b outside the normal universe and hence is out o control This indicates abnormal performance an is cause for investigation and correction or ad justment of the operation The most commonly used charts are the $\bar{X}$ and R chart, the p-chart, the c chart, and the $\bar{c}$ chart

Average and range The chart most frequently used by the quality control engineer is the $\bar{X}$ ($\bar{X}$ bar) and R chart This chart displays the average characteristic X of production units and the *range* R of the characteristic The first step toward an $\bar{X}$ and R chart is to collect the data and make the calculations In the example (Fig 1), four meas urements were made on each lot sampled and $\bar{X}$ and R computed for each sample The next step is to calculate, for the 10 samples grand average $\bar{\bar{X}}$ and average range $\bar{R}$

$$\bar{\bar{X}} = \sum_{i=1}^{i=10} \frac{\bar{X}_i}{10} = \frac{2243}{10} = 224$$

$$\bar{R} = \sum_{i=1}^{i=10} \frac{\bar{R}_i}{10} = \frac{261}{10} = 26$$

Factors for computing control chart lines

Number of observations in sample, n	Chart for averages: Factors for control limits A_1	Chart for averages: Factors for control limits A_2	Chart for standard deviations: Factor for central line c_2	Chart for standard deviations: Factors for control limits B_3	Chart for standard deviations: Factors for control limits B_4	Chart for ranges: Factor for central line d_2	Chart for ranges: Factors for control limits D_3	Chart for ranges: Factors for control limits D_4
2	3 76	1 88	0 564	0	3 27	1 13	0	3 27
3	2 39	1 02	0 724	0	2 57	1 69	0	2 58
4	1 88	0 73	0 798	0	2 27	2 06	0	2 28
5	1 60	0 58	0 841	0	2 09	2 33	0	2 12
6	1 41	0 48	0 869	0 03	1 97	2 53	0	2 00
7	1 28	0 42	0 888	0 12	1 88	2 70	0 08	1 92
8	1 16	0 37	0 903	0 18	1 82	2 85	0 14	1 86
9	1 09	0 34	0 914	0 24	1 76	2 97	0 18	1 82
10	1 03	0 31	0 923	0 28	1 72	3 08	0 22	1 78

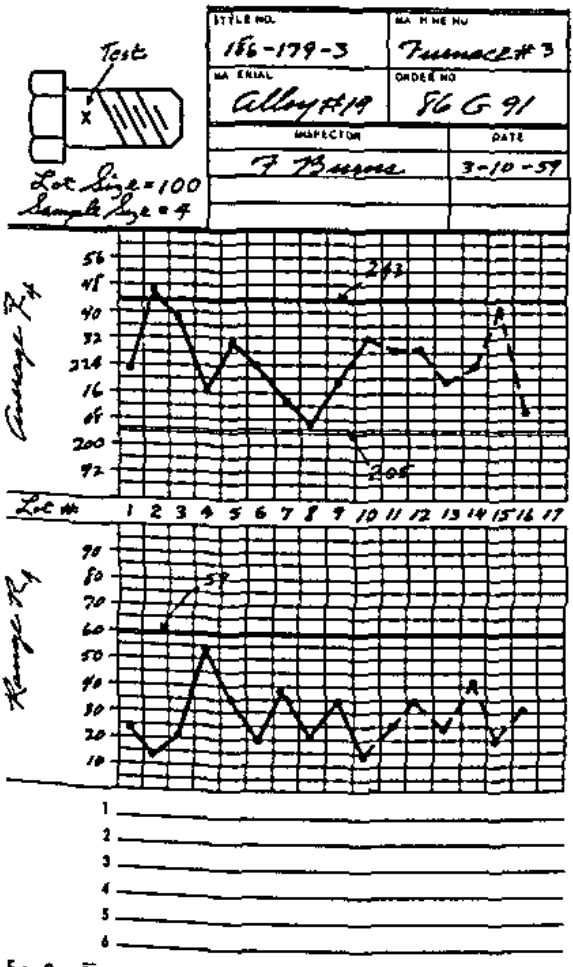


Fig 2 $\bar{X}$ and R chart constructed from data and calculations in Fig 1

From these parameters, control limits are calculated based on the normal distribution curve Tabulated chart factors simplify such calculations (see table) Thus, for $\bar{\bar{X}}$, control limits are

$$\text{Upper limit} = \bar{\bar{X}} + A_2\bar{R} = 224 + 0\,73 \times 26 = 243$$
$$\text{Lower limit} = \bar{\bar{X}} - A_2\bar{R} = 224 - 0\,73 \times 26 = 205$$

And, for R, control limits are

$$\text{Upper limit} = D_4\bar{R} = 2\,28 \times 26 = 59$$
$$\text{Lower limit} = D_3\bar{R} = 0 \times 26 = 0$$

Finally an $\bar{X}$ and R chart is constructed from the calculations (Fig 2) With the control limits thus established subsequent lots are inspected and $\bar{X}$ and R (dotted lines in Fig 1) are recorded Points outside the control limits such as for lot 2 indicate a need for a change in the manufacturing process

Fraction defective. There are situations in which the quality characteristic being inspected is judged as accepted or not accepted This is inspection by attributes No measurements are made, and the inspected unit is either passed or rejected, without reference to any degree of goodness The product may be inspected for one characteristic or for several (Fig 3)

The fraction defective is represented by small letter p and is the ratio of the number of rejected units in a lot or sample to the number of units in the lot or sample Control limit lines are

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$$

QUALITY CONTROL CHART NO 1 (WESTINGHOUSE FORM 284 B)

PRODUCT Hermetic Seal Armature | DEPT A 13 | MACHINE GlobeWinder | DATE April 18→

Fraction defective (Daily)

CHARACTER BY C Surge Test | INSPECTOR Secrist | OPERATOR #141

NO	TIME	DEFECTS A	B	C	D	E	TOTAL DEFECTS	TOTAL INSP	TOTAL PROD	p DEFECT
	4 18	5	4	7	2	3	21		538	047
	4 21	6	3	11	6	6	32		316	101
	22	3	1	6	4	2	16		523	031
	23	4	3	10	5	4	26		434	.060
	24	3	2	8	1	0	14		395	036
	25	2	3	9	1	1	16		499	.032
	4 28	6	3	30	1	2	42		421	104
	29	4	5	11	1	1	22		288	076
	30	1	2	3	1	1	8		230	035
	5 1	2	0	1	0	0	3		396	008
							200		4040	
	$\bar{p}$ =	200 / 4040	=	.0495	=	05				
	5-2	2	1	3	4	3	13		545	024
	5-5	5	4	4	1	1	15		395	.038
	6	3	1	1	2	1	8		403	020
	7	2	1	0	1	0	4		437	009
	8	4	3	3	3	2	15		387	.039
	9	1	4	2	1	1	9		620	.015

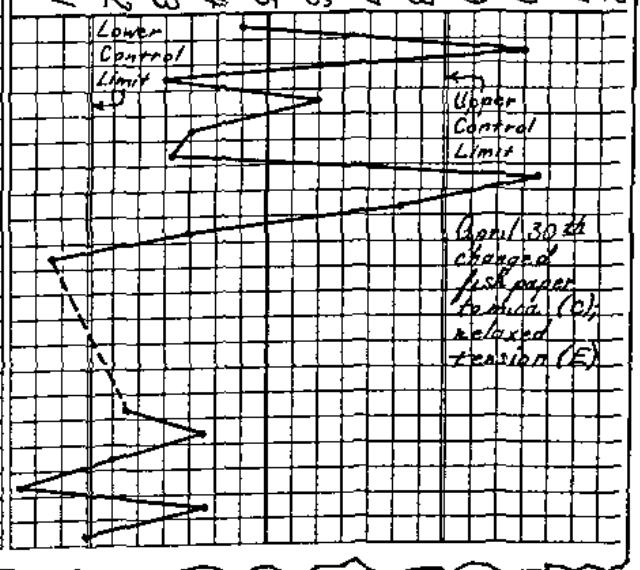


Fig 3 Work sheet and p-chart Defects are classified to assist in determination of corrective action

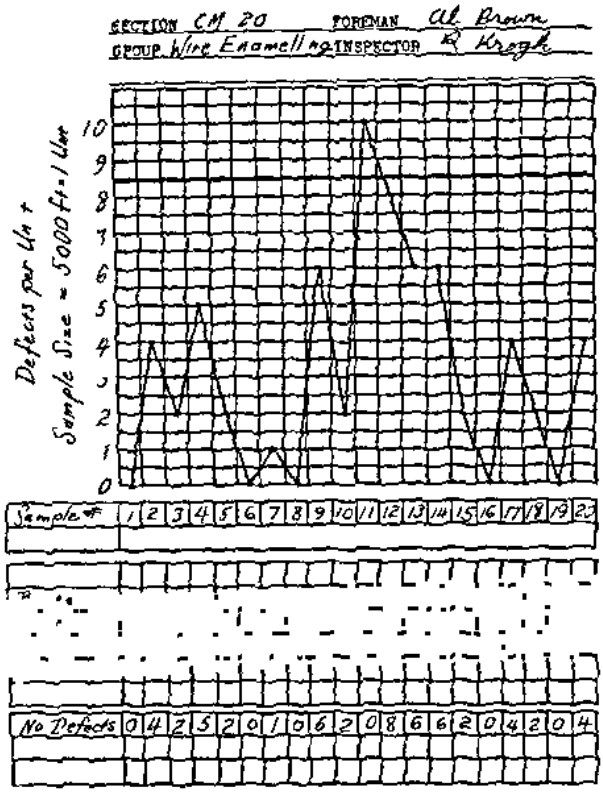


Fig 4 Control chart for defects per unit

where $$\bar{p} = \frac{\text{total units rejected}}{\text{total units inspected}}$$

$$\bar{n} = \frac{\text{total units inspected}}{\text{number lots inspected}}$$

The cause of points falling outside control limit lines should be determined and corrective action should be taken to correct the situation

Defects per unit. The *c* chart, generally known as a defects per unit chart, is used to show the number of defects found in one unit of product For this purpose the item is inspected and the number of defects found is recorded One or more items in a lot may be inspected, but a separate record is made of the number of defects found on each unit, and this number is plotted on the chart (Fig 4)

The control limits for a *c* chart are

$$\bar{c} \pm 3\sqrt{\bar{c}}$$

where $\bar{c}$ is the average number of defects per unit, calculated from the inspection of a number of units

$$\bar{c} = \frac{\text{total number of defects}}{\text{total number of units inspected}}$$

Recording different classes of defects facilitates corrective action when required In the example (Fig 4), 64 defects were found in 20 units inspected Therefore $\bar{c} = 64/20 = 3.2$ giving an upper control limit of 8 6 and a lower control limit of 0, because a negative control is meaningless

Average number of defects per unit. The $\bar{c}$ chart is used to show the average number of defects per unit in a sample For this purpose a number of items, generally four or five, are inspected and a record is made of the number of defects found in all units in the sample Then, the number of defects found is divided by the number of units in the sample, and this average number is plotted on the $\bar{c}$ chart Hence

$$\bar{c} = \frac{\text{number defects found in sample}}{\text{number units in sample}}$$

The control limits are

$$\bar{\bar{c}} \pm 3\sqrt{\bar{\bar{c}}/n}$$

where n is the number of units in the sample and $\bar{\bar{c}}$ is the average number of defects in all units in a number of samples, usually 10 or more

$$\bar{\bar{c}} = \frac{\text{total number defects}}{\text{total number units inspected}}$$

Figure 5 shows a simple form of $\bar{c}$ chart This form provides for recording the size of sample inspected and the number of defects found in each sample In this case, 294 defects were found in 500 units Therefore $\bar{c} = 294/500 = 0.6$ giving upper and lower control limits of 1 06 and 0 14 respectively

Special charts. The quality control engineer will find many uses for control charts The $\bar{X}$ and R charts are widely used The $\bar{c}$ chart and *c* chart are less widely used but are as informative and could be used more widely For unusual situations the quality control engineer may have to design special charts His ingenuity, initiative, and knowl

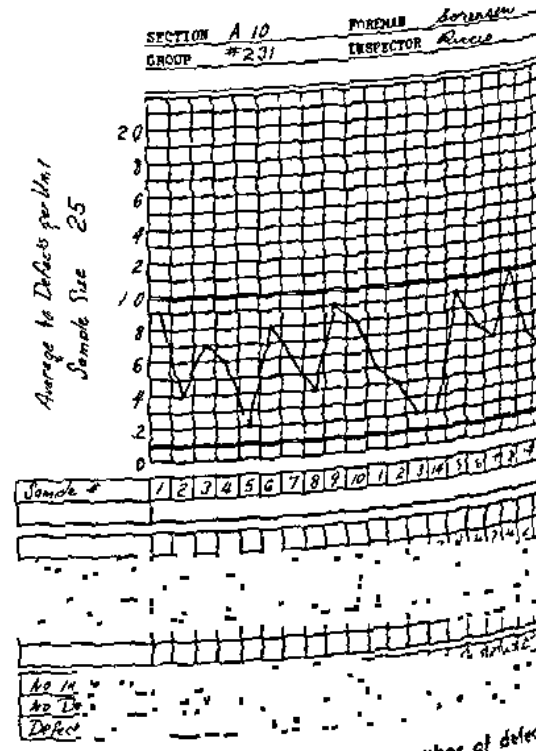


Fig 5 Control chart for average number of defects per unit in a sample

edge of statistical methods are the only limiting factors on the types of charts available to him

[J MN]

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Control systems

Systems in which one or more of the outputs must be constrained to follow a prescribed behavior Con trol systems are classified as either open loop or closed loop systems

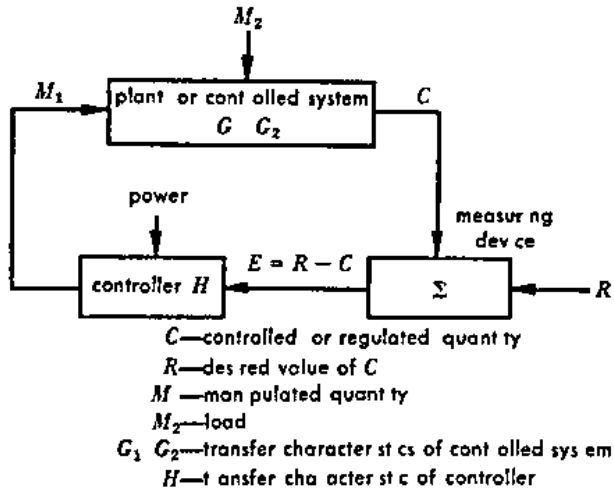
In an open loop control system the value of the output is directly determined by the input The heat supplied by an electric radiator is determined by the position of the adjusting switch not by the tem perature of the room For a different outside tem perature a different setting must be used to obtain the same desired room temperature The clock is another example of an open loop control system de signed so that regardless of changes in inputs to the system (temperature humidity location) the rate of movement of the hands remains the same For further discussion *see* OPEN LOOP CONTROL SYSTEM

In a closed loop or feedback control system the d fference between the actual value of the con trolled output and the desired value of that output is used to change the value of the input to the sys tem in such a manner as to maintain the output at or close to the desired value A temperature con trolled room is an example of a closed loop or feedback control system in which deviations in the controlled quantity (the temperature) from the de sired value are measured and used to regulate the flow of energy into the room in such a manner as to restore the room temperature to its desired value A regulated system is a closed loop control system in which the controlled quantity is held substan tially constant In such a system the controller is called the regulator Closed loop control systems are covered in this article

There exists a category of systems in which the output must be controlled to change its value more or less continuously in accordance with changes in one or more inputs In an antiaircraft gun system the position of the gun must be accurately con trolled to change its position according to informa t on received from a tracking device which instan taneously measures the position of the target This information is used to compute automatically the required instantaneous gun position which in turn must be imposed upon the gun

PRINCIPLES OF OPERATION

A feedback con r l L ad s
shown
of the
v ce
the va ue of the quantity to be controlled and com pares it cont nuously with the desired value of that



Fg 1 Block d agram of a feedback control system

quantity The controller accepts this information usually at low power level and provides an output the manipulated quantity at a power level required to control the plant The man pulated quantity is thus an input to the plant modulated in such a man ner as to force the controlled quantity to approach its desired value The controller often consists of an amplifier to raise the power level of the error sig nal a compensating circuit to provide desirable op erating characteristics and an actuator to produce a mechanical motion at relatively high power level

The controlled system or plant has one or more outputs which are to be controlled by manipulating

given by

$$C = G_1M_1 + G_2M_2 \tag{1}$$

where M_1 is the input to be manipulated to achieve control and M_2 represents the load which may change randomly with time G_1 and G_2 are mathe matical relationships known as the transfer charac teristics of the system

The controller receives as its input the measured difference E between the desired value R and con trolled quantity C

$$E = R - C \tag{2}$$

The output of the controller is the manipulated quantity M_1 The transfer characteristic H of the controller mathemat cally relates the controller output M_1 to its input E

$$M_1 = HE \tag{3}$$

In general the input E is a low energy level signal Since the output M_1 must be at a relatively h gh energy level external power must be supplied to the controller From Eqs (1) (2) and (3) the difference between the desired value and the ac tual value of the controlled quantity is

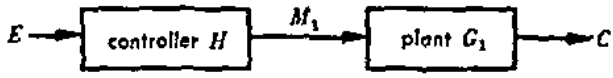


Fig 2 Control system of Fig 1 with feedback removed

$$E = \frac{R - G_2M_2}{1 + HG_1} \tag{4}$$

Equation (4) is basic to the understanding of linear feedback control systems When the system is complex and the load M_2 varies in a complicated fashion this expression is difficult to deal with However a number of important conclusions can be drawn directly from Eq (4) in its general form

1 The term HG_1 is the open loop transfer characteristic of the combined controller and plant (see Fig 2)

$$C = (HG_1)E$$

2 Zero errors in the presence of load disturbances M_2 and changes in the reference quantity R can be obtained only if HG_1 can reach an infinite value

3 Infinite values of error (instability) result theoretically if HG_1 ever has a value of -1

4 The properties of the controlled element mathematically expressed as G_1 are equally as influential in determining closed loop performance as the properties of the controller expressed by H Therefore to secure optimum performance the over all system must be designed as a careful integration of elements The familiar practice of designing the plant independent of its control and then fitting a controller to the system does not produce the best performance As the required level of performance becomes more exacting the need for careful systems design becomes imperative *See* SYSTEMS ENGINEERING

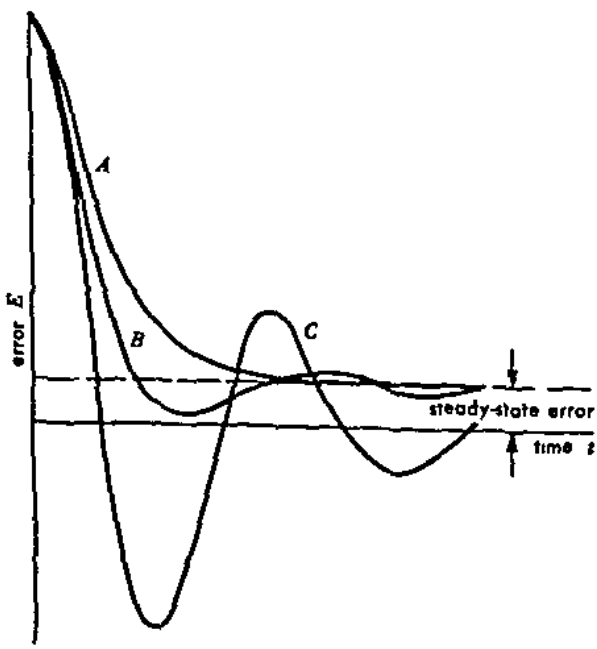


Fig 3 Responses to a step change of reference value Curve A is nonoscillatory Curve B is oscillatory but stable Curve C is excessively oscillatory

Performance objectives There are a number of criteria in use for judging the performance of feedback control systems All are aimed at establishing a reference against which the performance of any system may be evaluated These criteria must include the following objectives of control (1) the error E should be reduced to acceptable values after the application of disturbances M_2 or R to the system, for example, a speed governor may require that the steady state error in speed shall be less than 10% of rated speed when the load varies from zero to rated loads, (2) the error must reach its steady state value rapidly, and (3) the system must be stable—it must not oscillate excessively

It should be observed that although the above objectives are common to all control systems, it is not possible to give specific numbers that hold for all cases For example in the temperature regulation of a home, a steady state error of $\pm 2°F$ is acceptable, a time of 30 min in reaching the steady state after a disturbance (such as a sudden drop in outside temperature) is considered adequate, and minor oscillation is not regarded as disastrous In comparison, the specifications for certain controlled atmosphere chambers limit steady state errors to an order of 0 1°F, and require a speed of response of a few seconds with zero or very small overshoot Thus system performance is always measured relative to the requirements which the system must meet to fulfill its function

System response *Figure* 3 shows three responses to step changes in desired value for a closed loop system Curve A is a nonoscillatory response in which the error gradually approaches the steady state error In curve B some oscillation is present and a considerably shorter time is required for the error to pass through the steady state position While there is some oscillation in this case it dies out rapidly and in many applications would not be regarded as harmful In the response shown by curve C the damping is considerably lower the oscillation is of large amplitude and requires considerable time to damp out A response of this kind would be considered too oscillatory or too unstable for almost all applications In this case the response is shown oscillating about the zero steady state error position indicating that when the system does become steady, the steady state error will be zero

The steps taken to ensure small errors and fast response time often result in reduced stability of operation The final design is usually a compromise yielding the lowest errors and fastest response consistent with adequate stability

APPLICATIONS

Control systems have been employed in growing volume in many areas of industrial and domestic activity Temperatures pressures levels and flow rates in oil refineries and chemical plants are usually regulated by such systems The temperature of

houses the voltage of storage batteries in automobiles and the speed of steam turbines are additional examples of such systems

In an increasing number of situations control systems are being used to replace people on repetitive minor-decision making jobs In other cases it is possible to do things previously impossible without such systems Control systems can be much more rapid in response than a human being They are not subject to fatigue or distraction They can be used in destructive situations where if human aid were employed life would be endangered (such as in the guidance of unmanned aircraft and missiles) They are being used in complicated and expensive applications where accurate prediction of behavior must be made in advance of the actual building of the system This need became manifest early in World War II and sparked a great effort, still in progress which has made available powerful methods for the analysis and synthesis of control systems

A summary of commonly used aspects of this [illegible]

to construct control systems of the complexity and capability of those existing in the human body The systems which control the temperature of the body the movement of limbs, and other body functions and actions are truly marvelous examples of control systems of tremendous versatility *See* CYBERNETICS

There are many systems in which man is an element in the loop of a control system Logical design of such systems is demanding an increased knowledge of the human being as a dynamical system At the present time such knowledge is extremely limited *See* HUMAN ENGINEERING

ANALYSIS

The systematic determination of the behavior of a physical system in the presence of known disturbances is based upon a well developed body of mathematics The design and prediction of behavior of control systems rests heavily upon the effective use of certain powerful tools These tools can be used only after a model expressible in mathematical terms of the system under consideration has been established The creation of such a model involves important decisions of what is of first rank importance and what is of low-order importance and hence can be neglected The skillful building of relatively simple models of complex systems is the work of the expert engineer and the powerful methods of analysis available can be used only when the mathematical description of the model is in the relatively simple forms that permit handling in a reasonable time The validity of the model adopted must always be eventually checked by measurements made on the actual system

Types of controlled system or plant vary in complexity In the simplest types all the energy con

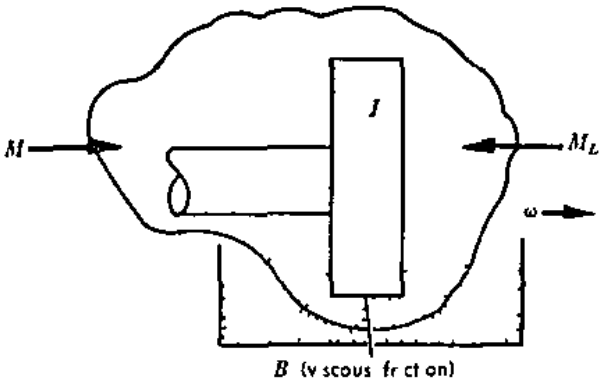


Fig 4 A viscous-damped rotating disk

tained can be expressed in terms of a single variable In complex distributed parameter systems an infinite number of variables is required to describe explicitly the energy stored in the system at any given time

Single capacity system Examples of single capacity systems include the rotating disk and the container of well stirred liquid In such systems all or nearly all of the energy stored within the boundaries of the system can be thought of as being held in a single reservoir and hence can be precisely stated if one and only one output quantity is known Thus the angular speed of the rotating disk completely determines the amount of energy stored In the case of the well stirred liquid the temperature of the liquid completely defines the energy content of the system

If the systems are linear the dynamic behavior of single capacity systems can be expressed by a linear differential equation of first order For the disk shown in Fig 4

$$J\frac{d\omega}{dt} + B\omega - M - M_L$$

where $\frac{d\omega}{dt}$ angular acceleration of disk

ω = angular speed of disk

J – moment of inertia of disk about axis of rotation

B – damping constant (damping torque is $B\omega$)

M = driving torque

M_L = load torque

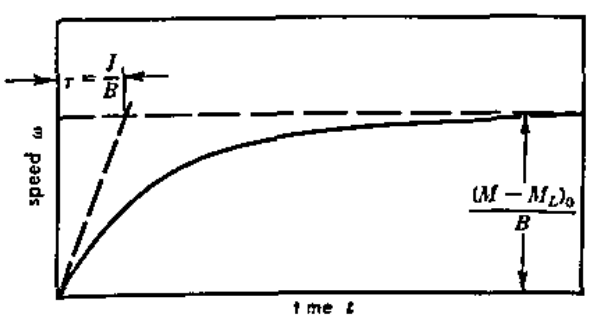


Fig 5 Speed vs time response to a step change in torque

If the net torque on the disk is suddenly changed from zero to the value $(M - M_L)_0$ the change of the speed of the disk is shown in Fig 5 Mathematically

$$\omega = \frac{(M - M_L)_0}{B}[1 - \epsilon^{-t/\tau}]$$

or $$\omega = \omega_{ss}[1 - \epsilon^{-t/\tau}]$$

where $\tau (= J/B)$ is the time constant of the response The response of the disk to a sudden change in applied torque can be thought of as the sum of two responses the transient response and the steady state response

$$\omega = \omega_t + \omega_{ss}$$

The transient response is

$$\omega_{tr} = \omega_{ss}\epsilon^{-t/\tau}$$

This indicates how fast the system reaches a new steady state after an applied disturbance The time constant τ is a direct measure of system speed of response The system output reaches about 98% of its new steady state value in a time equal to 4τ

While the foregoing discussion has concerned only the rotating disk system the results presented apply to all single capacity systems Thus when the electrical system shown in Fig 6 is subjected to a step change in input voltage V the change in output voltage takes the form

$$V_o = V_i(1 - \epsilon^{-t/\tau})$$

This response is shown in Fig 7

Other systems that can be approximated as single capacity systems are shown in Figs 8 and 9 Figure 8 is a fluid flow system Fig 9 shows a heat flow system The responses of all such systems to step changes in input are identical and are shown in Fig 10 which is nondimensional and therefore applicable to all such systems

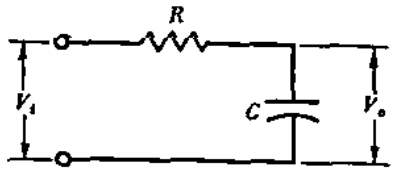


Fig 6 An *RC* circuit

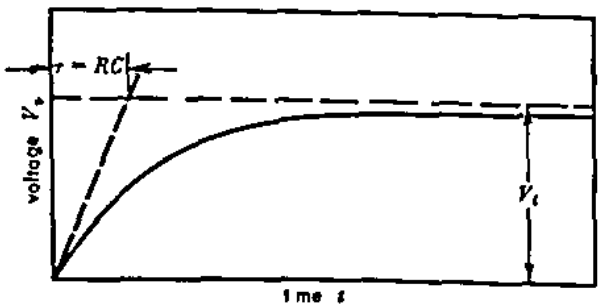


Fig 7 Response of *RC* circuit to step change in input voltage

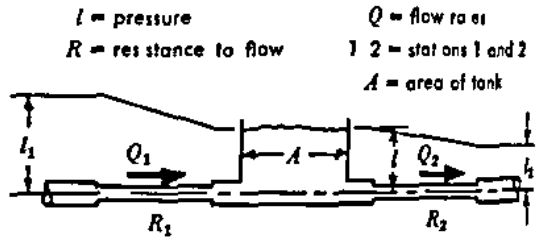


Fig 8 A fluid flow system

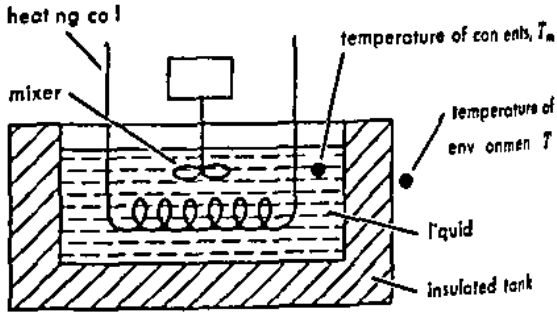


Fig 9 A heat transfer system

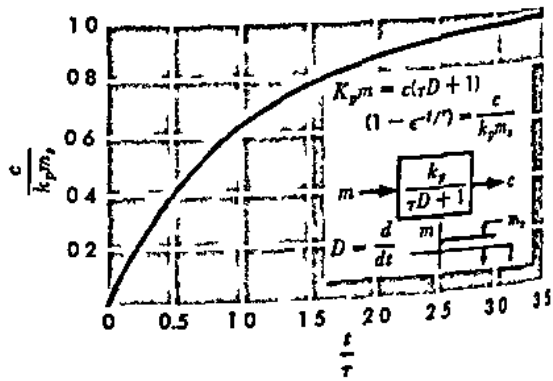


Fig 10 Transient response of a single-capacity system

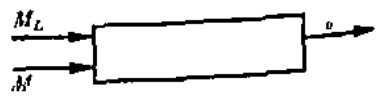


Fig 11 Block diagram of rotating disk

Control of a single capacity system The uncontrolled plant is shown in Fig 11 It is desired to maintain the speed at a value ω^* while changing the load M_L The actual speed ω is measured and compared with desired speed ω^* The difference $(\omega^* - \omega)$ serves as the input to a controller The output of the controller is the manipulated quantity M the change in the driving torque (see Fig 12) The controller must be so designed that the relation of its output M to the input error signal E yields desirable results

One of the most commonly used controllers produces an output proportional to the input error Such a controller would have the input output relationship $\Delta M = KE$ If the system is initially adjusted to have zero speed error under rated load conditions then it is convenient to express all variables as changes from equilibrium values at that

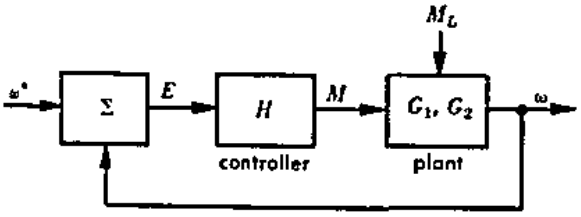


Fig 12 Feedback speed-control system

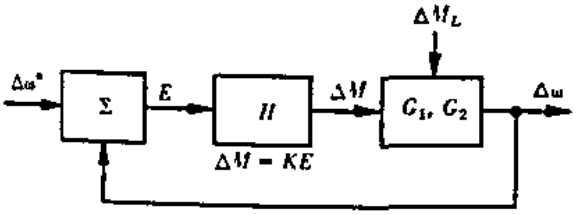


Fig 13 Variables as changes from an initial equilibrium condition

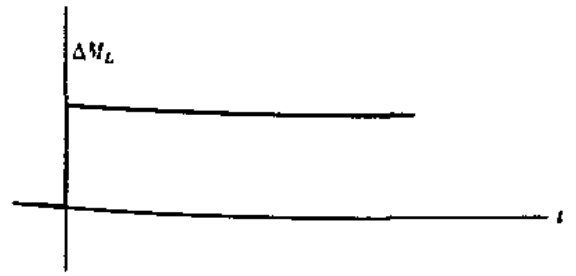


Fig 14 A step change in load

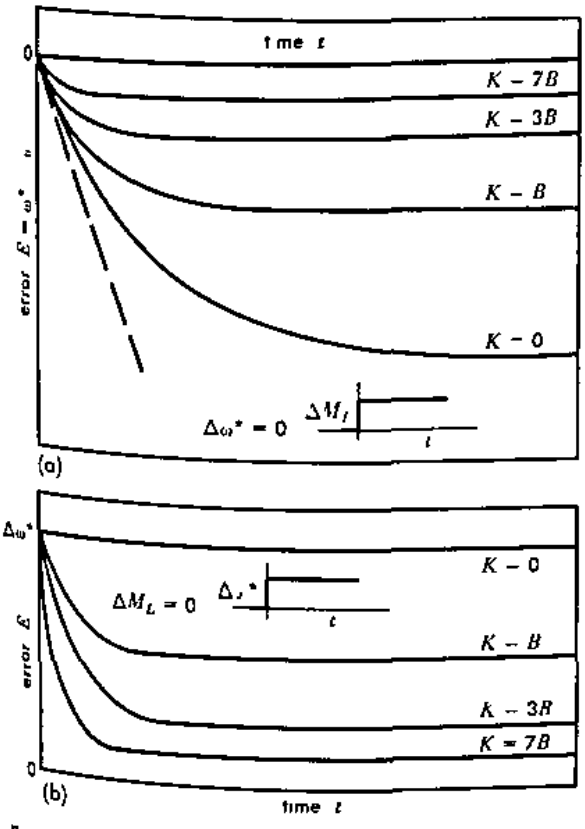


Fig 15 Transient response of speed control system (proportional control) (a) for step change of load, (b) for step change at desired speed

rated load condition (see Fig 13) The constant K is the gain of the controller, and it is important to determine an appropriate value for K The equation which describes the behavior of this closed loop system is

$$E = \frac{\omega^* - G_2 M_L}{1 + G_1 H}$$

When the correct quantities for the rotating disk system are inserted the following equation results

$$J\frac{dE}{dt} + (B + K)E = J\frac{d(\Delta\omega^*)}{dt} + B\,\Delta\omega^* + \Delta M_L \quad (5)$$

If no change in the desired speed is made ($\Delta\omega^* = 0$) but a step change in load (Fig 14) ΔM_L occurs Eq (5) becomes

$$J\frac{dE}{dt} + (B + K)E = \Delta M_L$$

The solution is

$$E = \frac{\Delta M_L}{B + K}[1 - \epsilon^{-t/\tau}] \quad (6)$$

where $\tau = J/(B + K)$ The nature of result is shown in Fig 15 The form of the solution is identical to that of the uncontrolled system However, as the value of the controller gain K is increased, the steady error in speed decreases and the time required to reach that steady state also decreases

Steady state error The steady state error is the error that remains after the transient influence of system disturbances has disappeared By allowing time t to go to ∞ in Eq (6), the steady error is found to be

$$E_{ss} = \frac{\Delta M_L}{B + K}$$

Important conclusions result

1 There will be a steady state error E_{ss} for all values of K other than ∞

2 The magnitude of E_{ss} will be proportional to the load change ΔM_L

3 The larger the value of gain K the smaller the steady state error

Speed of response The time constant $\tau = J/(B + K)$ is a measure of how fast the system reaches a new steady state following a disturbance Small values of τ indicate fast responses, large values of τ indicate slow responses Hence, the smaller the moment of inertia J and the larger the values of B and K, the faster will be the response The obvious but nonrealizable conclusion is that an infinite gain controller ($K = \infty$) is optimum because it would produce no steady state and no transient error Since such a device would put out an infinite torque in response to a very small input error signal, it cannot be realized physically An approximation of this response is obtained from the on off controllers sometimes used for single capacity systems This type of controller is a proportional controller with very high gain between its saturation points The improved performance

of the system for higher values of K is shown in Fig 15 The speed governing problem discussed above is important in many applications Historically it was the first application of automatic control in which the serious problem of dynamics which closed loop control poses was successfully faced The speed governor developed by James Watt in the eighteenth century was critical to the use of the steam engine in various applications

The model of a speed control system used in this discussion is an idealized one which neglects the mass of parts in the controller as well as the possible presence of backlash dead zones and other factors Thus problems of stability encountered in practice have not been indicated A somewhat more sophisticated model of the system can be readily devised which can be studied in the same manner

Multiple capacity systems The accurate prediction of the behavior of many important systems requires the use of a more complicated model Such a model must provide representation for more than one energy storage reservoir in the system The system shown in Fig 16 has three energy storage reservoirs Such a system could be represented by a single capacity model only if one of the tanks were very much larger than the others

The order of the differential equation describing the system is a direct function of the number of energy storage reservoirs Thus the rotating disk system—a single capacity—was represented by a first order differential equation The behavior of the triple tank system would be represented by a third order differential equation of the form

$$A\frac{d^3p_3}{dt^3} + B\frac{d^2p_3}{dt^2} + C\frac{dp_3}{dt} + Dp_3 - f(P_i) + f(P_o)$$

where A B C D = constants $f(P)$ = mathematical function of P and $f(P_o)$ = mathematical function of P

When the relationships concerning the controller and other elements of a feedback control loop are introduced the resulting equations become difficult to handle Various methods are available for obtaining solutions A few of the more commonly used ones are mentioned here Excellent references are available

Solution of differential equations Various methods are as follows

1 The classical method This method employs the assumption of certain general forms of solution

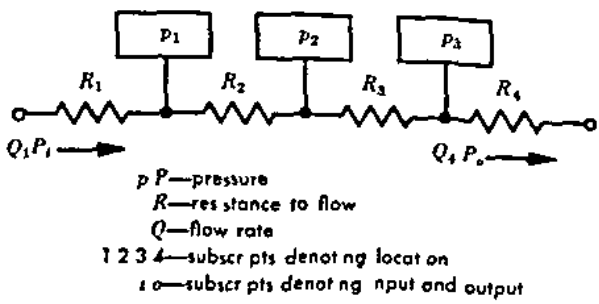


Fig 16 A three-capacity pneumatic system

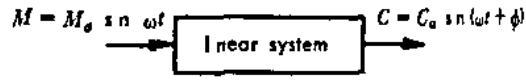


Fig 17 Frequency response of a linear system

substitution of the assumed general answer (such as $e^{\lambda t}$) in the differential equations and the use of known conditions (such as initial conditions) to solve for coefficients As the order of the differential equation rises this method becomes increasingly cumbersome and the determination of the roots of the characteristic equation becomes especially tedious It is nevertheless a widely used method *See* DIFFERENTIAL EQUATION

2 The Laplace transform method The differential equation is transformed into an algebraic equation with initial conditions inserted Manipulations are then algebraic and are simpler to handle than differential equations The last step involves inverse transformation to yield the final answer in the time domain *See* LAPLACE TRANSFORM

3 Analog computation An analog computer consists of physical elements whose behavior can be represented with differential equations Hence they find greatest application in the solution of control system problems They make possible solutions of systems with nonlinear components Because a solution can be obtained in a short time (order of seconds) once the computer is set up a survey of wide ranges of values of important parameters can be conducted quickly thus providing a clear insight into the optimum design of the system *See* ANALOG COMPUTER

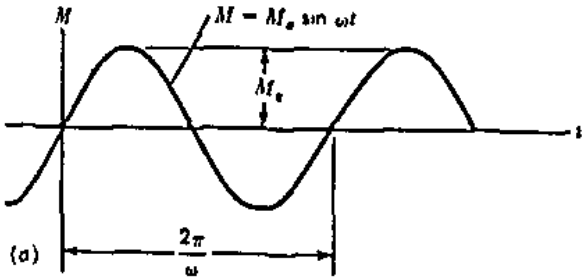
4 Digital computation While basically not as well suited to differential equations as it is to algebraic equations the digital computer is effectively used to obtain the transient solutions of control system problems *See* DIGITAL COMPUTER

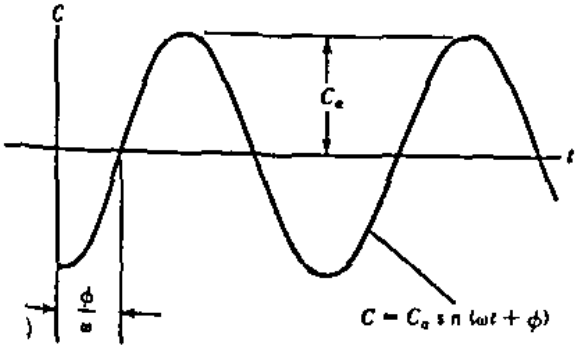
5 Root locus techniques Knowledge of the values of the roots of the characteristic equation of a feedback control system permits full understanding of the system behavior Classical methods are such as to make this root determination extremely tedious Using the basic relationship of a single loop feedback control system

$$(1 + HG_1)E = 0$$

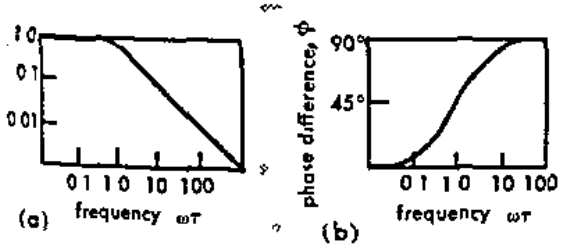
W R Evans developed a rather simple technique for determining from the roots of the open loop system the roots of the closed loop system for various controller characteristics For further discussion of these methods consult the bibliography

Steady state frequency response If the input M to the linear system shown in Fig 17 is sinusoidal and if sufficient time is allowed for the initial transient to die out the output C will also be sinusoidal with the same frequency as the input, but out of phase with it (see Fig 18) If the amplitude ratio C_a/k_pM_a and the phase angle ϕ between output and input are recorded as the test is repeated at a number of frequencies the accumulated results may be plotted as shown in Fig 19 Amplitude and frequency are plotted to logarithmic





: 18 Input and output relationships in a linear sys
n (a) Input (b) Output



) 19 Frequency response of a single capacity sys-
n (a) Amplitude response (b) phase angle response

ales Phase angle is plotted to a uniform scale he data to build such plots can be obtained di ctly by the substitution of $j\omega$ for the operator $/dt$ in the differential equation Thus for a single apacity system as in Fig 14

$$A\frac{dC}{dt} + BC = FM$$

here A B and F are constants

$$(Aj\omega + B)C_a \sin \omega t = FM_a \sin \omega t$$

$$\frac{C_a}{FM_a} = \frac{1}{Aj\omega + B}$$

Using complex number notation

$$\frac{C_a}{FM_a} = \frac{\epsilon^{-j\phi}}{\sqrt{(A\omega)^2 + B^2}}$$

here

$$\phi = \tan^{-1}\frac{A\omega}{B}$$

ubstitution of various values of ω in the above quations gives the information plotted in Fig 19, here $F = k_p$

The frequency response method is based upon a teady state condition and thus is often easier to nstrument It is easy to handle analytic

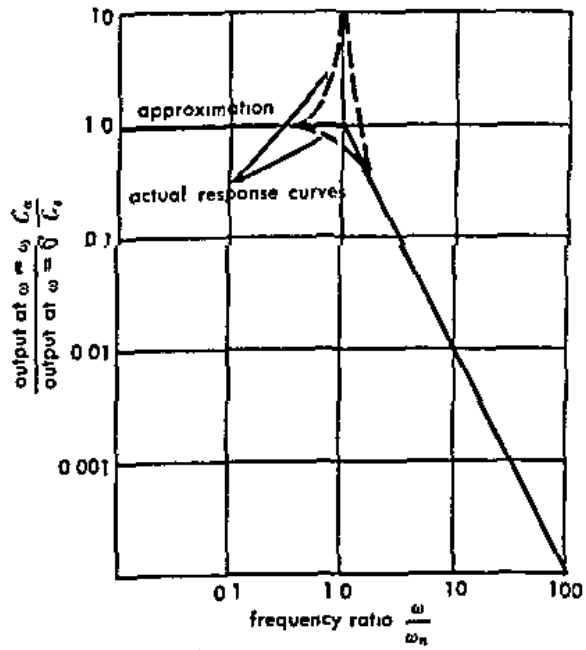
it gives the same information concerning perform ance that can be obtained by transient solution methods Because of the simple geometry of the amplitude frequency data when plotted to log log scales computation of high order differential equa tions is not difficult (see Fig 20 for frequency re sponse of a system represented by a second order differential equation) For complete information consult the bibliography

Stability of physical systems. A system is stable when it reaches a new steady state following the cessation of a disturbance Consider the position servomechanism shown in Fig 21 The differential equation relating error E to the input desired position θ^* and load M_L is

$$J\frac{d^2E}{dt^2} + B\frac{dE}{dt} + K_cE - J\frac{d^2\theta^*}{dt^2} + B\frac{d\theta^*}{dt} + M_L$$

If no change in position is demanded ($\theta^* = 0$) but the load M_L is suddenly changed, the result ing response of the system is shown in Fig 22 for various values of the damping ratio $\zeta = B/4JK_c$ For high values of damping $\zeta \geqq 1$, the system reaches a new steady state without oscillation For values of $\zeta \leqq 1$ an oscillation occurs before the steady state is reached When $\zeta = 0$ the oscillation is unending and a new steady state is never reached the system is therefore unstable This condition is often referred to as hunting The higher the order of the differential equation the greater the probability for instability

enough
not The



C_a = output amplitude
C_s = output amplitude when $\omega = 0$
ω = frequency of sinusoidal input
ω_n = undamped natural frequency of system

Fig 20 Frequency response of second order system

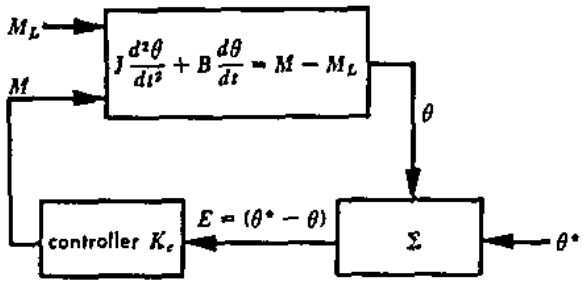


Fig 21 Position servo

Criteria of stability The behavior of a linear feedback control system is represented by a linear differential equation of the following form

$$a\frac{d^nE}{dt^n} + b\frac{d^{n-1}E}{dt^{n-1}} + \qquad m\frac{dE}{dt} + nE = 0$$

The solution of this equation is

$$Ae^{\lambda_n t} + Be^{\lambda_{(n-1)} t} + \qquad Me^{\lambda t} + N = E$$

where λ λ_2 λ_n, λ_{n-1} are the roots of the characteristic equation For stability the real part of all roots must be negative, otherwise the error E will reach infinity

The Routh criterion of stability makes it possible to determine whether the system is stable by examining the coefficients of the differential equation The conditions for stability of second third and fourth order differential equations are given below

For $$A_2\frac{d^2C}{dt^2} + A_1\frac{dC}{dt} + A_0 = 0$$

the conditions for stability are A_2 A_1 and $A_0 > 0$

For $$A_3\frac{d^3C}{dt^3} + A_2\frac{d^2C}{dt^2} + A_1\frac{dC}{dt} + A_0 = 0$$

the conditions for stability are

$$\frac{A_2A_1 - A_3A_0}{A_2} > 0$$

and $$A_3\ A_2\ A_1,\ A_0 > 0$$

For $$A_4\frac{d^4C}{dt^4} + A_3\frac{d^3C}{dt^3} + A_2\frac{d^2C}{dt^2} + A_1\frac{dC}{dt} + A_0 = 0$$

the following conditions of stability must be satisfied

$$\frac{A_3A_2 - A_4A_1}{A_3} > 0$$

and $$\frac{A_1(A_3A_2 - A_4A_1) - A_3^2A_0}{A_3A_2 - A_4A_1} > 0$$

and $$A_4\ A_3\ A_0 > 0$$

Stability–frequency response analysis The basic expression for the behavior of a linear feedback control system is that the error goes to infinity and the system is unstable when

$$1 + HG = 0 \quad \text{or} \quad HG = -1$$

Thus, the conditions for the stability of a closed loop system are expressed in terms of the simpler open loop transfer characteristic HG In other words when the absolute value of HG reaches one with a phase lag of 180° between input and output computed for the open loop the system is unstable Because of the ease in computing HG for a sinusoidal input frequency response data are used to test for the above conditions

As an example consider the system shown in Fig 23 The amplitude ratio and phase-angle vs.

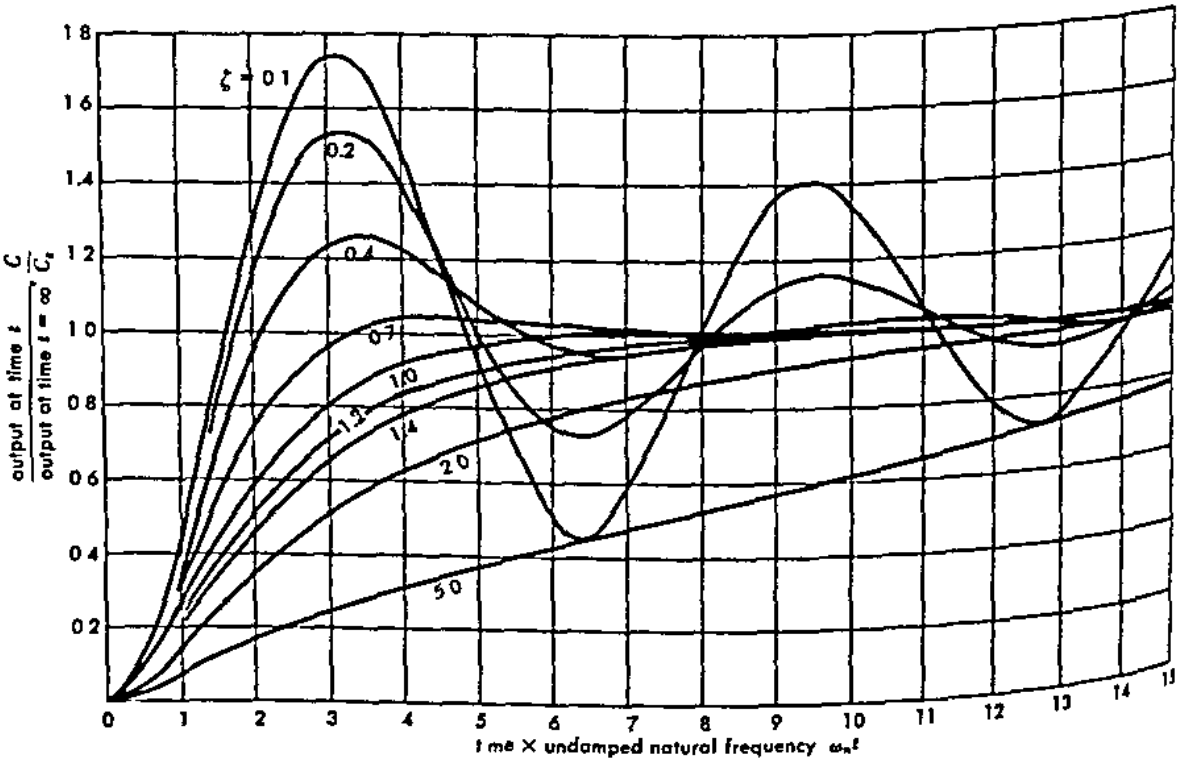


Fig 22 Response of a second-order system to a step input

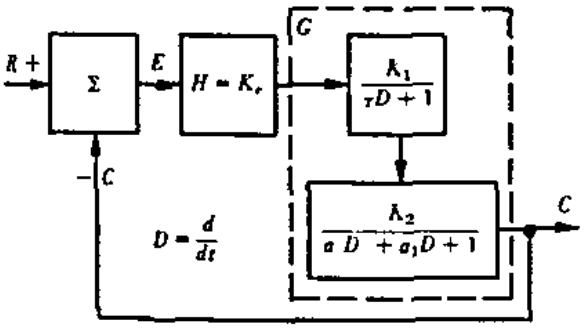


Fig 23 A feedback control system

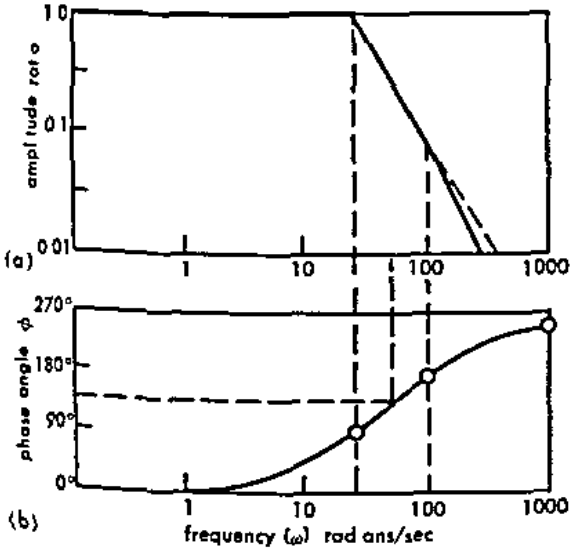


Fig 24 Frequency response of a system (a) Amplitude ratio (b) phase angle

frequency plots for the open loop transfer characteristic are shown in Fig 24 The gain of the system $k\,k_1k_2$ is assumed to be one

When the phase angle ϕ is 180° the amplitude ratio is 0 1 The frequency for this condition is about 100 rad/sec Hence the gain value $k_c k_1 k_2$ can be increased to 10 before instability occurs

For satisfactory operation of the feedback system some margin of stability must be provided Values of gain from 25% to 40% of the value that produces instability are often used The gain margin is defined as

$$\text{Gain margin} = \frac{\text{gain to just produce instability}}{\text{actual gain}}$$

A margin of safe operation can also be established by selecting a gain such that the phase angle does not exceed a certain value (usually 90° to 150°) when the amplitude ratio is 1 The difference between this angle and 180° is called the phase margin If a phase margin of 45° is selected ϕ cannot exceed 135° The amplitude ratio of the open loop system (Fig 24) is about 1/3 at ϕ = 135° Hence an over all system gain of 3 can be used

The information contained in the amplitude ratio and phase angle vs *frequency plots* is often combined in a single polar plot It is constructed by representing amplitude ratio and phase angle at any one frequency as a vector whose length is determined by the amplitude ratio and whose direction is determined by the phase angle A polar plot constructed from the information given in Fig 24 is shown in Fig 25 The terminal points of the vectors are plotted and joined in a smooth curve Each point is marked with the frequency for which it applies

H Nyquist developed the necessary conditions that the polar plot must satisfy in order to represent a stable system For almost all cases that are encountered in automatic control work the following single statement is valid

A closed loop system is stable if in traversing the open loop polar plot in the direction of increasing positive frequencies the −1 point lies at the left of the point of closest approach and is unstable if the −1 point is on the right Examples are given in Fig 26 The Nyquist concept can be used to synthesize desirable values of feedback control system parameters

Stabilization of control systems In almost every feedback control system the primary property of the controller establishes an output M proportional to the error E

$$M = K_c E$$

where K_c is the gain of the controller To obtain low steady state errors and fast response the gain *must be high* However high gains often lead to instability unless additional efforts to suppress excessive oscillation are exerted Such efforts can be classified as either high energy level methods or low or signal energy level techniques

The first category includes the use of elements that dissipate energy from the system such as viscous dampers and eddy current and magnetic devices Such methods are widely used with considerable success The chief drawbacks are that they often waste space and power

Devices in the second group are more widely employed These accept a low energy signal and modify it so that output of the controller contains the required stabilizing influences The use of tacho-

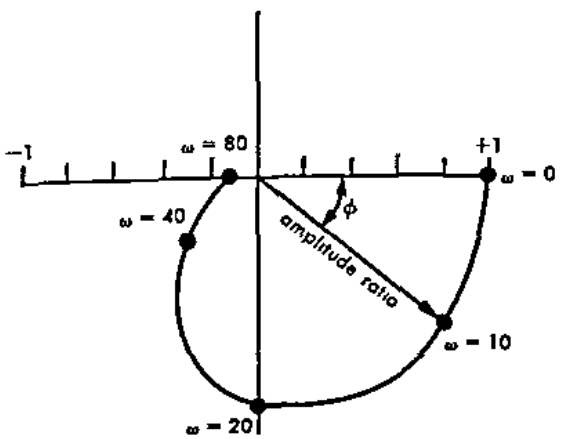


Fig 25 Polar plot of data shown in Fig 24

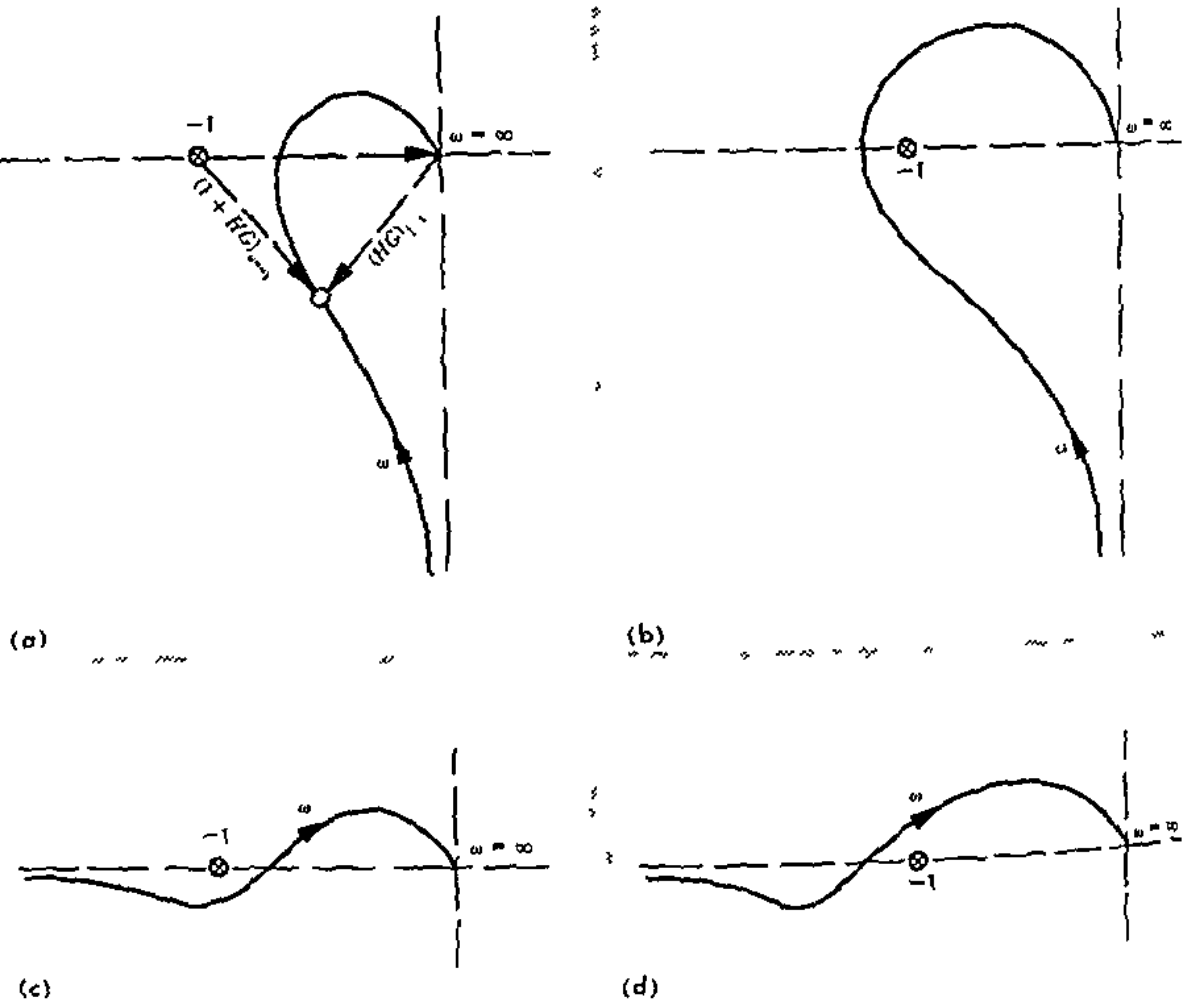


Fig 26 Nyquist stability criterion (*a* c) Stable (b d) unstable

metric feedback is an example Tachometric feedback achieves the same stabilization as that obtained with a viscous damper but has an advantage in that no power is lost due to the damping effect The viscous damper provides a load torque proportional to speed, the tachometer provides a controller input signal proportional to speed Thus the tachometer input modifies input torque to the system in response to the speed signal *See* TACHOMETER

Another widely used low energy method employs compensating networks Such networks commonly occur in electronic, pneumatic hydraulic and mechanical forms but recent trends are to increased use of electronic components Derivative or lead networks produce high gain at high input frequencies and low or zero gain at low frequencies Hence the controller output is high when the controller input is changing at a high rate Integral, or lagging networks produce high gain at low input frequencies and low gain at high frequencies Hence they are useful in achieving low steady state errors The determination of character of the compensating networks and the values of the parameters used in any given instance to give optimum performance is a challenging task which often involves the complete resources of the engineer

For examples of control systems see PRESSU CONTROL, AUTOMATIC, PROCESS CONTROL SER MECHANISM, TEMPERATURE CONTROL AUTOMA [J A P

Bibliography W R Ahrendt and J F Tapl *Automatic Feedback Control* 1951 W R Ext *Control system Dynamics*, 1954, H M Jam N B Nichols and R S Phillips *Theory of Ser mechanisms* Vol 25 1947, J G Truxal *Automa Feedback Control System Synthesis* 1955

Controlled rectifier

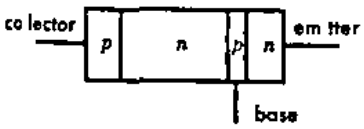
A three-terminal semiconductor junction devi with four regions of alternating conductivity ty (*p n p n*) This switching device has a characteri tic similar to that of a thyratron Such devices a useful as high current switches and may be used drive electromagnets and relays

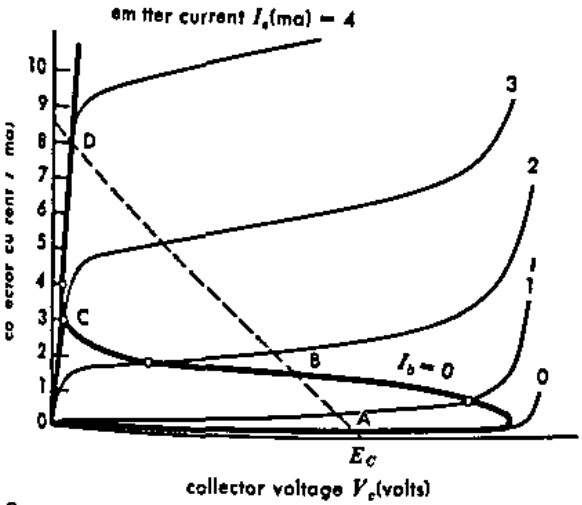
The principle of operation can be understood referring to the illustration The collector junct is the central junction which is reverse-bia (positive collector, grounded emitter) The wide region to the left prevents holes injected at the le hand junction from reaching the collector barri by diffusion The right hand junction is the em When operated as a normal transistor this dev shows a rapid increase of current gain of α (eq

to I/I_e) with collector current This effect is due to the electric field produced by the collector current in the floating n region which now helps to bring holes injected at the left hand junction over to the collector barrier

With a floating base region ($I_b = 0$) the device is a two terminal device and the collector current I must equal the emitter current I_e

By selecting the points on the illustrated characteristics where $I_c = I_e$ the characteristics for the base current $I_b = 0$ are shown as the heavy curve with the negative resistance characteristic This characteristic will be found in any transistor which shows an integrated α increasing from below unity at low collector currents to above unity at high collector currents



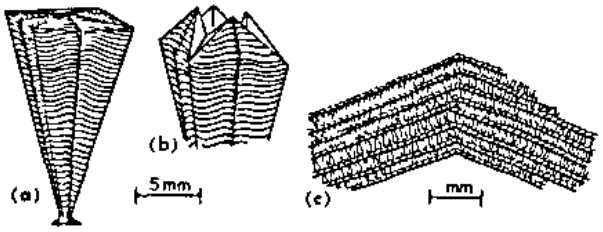


Controlled rectifier diagram and characteristics

If this device is operated as a three terminal device the switching between the nonconducting and conducting states can be controlled by the base If in the grounded emitter case the collector is biased to $+E$ as shown the device will remain at point A until the base is pulsed positive by at least enough current to carry the emitter current to point B At this point α exceeds unity and the device will spontaneously switch to point D in the conducting state To reset the unit either the emitter must be cut off or the collector voltage must be reduced so that the load line falls below the valley point C Either of these results can be achieved by appropriate pulses on the base For further discussion of $pnpn$ structures *see* TRANSISTOR [L P HU]

Conularida

A small group of extinct invertebrates showing a fourfold symmetry and a narrow pyramidal shape the cross section commonly is square Specimens are



Conular dorsal restorations (a) Attachment disk (b) Distal part of same individual with triangular flaps raised (c) Part of exterior showing ornamentation (*Adapted from R C Moore C G Lalicker and A G Fischer Invertebrate Fossils McGraw Hill 1952*)

chitinous and frequently impregnated with calcium phosphate The four side walls are characteristically ornamented by numerous transverse lines The anterior part of each side wall is a triangular flap which may be bent over covering the aperture suggesting that the walls may have been flexible during life The posterior tip may bear an attachment disk or may be broken off and sealed with a septum Internal structures are rare the few known show fourfold symmetry

Conularida are now regarded as a subclass of the Coelenterata because of the characteristic symmetry In the past there has been uncertainty as to their affinities they have been considered related to worms gastropods cephalopods and bryozoans among others Several authorities still suggest that they are allied to the mollusks or to tube building worms *See* COELENTERATA FOSSILS

Specimens are worldwide in occurrence and are known from rocks of Cambrian through Triassic age They have been found in sandstone shales and limestones Some may have been attached but others are found in geologic settings suggestive of a floating mode of life About 20 genera and 150 species are known Except for a few local occurrences Conularida are rare fossils [E L Y]

Convection (heat)

The transfer of thermal energy by actual physical movement from one location to another of a substance in which thermal energy is stored A familiar example is the free or forced movement of warm air throughout a room to provide heating Technically convection denotes the nonradiant heat exchange between a surface and a fluid flowing over it Although heat flow by conduction also occurs in this process the controlling feature is the energy transfer by flow of the fluid hence the name convection Convection is one of the three basic methods of heat transfer the other two being conduction and radiation *See* CONDUCTION (HEAT) HEAT RADIATION HEAT TRANSFER

Natural convection This mode of energy transfer is exemplified by the cooling of a vertical surface in a large quiescent body of air of temperature t_∞ As shown in Fig 1*a* the lower density air next to a hot vertical surface moves upward because of the buoyant force of the higher density cool air farther away from the surface At any

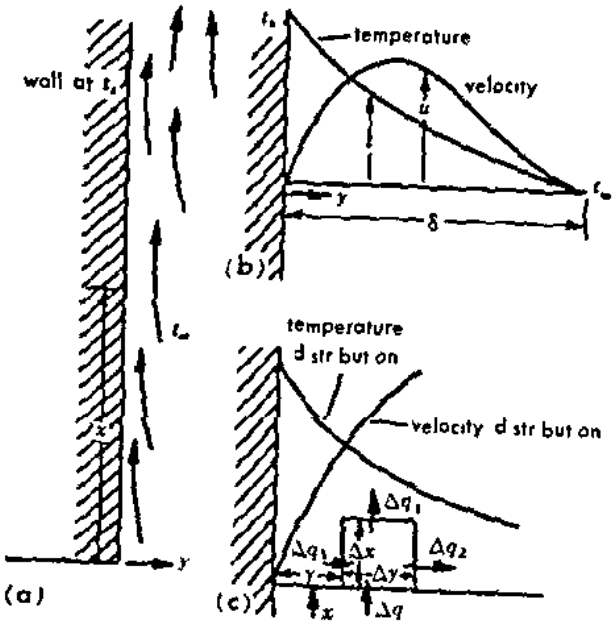


Fig 1 Temperature and velocity distributions in air near a heated vertical surface (a) Upward movement of hot air (b) Distributions at arbitrary vertical location The distance δ is that distance at which the velocity and the temperature reach ambient surrounding conditions (c) Distributions in boundary layer

vertical location x the actual velocity variation parallel to the surface will be similar to that sketched in Fig 1b increasing from zero at the

pe about These temperature and velocity distributions are clearly interrelated and the distances from the wall through which they exist are coincident because when the temperature approaches that of the surrounding air the density difference causing the upward flow approaches zero

The region in which these velocity and temperature changes occur is called the boundary layer Because velocity and temperature gradients both approach zero at the outer edge there will be heat flow out of the boundary layer by conduction or convection *See* BOUNDARY LAYER FLOW

An accounting of all of the energy streams entering and leaving a small volume in the boundary layer (Fig 1c) during steady state conditions yields

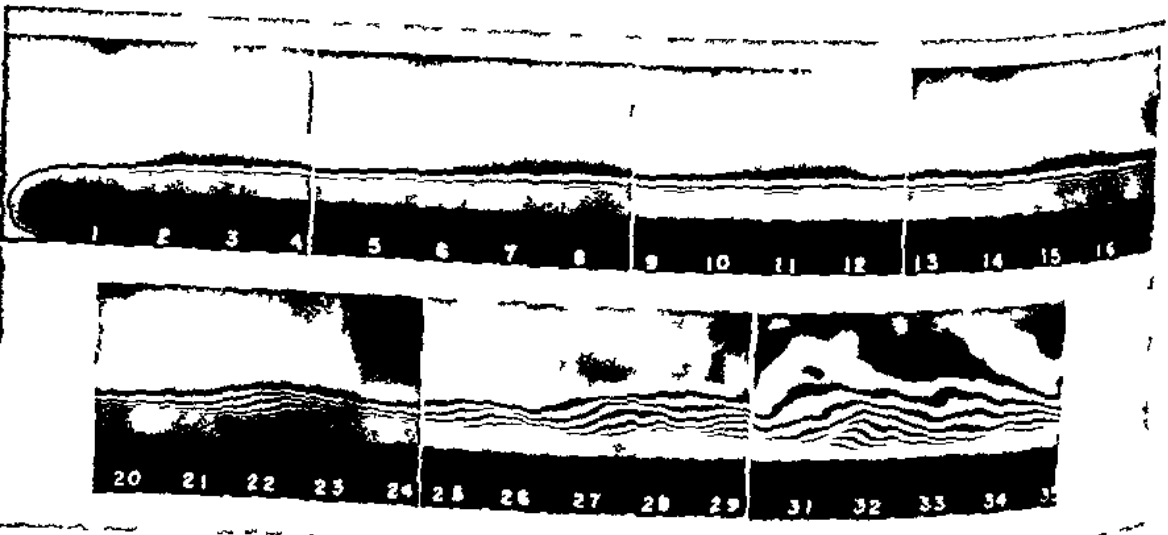
$$\kappa\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}\right)=wc_p\left(u\frac{\partial t}{\partial x}+v\frac{\partial t}{\partial y}\right)$$

where κ, w, and c_p are the thermal conductivity, the weight density, and specific heat at constant pressure of the air, and u and v are the velocity components in the x and y directions respectively Equation (1) states that the net energy conducted into the element equals the increase in energy of the fluid leaving (convected) over what it had entering

At the surface, $u=v=0$ and $\partial t/\partial x=\partial t/\partial x=0$ Thus, $\kappa(\partial^2 t/\partial y^2)=0$ and

$$\kappa\frac{\partial t}{\partial y}=\text{constant}=q/A \qquad (2)$$

where q is the time rate of flow through an infinitesimally thin layer dx and A is the cross-sectional area normal to the direction of flow This shows that the heat transfer in the immediate vicinity of the wall is by conduction through a thin layer of air which does not move relative to the surface At a very small distance from the surface the velocity becomes finite and some of the energy conducted normal to the surface is convected parallel to it This process causes the temperature gradient to decrease eventually to zero The solution of a problem requires determination of the temperature distribution throughout the boundary layer From this the temperature gradient at the wall and rate of heat flow can be computed



g 2 Laminar and turbulent natural convection flow along a vertical plate as revealed by interference photographs (From E R G Eckert *Introduction to the Transfer of Heat and Mass* McGraw Hill 1950



g 3 Isotherms around a heated horizontal cylinder, i revealed by an interference photograph (*From* L. Doughty and W H Giedt, Proc Instr Soc Am, 115–119, 1952)



ig 4 Interference photograph showing isotherms round a heated cylinder normal to a 33 ft/sec air tream (*From* D L Doughty and W H Giedt, Proc nstr Soc Am, 7 115–119, 1952)

The effect of energy leaving a surface and remaining in the boundary layer is (1) a gradual increase in temperature of the air in this layer as it moves upward, and (2) diffusion of energy farther from the surface, entraining more air in (thickening) the boundary layer This is shown in Fig 2, where the interference fringes indicate lines of constant temperature Figure 3 is a similar visualization of the free convection temperature field around a horizontal cylinder The outer broad fringe indicates approximately the edge of the boundary layer which by comparison with the cylinder (4 in in diameter), is about ¾ in thick

Forced convection. The effect of blowing air across the cylinder is shown in Fig 4 Here the boundary layer on the forward half of the cylinder has become so thin that it is not possible to resolve the isotherms within it Although the natural convection forces are still present in this latter case, they are clearly negligible compared with the imposed forces The process of energy transfer from the heated surface to the air is not, however, different from that described for natural convection The major distinguishing feature is that the maximum fluid velocity is at the outer edge of the boundary layer as is illustrated in Fig 5 for flow along a flat plate This difference in velocity profile and the higher velocities provide more fluid near the surface to carry along the heat conducted normal to the surface Consequently, boundary layers are very thin (they are greatly enlarged in Fig 5 for clarity)

The properties of a fluid which influence its heat convecting ability are the dynamic viscosity μ, heat capacity at constant pressure c_p, and thermal conductivity κ These combine in a single significant property in the form $\mu c_p/\kappa = \mu/(\kappa/c_p)$, which is the ratio of the fluid viscosity to the quotient of its heat conducting and storage capacities With proper units, this ratio is dimensionless and is

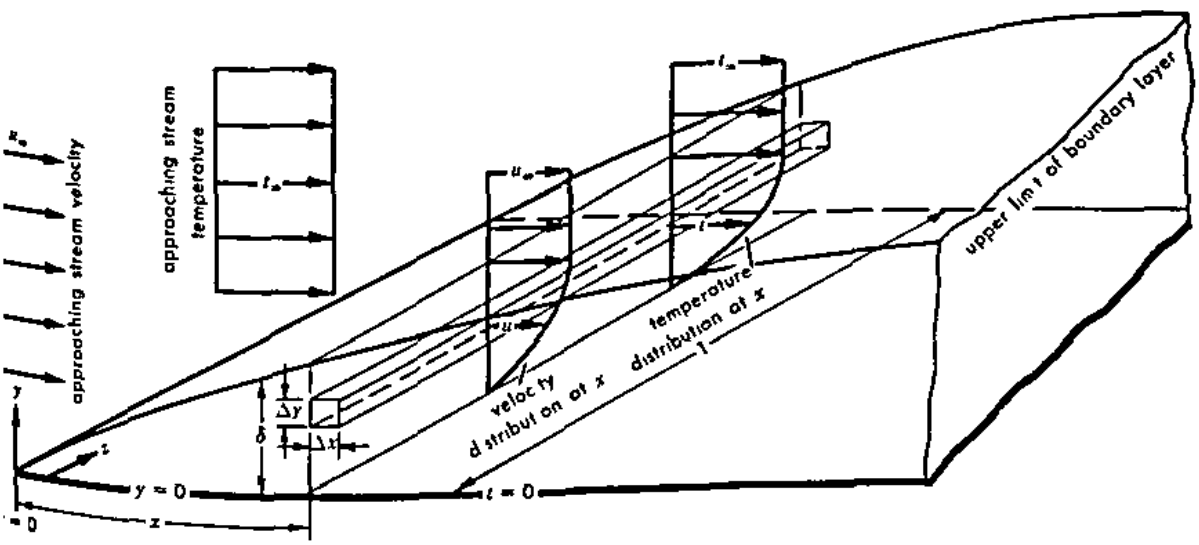


Fig 5 Velocity and temperature distributions in a laminar boundary layer along a flat plate Fluid assumed to have a Prandtl number of 1, for which velocity and temperature boundary layers are of equal thicknesses (*From* W H Giedt, Principles of Engineering Heat Transfer, Van Nostrand, 1957)

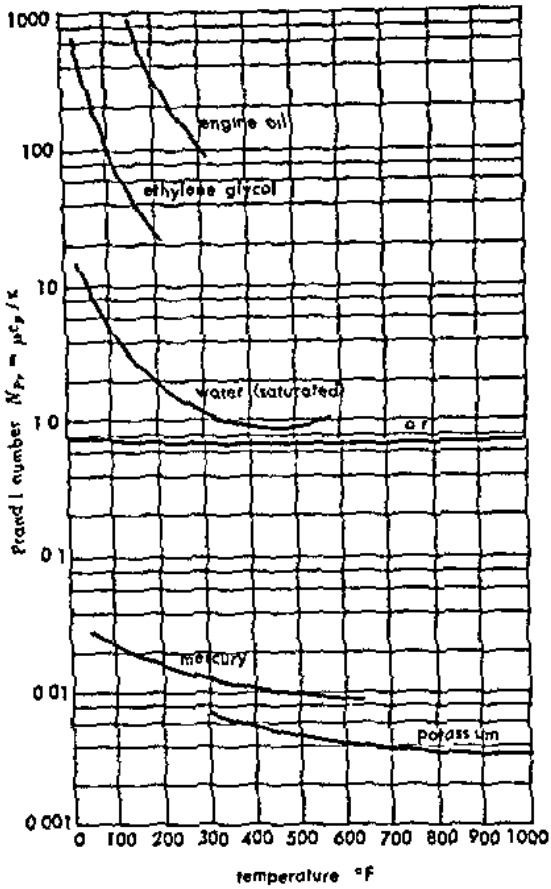


Fig 6 Variation of Prandtl number of several fluids with temperature

called the Prandtl number N_P Fluids such as liquid metals having low values of N_P (see Fig 6) are particularly effective for convective heat transfer applications

Heat transfer coefficient The convective heat transfer coefficient h is a unit conductance used for calculation of convection heat transfer It was introduced by Sir Isaac Newton and until the mechanism of convection was properly interpreted was thought to be a characteristic of the fluid flowing To describe quantitatively the cooling of objects in air Newton suggested the equation

$$q = hA(t_{\text{surface}} - t_{\text{fluid}}) \qquad (3)$$

This equation known as Newton's law of cooling is really a definition of h This coefficient is determined by the slope of the fluid temperature distribution right at the surface and the thermal conductivity κ of the fluid Engineering units are $Btu/(hr)(ft^2)(°F)$

Local and average coefficients As the fluid in the heated or cooled boundary layer moves along an isothermal surface it gradually approaches the temperature of the surface This causes the temperature gradient in the fluid at the surface (and the rate of heat transfer) to decrease in the direction of flow Taking for example an airstream at 80°F moving over a flat plate at 30°F the local heat transfer coefficient h_x varies by nearly a factor of ten For practical calculations an average heat transfer coefficient h is more useful This is obtained by integrating h_x over the heat transfer surface and dividing by the surface area For this system h is a function of the Prandtl number $N_{Pr} = \nu$, and u_∞ of the fluid For comparing geometrically similar systems involving different fluids dimensional analysis shows that the specific properties can be combined into dimensionless parameters, conveniently reducing the number of independent variables For the flat plate these are the Nusselt number, $N_{Nu} = hl/\kappa$ the Reynolds number $N_R = lu_\infty/\nu$ and the Prandtl number For example it can be shown that in this case

$$N_{Nu} = 0.664 N_{Pr}^{1/3} \sqrt{N_R} \qquad (4)$$

In the case of free convection the Grashof number $N_G = \beta g l^3 \Delta t/\nu^2$ (where β is the coefficient of thermal expansion) replaces the Reynolds number Other dimensionless numbers pertinent to convection include the Stanton number $N_{St} = h/\rho u c_p = N_{Nu}/N_R N_P$ which is related to the skin friction coefficient *See* DIMENSIONAL ANALYSIS REYNOLDS NUMBER, SKIN FRICTION

Turbulent flow Heat convection in turbulent flow is interpreted similarly to that in laminar flow which has been implied in previous paragraphs (*see* LAMINAR FLOW, TURBULENT FLOW) Rates of heat transfer are higher for comparable velocities, however because the fluctuating velocity components of the fluid in a turbulent flow stream provide a macroscopic exchange mechanism which greatly increases the transport of energy normal to the main flow direction Because of the complexity of this type of flow most of the information regarding heat transfer has been obtained experimentally Such results combined with dimensional analysis have yielded useful design equations typical of which is the following for predicting the heat transfer in a pipe

$$\frac{hd}{\kappa} = 0.023 \left(\frac{du}{\nu}\right)^{0.8} \left(\frac{\mu c_p}{\kappa}\right)^{0.4} \qquad (5)$$

where d is the pipe diameter

Aerodynamic heating Convection heat transfer which occurs during high speed flight or high velocity flow over a surface is known as aerodynamic heating This heating effect results from the conversion of the kinetic energy of the fluid as it approaches a body to internal energy as it is slowed down next to the surface In the case of a gas (see Fig 7) its temperature increases first because of compression as it passes through a shock and second because of frictional dissipation of kinetic energy in the boundary layer along the surface Typical velocity and temperature distributions near the surface of a missile are shown in Fig 7 The maximum temperature possible would result from an adiabatic compression of the gas as it is slowed from the free stream velocity to zero This maximum temperature depends on the square of the missile velocity being for example around 1500°F for a speed of 4000 ft/sec (a Mach number of 4) Temperatures

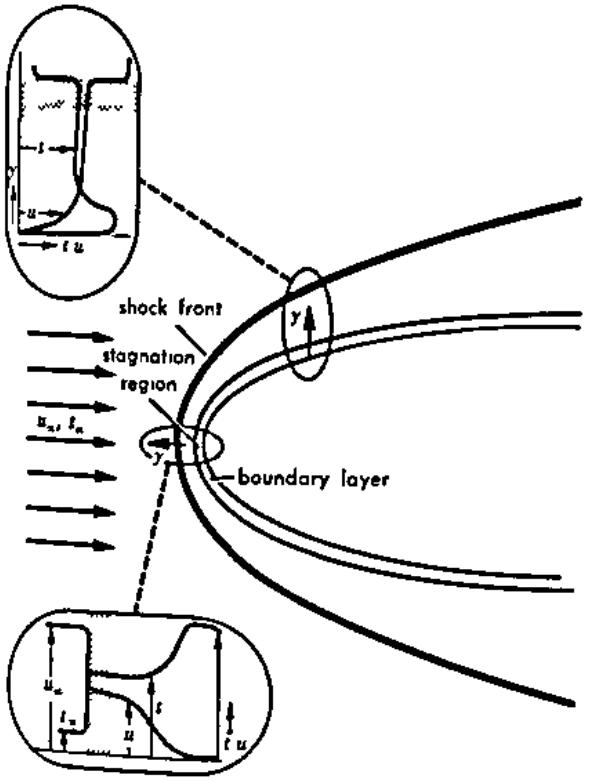


Fig 7 Velocity and temperature distributions in the gas around a high speed missile (thicknesses of shock wave and boundary layer exaggerated)

very close to the maximum may occur in the stagnation region, downstream maximum temperatures are lower because of decreasing pressure and heat convection toward the outer edge of the boundary layer

Condensation and boiling The phenomena of condensation and boiling are important phase change processes involving heat release or absorption Because vapor and liquid movement are present, the energy transfer is basically by convection Local and average heat transfer coefficients are determined and used in the Newton cooling law equation for calculating heat rates which include the effects of the latent heat of vaporization

Condensation Consider a saturated or superheated vapor of a single substance in some region When it comes in contact with a surface maintained at a temperature lower than the saturation temperature, heat flow results from the vapor, releasing its latent heat and condensing on the surface The condensation process may proceed in two more or less distinct ways If there are no impurities in the vapor or on the surface (which need not be smooth), the condensate will form a continuous liquid film If however, such contaminants as fatty acids or mercaptans are present the vapor will condense in small droplets These increase in size until their weight causes them to run down the surface In doing so, they sweep the surface free for formation of new droplets For the same temperature difference between the vapor and surface heat transfer with dropwise condensation may be fifteen to twenty times greater than filmwise condensation The dropwise type is therefore very desirable, but conditions under which it will occur are not predictable, and designs are limited to systems for which experimental results are available

Boiling In boiling results indicate the existence of several regimes, as shown in Fig 8 The important independent variable is the temperature difference between the hot surface and the fluid relatively far from the surface For values of Δt up to approximately 10°F (A to B on the curve), the liquid is being superheated by natural convection, and q/A is proportional to $\Delta t^{5/4}$ With further increase in Δt (B to C), bubbles form at active nuclei on the heated surface These bubbles break away and rise through the pool, their stirring action causing the heat transfer to be much above that due to natural convection This phenomenon is called nucleate boiling and q/A varies as Δt^3 to Δt^4 When the rate of bubble [illegible]

heating then decreases with Δt until complete film boiling is reached and heat flows by radiation and conduction through the film Point F corresponds to the melting point of the wire

The high heat rates which occur during boiling make it a very effective means of absorbing the energy capable of being released in furnaces and nuclear reactors This is also one reason why the vapor power generating cycles have been successful

Mass and momentum transfer. In a gas, heat conduction occurs by transfer of kinetic energy from high temperature to lower temperature molecules This process requires a change in location of molecules called mass transfer If, in addition to their random velocities, the molecules have definite but different flow velocities, the molecular (mass) interchange will also result in a momentum transfer This means that mass, momentum, and heat exchange are interrelated This interrelationship exists in both conduction and convection phenomena (Fig 9)

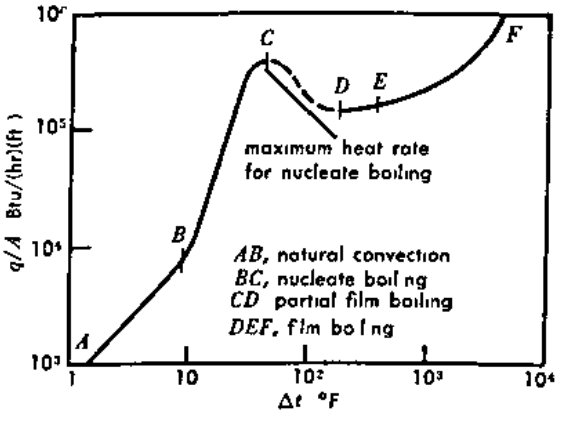


Fig 8 Heat rate vs temperature difference during boiling of water at 212°F on an electrically heated platinum wire (*After S Nukiyama, J Soc Mech Engrs Japan, 37*(206) 367–379, 1934)

These three processes are described by similar equations which are listed in the table As mass conduction W/A denotes the mass transfer per unit time and area of component A through B The coefficient D_{AB} is a diffusion coefficient characterizing the diffusion of molecules of gas A through

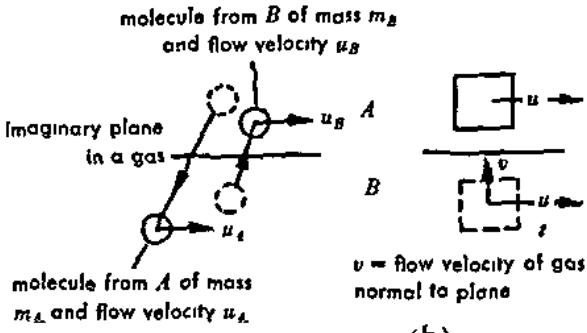


Fig 9 Mass, momentum, and heat transfer (a) By conduction mass transfer $\propto m_B - m_A$, momentum transfer $\propto m_B u_B - m_A u_A$ heat transfer $= m_B c_B t_B - m_A c_A t_B$ (b) By convection mass transfer (per unit time and area) $= \rho v$ momentum transfer $= (\rho v)u$, heat transfer $= (\rho v)c_p t$

Transfer equations

	Transfer of		
	Mass (Diffusion)	Momentum (Introducing shear stress)	Heat
By conduction	$\frac{W}{A} = D_{AB}\frac{\partial C}{\partial y}$	$\sigma = \frac{W}{A}\Delta u = \mu\frac{\partial u}{\partial y}$	$\frac{q}{A} = -\kappa\frac{\partial t}{\partial y}$
By convection	$\frac{W}{A} = (\rho v)C$	$\sigma = (\rho v)u$	$\frac{q}{A} = (\rho v)c_p t$

gas B (*see* DIFFUSION IN GASES AND LIQUIDS), and C denotes the concentration of A (pounds per cubic foot) which is the driving potential for the process The equation describing momentum transfer is basically an expression of Newton's second law of motion The three coefficients D_{AB} μ, and κ, in these transport processes are referred to as the transport properties

In the case of convection the same mass flux ρv carries with it the concentration of C of a given species, the velocity u, and the enthalpy $c_p t$

The similarity between the fundamental equations suggests that solutions for one process may be applicable to the others The validity of this has been established for such cases as evaporation and condensation from a liquid surface into a gas, such as air, above it

The applicability of these analogous solutions is, however, limited to conditions where one process can be regarded as independent of the others When exchange rates are high and the properties of the species involved vary with temperature and pressure it may be necessary to solve the differential equations governing each transport process simultaneously [W.H.L]

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Converter, synchronous

A synchronous machine used to convert alternating current (ac) to direct current (dc) or vice versa If the conversion is from dc to ac it is called an inverted converter, or inverter The ac to dc converter has been superseded by the mercury arc rectifier (for reasons of efficiency, lower maintenance costs and less trouble) or by motor generator sets Converters are no longer manufactured in large quantities, but there are many converters still in use

The synchronous converter has an armature similar to those used in dc machines, with connections to a commutator and brushes on the dc end and to slip rings on the ac end The field is similar to that of a dc machine and may have shunt and series windings on the main poles interpoles with series windings to assist commutation and amortisseur windings for starting and to prevent hunting The machine is thus a combination of a synchronous motor and a dc generator, having all the essential elements of each but with no duplication of parts As compared with a motor generator set consisting of a synchronous motor driving a dc generator it presents the following advantages (1) a single magnetic circuit comprising field poles, yoke, armature core and teeth, (2) a single armature in the conductors of which the ac and dc currents tend to cancel thereby reducing greatly the copper losses, (3) a single pair of bearings and a smaller and shorter shaft (4) higher efficiency, lower first cost and lighter weight. There are, however, attendant disadvantages (1) the ratio of dc to ac voltage is fixed and cannot be changed materially by adjusting the field excitation, (2) the machine is quite sensitive to sudden load changes and may hunt or flashover its commutator, (3) the heating in the armature is not the same for all conductors, and (4) power factor correction by field adjustment is quite limited *See* DIRECT CURRENT GENERATOR, SYNCHRONOUS MOTOR

The converter is very versatile In theory it may operate as a synchronous generator motor or condenser, as a dc motor or generator, as an *ac to dc* converter, as a double current (ac and dc) generator, as an inverter changing dc to ac, or as any combination of these It comes nearer to being the ideal generalized or universal machine than any other and its complete theory is the most elegant of any machine Its use, however, is somewhat limited to its intended role because of its sensitivity tendency to instability, and enormous increase in losses and heating when not operating at near unity power factor as a converter [L.V.B.]

Convertiplane

An aircraft combining vertical take off and landing capabilities of the helicopter with forward flight effectiveness and high speed potentials of the air plane In forward flight a convertiplane relies at least partially on the fixed wing while for vertical take-offs landings and hovering a separate verti cal thrust generator is provided Between vertical and forward flight regimes the aircraft goes through a conversion

Of many systems suitable as vertical thrust generators those applied to practical converti planes will probably be either of the direct type in which combustion products are used directly for thrust generation (turbojets and rockets) or of the indirect type in which all or a part of the available combustion energy is used to drive a mechanical system functioning as an actuator disk to accelerate the ambient air The actuator disks may be either free (helicopter rotors and propel lers) or shrouded (shrouded propellers and ducted fans)

The effectiveness of static thrust generators can be compared on the basis of energy expenditure per unit of time and per unit of thrust as power/thrust The ideal power required per pound of thrust is proportional to the fully developed downwash ve locity of the slipstream affected by the thrust generator (Fig 1) In an unshrouded actuator disk the fully developed downwash velocity amounts to twice the speed of flow through the disk whereas in ducted fans jet engines and rockets it equals the exit velocity

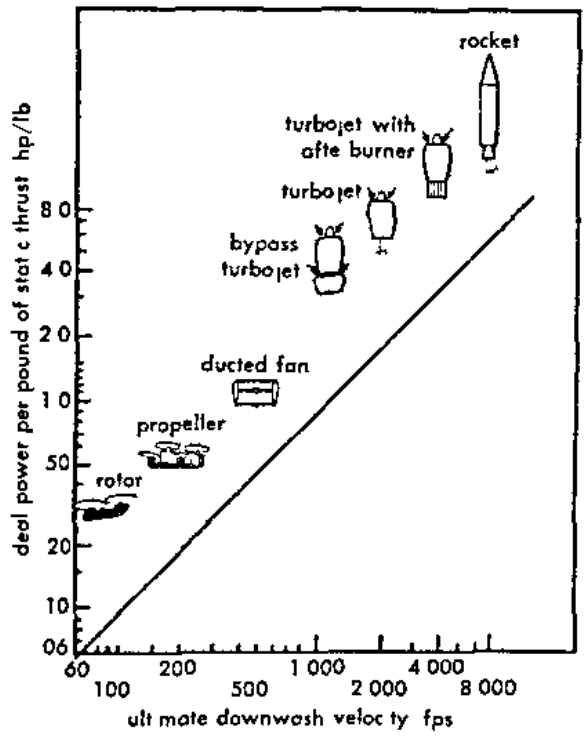
Actual shaft horsepower of an engine driving an actuator disk or the rate of release of thermal energy in a jet and a rocket will be proportional to the ideal values shown in Fig 1

Loading of rotors and propellers (thrust per square foot of the disk) as well as that of ducted fans jets and rockets (thrust per square foot of the jet exit area) is proportional to the square of the fully developed downwash velocity Hence it follows from Fig 1 that lightly loaded static thrust generators will show a low ideal horsepower per pound of thrust and should be used therefore whenever a long time in hovering or near hovering is required Such use will result in economy of power installed and fuel consumed in the aircraft

Effectiveness of a lift generator in forward flight can be compared on the basis of the ideal energy expend ture (in Btu) required per unit of lift (as 1 lb) and a unit of distance flown (as 1 nautical mile) at a given speed

In Fig 2 values of the ideal energy expenditure are shown as functions of flying speed for fixed wing free and shrouded actuator disk and weight supporting rocket The wing is by far the most efficient means of providing lift in horizontal flight At slow speed the rotor is next but it still requires at least about three times more energy per unit of lift and distance flown At speeds exceeding 150–160 knots the combined effect of the stall of the retreating blade and compressibility make the rotor even less effective

The shrouded devices (from ducted fans to turbo-jets) when used solely as vertical lift generators



Fg 1 Ideal energy expend ture n un t time (power) requ red per pound of stat c thrust as a funct on of ult mate downwash veloc ty

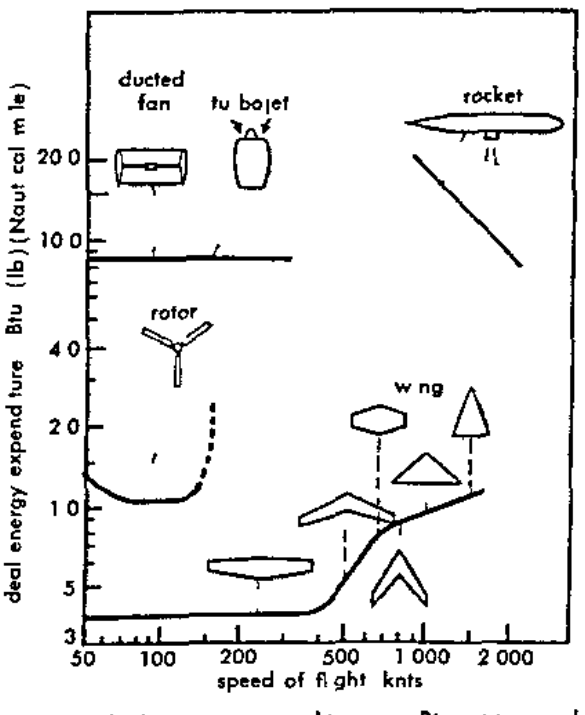


Fig 2 Ideal energy expend ture in Btu per pound of l ft and naut cal m le of d stance flown as a func t on of flying speed



Fig 3 McDonnell XV 1 first flown in 1956 with helicopter rotor for hovering and fixed wing and propeller for forward flight

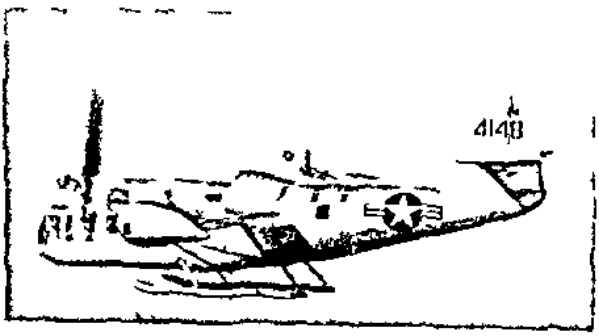


Fig 4 Bell XV 3 conversion of late 1958 in which rotopropellers tilt 90°

(axis vertical) have a low effectiveness due chiefly to the high momentum drag (equal to the lift) Inclination of the axis or a provision of exit vanes to discharge the flow at a sharp angle with reference to a flight path would reduce the momentum drag but the effectiveness of ducted actuator disk is still far below that of the fixed wing Rocket although free of momentum drag are nevertheless a poor source of lift even at 2000 knots (Fig 2

In the convertiplane the fixed wing optimized for forward flight is combined with a vertical thrust generator whose selection is governed by the desire of obtaining a well balanced design This usually means that the installed power or thrust established from hovering at a given altitude and ambient temperature should differ as little as possible from that resulting from the requirements of the forward flight speed at a given altitude In principle the higher the speed requirements of the convertiplane the more highly loaded the vertical thrust generator that can be used However such operational requirements as limitations on downwash velocity in hovering may force a deviation from this principle toward vertical thrust generators more lightly loaded than the design optimum. For any one vehicle the final design is the one that achieves optimum performance at design center and acceptable performance off center

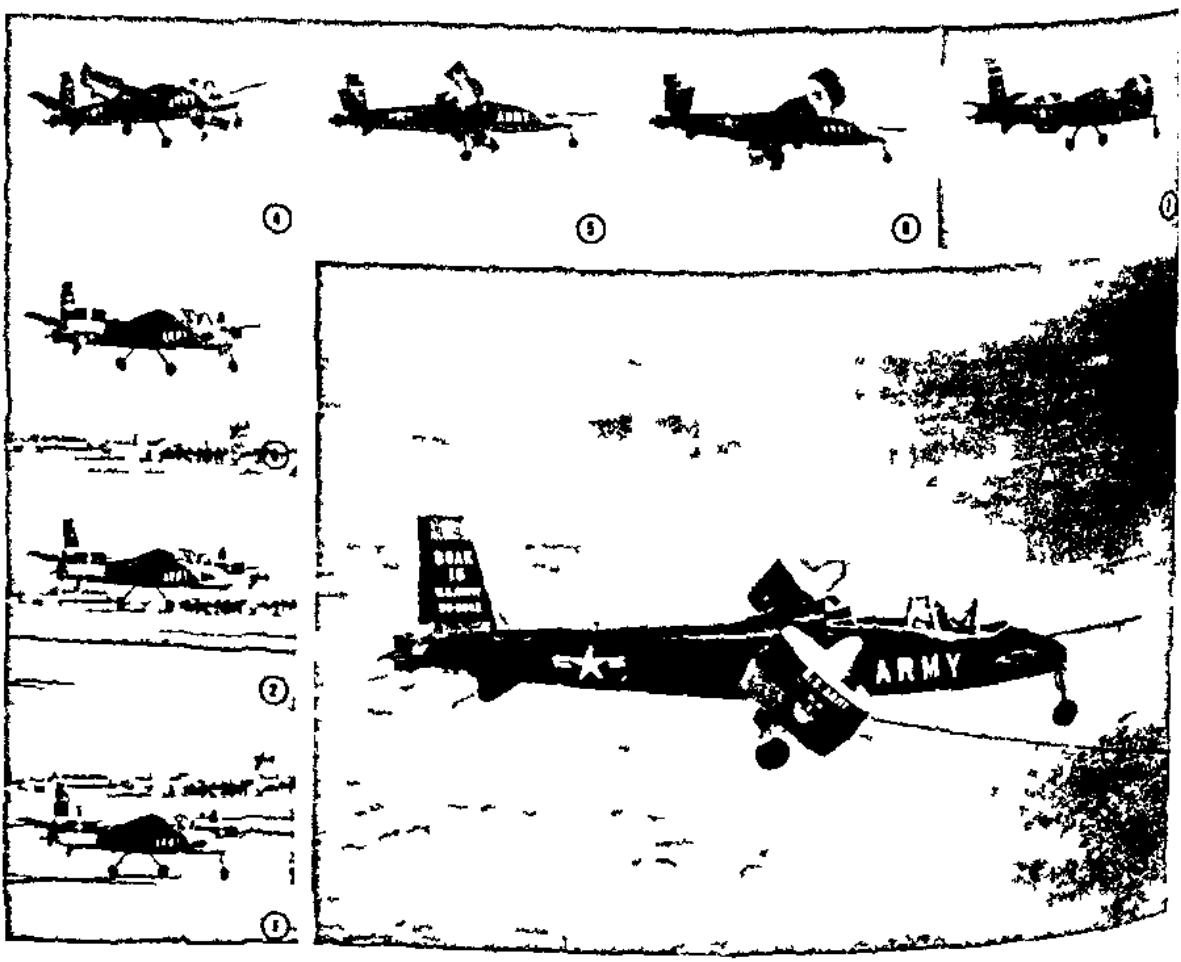


Fig 5 Doak 16 of early 1959 in conversion ducted fans tilt 90°

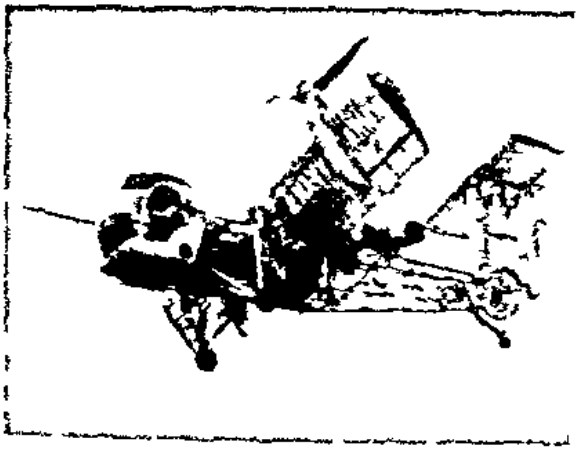


Fig. 6. Vertol 76 with wing partially tilted in conversion from forward flight to hovering. Tufts on surfaces show air flow.

The principle of the convertiplane can be applied to many types of aircraft. The first practical attempts were directed toward rotary wing aircraft. The presently used scheme consists of transferring as much lift as possible in forward flight from the rotor (which is put into autorotation) to the more efficient fixed wing while a propeller or propellers provide the necessary forward thrust. The McDonnell XV-1 and the Fairey Rotodyne, flying since 1958, are examples of this approach (Fig. 3). Because convertiplanes of this type use lightly loaded helicopter type rotors as vertical thrust generators they have good hovering and low speed performance but because of the inherent deficiencies of the rotor such as blade flutter and drag their high speed capabilities are probably limited to about 250 knots.

To achieve high speed potentials the helicopter type rotor must be eliminated from the forward flight configuration, which should be as close as possible to that of conventional aircraft. Under such circumstances the propeller-driven convertiplane could achieve cruising and maximum flying speeds similar to those of its fixed wing counterparts; the jet propelled convertiplane could fly as fast as the conventional jet plane.

In the nonhelicopter type convertiplane the same device can be used both as a vertical thrust generator and as a means of forward propulsion. Two basic solutions are possible: (1) either the entire vertical thrust generator or only the thrust vector tilts from the vertical to the horizontal position while the wing remains fixed; and (2) both the vertical thrust generator and the wing tilt. Various aircraft have demonstrated the technical feasibility of complete conversion. The first group to do so is represented by such vehicles as the Bell XV-3 and the Doak 16 (Figs. 4 and 5). The flight research aircraft of Bell first flown in 1954 used two J44 jet engines that tilted through 90°. In the Bell X-14 conversion of early 1958, the thrust vector of two jet engines is rotated from the vertical to the horizontal position by redirecting the exhaust. The Vertol 76 conversion flown in 1958 represents the second group (Fig. 6). *See* ORNITHOPTER; VERTICAL TAKE-OFF AND LANDING (VTOL). [W.Z.S.]

Bibliography: D. Kuchemann and J. Weber, *Aerodynamics of Propulsion*, 1953; W. Z. Stepniewski, *Introduction to Helicopter Aerodynamics*, 2d ed., 1958; M. J. Zucrow, *Aircraft and Missile Propulsion*, 2 vols., 1958.

Conveying machines

A family of material-handling machines designed to move individual articles or solid free-flowing bulk materials over fixed horizontal, inclined, declined or vertical paths of travel with continuous motion. The actuating medium may be the force of gravity, compressed air or suction, vibration, or powered components of the machine such as continuous belts, chains, or cables. Of the many varieties some are used almost exclusively to convey bulk materials (*see* BULK HANDLING MACHINES). The kinds described in this article fall largely in a category popularly referred to as package conveyors and consist of gravity and powered belt, chain, and cable conveyors. Air actuated conveyors or pneumatic tubes are discussed briefly.

Gravity conveyors. The most economical means for lowering articles and materials is by gravity conveyors. Chutes depend upon sliding friction to control the rate of descent; wheel and roller conveyors use rolling friction for this purpose (Fig. 1).

With a body resting on a declined plane friction F opposes the component P of weight W of the body parallel to the surface of the plane. When the angle of elevation equals the angle of repose the body is just about to start sliding, or to express it another way, when the inclination of the plane equals the angle of repose $F = P$. In this position the tangent of the angle of repose equals the coefficient of friction. For metal on metal the

wooden cases

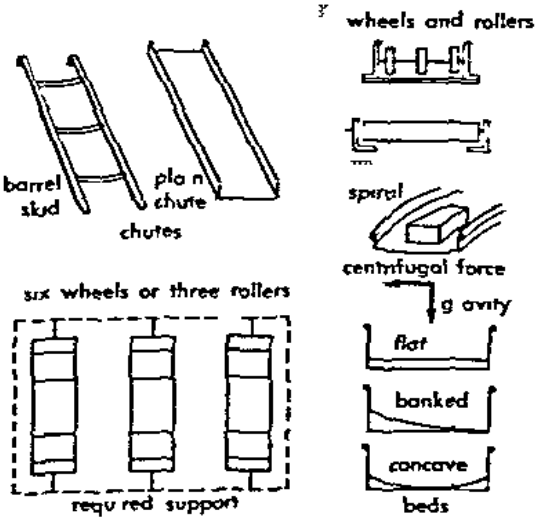


Fig. 1. Elements used in gravity conveyors.

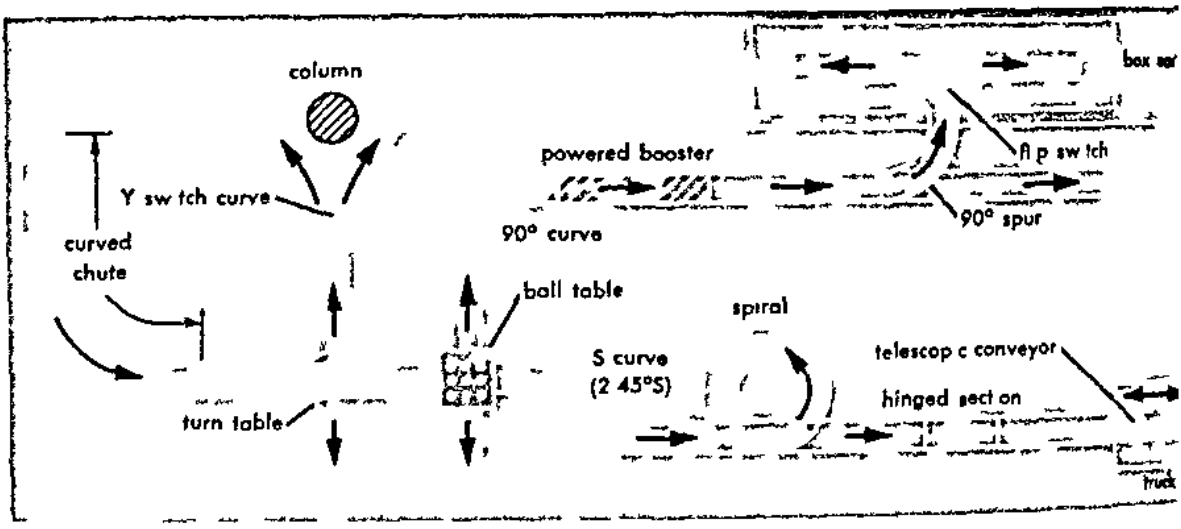


Fig 2 Gravity components for conveyor l nes

When the body is a smooth surfaced container and the inclined plane is replaced by rollers the rollers are spaced so that at least three rollers will support the smallest container to be conveyed Then each roller supports one third the weight of the load Component P of the weight W which acts downward and parallel to the inclination of the plane produces a turning moment Pr about the roller s axle where r is the radius of the roller As the inclination of the conveyor is increased P in creases until at the point where rolling is about to start $Pr = Fr$ In this case however the force of friction is made up of the friction between the contacting surfaces and the friction in the bearings of the rollers The mass of a tubular roller is con centrated near its circumference hence rollers have greater starting inertia than wheels but after they have started rolling they have a flywheel effect which tends to keep products in motion especially when packages follow each other in close succes sion

Inclination (or declination) is expressed as the number of inches of rise or fall per foot of con veyor or per 5 ft or 10-ft length

Gravity chutes In construction gravity chutes may be straight or curved and are made of sheet metal or wood the latter being sometimes covered with canvas to prevent slivering The bed can be shaped to accommodate the particular products to be handled In spiral chutes centrifugal force is a second controlling factor When bodies on a spiral move too fast they are thrown out toward the guardrail contact with the rail increases the fric tion the bodies slow down a bit and settle back into the center of the runway and continue their descent at a controlled rate Spirals with roller beds provide smooth easy descent for barrels on their ends and similar articles If wheels are used in place of rollers at least six wheels must be at all times under the smallest article to be carried

The faces of wheels can be shaped and made of materials adapted to the handled product Rollers of steel aluminum magnesium wood and plastic are available or they can be coated to provide pr tection Both wheels and rollers can be set lo high or flush with the frames in which they a mounted They can also be arranged to form a for carrying such articles as artillery shells lu ber or pipe However this arrangement provid for straight line flow only curves cannot be use

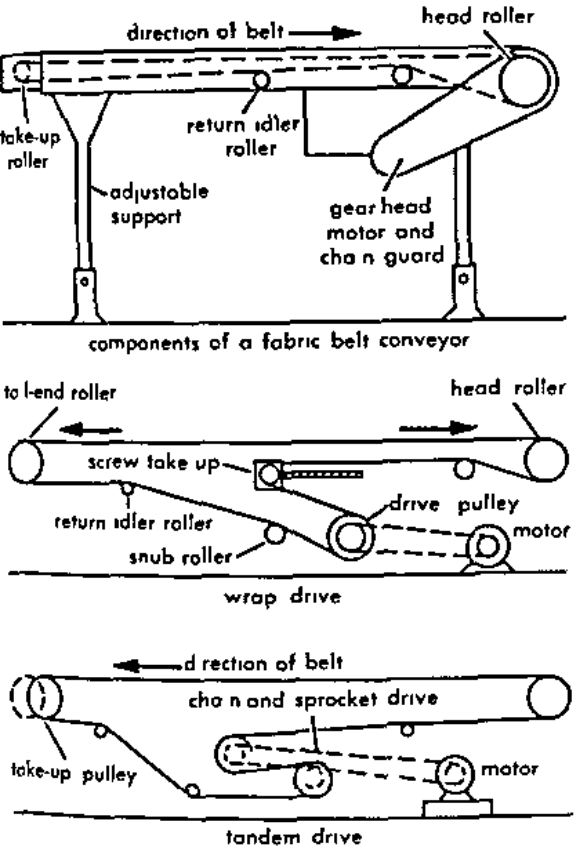
Conveyor systems include such accessories switches spurs Ys and adjustable stationary castered stands Diverting of articles from smoo rollers is easier than from wheels Ball transf tables are useful for making 90° changes in dire tion provided the bottom of the product is smoo and hard (Fig 2) The length of gravity lines limited by the gradual loss of elevation which mu be restored where necessary by powered boos ers

Economic considerations and the nature of th contacting surface of the products being hand are factors in selecting these machines In genera wheel types are less expensive per unit than roll varieties However the latter are apt to stand u under greater punishment than the former To m successfully on rollers one surface of the art must be smooth and firm In some instances whe the container is strapped wheels can be arrange so the protrusions will ride between rather tha on these members

Wheel and roller conveyors are frequently set u as level push lines in warehousing operat ons h distributing incoming goods and assembl ng ou going orders Wheel or roller sections may be a ranged in vertical tiers Packages fed in at the re of these lines ride down the slight incline and a picked off at the front in assembling orders Leve set wheel and roller lines are used for l ve fix storage of drums and kegs

Heavy duty roller conveyors sometimes mounte on springs to absorb shocks are used in s e mills foundries and other ind stries where la units of considerable weight are handled regular

Powered conveyors Loads are moved on a lev or inclined path by means of power-dr ven belt



Fg 3 Arrangements of driven belt conveyors

chains or cables Fabric conveyor belts are made of woven canvas or cotton duck Some are inter woven with two or more plies, others are made by folding 60 in widths in various combinations and then stitching them together The weight of con veyor belts is designated by the weight in ounces of a swatch 36 in by 42 in Belts may be used plain or they may be impregnated or coated to fit them for a particular product or operating condi tion There are belts suitable for handling food stuffs and rough top belts make possible inclines up to 28° Cleated belts are limited on inclines only by the position of the center of gravity of the conveyed item

Essential components of belt conveyors (Fig 3) in addition to the belt itself are (1) a bed which may be a combination bed and frame (2) end roll ers (3) a takeup to adjust belt tension as it varies with age and atmospheric conditions and (4) a power unit The bed of a fabric belt conveyor may be wood or more usually sheet metal flat or concave or it may be made up of rollers The for mer are called slide the latter roller beds Slide beds provide quiet smooth conveying but they re quire more power than roller beds The two end rollers are mounted in antifriction bearings with provision for lubrication Where the tail roller is mounted in adjustable end arms to provide takeup the length of the conveyor is not constant Where this feature is objectionable automatic gravity screw or spring takeups can be used Another re quired adjustment is provided by mounting the roll ers so that their bearings can be shifted slightly either forward or backward in order to train the belt to run true

Belts can be powered in several ways A gear head motor can be connected directly to the head roller or the drive may be through a chain and sprockets These arrangements necessitate placing the drive outside of the frame When this is un desirable one of two drives can be located under the frame Power units usually provide fixed or variable speeds from a few feet per minute to over 50 fpm, 50 fpm is usual with package conveyors Normally ⅓ hp motors power these units but others are available for heavier duty

Powered package conveyors can be combined in various ways to meet specific conditions Powered curves are used but wheel and roller sections are more usually employed to change direction In clined belt conveyors usually have a hump (Fig 4) at the upper end to reduce the slapping by pack ages on the belt as they move from inclined to horizontal travel Cleats can be used but they com plicate the feeding of packages onto the line and require special construction features so that the cleats can pass around pulleys and be properly sup ported on the return portion of the conveying cycle

Metal belts made of woven and flat wire linked rods and steel bands are engineered to make up conveyors which are essentially the same as fabric belt conveyors For example woven wire belts can be driven by pulleys and these may be lagged that

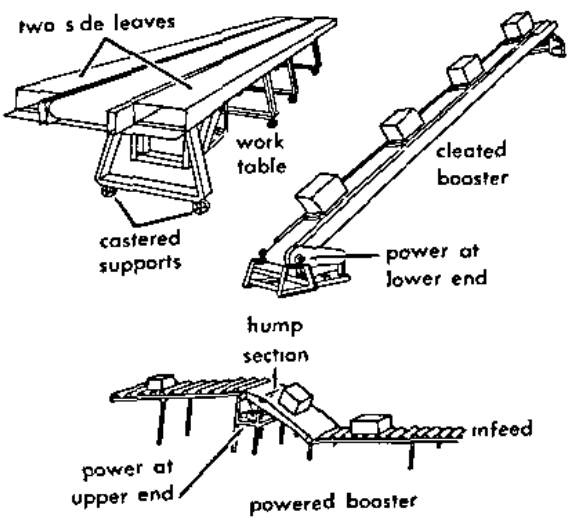


Fig 4 Fabric belt conveyors

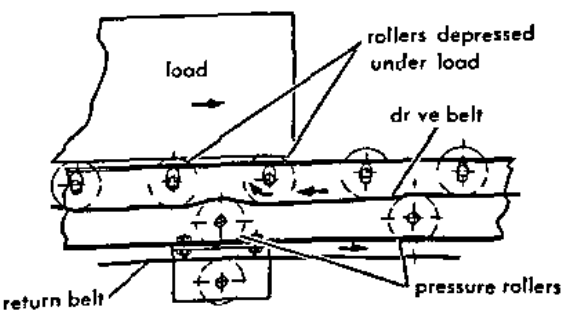


Fig 5 Live rollers provide power for gravity curves

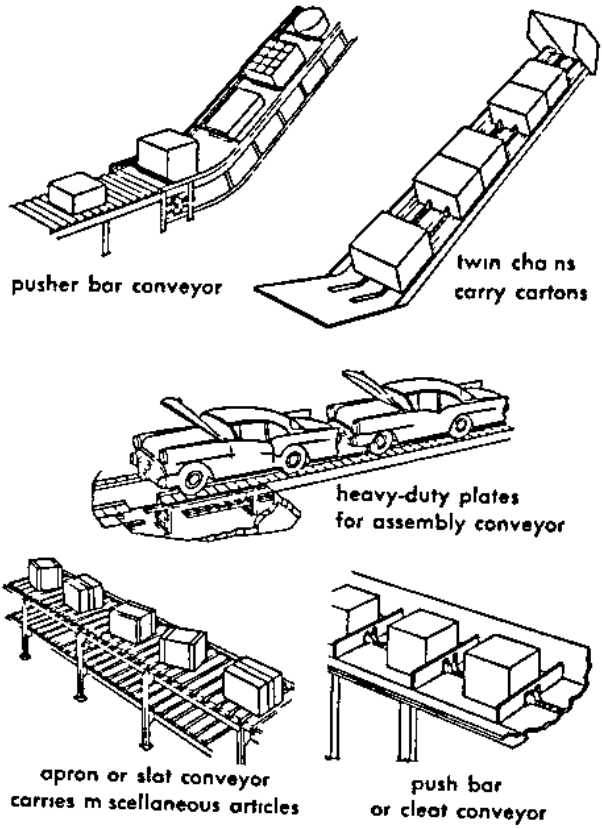


Fig 6 Examples of the basic types of chain conveyors (*From Conveyor Equipment Manufacturers Association Conveyor Terms and Definitions 2d ed 1958*)

is covered with a material to improve traction Contact with the drive pulley can be increased by snubbing with small diameter idler pulleys which guide the belt to increase the angle of contact Flat wire linked rod and woven wire belts with chain edges are driven positively by pulleys with sprocket teeth or by true sprockets Steel band conveyors are driven by pulleys with unusually large diameters Other components are similar to those used in fabric belt conveyors but are more rugged in construct on to hand t i

the ir
belts
high temperature operations such as baking annealing brazing and heat treating The choice of a belt for a given situation depends on the effect of the belt's surface on the product amount of drainage required and similar factors

Live roller conveyors Rollers and powered drives are combined in one arrangement in which a belt drive running under, and in contact with, the rollers turns them (Fig 5) In another setup small sprockets on the ends of the roller shafts are actuated by chain drive The first type permits packages to be stopped on the line without shutting down the entire conveyor, both types provide powered rollers on inclines and on curves

Chain conveyors There are three types of chain conveyors (1) those that support the product being conveyed (2) those that carry actuating elements between two chains and (3) those that operate overhead or set in the floor (Fig 6)

One or more chains either plain links or with such attachments as lugs are made up into conveyors to handle cases milk cans logs lengths of pipe and similar products Small dollies and fixtures dragged by chains are used in assembly lines to move the product through successive operations

Flat top chains, both rectangular and crescent shaped, are standard equipment in packaging h conveyors The former operate in straight lin whereas the latter can negotiate curves Hea plates are mounted flush with the floor in autom bile assembly departments to provide for progre sive operations

Slat or apron conveyors are fitted with slats wood or metal possibly in special shapes betwe two power driven chains The slats handle suc freight as barrels, drums and crates With cleat slat conveyors carry articles up rather steep i clines

Pusher bar conveyors are variations of the prev ous types The bars are used to push package which are fairly uniform in height

Overhead trolley conveyors can be operated b chains or cables They follow a closed path, bu can provide inclined and declined sections Both overhead and in floor types are used to tow trucks along loading platforms and through warehouse storage areas Large horizontal sprocket wheels mesh with and drive the chain, wheels carry the chain around turns The trolleys run on tracks much like those used in monorails many below the hook devices are used for special handling

Vertical conveyors consist of two types (1) two endless chains which carry supporting arms or similar devices to lift the loads and (2) suspended carriages, which move up through one path and down through another, but which are always level Various arrangements for automatic loading and discharge can be provided

Compressed air or suction propels carriers through pneumatic tubes to carry blueprints samples and job orders in plants and offices [D O K]

Bibliography Conveyor Equipment Manufacturers Association *Conveyor Terms and Definitions* 2d ed , 1958

Conveyor

A materials handling machine that moves its load with continuous motion over a fixed horizontal declined inclined or vertical path Although some vertical conveyors are frequently called conveyor elevators they do not in a strict sense, fall in the same category as freight elevators industrial lifts, and stackers all of which move their loads with intermittent or reciprocating motion

The more usual basic types of conveyors and their normal, rather than their exceptional operating characteristics are shown in the accompanying chart Almost all these basic types can be varied in a number of ways For example fabric

belts are usually made of woven cotton untreated impregnated or coated but several kinds of synthetic fibers are also used for this purpose Further the beds over which these belts operate can be wood sheet metal or rollers (flat or troughed)

Factors to be considered in selecting conveyors for specific applications include (1) product characteristics such as shape dimensions weight nature of the contacting surface and other features of solids and the size flowability abrasiveness and similar critical features of bulk materials (2) product activity including frequency and quantities handled and (3) peculiarities of the operating area and environment whether in a build

Normal operating characteristics of typical conveyors

Conveyor Type	Paths						Typical products										Bulk materials							
	horizontal	declined	inclined	vertical	straight	curved	cases boxes etc.	barrels and kegs	drums	textile bags	paper bags	bottles and jars	cans	small parts	hooded products	lumber pipe etc	towing trucks	free flowing	sluggish	dry	wet	cold	hot	nonabrasive	abrasive
GRAVITY CONVEYORS																									
Sliding friction																									
Skid		X			X			X	X																
Chute		X			X	X	X			X	X				X			X		X		X	X	X	
Spiral chute		X				X	X			X	X				X										
Rolling friction																									
Wheel	X	X			X	X	X				X					X									
Roller	X	X			X	X	X	X	X							X									
Spiral wheel		X				X	X																		
Spiral rolls		X				X	X	X	X																
POWERED CONVEYORS																									
Continuous belt																									
Fabric	X	X	X		X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Flexible tube with zipper	X	X	X	X	X	X												X		X		X	X	X	X
Steel band	X	X	X		X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Woven or flat wire	X	X	X		X							X	X	X	X										
Linked rod	X	X	X		X	X						X	X	X	X										
Live roller (drive)																									
Flat belt	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
V belt	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
Sprocket	X	X	X		X	X	X	X	X	X	X	X	X	X	X										
Chain																									
Apron (slat)	X	X	X		X		X	X	X	X	X														
Flexible	X	X	X		X		X	X	X																
Pan	X	X	X		X								X	X	X										
Pusher bar	X	X	X		X		X																		
Hinged plate	X	X	X										X	X	X										
Flat top plate	X				X	X						X	X												
Bucket*	X	X	X	X	X													X		X	X	X	X	X	X
Flight	X	X	X	X	X													X		X		X	X	X	
Drag chain																									
Pan links with lugs	X	X	X		X	X	X		X				X			X									
Overhead trolley	X	X	X		X	X											X								
Infloor trolley	X				X	X											X								
Cable																									
Overhead trolley	X	X	X		X	X																			
Table-mounted trolley	X	X	X																						
Cableway*	X	X	X		X	X																			
Spar (screw)	X	X	X	X	X	X												X	X	X	X	X	X	X	X
Vertical																									
Rigid arm				X	X		X	X	X	X	X														
Pendant cage				X	X		X	X	X	X	X														
Pneumatic																									
Tube (with cases)	X	X	X	X	X	X								X											
Pressure or suction	X	X	X	X	X	X												X		X		X	X	X	X
Vibrating	X	X	X	X	X													X		X		X	X	X	X

Some bucket conveyors may use endless belts Most products or bulk materials can be conveyed by selection of attachments to the troughs.
*Cableways or aerial tramways are used primarily for cross country conveying of coal ashes lumber concrete and similar products used in construction

ing a yard or over open country, the distances involved, and unusual ambient temperatures and humidities

These controlling factors account for the several variations in the basic types of conveyor to make them more flexible in their applications *See* BULK HANDLING MACHINES, CONVEYING MACHINES

[D O H]

Convulsive disorders

Disorders in which involuntary general paroxysms of muscular contraction (convulsions) are a leading or an important symptom Diseases in which convulsions occur are degenerative and inflammatory diseases of the brain cerebral traumas tumors, birth injuries and malformations of the brain The most important convulsive disorder is epilepsy which however is not always characterized by true convulsions (*see* EPILEPSY) Convulsions may affect the whole body or part of the body Most convulsions are accompanied by loss of consciousness but some are not

Hysterical patients may also have fits which may resemble convulsions but are of an entirely different character The occurrence of convulsions should be the signal for a thorough neurological as well as psychiatric investigation Treatment of convulsions should be directed if possible towards the treatment of the underlying disorders There are effective drugs such as phenobarbital and dilantin to treat symptomatic convulsions *See* ABNORMAL BEHAVIOR

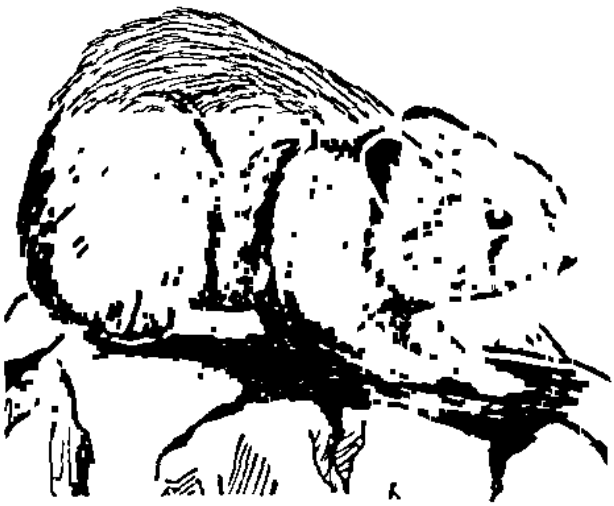
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Cony

A name applied in North America to *Ochotona princeps* a short legged small relative of the rabbit with a rudimentary tail These rodentlike animals sometimes called pikas are about 8 in long and live in higher elevations on the talus slopes of the mountains in the western United States They are well known for their habit of harvesting drying and storing grass for winter feed This species and an Asian species comprise the family Ochotonidae, of the order Lagomorpha The Biblical conies, *Hyrax* (*Procavia*), are wholly unrelated animals *See* LAGOMORPHA

[J D B]



The pika *Ochotona princeps* length to 8 in (*From E L Palmer, Fieldbook of Natural History, McGraw Hill* 1949)

Cooling tower

A towerlike device in which atmospheric air (the heat receiver) circulates in direct contact with warmer water (the heat source), and the water is thereby cooled A cooling tower may serve as the heat sink in a conventional thermodynamic process such as refrigeration or steam power generation or it may be used in any process in which water is used as the vehicle for heat removal and when it is convenient or desirable to make final heat rejection to atmospheric air Water, acting as the heat transfer fluid gives up heat to atmospheric air and thus cooled is recirculated through the system affording economical operation of the process

Cooling means The transfer of heat from warmer water to cooler air in a cooling tower is accomplished mainly by evaporation and in some measure by sensible heat transfer When the air enters its moisture content is generally less than saturation, it emerges at a higher temperature and with a moisture content approaching saturation Evaporative cooling takes place even when the incoming air is saturated because as the air temperature is increased in the process of absorbing sensible heat from the water there is also an increase in its capacity for holding water vapor

The wet bulb temperature of the incoming air is the theoretical limit of cooling A cooling of the water within 5–10°F above wet bulb temperature represents good practice The amount of water evaporated is relatively small Approximately 1000 Btu is required to vaporize 1 lb of water at cooling tower operating temperatures This represents a loss of water from evaporation of approximately 1% of the water circulated for each 10°F of cooling provided the cooling is primarily the result of evaporation Drift losses are generally about 0 1 0 2% of the water flow to the tower and must be added to the evaporative loss to account for all water lost in the practical cooling operation

Types Cooling towers are classified as to type by the means employed for producing air circulation through them (1) atmospheric (2) natural draft and (3) mechanical draft

Atmospheric cooling Some towers depend upon natural wind currents blowing through them in a substantially horizontal direction for their air supply Louvers on all sides prevent water from being blown out of these atmospheric cooling towers and allow air to enter and leave independently of wind direction Generally towers are located broadside to prevailing winds for maximum sustained air flow

Thermal performance varies greatly because it is a function of wind direction and velocity as well

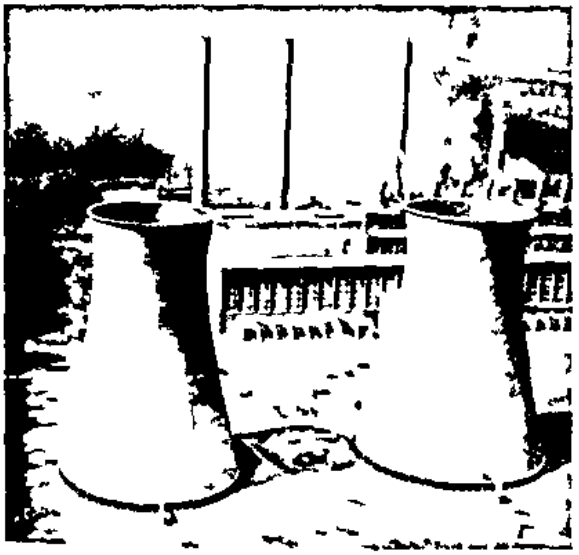


Fig 1 Natural-draft cooling tower (*Hamon Inc*)

as wet and dry bulb temperatures The normal loading of atmospheric towers is from 1 2 gal/min of cooling water per square foot of cross section They require considerable unobstructed surrounding ground space in addition to their cross-sectional area to operate properly Because they need more area per unit of cooling than other types of towers they are usually limited to small sizes

Natural draft Other cooling towers depend upon natural convection of air flowing upward and in contact with the water to be cooled for their air supply Essentially natural draft cooling towers are chimneylike structures with a heat transfer section installed in their lower portion directly above an annular air inlet (Fig 1) Sensible heat absorbed by the air in passing over the water to be cooled increases the air temperature and reduces its density so that the air is forced upward and out of the tower by the surrounding heavier atmosphere The flow of air through the tower varies with the difference in specific weights between ambient air and air leaving the heat transfer surfaces Thus the reduced performance generally associated with constant air flow towers and which occurs when relative humidity increases at constant temperature is lessened

Normal loading of a natural draft tower is 2–4 gal/(min) (ft²) of ground level cross section Unlike the atmospheric cooling tower the natural draft cooling tower does not require as much unobstructed surrounding space and is generally suited for both small and large installations It is common in Europe however economic justification for the use of this type of tower in the United States is at present controversial

Mechanical draft Those cooling towers that depend upon fans for their air supply may have the fans arranged to produce either a forced or induced draft Induced draft designs are more commonly used than forced draft designs because of lower initial cost improved air water contact and less recirculation (Fig 2) With controlled air

capacity of the mechanical draft tower can be adjusted for economic operation in relation to heat load and in consideration of ambient conditions

Normal loading of a mechanical draft cooling tower is 2–6 gal/(min) (ft²) of cross section Unlike the atmospheric cooling tower the mechanical draft tower does not require as much unobstructed surrounding space to obtain adequate air supply but requires more surrounding space than natural draft towers This type of tower is suitable for both large and small installations

Tower components The more important components of cooling towers are the supporting structure casing cold water basin louvers discharge

assembling the parts are usually bronze stainless steel or aluminum Distribution systems may be in the form of piping usually steel and equipped with bronze spray nozzles or they may be in the form of troughs and weirs made of wood Structural framing may also be made of galvanized standard structural steel shapes Aluminum has been used for the casing and recently a tower completely fabricated of aluminum has been placed in service

Natural draft cooling towers especially in large sizes are made of reinforced concrete The

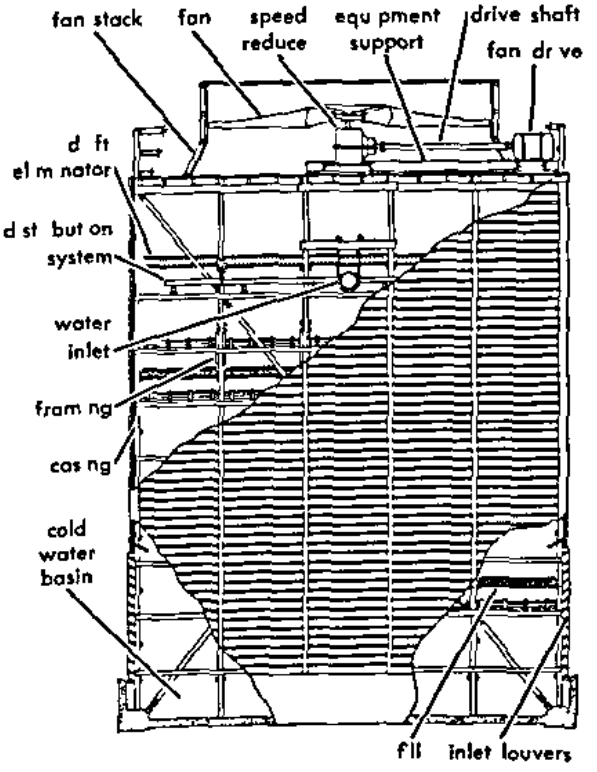


Fig 2 Induced-draft counterflow cooling tower (*Fostec Wheeler Corp*)

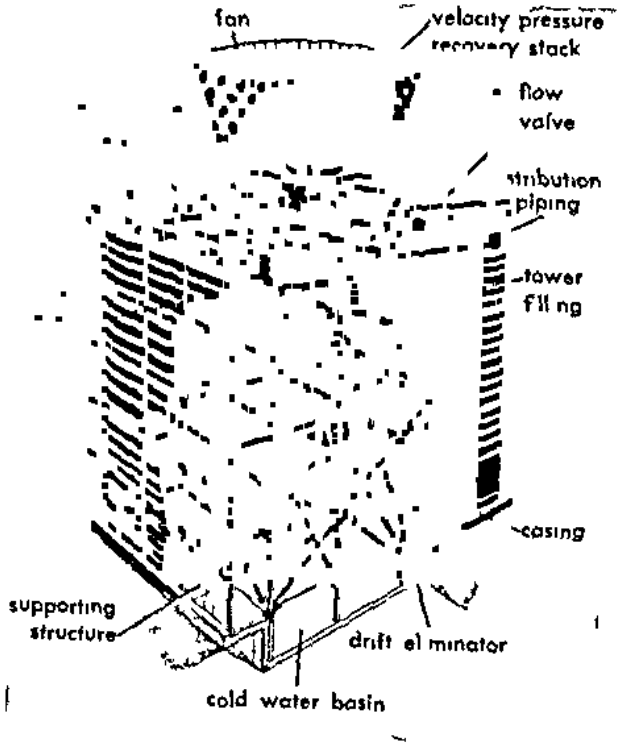


Fig 3 Induced draft cross-flow cooling tower (N P Green and Associates)

filling is usually made of asbestos cement although wood is sometimes used The cold water basins are usually made of concrete for ground mounted towers and wood or steel for roof mounted towers Fan blades are made of corrosion resistant material such as monel stainless steel or aluminum

Performance The performance of a cooling tower may be described by the generally accepted equation of F Merkel as follows

$$\frac{KaV}{L} = \int_{T_2}^{T_1} \frac{dT}{h'' - h}$$

where a = water air contact area ft^2/ft^3
h = enthalpy of entering air Btu/lb
h'' = enthalpy of leaving air Btu/lb
K = diffusion coefficient $lb/(ft^2)(hr)$
L = water flow rate $lb/(hr)(ft^2)$
T = water temperature °F
T_1 = inlet water temperature °F
T_2 = outlet water temperature, °F
V = effective volume of tower ft^3/ft^2 of ground area

The integration of the Merkel equation is usually done graphically or by Simpson's rule *See* INTEGRATION

Cooling tower performance is based on cooling of a specified quantity of water through a given range and to a specified temperature approach to the wet bulb temperature for which the tower is designed Because exact design conditions are rarely experienced in operation estimated performance curves are usually prepared for a specific installation and provide a means for comparing the measured performance with design conditions *See* HEAT EXCHANGER, *see also* CONDENSER VAPOR

[J T S]

Coordinate systems, graphical

Schemes for locating points in a given space by means of numerical quantities specified with respect to some frame of reference These quantities are the coordinates of a point To each set of coordinates there corresponds just one point in any coordinate system, but there are useful coordinate systems in which to a given point there may correspond more than one set of coordinates

A coordinate system is a mathematical language that is used to describe geometrical objects analytically, that is, if the coordinates of a set of points are known, their relationships and the properties of figures determined by them can be obtained by numerical calculations instead of by other descriptions It is the province of analytic geometry and chiefly by calculus, to investigate the means for these calculations

The most familiar spaces are the plane and the three-dimensional euclidean space In the latter a point P is determined by three coordinates (x, y, z) The totality of points for which x has a fixed value constitutes a surface The same is true for y and z so that through P there are three coordinate surfaces The totality of points for which x and y are fixed is a curve and through each point there are three coordinate lines If these lines are all straight the system of coordinates is said to be rectilinear If some or all of the coordinate lines are not straight the system is called curvilinear If the angles between the coordinate lines at each point are right angles the system is called rectangular

Cartesian coordinate system This is one of the simplest and most useful systems of coordinates It is constructed by choosing a point O designated as the origin Through it three intersecting directed lines OX, OY, OZ, the coordinate axes are constructed The coordinates of a point P are x the distance of P from the plane YOZ measured parallel to OX, and y and z which are determined similarly (Fig 1) In this system the coordinate lines through P are straight lines respectively parallel to the three coordinate axes Usually the three axes are taken to be mutually perpendicular in which case the system is a rectangular cartesian one Obviously a similar construction can be made in the plane in which case a point has two coordinates $(x\ y)$ It is this system that is used in the construction of graphs and charts of various data whether observed or computed

Polar coordinate system This system is constructed in the plane by choosing a point O called the pole and through it a directed straight line the initial line A point P is located by specifying the directed distance OP and the angle through which the initial line must be turned to coincide with

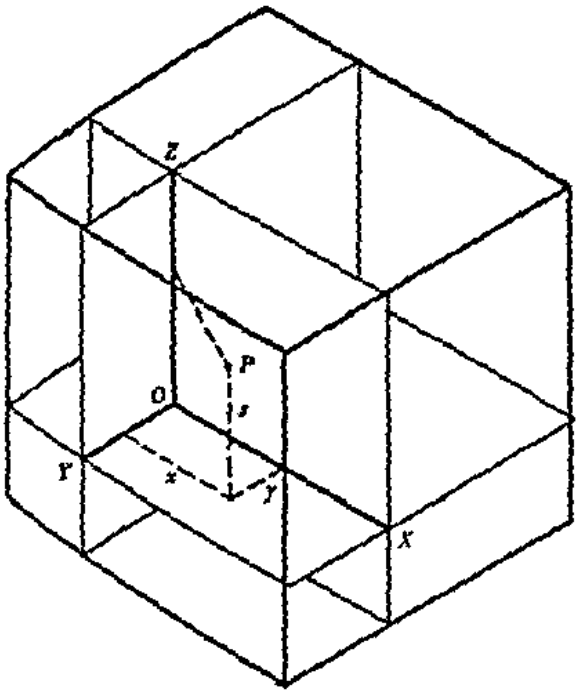


Fig 1 Cartesian coordinate system

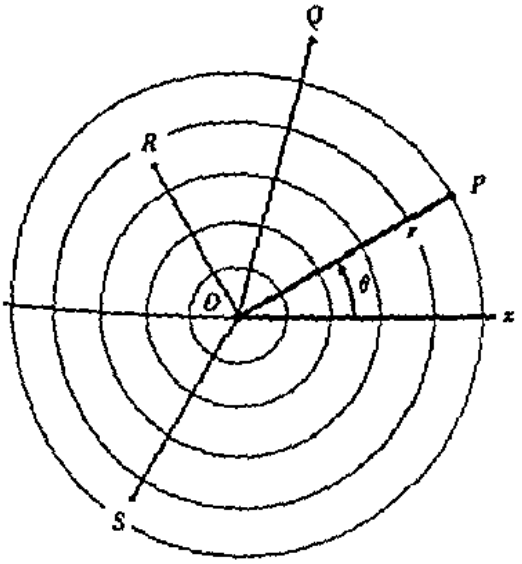


Fig 2 Polar coordinate system

OP in position and direction (Fig 2) The coordinates of P are $(r\,\theta)$ The *radius vector* r is the directed line OP and the vectorial angle θ is the angle through which the initial line was turned + if turned counterclockwise — if clockwise To each pair of values $(r\,\theta)$ there corresponds just one point but any point has an endless number of sets of coordinates. The coordinate lines in this case are radial lines through the pole (θ = constant) and concentric circles with center at the pole (r = constant) In spite of this lack of *unique* reciprocity between points and their coordinates the polar system is useful in the study of spirals rotations or motions under the action of central forces such as those of planets and comets

Spherical coordinates In *three-dimensional* euclidean space this system of coordinates is constructed by choosing a plane and in it constructing a polar coordinate system At the pole O a polar axis OZ is constructed at right angles to the chosen plane A point P not on OZ and OZ determine a plane The spherical coordinates of P are then the directed distance OP denoted by ρ the angle θ through which the initial line is turned to lie in ZOP and the angle $\phi = ZOP$ (Fig 3) The coordinate lines are radial lines through O (θ and ϕ constant) meridian circles (ρ and θ constant) and circles of latitude (ρ and ϕ constant) This is an example of a curvilinear rectangle coordinate system It is used in locating stars in the study of spherical waves and in problems in which there is spherical symmetry

Cylindrical coordinates These are constructed by choosing a plane with a pole O an initial line in it and a polar axis OZ as in spherical coordinates A point P is projected on to the chosen plane The cylindrical coordinates of P are $(r\,\theta,z)$ where r and θ are the polar coordinates of Q and $z = QP$ (Fig 3) This is also a curvilinear rectangular system the coordinate lines being mutually perpendicular This system is used in problems of fluid flow and in others in which there is axial symmetry

What has been done above in the plane and in euclidean space of three dimensions can be extended to curved spaces of any number dimensions For a space S of n dimensions with some known geometrical or physical properties, a coordinate system in which a point has coordinates $(u_1\ u_2\ \ldots\ u_n)$ is chosen The coordinate lines are curves along which only one coordinate varies. When the known properties of S are expressed in terms of these coordinates it is then the province of differ

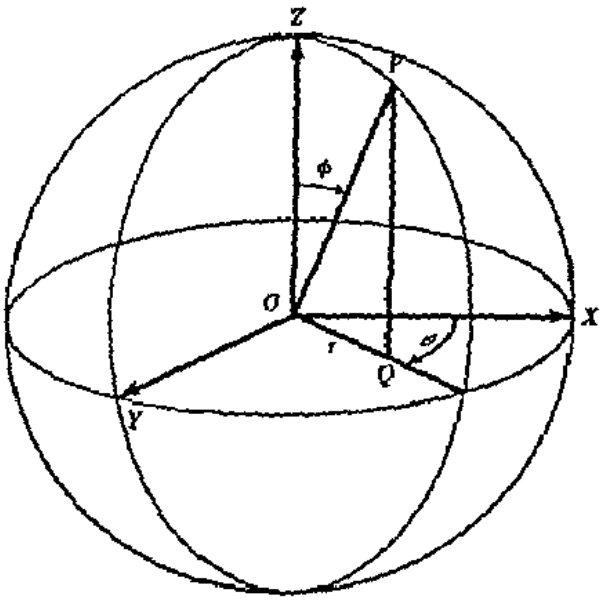


Fig 3 Spherical coordinate system

ential geometry to investigate their consequences. (*See* GEOMETRY DIFFERENTIAL)

Transformation of coordinates By means of a system of equations the description of a geometrical object in one coordinate system may be translated into an equivalent description in another coordinate system Thus in a given space of n dimensions if there is a coordinate system A in which a general point P has coordinates $(u_1\ u_2 \quad u_n)$ and a coordinate system B in which P has the coordinates $(v_1\ v_2 \quad v_n)$ the transformation from system A to system B is the set of equations $u_i = f_i(v_1 v_2 \quad v_n)$ for $i = 1\ 2 \quad n$ which expresses each u in terms of the vs These functions are obtainable from the relation between the two coordinate systems They are not completely arbitrary for they must be single valued independent and such that if in the B system P has another set of coordinates say $(v'_1 v'_2 \quad v'_n)$ then $f(v_1 v_2 \quad v_n) = f(v'_1 v'_2 \quad v'_n)$ Then if a geometrical locus in the space S is described by one or more equations of the form $F(u_1 u_2 \quad u_n) = 0$ in system A the equivalent description in system B is one or more of the equations of the form

$$F[f_1(v)\ f_2(v) \quad f_n(v)] = 0$$

Other geometrical objects such as vectors and areas have more complicated laws of transformation but each such law is expressible in terms of the equations of transformation As remarked above a coordinate system is a mathematical language a transformation of coordinates plays the role of a dictionary that translates from one language to another

The most important transformations of coordinates are between rectangular cartesian coordinate systems One such set of coordinate axes is obtainable from another by a translation (in the physical sense) and a rotation Consider a coordinate system A with coordinate axes OX OY OZ and coordinates of a point $P(x\ y\ z)$ System B is obtained by moving the axes without turning to a point O' with coordinates $(a\ b\ c)$ The new axes are $O'X'$ $O'Y'$ $O'Z'$ and the coordinates of P in this system are $(x'\ y'\ z')$ then the equations of transformation are $x = x' + a \quad y = y' + b \quad z = z' + c$ If the new system is obtained from A by a rotation of the coordinate axes let α_1 α_2 α_3 β_1 β_2 β_3 γ_1 γ_2 γ_3 be the angles which the new axes $O'X'$ $O'Y'$ $O'Z'$ make with the original axes (only three of these angles are independent) then the equations of transformation are

$$x = x' \cos\alpha_1 + y' \cos\beta_1 + z' \cos\gamma_1$$
$$y = x' \cos\alpha_2 + y' \cos\beta_2 + z' \cos\gamma_2$$
$$z = x \cos\alpha_3 + y' \cos\beta_3 + z' \cos\gamma_3$$

The equations of transformation may be differently interpreted The equations of transformation make the point P of coordinates $(x\ y\ z)$ in the same coordinate system correspond to a point P' of coordinates (x',y',z') This constitutes a mapping of the space upon itself which maps a figure into some other figure In applications one usually seeks a mapping that carries some pertinent loci into simpler loci while preserving some relevant properties *See* ANALYTIC GEOMETRY BARYCENTRIC CALCULUS, CALCULUS DIFFERENTIAL AND INTEGRAL, CONFORMAL MAPPING CURVE FITTING SPHERICAL HARMONICS [M.S.K.]

Coordinate systems, terrestrial

Methods for establishing relative position on the earth utilizing two sets of coordinates perpendicular to each other The orientation of the coordinates also establishes earth directions. The fact of earth rotation establishes the geographic poles which serve as reference points upon which the coordinate system is based The system was devised in the Greek classical period and no alternative has been seriously considered

Position within the coordinate system is determined by direct astronomic observation (or by derivatives of it) and is stated in terms of arc distance from reference positions Position between the poles is designated as latitude and corresponds to a Y value on a cartesian system Position corresponding to an X value on a cartesian system is designated as longitude

Latitude Arc distance of latitude toward the poles is reckoned from a great circle on the earth which is everywhere midway between the poles This line designated as the Equator is therefore everywhere 90° arc distance from the poles Any other line a given lesser distance from a pole will be a small circle parallel to the Equator Direction along such a line is designated as east west. All such lines on the earth are termed parallels

Determination of latitude is possible by astronomic means since the axis of the earth remains

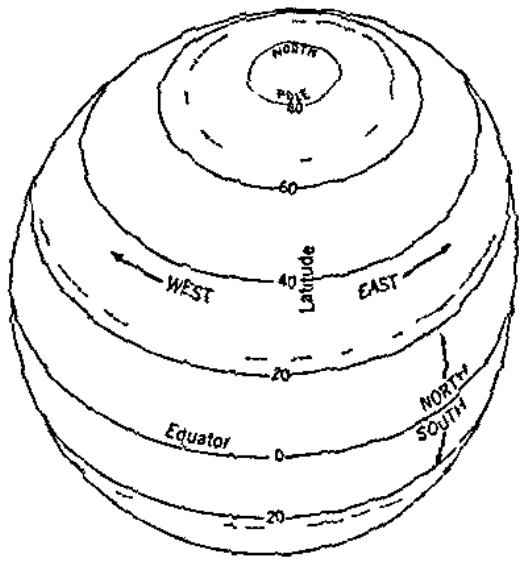


Fig 1 The parallel system of the earth's coordinate net It establishes the directions east and west and provides a method for designating position north and south (*From V C Finch G T Trewartha A H Robinson and E H Hammond Elements of Geography 4th ed McGraw-Hill 1957*)

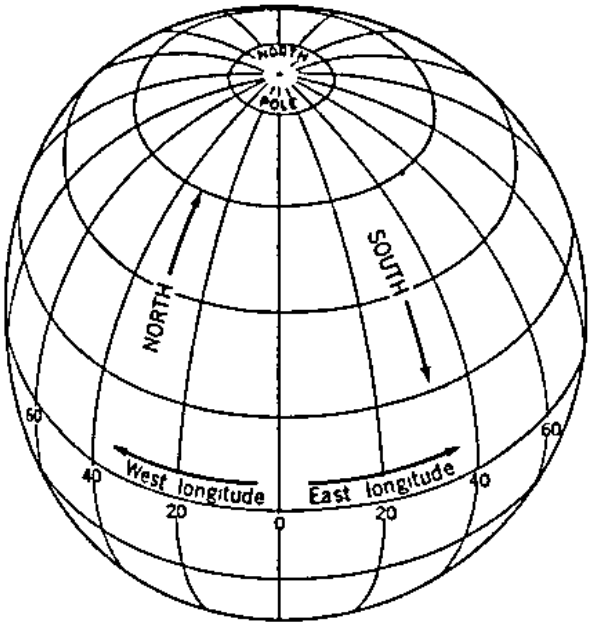


Fig 2 Adding the meridian system of the earth s coordinate net to the parallel system establishes the d rections of north and south, and provides a method for designating position east and west (*From V C Finch, G T Trewartha, A H Robinson, and E H Hammond, Elements of Geography, 4th ed , McGraw Hill 1957*)

parallel to itself during revolution around the sun Because the earth's surface is spherical, simultaneous observations at two points of the angle between the horizontal on the earth's surface and the elevation of a given celestial body will supply directly the polar arc distance between the two points when the difference between the observed angles is found Because of earth rotation and minor shifts in celestial relations, the position of celestial bodies relative to a single point on the earth is constantly changing, but by reference to an ephemeris (astronomical almanac) latitude can be computed from observations at a single point

Because the earth is not a true sphere but an oblate spheroid of revolution, the quadrant from the Equator to a pole is not a true arc but curves less rapidly near the pole Since latitude is astronomically derived, it follows that near the poles one must move a greater distance on the earth's surface than near the equator to observe a change of one degree in the elevation of a celestial body above the horizontal Consequently degrees of latitude are slightly shorter near the Equator (68 7 miles) and slightly longer near the poles (69 4 miles)

Latitude is numbered from 0° at the Equator to 90° at the poles Distance toward the North or South Pole is designated as north or south latitude respectively

Longitude Arc distance of longitude is measured along a parallel from some starting point Each parallel circle on the earth contains 360°, and since the earth rotates on an ax

pendicular to the planes of the parallel circles, each parallel therefore rotates 360° in one day, or 15° in 1 hour Consequently the difference in sun time between two points may be expressed as an angular difference in longitude Local sun time at one place is easily observed by noting the instant the sun reaches its zenith, but the difference in sun time at two places cannot easily be determined by celestial observation Time at one of the places must be known at the other in order to determine longitude This may be done by carrying a chronometer (an accurate clock) set to the time of a known place or by means of radio time signals from a known place

A great circle from pole to pole has everywhere along it the same sun time Such a line is called a meridian Direction along such a line is designated as north south All meridians are alike and, unlike latitude there is no natural starting point from which to begin their numbering Confusion over which meridian should be chosen became so great that in 1884 the meridian passing through the Royal Astronomical Observatory in Greenwich, near London was internationally agreed upon as the 0° meridian, or the Prime Meridian Longitude is measured and designated as east or west longitude from the Prime Meridian to 180°, the meridian opposite 0° longitude The earth's coordinate system therefore, "originates" with coordinates numbered zero intersecting in the Gulf of Guinea

Since only the Equator among the parallels is a great circle and all other parallels are small circles decreasing in radius to nil at the poles, it follows

gree of longitude is nearly the same length as a degree of latitude [A H R]

Coordination chemistry

A field which in its broadest usage, is acid base chemistry as defined by G N Lewis For a discussion of the Lewis acid base theory *see* ACID AND BASE However the term coordination chemistry is generally used to describe the chemistry of metals and metal ions in their interactions with other molecules or ions For example, the reactions

$$Mg^{2+} + 6H_2O \rightarrow Mg(H_2O)_6^{2+}$$
$$Ni + 4CO \rightarrow Ni(CO)_4$$
$$Fe^{2+} + 6CN^- \rightarrow Fe(CN)_6^{4-}$$

are acid base type reactions, the products formed are coordination ions or compounds, and this area of chemistry is known as coordination chemistry

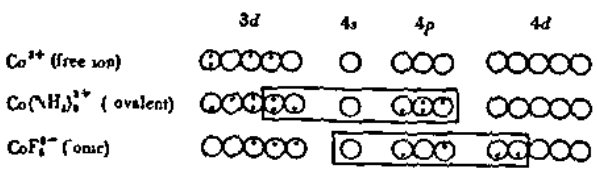
Thus, it follows that coordination compounds are

The charge on the coordinated species may be positive, zero, or negative, depending on the charges carried by the central atom and the coordinated groups These groups are called ligands, and the

tal number of attachments to the central atom is called the coordination number Other names commonly used for these compounds include complex compounds complex ions Werner complexes coordinated complexes chelate compounds or simply complexes For a more detailed discussion of these compounds *see* CHELATION COMPLEX COMPOUNDS

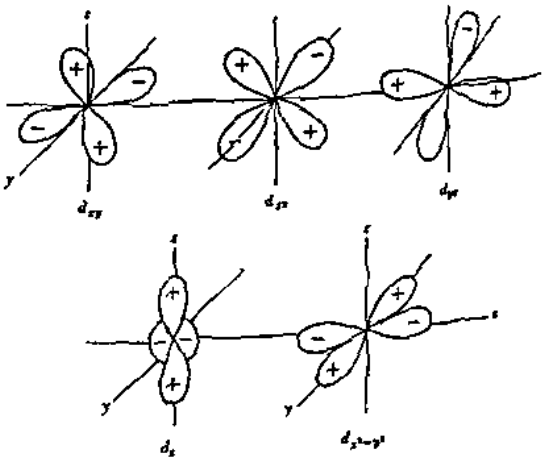
Experimental observations as early as the middle of the eighteenth century reported the isolation of coordination compounds During that time and for the following 150 years the valence theory could not adequately account for such materials As a result they were referred to as complex compounds the term which is still in common usage but not for the same reason The correct interpretation of these compounds was finally given by Alfred Werner in 1893 He introduced the concept of residual or secondary valence and suggested that elements have this type of valence in addition to their normal or primary valence Thus platinum(IV) has a normal valence of 4 but a secondary valence or coordination number of 6 This then led to the formulation of $PtCl_4\ 6NH_3$ as $[Pt(NH_3)_6]^{4+}\ 4Cl$ and of $PtCl_4\ 5NH_3$ as $[Pt(NH_3)_5Cl]^{3+}\ 3Cl$ The compound with 5 ammonias has only 3 ionic chlorides the fourth is inside the coordination sphere and therefore is not readily precipitated upon the addition of silver ion Although the exact nature of the coordinate bond between metal and ligand remains the subject of considerable discussion it is agreed that the formulations of Werner are essentially correct

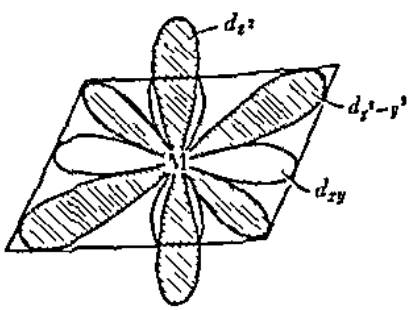
The coordinate bond There are three theories which are currently used to explain the nature of the coordinate bond These are (1) the valence bond theory (2) the electrostatic theory including crystal field corrections and (3) the molecular orbital theory The valence bond theory for metal complexes was developed chiefly by Linus Pauling This theory considers that the pair of electrons on the ligand enter the hybridized atomic orbitals of the metal and that the bond is either essentially covalent or essentially ionic Several of the properties of these substances can be explained on the basis of this theory For example cobalt(III) complexes are represented as follows



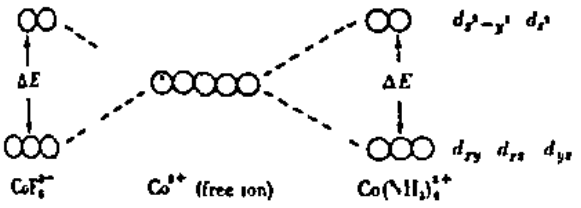
The orbital hybridization of $Co(NH_3)_6^{3+}$ is designated as d^2sp^3 and the complex is referred to as an inner orbital complex Such a representation is consistent with the diamagnetic properties of this cation for all electrons are paired The orbital hybridization of CoF_6^{3-} is designated as sp^3d^2 and it is called an outer orbital complex This ion is known to be paramagnetic, which is in keeping with the 4 unpaired electrons in the 3*d* orbitals The term inner orbital is applied if the *d* orbital of a lower energy than the *s* and *p* is used in bonding whereas outer orbital has reference to systems in which the *d* orbital used is at the same energy level as the *s* and *p*

The electrostatic theory plus the crystal field theory for the transition metals assumes that the metal ligand bond is caused by electrostatic interactions between point charges and dipoles and that there is no sharing of electrons Physicists have made good use of this theory to explain the properties of ionic crystalline solids and it has now been extended to the metal complexes For the nontransition metals the parameters needed to determine the strength of the metal ligand bond are the charges and sizes of the central ions and the charges, dipole moments polarizabilities and sizes of the ligands In order to give an adequate explanation of the bonding for transition metals, it is also necessary to consider the orientation of the *d* orbitals in space For the gaseous ion all 5 of the *d* orbitals are of equal energy However the $d_{x^2-y^2}$ and d_{z^2} orbitals are pointing directly toward the 6 ligands at the corners of an octahedron and because of repulsive interaction with the *ligands* are at a higher energy than the d_{xy} d_{xz} and d_{yz} orbitals which do not point toward the ligands





Thus on the basis of the crystal field theory the cobalt(III) complexes referred to above are designated as follows

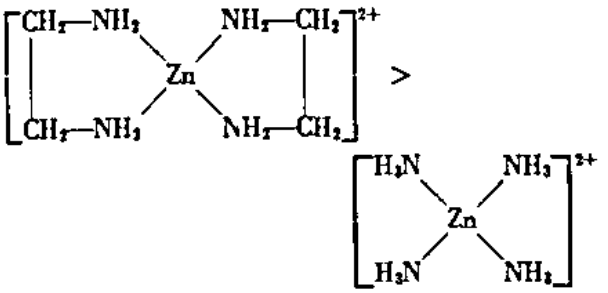


The $Co(NH_3)_6^{3+}$ is called a spin paired complex whereas CoF_6^{3-} is called spin free This refers to the fact that the electrons are all paired in the former because of the larger crystal field splitting ΔE whereas in the latter ΔE is small and the electrons are not paired In addition to explaining the structure and magnetic properties this theory affords an adequate interpretation of the visible spectra of metal complexes

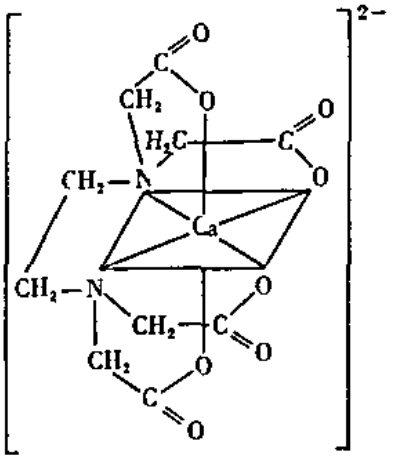
The molecular-orbital theory assumes that the electrons move in molecular orbitals which extend over all the nuclei of the metal ligand system In this manner it serves to make use of both the valence-bond theory and crystal field theory The molecular-orbital theory is therefore the best approximation to the nature of the coordinate bond because it is sufficiently flexible to permit both covalent and ionic bonding as well as the splitting of d orbitals into various energy levels

Stabilities of complexes The stability of metal complexes depends both on the metal ion and the ligand There is a great deal of quantitative information on the stability of coordination compounds These data show that in general the stability of metal complexes increases if the central ion increases in charge decreases in size and increases in electron affinity Thus alkali metal ions have the least tendency to form complexes and the highly polarizing transition metal ions have the greatest tendency However even in the least favorable cases of the alkali metal ions there is ample evidence that coordination with certain ligands does occur For the transition metal ions it also appears that the electronic configuration of the ion is significant with regard to the stability of its complexes For example regardless of the nature of the ligand the stability of complexes of bivalent transition metals is $Mn < Fe < Co < Ni < Cu > Zn$ This so-called natural order of stability is explained in terms of the crystal field theory which indicates that a maximum stabilization effect in spin free complexes is realized with d^3 systems such as exists in Ni^{2+} The platinum metals because of their large polarizing ability generally form the most stable metal complexes

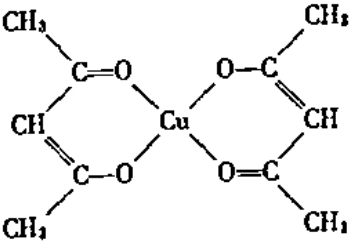
Effect of ligand Several characteristics of the ligand are known to influence the stability of complexes (1) basicity of the ligand (2) the number of metal chelate rings per ligand (3) the size of the chelate ring (4) steric effects (5) resonance effects and (6) the ligand atom Since coordination compounds are formed as a result of acid base reactions where the metal ion is the acid and the ligand is the base it follows that generally the more basic ligand will tend to form the more stable complex Much of the available quantitative data on the formation constants of coordination compounds gives a good linear correlation with the base strength of the ligand It is also known that a polydentate ligand one attached to the metal ion at more than one point forms more stable complexes than does an analogous monodentate ligand For example ethylenediamine forms more stable complexes than does ammonia



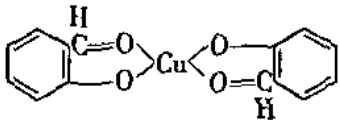
The ethylenediamine complex is referred to as a chelate complex In general an increase in the extent of chelation results in an increase in the stability of the complex Ethylenediaminetetraacetate ion a sexadentate ligand is an excellent chelating agent and has found numerous applications as a sequesterant for metal ions



The size of the chelate ring is likewise an important factor For saturated ligands such as ethylenediamine 5 membered rings are the most stable whereas 6 membered rings are the most stable for chelates containing one or more double bonds for example (I) and (II) Examples of smaller and of



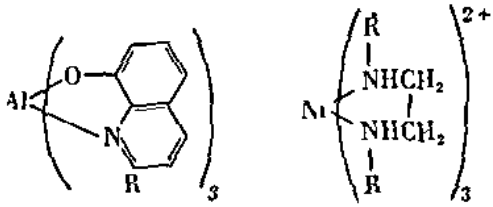
(I)



(II)

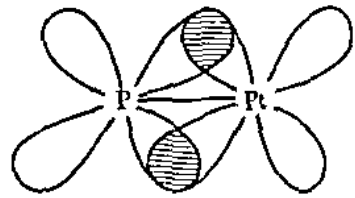
larger chelate ring systems are known but these are much less common and less stable It has been observed that for analogous systems an increase in double bonding in the chelate ring increases the stability of the complex For ligands of comparable base strengths the acetylacetonate complexes of type (I) above are more stable than the salicylaldehyde compounds of type (II) There are in effect two double bonds per chelate ring in (I) compared to one and a half in (II) This same phenomenon is believed to be responsible for the marked stability of the porphyrin complexes such as chlorophyll hemoglobin and the phthalocyanine dyes

Steric factors often have a very large effect on the stability of metal complexes This is most frequently observed with ligands having a large group attached to the ligand atom or near it



Thus complexes with alkyl groups in the position designated are much less stable than the parent complex where R = H This results from the steric strain introduced by the size of the alkyl group on or adjacent to the ligand atom In contrast to this alkyl substitution at any other position results in the formation of more stable complexes because the ligand becomes more basic and the bulky group is now removed from a position near the coordination site

Finally the ligand atom itself plays a significant role in controlling the stability of metal complexes For most of the metal ions the smallest ligand atom with the largest electron density will form the most stable complex This means that the second period elements form more stable metal ligand bonds than do other members of the same group for example $N > P > As > Sb$ $O > S > Se > Te$ $F > Cl > Br > I$ It is also known that for this same class of metal ions the stability order is $N > O > F$ These trends are in accord with the coordinate bond strengths expected on the basis of electrostatic interactions A different trend in stability is found for a second class of metal ions for example Cu(I) Rh(I) Pd(II) Ag(I) Pt(II) and Hg(II) The stability trends observed for these metal ions are $N \ll P > As \sim Sb$ $O \ll S > Se \sim Te$ and $F \ll Cl < Br < I$ Since the metal ions in this class have a large number of *d* orbital electrons and the third period ligand atoms have vacant *d* orbitals the enhanced stability is attributed to the formation of *dd*-π bonding This means that the filled *d* orbitals of the metal ion overlap with the empty *d* orbitals of the ligand atom This same class of metal ions is the one that forms olefin complexes such as Zeise's salt $K[Pt(CH_2{=}CH_2)Cl_3]$ The stability of these compounds is likewise attributed to π bonding



Stability and reactivity Often the most stable complex is also the least reactive or most inert. [illegible] exceptions to this for instance the rapid exchange of radiocyanide with the coordinated cyanide in the stable tetracyano complexes $Hg(CN)_4^{2-}$ and $Ni(CN)_4^{2-}$ Several factors such as the electronic configuration of the central metal ion its coordination number and the extent of chelation all have a marked effect on the rate of reaction of a given compound Sufficient data are available to permit a fairly reliable classification for the relative reacti[vities] [illegible] as the instantaneous formation of the deep [blue] color of $Cu(NH_3)_4^{2+}$ upon the addition of excess ammonia to $Cu(H_2O)_4^{2+}$ Complexes are designated as being inert if their reactions at room temperature proceed at a detectable rate and have *half* lives longer than 2 min On the basis of such a definition it is possible to classify the labile complexes as being those of either the outer orbital type such as CoF_6^{3-} $Al(C_2O_4)_3^{3-}$ $SnCl_6^{2-}$ $Ni(NH_3)_6^{2+}$ or the inner orbital type with one or more vacant *d* orbital such as TiF_6^{2-} $V(CN)_6^{3-}$ $Mo(SCN)_6^{2-}$ The inert complexes are then the inner orbital type with no vacant *d* orbital for example

$$Co(NH_3)_6^{3+} \quad Cr(H_2O)_6^{3+} \quad RhCl_6^{3-}$$

A similar classification on the basis of the crystal field theory is done in terms of the labile systems being those that are not stabilized greatly by the crystal field

Reactions of complexes The reactions referred to above are acid base reactions where one basic ligand takes the place of a less basic ligand to coordinated to the acidic metal ion for example

$$Co(NH_3)_5Cl^{2+} + H_2O \rightarrow Co(NH_3)_5H_2O^{3+} + Cl^-$$

A reaction of this type is called a nucleophilic substitution reaction and is designated by the symbol S_N There are at least two fundamentally different pathways conceivable for such a reaction These are the dissociation and displacement mechanisms which are designated as S_N1 and S_N2 respectively

An S_N1 reaction goes by a two step process where the first step is a slow unimolecular heterolytic dissociation

$$Co(NH_3)_5Cl^{++} \xrightarrow{Slow} Co(NH_3)_5^{3+} + Cl^-$$

followed by the rapid coordination of the entering group

$$Co(NH_3)_5^{3+} + H_2O \xrightarrow{Fast} Co(NH_3)_5H_2O^{3+}$$

An S_N2 reaction is one involving a bimolecular rate determining step in which one nucleophilic reagent displaces another

$$Co(NH_3)_5Cl^{2+} + H_2O \xrightarrow{Slow} H_2O \quad Co(NH_3)_5 \quad Cl^{2+} \xrightarrow{Fast} Co(NH_3)_5H_2O^{3+} + Cl^-$$

Examples of both types of substitution are known for the reaction of metal complexes The specific reaction just cited as well as analogous reactions of $Co(NH_3)_4Cl_2^+$ and $Co(NH_3)_4OHCl$ appear to proceed by an S_N1 mechanism However reactions of platinum(II) complexes are believed to involve an S_N2 process for example

$$Pt(NH_3)_3Cl^+ + NO_2^- \xrightarrow{Slow} O_2N \quad Pt(NH_3)_3 \quad Cl \xrightarrow{Fast} Pt(NH_3)_3NO_2^+ + Cl^-$$

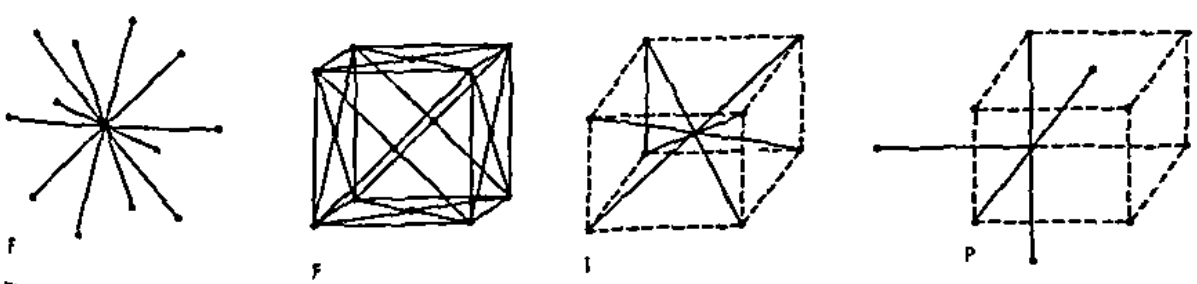
Finally coordination may have the effect of stabilizing an unusual oxidation state of the coordinated metal For example ligands such as CO CN CNR 2 2′ bipyridine and PR_3 are most effective in stabilizing low valent states Thus compounds of the type $Na_2[Fe(CO)_4]$ Na[V(2 2 bipyridine)$_3$] $K_4[Ni(CN)_4]$ and $Pt(PR_3)_4$ are known where the assigned oxidation states are Fe (2−) V (I−) Ni (0) and Pt (0) It is believed that the low oxidation states in these systems are stabilized by the formation of π type molecular orbitals between the metal and ligand atoms If the ligand orbitals are of low energy and vacant they can accommodate the *d* orbital electrons of the metal and permit the addition of other electrons leading to the reduction of the complex In contrast to this ligands such as O^2 OH and F tend to stabilize high valence states giving complexes of the type K_3FeO_4 Na_3BiO_4 K_2NiF_6 and K_3CuF_6 where the oxidation states are Fe (6+) Bi (5+) Ni (4+) and Cu (3+) These *ligands have no d* orbitals but only filled *p* orbitals One explanation for the stabilization of higher valent states by such ligands is that in these systems the π type molecular orbitals cannot be formed so that the metal electrons are forced into higher energy antibonding orbitals from which they may be readily removed *See* CHEMICAL BINDING MAGNETOCHEMISTRY SOLID-STATE CHEMISTRY STEREOCHEMISTRY SUBSTITUTION REACTION [F B]

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Coordination number

The number of nearest neighbors of a point in a space lattice of an atom or an ion in a structure or of an anion or cation in a complex ion The figure shows that the coordination number in the three cubic lattices *P I* and *F* is respectively 6 8 and 12 In closely packed structures this number is 12 The structures of the subgroup elements are easily described by means of the coordination number of each atom which is given by the rule of Hume Rothery or the 8-*N* rule Here *N* is the number of the subgroup Diamond germanium and silicon are in subgroup four the coordination number is 4 Tellurium and selenium are in subgroup six each atom having two nearest neighbors Accordingly the structure is an assembly of strings

In ionic structures each ion is surrounded by a number of ions of opposite sign This coordination is respectively 8/8 6/6 4/4 8/4 in the cesium chloride sodium chloride zinc sulfide and calcium fluoride structures (For a discussion of these structures *see* CRYSTAL STRUCTURE) The anions are in nearly all cases larger than the cations For any given coordination the distribution of the anions is as regular as possible Each cation is in the center of a coordination polyhedron The structures can therefore be described in terms of the way in which the anion polyhedra are packed As an example in the rock salt structure each cation is in the center of an octahedron formed by six anions Two neighboring octahedra have a common edge Along these lines L Pauling has deduced a number of rules which



The coordination number in the three cubic lattices *P I* and *F* is shown to be 6 8 and 12 respectively

summarize general features of ionic compounds The most important are listed here

1 A coordinated polyhedron of anions is formed about each cation the cation *anion distance being* determined by the radius *sum and the coordination* number of the cation by the radius ratio

2 In a stable coordination structure the total strength of the valence bonds *which reach an* anion from all the neighboring cations is *equal to* the charge of the anion

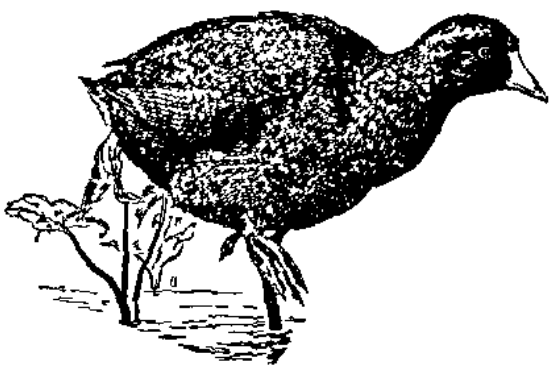
3 The existence of edges and particularly of faces common *to two anion* polyhedra decreases stability This effect is large *for cations* with high valency and small coordination number and is especially large *when the* radius ratio approaches the lower limit of *stability* of the polyhedron

4 In a crystal containing *different cations those* of high valency and small coordination number tend not to share *polyhedron* elements with each other [W D]

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Coot

The bird *Fulica americana* a member of the family Rallidae which is distinctly *different* from the other



The coot or mud hen *Fulica americana length to* 16 in (*From E L Palmer Fieldbook of Natural History McGraw Hill* 1949)

tail coverts a whitish bill red eyes and green feet The toes have scalloped *marginal flaps* Coots often called mud hens nest *on the fresh* water streams ponds and lakes of North *America from mid* Canada to Tennessee and Lower California They winter from the central *United States* southward into South America There are also *resident* populations in Latin America Although looked upon *with scorn* by many duck hunters the coot is a protected game bird and is a better *food bird than* several of the ducks The coot is one of the most common of *American waterfowl and* congregates in large flocks during migration *See* GRUIFORMES [J D B]

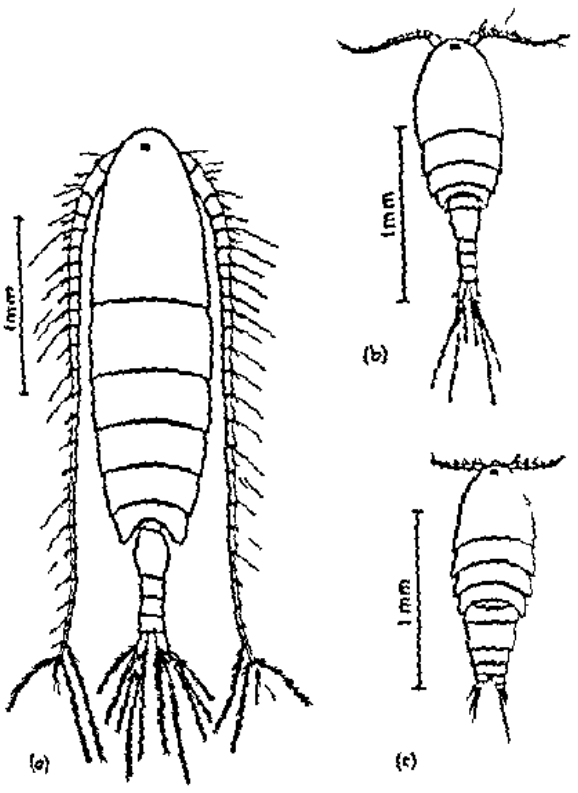
Copepoda

An order of Crustacea commonly grouped with other small crustacea as the Entomostraca There are over 6000 species most of which are free-living *in aqueous* environments though many are parasitic or symbiotic with other aquatic animals The *free living* forms are the most abundant of all animals *in the sea and directly* constitute the main *food for* vast numbers of fishes many invertebrates, and also at times for baleen whales

Copepod structure The structure of copepods, although similar in basic pattern varies greatly In free living forms the body is composed externally of a series of small chitinous cylinders, or segments, some of which may be more or less fused The head is regarded as one segment and bears two pairs of antennae used for swimming floating or in some forms for grasping The feeding appendages are 1 pair of mandibles 2 pairs of maxillae, and 1 pair of maxillipeds The thorax consisting of 6 segments bears the swimming feet The genital aperture occurs on the sixth thoracic segment The abdomen consists of 1–5 segments and bears no appendages except a pair of terminal processes known as caudal rami The sexes are separate and sexual dimorphism is frequently evidenced especially by modification in the male of one or both of the first antennae for clasping and in many by marked specialization in the fifth pair of feet for the transfer of spermatophores or packets of spermatozoa to the female (*see* SEXUAL DIMORPHISM) Free living species usually range in size from less than 0 5 mm to about 10 mm in length A few deep oceanic species like *Bathycalanus sverdrupi* attain a length of 17 mm Some parasitic copepods such as *Penella* are greatly elongate reaching up to 250 mm in length

Classification Eight suborders of copepods are usually recognized Three of these Calanoida Cyclopoida and Harpacticoida are wholly or primarily free living and because of overwhelming numbers are of greatest general interest The anatomical differences that set these three apart are among others the shape of the body and the position of the movable articulation separating the forebody (metasome) from the hindbody (urosome) In the calanoids and cyclopoids the urosome is distinctly narrower than the metasome In the calanoids the movable articulation falls between thoracic segments 5 and 6 whereas in the cyclopoids it is between segments 4 and 5 In the harpacticoids the urosome is commonly not narrow and the movable articulation falls between the fourth and fifth thoracic segments In many harpacticoids there is considerable flexibility also between other segments *See* CALANOIDA CYCLOPOIDA HARPACTICOIDA

The remaining suborders are parasitic at least part of their lives In the adult stage many are so greatly modified that their crustacean relationship is obscure Their numbers are relatively small but they may be conspicuous and important as fish



(a) Calanus finmarchicus a calanoid (b) Cyclops a cyclopoid (c) Harpacticus a harpacticoid

lice" burrowing deep into the flesh or feeding externally upon the skin and gills

Life history The life histories of copepods differ in details but in all development takes place from fertilized eggs which are either attached to the genital segment or are cast free in the water The spermatozoa transferred to the female genital segment in spermatophores are stored in spermathecal sacs in the female Usually one mating suffices for all subsequent eggs laid by the female A nauplius larva hatches from the egg This larva usually undergoes 5 molts in its growth Most nauplii are self sustaining gathering their own food but some nauplii hatched from yolky eggs are sustained by the yolk through one or more stages The sixth nauplius stage metamorphoses into the first of 6 copepodid stages the last of which is the adult Only a few life histories have been studied completely In *Calanus finmarchicus* a calanoid a summer brood in boreal waters requires about 2 3 months to reach maturity but broods produced in the autumn live longer because they winter in deep water as subadults The number of broods produced is related to latitude fewer being produced in the far north

In *Tisbe furcata* a bottom living harpacticoid individual females may live for 70 days, producing 5–10 broods averaging 43 eggs per brood The young may produce the first batch of eggs in 15 days

Habitats Copepod habitats are extremely varied but the vast majority of species live in the sea They are mostly planktonic throughout their lives some occurring only in coastal waters while others live in the open sea Many frequent only the upper layers to about 200–300 meters depth Others are bathypelagic at great depths The harpacticoids however are primarily a benthic or bottom dwelling group though many are truly planktonic A great many harpacticoid species live upon aquatic vegetation to which they cling with tiny claws Others are found on the bottom feeding upon detritus Some are especially adapted by slender worm like bodies to burrow or creep into the bottom among the grains of sand

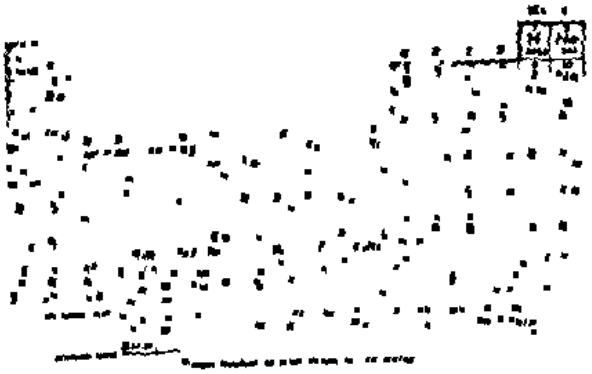
There are also many fresh water copepods living in ponds lakes and streams in all parts of the world Their wide dispersal to isolated bodies of water is probably brought about largely through transport on birds A few copepods live naturally in damp moss

Economic biology The role of copepods in the economy of the sea consists mainly of converting plant into animal substance They are adapted to graze directly upon the chief synthesizers of organic material the microscopic diatoms and dinoflagellates that constitute the great pasturage of the sea Commonly copepods constitute about 70% of the zooplankton and at times their numbers are so great as to impart a pinkish color to the sea They are of size sufficient to be fed upon individually by young fishes and to be filtered from the water by the filtering apparatus (gill rakers) of such fishes as the herring sardine and others that require animal protein as food which are the most abundant of all fishes At higher trophic levels these fishes in turn are directly or indirectly food for the more predatory fishes and mammals Some copepods also serve as food for baleen whales *See* COMMUNITY, MARINE ECOSYSTEM [M W J]

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Copper

Chemical element number 29 copper Cu is one of the most important nonferrous metals Its usefulness is accounted for by its combination of chemical physical electrical and mechanical properties and it is in fairly abundant supply Copper is one of the first metals to have been used by man



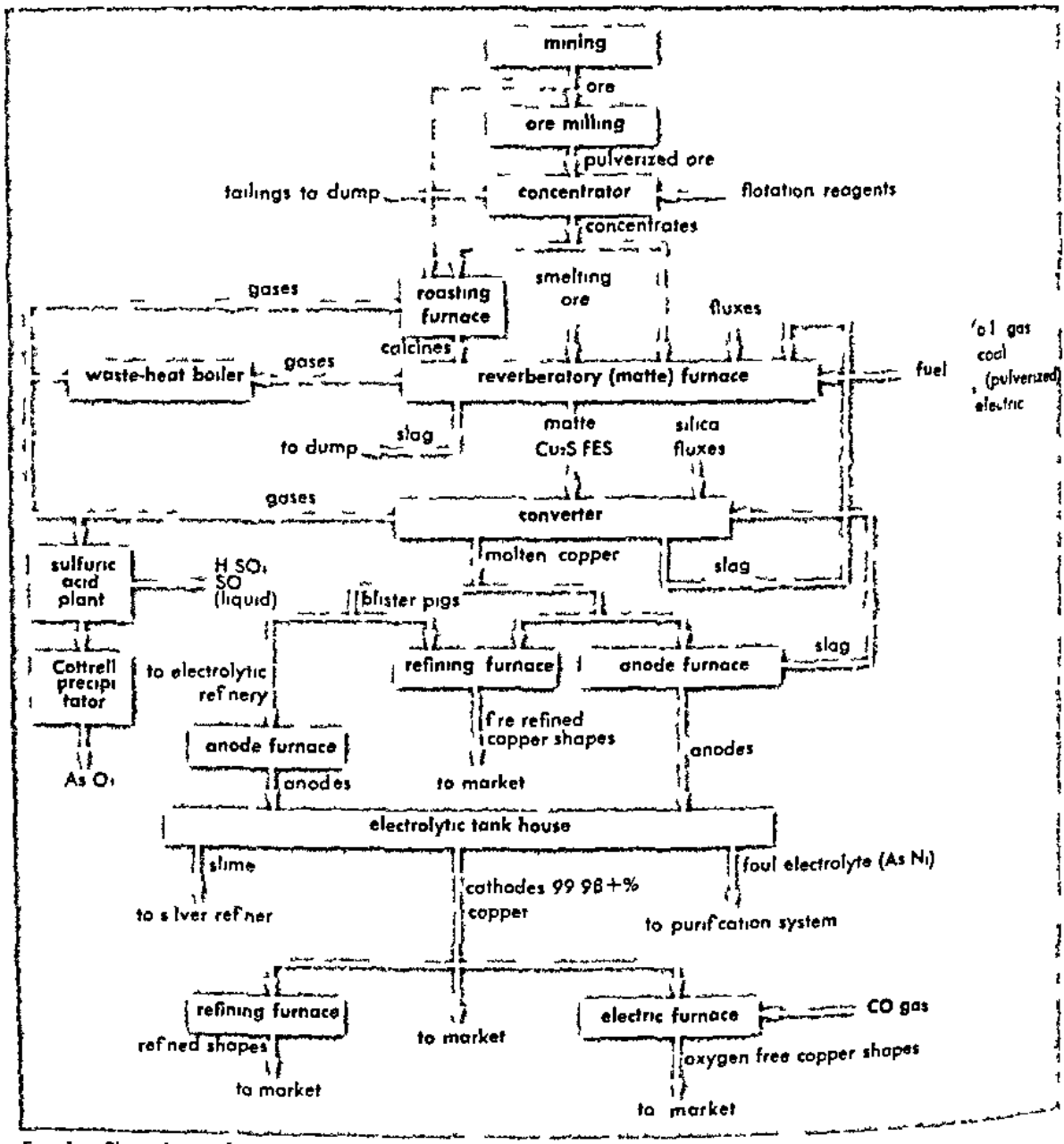


Fig 1 Flow sheet of copper extraction from sulfide minerals

Natural occurrence By far the greater part of the world's copper is obtained from the sulfide ores chalcocite Cu_2S, covellite CuS, chalcopyrite $CuFeS_2$, bornite Cu_5FeS_4, and enargite $Cu_3(As\,Sb)S_4$ Oxidized ores include cuprite Cu_2O tenorite, CuO, malachite, $CuCO_3Cu(OH)_2$, azurite $2CuCO_3Cu(OH)_2$, chrysocolla $CuSiO_3\,2H_2O$, and brochantite, $Cu_4(OH)_6SO_4$ Native copper once widespread in the United States, is now mined in quantity only in Michigan The grade of ore used for copper production has been going steadily downward as the richer ores have become exhausted and the demand for copper has grown The average ore in the United States contains less than 1% copper, but the average is higher in other countries There are vast amounts of copper in the ground available for future use if ores of still lower grades are utilized, and there is no prospect of exhaustion for a long time to come At the same time the use of lower grade ore increases production costs

Production metallurgy. There are many variations in the production processes and improvements are constantly being made *In the following* outline, only the most common methods can be indicated because of space limitations (Fig 1)

The ores are first concentrated usually by flotation to yield concentrates containing 20–40% copper, the grade has been improved in recent years and may exceed 40% *See* ORE DRESSING

Roasting the concentrates to lower the sulfur content has usually been the next step Because the richer concentrates require no roasting this step is omitted in many plants Roasted concentrates are mixed with raw concentrates before smelting to obtain a sulfur content that will yield the desired

grade of matte in the reverberatory smelting furnace

Smelting may be done in blast furnaces but this practice has been replaced except in a few instances by reverberatory smelting The reverberatory furnace has the advantage of being able to smelt finely divided flotation concentrates without sintering and it is not dependent on coke as fuel Natural gas oil or pulverized coal whichever is cheapest in the locality of the smelter can be used. The basis of the process is that reactions between copper oxide and iron sulfide in the molten charge have negative free-energy changes forming copper sulfide and iron oxide With excess iron sulfide the copper sulfide forms a molten solution called copper matte The iron oxide formed in the reactions together with that added as flux unites with silica in the ore to form a slag

The matte is taken to a converter in which air is blown through the molten matte to oxidize the iron chiefly to FeO which is slagged by addition of a siliceous flux The sulfur in the matte is oxidized to SO_2 and passes off in the gases leaving copper in the converter When cast the copper forms cakes with a surface roughened and blistered by the escape of gases during freezing and hence is called blister copper (*Fig* 2) It is usually 98–99% Cu

The blister copper is next partly refined in a furnace and cast into anodes It may be poured in molten form into the anode furnace or it may be cast into cakes which are charged to the furnace and remelted An oxidation refining takes place in the furnace assisted by introduction of a small amount of air below the surface of the molten copper Little or no flux is required Impurities whose oxides have a more negative free energy of formation than copper are oxidized and removed as a slag or in the gases The copper is cast into anodes containing about 99 0–99 3% Cu *See* PYROMETALLURGY NONFERROUS



Fig 2 Blister copper being poured from a converter (Anaconda Company)

The anodes are hung in electrolytic tanks spaced alternately with cathodes in an electrolyte of copper sulfate and free sulfuric acid contaminated with soluble impurities Insoluble impurities in the main those below copper in the electrochemical series of metals fall to the bottom of the tank these include gold silver selenium and tellurium Soluble impurities in the main those above copper in the electrochemical series enter the electrolyte and do not plate out at the cathode These are chiefly nickel and arsenic together with smaller amounts of other elements. Some of the impurities form insoluble compounds Thus the copper is freed of nearly all impurities whereas a furnace refining process can remove only those more easily oxidized than copper *See* ELECTROMETALLURGY

The cathodes are usually remelted for casting into shapes such as wirebars, cakes billets or ingots Some of the cathodes are sold without remelting but the shapes are required for fabrication into such forms as rods, wire sheet and tubes Remelting is done in large reverberatory furnaces, arc furnaces or induction furnaces In reverberatory melting oxygen and sulfur are taken up and although the cathodes are already 99 98% Cu the steps carried out in the anode-refining furnace must be largely repeated in order to remove the sulfur and reduce the oxygen content to the amount desired in tough pitch copper usually containing 0 02–0 05% O After being blown with air introduced through small steel pipes the copper is subjected to poling This consists of inserting poles of green wood beneath the surface of the molten copper to cause a reaction with the hydrogen and hydrocarbon gases evolved from the wood Sulfur in the copper is removed as hydrogen sulfide and most of the copper oxide is reduced The remaining copper oxide separates in a Cu-O Cu eutectic between the grains of copper a close adjustment of the amount of eutectic is necessary to produce a casting with a nearly level surface Casting is commonly done in horizontal open molds Billets and sometimes other shapes are cast in vertical molds

Continuous casting of oxygen free copper is practiced on a large scale the copper being protected from air while molten

Most copper ores contain gold and silver The recovery of these and other metals as by products is an important part of the metallurgy of copper When the ore is smelted gold and silver dissolve in the matte remaining with the copper through the steps of converting and furnace refining to be separated in the electrolytic refining tanks

A considerable amount of copper is produced by hydrometallurgy The ore is leached without being concentrated dilute sulfuric acid being the solvent most often used The process is applied chiefly to oxidized ores A further limitation of leaching is that the solvents employed do not dissolve gold or silver

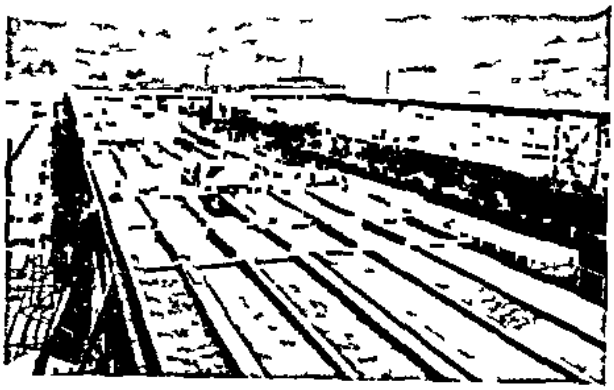


Fig 3 Mine water containing copper sulfate being passed over shredded detinned cans to precipitate the copper (*Anaconda Company*)

After leaching it is necessary to recover the copper from the leaching solution When sulfuric acid is the solvent the resulting copper sulfate solution may be electrolyzed by use of insoluble anodes The cathode deposit is pure comparable with electrolytically refined copper Another method of precipitating the copper from the leaching solution is to pass it over scrap iron or sponge iron (Fig 3) Copper is replaced in the solution by iron and precipitates as so-called cement copper In this case the precipitated copper is not pure and must be refined

Chemical properties Copper is the first element in subgroup Ib of the periodic table which also includes the other coinage metals silver and gold The copper atom has the electronic structure $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ The low ionization potential of the $4s^1$ electron results in easy removal to give the copper(I) or cuprous ion Cu^+ and the copper(II) or cupric ion Cu^{++} is readily formed by removal of one electron from the 3*d* shell

The copper crystal is face centered cubic with lattice dimension $a = 3.6080$ *kX* units at 18°C and the closest approach of atoms 2.551 *kX* units

The atomic weight of copper is 63.54 It has 2 stable natural isotopes Cu^{63} consisting of 29 protons and 34 neutrons and Cu^{65} with 29 protons and 36 neutrons There are also known at least 6

aving the mass

The half lives

) min 12.88 hr

4.34 min and 5.6 hr respectively

Copper is characterized by low chemical activity The standard potential of the ionization $Cu \rightarrow Cu^{++}$ is 0.34 ± 0.01 volt in normal ionic solution at 25°C The heat of oxidation of copper is 38 500 cal/mole (606 cal/g of Cu) in formation of CuO and 42 500 cal/mole (335 cal/g of Cu) in formation of Cu_2O

The element combines chemically in one of three valences The most common valence is 2+ (cupric), but 1+ (cuprous) is also frequent, the valence 3+ occurs in only a few unstable compounds The electrochemical equivalent of bivalent copper is 0.0003294 g/coulomb

Physical properties Copper is a comparatively heavy metal The density of the pure solid is 8.96 g/cm³ at 20°C The density of commercial copper varies with method of manufacture ranging 8.90–8.92 in cast refinery shapes 8.93 for annealed tough pitch copper and 8.94 for oxygen free copper The density of liquid copper is 8.2 near the freezing point

The melting point of copper is 1083.0 ± 0.1°C (1981.4 ± 0.2°F) Its normal boiling point is 2595°C (4703°F)

The coefficient of linear expansion of copper is 1.65×10^{-5}/°C at 20°C

The specific heat of the solid is 0.092 cal/g at

copper in the vapor state it is about 0.08 cal/g

The latent heat of fusion is 48.9 cal/g and of vaporization about 1750 cal/g

The shrinkage of copper in solidification is 4.92%

Copper is nonmagnetic or more precisely it is slightly paramagnetic having a mass susceptibility of -0.080×10^{-6} cgs units/g at 20°C, equivalent to -5.1×10^{-6} cgs units/mol

ing its elec

)941 cal/

equivalent

to a resistivity of 0.254 thermal ohms/(cm²)(cm)

Electrical properties The electrical resistivity of copper in the usual volumetric unit that of a cube measuring 1 cm in each direction is 1.6730 10^{-6} ohm cm at 20°C Only silver has a greater volumetric conductivity than copper On a relative basis in which silver is rated 100 copper is 9 aluminum 57 and iron 16

The mass resistivity of pure copper for a length of 1 m weighing 1 g at 20°C is 0.14983 ohm The conductivity of copper on the mass basis is surpassed by several light metals notably aluminum The relative values are 100 for aluminum 50 for copper and 44 for silver

By far the largest use of copper is in the electrical industry and therefore high electrical conductivity is its most important single property although for industrial use this property must be accompanied by suitable characteristics in other respects The conductivity of commercial copper is commonly rated on a percentage basis This method affords a convenient standard for buying and selling for comparison of quality for electrical purposes and for comparison with other metals The rating is based on percentage of a mass conductivity, adopted as a standard by the International Electrotechnical Commission in 1913 and subsequently by the American Standards Association American Society for Testing Materials and

other bodies The adopted standard mass resistivity is 0 15328 ohm (m g), and to its reciprocal is assigned the value 100 the conductivities of other specimens being stated in percentages of this conductivity This standard conductivity is designated the International Annealed Copper Standard (IACS) Commercial electrolytic copper of the highest purity regularly produced has a conductivity of about 102 IACS and most of the copper sold averages between 100 5 and 101 8

The volumetric resistivity equivalent to 100 IACS is 1 7241 × 10 ^{6} ohm cm Other IACS equivalent resistivity figures commonly used in engineering practice are 10 371 ohms (mil ft) and 875 2 ohms (mi lb)

The resistivity of copper increases with temperature the amount of change being given by the temperature coefficient 0 00393/°C at 20°C equivalent to an increase of 6 02 × 10^{-4} ohm (m g/°C) *See* CONDUCTOR ELECTRIC ELECTRICAL CONDUCTIVITY OF METALS

Mechanical properties Copper is one of the strongest pure metals It is moderately hard extremely tough, and wear resistant The strength of copper is accompanied by high ductility For example copper wire of commercial purity with a tensile strength of 42 000 psi and yield point of 36 000 psi has an elongation in 2 in of 14% These are typical values after 50% cold reduction Work hardened copper is readily softened by annealing Fully annealed copper wire has a tensile strength of 32,000 *psi* yield point of 10 000 psi and elonga

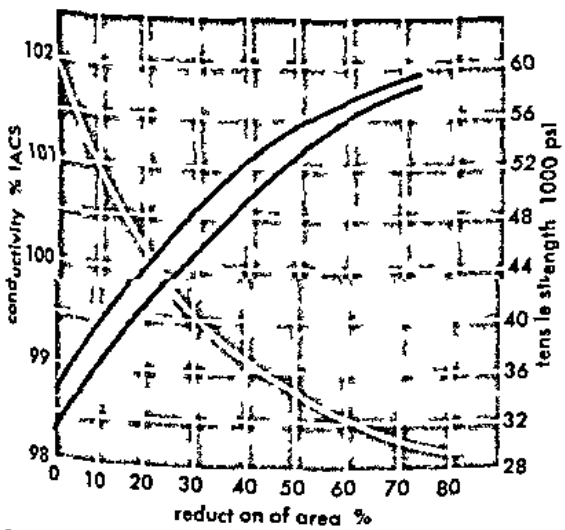


Fig 4 Effect of cold work on the electrical conductivity (black lines) and tensile strength (white line) of tough pitch copper Conductivity specimens were of 0 204-in diameter annealed and then cold drawn to several reductions of area Tensile specimens strip 0 040 in thick annealed to different grain sizes and then cold rolled to several reductions of area (*After data of* D K Crampton H L Burghoff and J L Stacy in R A Wilkins and E S Bunn *Copper and Copper Base Alloys* McGraw Hill 1943)

tion in 2 in of 45% The mechanical properties of metals and also their electrical properties are strongly dependent on the physical condition of the metal especially on the amount of strain hardening They are also affected by temperature and grain size Figure 4 shows the effect of cold reduction on the electrical conductivity of copper and on its tensile strength for two different grain sizes

The modulus of elasticity of copper in tension (Young s modulus) is 16 5 × 10^{6} psi *See* METAL MECHANICAL PROPERTIES OF

Commercial copper In order to draw a line between marketed grades of copper and copper alloys the American Society for Testing Materials has adopted specifications in which metal containing not more than 0 5% of an element or elements other than Cu is designated as copper These specifications cover the three main commercial varieties as determined by the method of refining namely electrolytic fire refined and Lake copper also as determined by the method of processing tough pitch oxygen free and deoxidized copper and a number of specific kinds which include casting copper phosphorized copper high residual phosphorus copper low residual phosphorus copper silver bearing copper arsenical copper selenium bearing copper and tellurium bearing copper

Electrolytic tough pitch copper designated ETP is the most used type It has been electrolytically refined and the cathodes remelted and cast according to procedures which will result in an oxygen *content of about 0 02–0 05% The specifications* for ETP copper require a minimum copper content of 99 90% (silver being counted as copper) and electrical conductivity not less than 100 0 IACS

Oxygen free copper has been electrolytically refined and (1) cast under conditions that exclude oxygen (2) coalesced by heat and pressure into massive form without remelting or (3) cast with addition of a small amount of a deoxidizing element usually phosphorus This last variety is termed deoxidized copper to distinguish it from the other types

Casting copper is refined in a furnace (fire refined) It usually contains more oxygen and impurities than electrolytic copper Little of it is used in the United States but it is of some importance in England and European countries especially for nonelectrical purposes Remelted secondary

after deoxidation does not have sufficiently high conductivity to meet electrical specifications The other types of copper free from oxygen have about the same conductivity as ETP The absence of copper oxide in itself would result in higher conductivity but this factor may be offset by a slightly lower density which tends to lower conductivity Another factor tending to lower conductivity is the fact that some impurities present in the copper

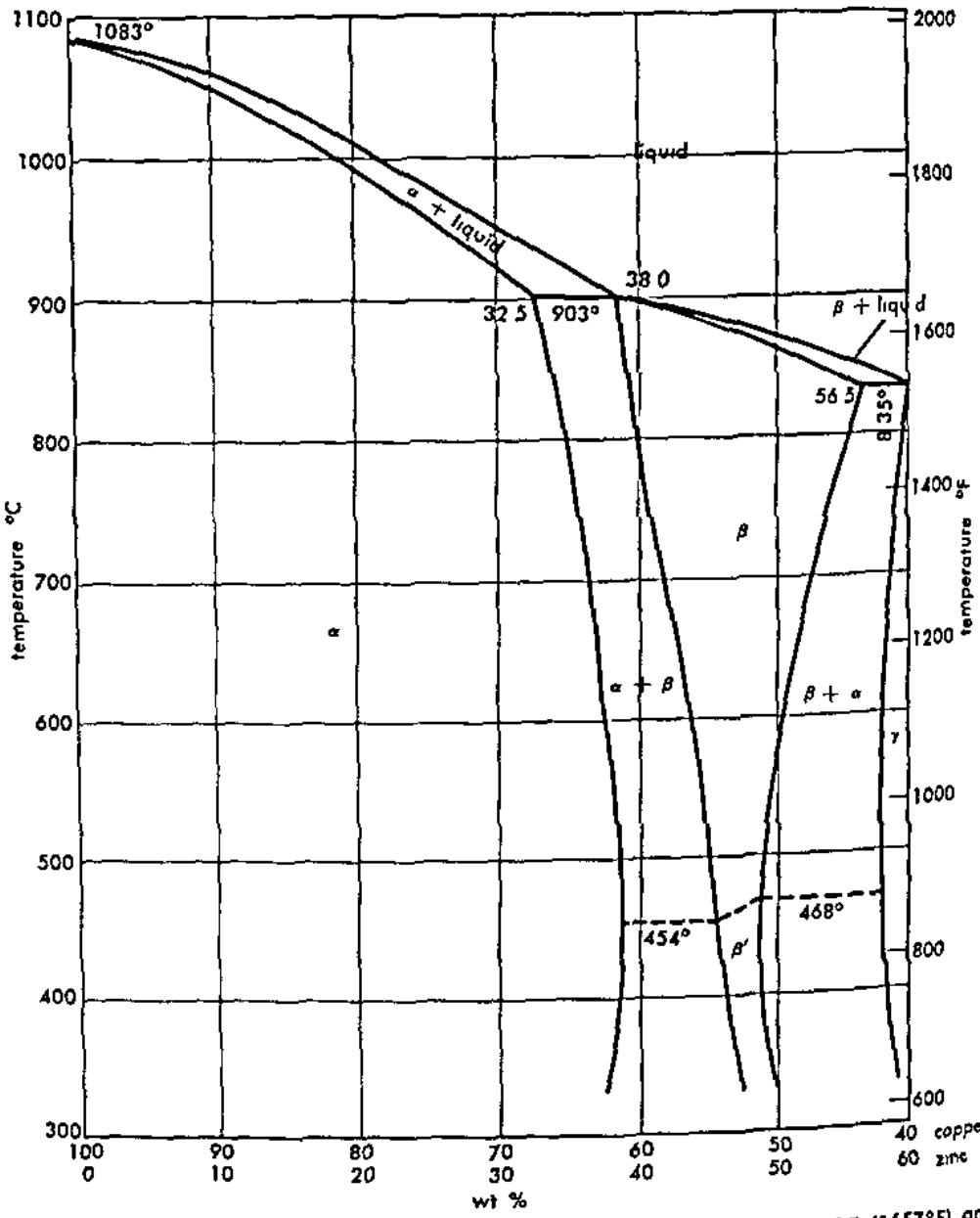


Fig 5 Constitution diagram of the copper-zinc system After cooling below 300°C (572°F), the alloys consist of a single solid solution α of zinc in copper containing zinc up to about 37% A second constituent β begins to separate from α at 903°C (1657°F) and at room temperature exists along with α from 37 to 47% zinc The amount of β increases as the percentage of zinc increases

will not exist as oxides but will be present in solid solution, in which form they have a greater effect in reducing conductivity The range of variation is relatively small in the first and second types, and electrical specifications are readily met

Oxygen free copper costs slightly more than ETP Any superiority in conductivity is not often the reason for its use, this copper is especially valuable for higher ductility, which enables it to undergo more severe cold work This ability, of course, is one of the valuable properties of copper in comparison with other structural materials, in the oxygen free type, this advantage is enhanced Another valuable characteristic of oxygen free copper is its ability to be heated in a reducing atmosphere, as in bright annealing, without developing porosity and brittleness because of reduction of copper oxide between the grains

Copper alloys. Copper is one of the few metals used to a greater extent in pure form than in alloyed form However, one of the features of copper is its ability to form a great number and variety of alloys Brass and bronze in their many varieties are among the oldest and most useful alloys (Fig 5)

The principal classes of copper alloys are listed below according to composition

Copper zinc (binary brasses)
Copper tin (binary bronzes)
Copper zinc tin (special brasses and bronzes)
Copper zinc lead and copper tin zinc lead (leaded brasses and bronzes)

Copper zinc nickel (nickel silvers)
Copper zinc manganese with or without tin iron or aluminum (manganese bronzes)
Copper tin phosphorus (phosphor bronze)
Copper aluminum and copper aluminum plus iron nickel or manganese (aluminum bronzes)
Copper silicon plus manganese tin iron or zinc (silicon bronzes)
Copper nickel (cupronickel)
Copper beryllium and copper cobalt beryllium (beryllium copper)

Other elements may be added to some of the above combinations to form other alloy brasses and bronzes *See* COPPER ALLOYS

Fabrication of copper and copper alloys Pure copper has poor casting qualities caused especially by the release of gases from the molten metal when it solidifies Machining also is difficult Castings of intricate or special shapes are seldom made of pure copper although there are exceptions when high thermal or electrical conductivity in a cast shape is a prime consideration Wirebars cakes billets and such objects of regular or simple shape intended for working are readily cast if the oxygen content of the molten material is adjusted In this case a certain amount of porosity may often be tolerated because it will be closed up during working

Most copper alloys have superior casting qualities and some of the bronzes and brasses are unexcelled in this respect Die castings are made with some compositions of brass (Fig 6)

Pure copper is highly workable and this is true also of many of the wrought alloys The most important methods of working are rolling extrusion wire drawing piercing (for billets) and stamping Other methods employed include forging pressing deep drawing flanging machining of various kinds spinning and cupping

For manufacture of copper wire copper wire bars are heated to 700–800°C (1300–1470°F) and rolled to rod ¼ ⅜ in in diameter This is drawn cold through a series of dies of tungsten carbide decreasing the diameter in each draw diamond dies are used for fine wire The metal becomes hardened through cold drawing If not softened by annealing it is termed hard drawn wire this has maximum strength but its electrical conductivity is relatively low When annealed at the end of the drawing operation the wire is soft drawn and has the maximum conductivity with lower strength Other tempers such as quarter hard and half hard are made by annealing after reduction to a certain point and then drawing to final size

Copper plate and sheet are rolled from cast copper cakes with annealing to adjust the final temper in a manner similar to that followed in wire drawing

The same type of procedure is used in rolling brass but an additional factor of considerable importance is grain size The size of grain is controlled by the temperature and time of annealing after partial reduction Large grain size yields higher ductility but causes the surface to roughen during working and makes it difficult to polish Grain sizes below 0 030 mm are used for operations requiring relatively little forming and in which a bright surface finish is wanted Sizes from 0 030 to 0 050 mm permit more severe cold work and yet produce a fairly bright surface these are most often used Sizes above 0 050 mm are used for heavy drawing and spinning when the surface finish is unimportant An orange peel appearance on the surface may result from drawing (especially deep drawing) material having too large a grain size *See* METAL FORMING

Copper is one of the principal metals used for electroplating Not only may the outside coating be of copper but in chromium plating on steel the usual method is to plate the steel first with thin undercoatings of copper and nickel Electroplating is sometimes done with brass or bronze *See* ELECTROPLATING OF METALS



Fig 6 Pouring a bronze melt into ingot molds (American Smelting and Refining Company)

alloys are very resistant to corrosion Copper resists corrosion for two main reasons its relative chemical inertness and the formation of a protective film Copper lies toward the bottom of the electrochemical series of metals well below hydrogen When an electrolytic couple is formed between copper and another metal copper is in most cases the cathode so that it is electrochemically protected

Copper becomes coated with mixtures of oxide most often green and may be porous and powdery at the surface while continuous and adherent at the junction of the coating and the metal

Brass especially high brass is subject to two special corrosion processes, season cracking and dezincification Both processes sometimes occur in other copper alloys and in other metals Season cracking is a form of stress corrosion cracking It is mostly intergranular occurring even under

mildly corrosive conditions when internal stress exists in the brass after cold work It develops slowly, in addition to stress and time, moisture and the presence of traces of ammonia in the atmosphere are causative factors It has been troublesome in brass cartridge cases It is usually avoided by a stress relieving anneal at a temperature high enough to permit crystalline readjustment but not so high as to cause softening, 30 min at 300°C (570°F) is often employed

In dezincification zinc atoms are removed from the solid solutions more readily than copper atoms Probably both copper and zinc dissolve initially copper then being deposited as it is replaced in solution by more zinc A layer of copper appears on the surface underlain by porous and weakened alloy Dezincification occurs in acids acidic or salt water and some impure or hard waters It may also occur in heating thin sections of brass through vaporization of zinc from the surface

Principal compounds Of the hundreds of compounds in addition to those mentioned above, only a few are manufactured industrially on a large scale The most important is copper(II) sulfate pentahydrate or blue vitriol $CuSO_4 5H_2O$ Others include Bordeaux mixture $3Cu(OH)_2CuSO_4$, Paris green a complex of copper metaarsenite and acetate, cuprous cyanide CuCN, cuprous oxide Cu_2O, cupric chloride $CuCl_2$, cupric oxide CuO, basic cupric carbonate, and copper naphthenate, the most widely used agent for prevention of rotting in wood fabric rope and fishing nets Leading uses of copper compounds are in agriculture especially as fungicides and insecticides as pigments in electroplating solutions in primary cells as mordants in dyeing, and as catalysts *See* COPPER CHEMISTRY TRANSITION ELEMENTS

[A BU]

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Copper alloys

Combinations of two or more metals including copper which predominates All copper alloys are characterized by good mechanical properties high corrosion resistance ready formability and ease of joining They are the only alloys aside from gold that have natural red and yellow colors Copper itself has the highest electrical and thermal conductivity of any metal except silver These properties result in widely different applications

Wrought alloys. Brasses containing 5–40% zinc constitute by far the largest volume of copper alloys One important brass is cartridge brass (70% copper, 30% zinc) which has innumerable uses including cartridge cases, radiator cores and tanks, lighting fixtures, eyelets rivets, screws, springs and plumbing goods Tensile strength ranges from 45 000 psi as annealed to 130 000 psi for spring temper wire

For improved machinability, lead up to about 3% is added to various brasses Free-cutting brass containing 61% copper 3% lead and 36% zinc is the most important alloy of this group In rod form, it has a strength of 55 000–70 000 psi depending on temper and size It is machined in high speed automatic screw machines into parts for a multiplicity of uses

For increased strength and corrosion resistance, tin or aluminum up to about 2% is added to various brasses Admiralty brass containing 70% copper, 29% zinc, and 1% tin and aluminum brass containing 76% copper, 22% zinc and 2% aluminum are two alloys widely used for heat exchanger tubes

Copper tin alloys or tin bronzes (less properly known as phosphor bronzes) form an important group Tin ranges from 3 to 10% the higher content giving increased strength hardness and corrosion resistance, but at the expense of workability These alloys find wide use for springs and for screens in paper making machines

Silicon bronzes containing up to about 3% silicon and sometimes lesser amounts of other elements are commonly used for hardware screws, bolts and welding rod

Melting Melting of alloys to be wrought is usually done in low frequency induction furnaces. For high zinc brasses the bath is covered with charcoal to prevent zinc vaporization and oxidation and heat loss For lower zinc brasses tin bronzes aluminum bronzes or silicon bronzes, a slightly oxidizing atmosphere is maintained by using dross from the alloy as a cover

The molten alloys are poured at 200–300°F above the melting point into water cooled copper molds dressed with mineral oil lard oil or tallow and additions of graphite The dressing protects the mold surface, produces a reducing atmosphere, and evolves gas which brings up dirt and dross preventing their inclusion in the casting

Since about 1950 continuous casting of many copper alloys has increased Molten metal enters the top of a mold as the solidified casting is withdrawn from the bottom Several variations exist but all use water jacket cooling of the mold proper in addition to cooling sprays on the casting below the mold

Because of their large grain size directional grain growth and segregation the mechanical properties of castings are relatively poor Subsequent hot working by forging piercing or extruding or cold working by rolling or drawing with necessary intermediate annealing corrects such defects and markedly improves properties

Processing Mill processing varies with alloy form and size Flat products are cast in heavy

cakes for initial hot rolling or in bars for initial cold rolling Copper and lead free brasses are readily hot rolled in a single heating to a thickness of ½ in or less Further rolling is done cold with intermediate anneals Lead bearing brasses tin bronzes, and other alloys not amenable to hot working must be rolled cold from cast to final size with annealing at intervals at temperatures from about 800 to 1400°F depending on the alloy

Round rods and wire of copper are started by hot rolling in grooved rolls but most alloys are hot extruded Both are subsequently worked down to smaller size by cold rolling drawing or both In extrusion a billet placed in a container in a press is forced through a die by a ram Tin and tin lead bronzes which are not suited to hot working are continuous cast in rod form and cold rolled or drawn to finish As with flat products extensive cold reduction requires intermediate annealing

Copper and high copper content lead free brass tubes are started by hot piercing wherein the solid billet is driven with a helical motion over a mandrel to form a tube Tubes of most other alloys are formed by extrusion because they will not withstand piercing In extrusion of tube a mandrel forms the inside of the tube while the die forms the outside

Many shapes other than round are formed by extrusion through dies of suitable contour The alloy most commonly used is brass containing 58% copper 3% lead and the balance zinc Being very malleable when hot it flows readily through the shaped die

Cast alloys These are used in the condition as solidified from a melt High copper alloys with varying amounts of tin lead and zinc account for a large percentage of all copper alloys used as cast. The tensile strength ranges from 36 000 to 43 000 psi depending on composition and size Leaded tin bronzes with 6–10% tin about 1% lead and about 4% zinc are used for high grade pressure castings valve bodies gears and ornamental work High lead tin bronzes with 7 24% lead and 5–10% tin are largely used for bearings High tin content is preferred for heavy pressures or shock loading but lower tin and higher lead for lighter loads higher speeds or where lubrication is less certain A leaded red brass containing 85% copper and 5% each of tin lead and zinc is a popular material for general use

High strength brasses containing 57–63% copper small percentages of aluminum and iron and the balance zinc exhibit tensile strengths from 0 000 to 120 000 psi high hardness good ductility and resistance to corrosion They are used for valve stems and machinery parts requiring high strength and toughness

Castings from coppers containing less than 2% alloying elements are used when relatively high electrical conductivity is needed This high conductivity is attained at the sacrifice of strength which is usually significantly less than in the other cast alloys discussed

Aluminum bronzes containing 5–10 5% aluminum small amounts of iron and the balance copper have high strengths maintained well at elevated temperatures high ductility and excellent corrosion resistance With the higher aluminum content, castings are amenable to heat treatment, which increases strength and hardness These alloys are used for acid resisting pump parts pickling baskets valve seats and guides and marine propellers *See* ALLOY COPPER METAL FORMING

[D K C]

Copper chemistry

The principal oxidation states of copper in its compounds are 1+ and 2+ with several unstable compounds exhibiting 3+ Compounds in which copper is 1+ copper(I) or cuprous are unstable in solution with respect to the reaction

$$2Cu^{+} \rightleftharpoons Cu^{++} + Cu$$

However with respect to heat the copper(I) compounds are the most stable and are the terminal product of the heating of many copper(II) or cupric compounds For example

$$2CuO \xrightarrow{\Delta} Cu_2O + \tfrac{1}{2}O_2 \quad \text{(at about 900°C)}$$

$$2CuS \xrightarrow{\Delta} Cu_2S + S \quad \text{(at red heat)}$$

$$CuF_2 \xrightarrow{\Delta} CuF + \tfrac{1}{2}F_2 \quad \text{(at 500°)}$$

Two oxides of copper are well known copper(I) oxide Cu_2O and copper(II) oxide CuO Red copper(I) oxide can be prepared by the thermal decomposition of copper(II) oxide or by the reduction of a copper(II) salt in basic solution with a weak reducing agent such as glucose Copper(II) oxide which is black in color is prepared by the action of heat on copper metal in air It is also the terminal product of the thermal decomposition of copper nitrate copper hydroxide copper carbonate and other oxygen containing compounds

Two series of copper halide salts are also known the copper(I) and copper(II) compounds The copper(II) halides with the exception of the iodide can be prepared by the direct combination of the elements

$$Cu(s) + X_2(g) \rightarrow CuX_2(s)$$

The colors of the anhydrous compounds vary widely CuF_2 is colorless CuCl is bright yellow

per(II) halides with elemental copper in hydrohalide acid solution according to the reaction

$$CuX_2 + Cu \xrightarrow{HX} 2CuX$$

All of the copper(I) halides are colorless Copper(I) iodide can be prepared by the reaction

$$2CuCl_2 + 4KI \rightarrow 2CuI(s) + 4KCl + I_2$$

in which brownish white CuI precipitates out of solution From vapor density studies at elevated temperatures it was concluded that the copper(I) halides were dimeric in structure or Cu_2X_2 However from other studies copper(I) chloride was found to be monomeric or CuCl To avoid confusion the monomeric structure is used throughout this article Copper(I) cyanide is similar to the halides in that it can be prepared in a manner identical to CuI or

$$2Cu^{++} + 4CN \rightarrow 2CuCN(s) + C_2N_2$$

Perhaps the most important compound of copper is copper(II) sulfate 5 hydrate This compound commonly called blue vitriol is used as a source of other copper(II) compounds as well as in electroplating and as a fungicide The 5 hydrate begins to lose water of hydration at about 27°C to form the 3-hydrate On further heating the white-colored anhydrous salt $CuSO_4$ is produced this decomposes at temperatures above 702°C to give CuO and SO_3 The addition of the anhydrous salt to water gives the blue colored 5 hydrate However on long standing in aqueous solution a small amount of basic copper sulfate is formed

The simple carbonate $CuCO_3$ is unknown however the addition of sodium carbonate to a copper(II) salt solution gives basic salts such as $CuCO_3 Cu(OH)_2$ commonly called malachite

The reaction of copper metal with nitric acid produces among other products copper nitrate the 6 hydrate of which is a deep blue color Anhydrous copper nitrate sublimes at 150°C in vacuum and is surprisingly volatile

Leading uses of copper compounds are in agriculture especially as fungicides and insecticides as pigments in primary electrical cells as mordants in dyeing and as catalysts *See* AMMINE COPPER, PIGMENT TRANSITION ELEMENTS [W W WE]

Copper loss

The power loss due to the flow of current through the resistance of the copper conductors in a transformer electric motor generator transmission line or any other device that uses copper wire Copper loss in watts is readily calculated by multiplying the resistance R in ohms by the square of the current I in amperes and is also called the I^2R loss

Copper loss is converted entirely into heat The permissible temperature rise governed by the type of insulation used on the copper conductors determines the current rating of a device and this temperature rise is determined by the copper loss In any electric machine that has constant losses along with the varying copper losses that increase with the square of the load maximum efficiency is obtained when the load is such as to make the constant and varying losses equal *See* WIRING (ELECTRIC) [J MR]

Copperhead

A moderate sized heavy bodied pit viper *Ancistrodon contortrix* found over much of the eastern and southeastern parts of the United States When mature the copperhead is usually 24–30 in long but lengths of up to 50 in have been recorded Its color varies from dull brown to bright reddish brown and it is marked with 10–20 dark blotches on the sides and back The top of the head is usually copper colored

The copperhead is found both in the lowland and the mountains of the southern United States and is common in the flint hills marking the eastern edge of the Great Plains It is relatively common in deciduous forests where its coloration blends perfectly with the dead leaves Although its bite is rarely fatal the copperhead is a dangerous snake In rural areas it has a tendency to hunt mice near woodpiles outbuildings and haystacks bringing it into frequent contact with man *See* SQUAMATA [JDB]

Copulatory organ

An organ utilized by the male animal for insemination, that is to deposit spermatozoa directly into the female reproductive tract Various types of copulatory organs are found among the vertebrates, whereas cloacal apposition occurs in most other vertebrates which lack these structures Amplexus or false copulation is peculiar to amphibians

In fish internal fertilization is restricted to certain groups The pelvic fin of male elasmobranch and holocephalians is modified for the transmission of sperm and is known as the clasper or clasping organ A pair of anterior claspers (Fig 1g) and a frontal clasper which protrudes from the head occur among holocephalians in addition to the modified pelvic clasper of elasmobranchs The anal fin of teleosts in which copulation occurs may be elongated to form a gonopodium Copulatory organs are lacking in amphibians even in those in which

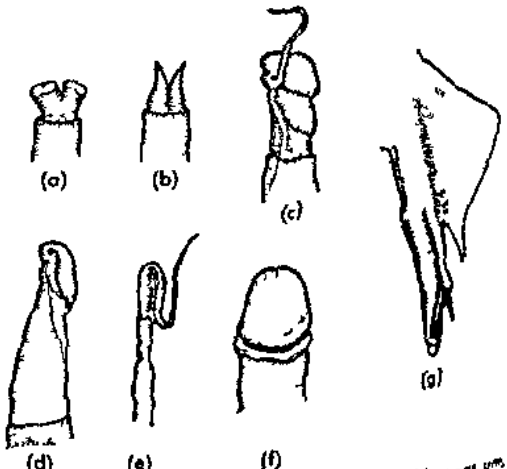


Fig 1 Glans penis of (a) *Echidna* (b) opossum (c) ram (d) bull (e) short tailed shrew and (f) man (g) Clasper of the dogfish *Squalus*

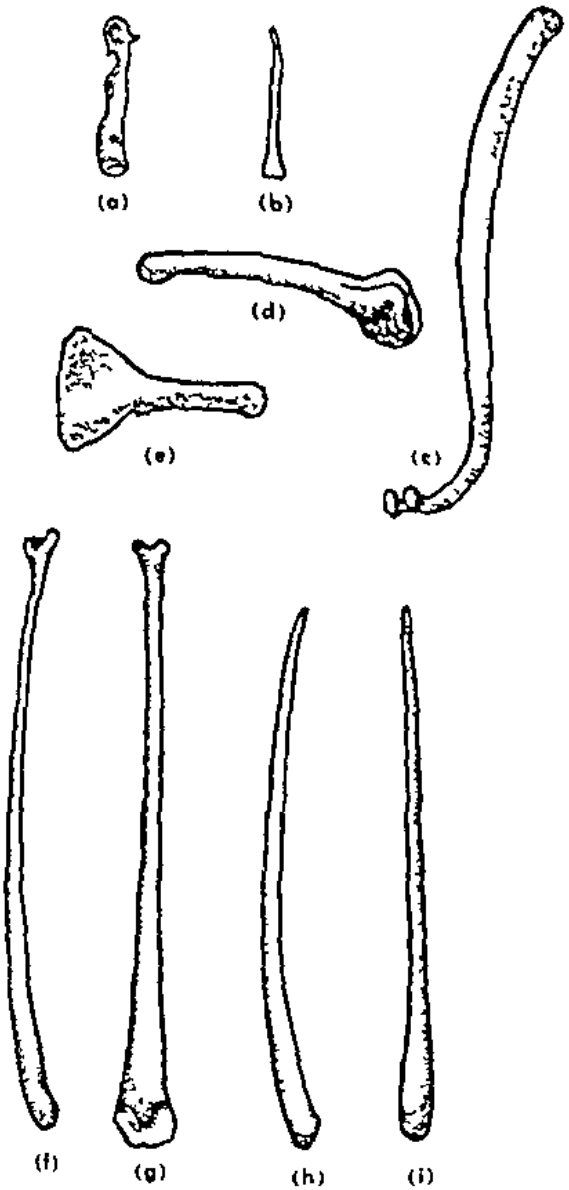


Fig 2 Bacula of (a) fox squirrel, (b) cotton mouse, (c) otter, (d) Neotoma lepida, lateral view, (e) Neotoma micropus (f), (g) Perognathus hispidus, lateral and ventral views, (h), (i) Perognathus baileyi, lateral and ventral views

internal fertilization occurs Among caecelians the cloaca of the male is muscular and protrusible, however, it is questionable that this structure is a true copulatory organ Hemipenes which can be everted during copulation are common to both snakes and lizards; however, these structures lack erectile tissue Turtles and crocodiles possess a single penis with associated erectile tissue, the corpora cavernosa which becomes distended with blood A few species of birds have a penis, among these are the ostriches and anseriforms The penis is present in all mammals

This organ (Fig 1*a f*) is variously modified morphologically Among certain mammals such as rodents, bats, whales, some carnivores, and lower primates, a penis bone or os priapi or baculum (Fig 2) occurs which aids in increasing the rigidity of the penis *See* Fertilization, Penis [C B C]

Coquina

A calcarenite or clastic limestone, whose detrital particles are chiefly fossils, whole or fragmented The term is most frequently used for an aggregate



Coquinoid limestone, encrinite, showing many entire fossils in fine-grained matrix Note lack of assortment and diversity of types (*From F J Pettijohn, Sedimentary Rocks, 2d ed , Harper, 1957*)

of large shells more or less cemented by calcite If the rock consists of fine sized shell debris, it is called a microcoquina Encrinite is a microcoquina made up primarily of crinoid fragments Some coquinas show little evidence of any transportation by currents, articulated bivalves are preserved in entirety and the shells are not broken or abraded *See* Calcarenite, Limestone [R S]

Coraciiformes

An order of birds comprising ten families, varying

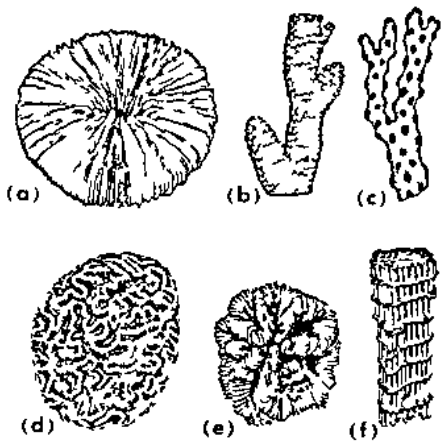
toes more or less joined at the base (syndactyl) Most of the families are predominantly tropical and frequently bright colored The only world wide family is Alcedinidae, the kingfishers The Todidae and the motmots (Momotidae) are found exclusively in the New World, and two families, the ground rollers (Brachypteraciidae) and cuckoo

Aves [K C P]

Coral

Any one of about 2500 species of the order Scleractinia (Madreporaria) phylum Coelenterata

Corals play an important part in the formation of islands reefs and atolls in tropical waters They are also significant in providing shelter for a great diversity of marine animals Most corals are found in shallow tropical seas but a few unimportant forms grow in relatively cold water and at substantial depths *See* ATOLL, CORAL REEF



Types of coral (*a*) Fungia (mushroom) (*b*) Acropora (elk horn) (*c*) Oculina (*d*) Meandrina (brain) (*e*) Meandrina (rose) (*f*) Tubipora (organ pipe) (*From T I Storer and R L Usinger, General Zoology, 3d ed, McGraw-Hill, 1957*)

The coral organism is a small polyp basically similar to *Hydra*, with numerous tentacles arranged in multiples of six, and with the gastrovascular cavity divided by septa also arranged in multiples of six Each individual lives in a stony cup secreted by the epidermis of the polyp The aggregate mass of these cups makes the rocklike substance called coral the basic material of which is calcium carbonate These deposits vary greatly in both form and color, depending on the species forming them

Reproduction is both sexual and asexual The medusa stage is unknown in corals The zygote develops into a planula which develops into the polyp Like other Coelenterata they feed on plankton which they secure by use of their tentacles

In the class Hydrozoa there are a few "corals," none of which should be confused with the true, or stony, coral considered here These so-called corals secrete a massive limestone skeleton outside the colony and protrude their polyps through numerous minute pores They are often called pore corals The horn corals are members of the subclass Alcyonaria and include the sea fan and the semiprecious red coral *See* COELENTERATA FOSSILS, SCLERACTINIA [J D B]

Coral reef

A reef of corals and associated calcium carbonate–secreting organisms, comprising the most widespread and, volumetrically, the most important type of organic reef Coral reefs first attracted wide scientific attention through the accounts of Charles Darwin, who divided them into three principal types· fringing reef, barrier reef and atoll Darwin considered that these developed in the order named as a result of persistent and profound subsidence Modern reef theory is more complicated but still retains subsidence as an important feature In modern seas, coral reefs are important as hazards to navigation, as natural breakwaters surrounding boat passages and harbors and as sites of complex life association and high biological productivity Fossil organic reefs are common reservoir rocks for oil fields *See* ORGANIC REEF REEF

Corals are exclusively marine and the typical reef building types are restricted to shallow warm water because of their symbiotic association with microscopic algae known as zooxanthellae (Fig 1) Although fossil representatives are known from Middle Ordovician time Paleozoic coral reefs were made by organisms quite different from those responsible for the Mesozoic and Cenozoic reefs *See* ALGAE, CORAL, CORALLINE ALGAE

Kinds and origins of coral reefs A fringing reef growing against the shore may, with subsidence and continued upward growth become separated from the beach by a lagoon to become a barrier reef (Fig 2) Continued subsidence and upgrowth can produce an atoll after all preexisting land has disappeared beneath a central lagoon which is surrounded and defined by the peripheral atoll reef Filling of an atoll lagoon independent upward growth, or emergence and planation may produce a table reef, which is less common than the other major types These are all open sea reef types, characteristically rising from oceanic depths Small reefs associated with these major categories

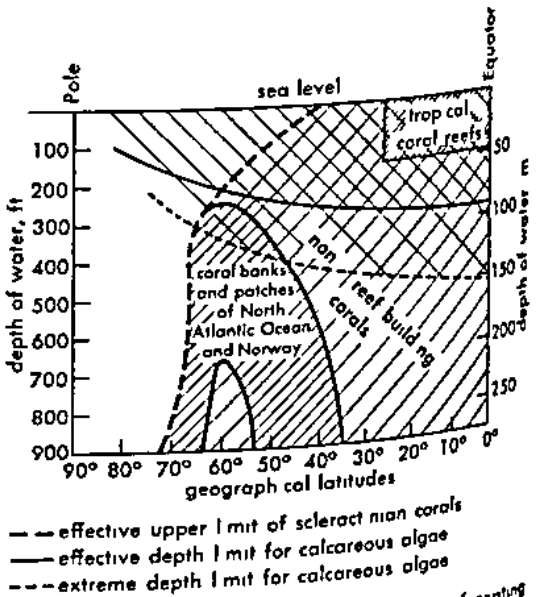


Fig 1 Broadly generalized depth ranges of existing corals and calcareous algae (*After C Te chert Cold- and deep water coral banks Am Assoc Petroleum Geol Bull, 42(5) 1064–1082, 1958*)

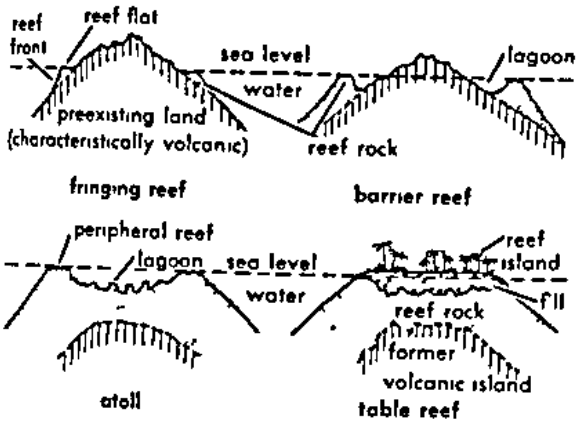


Fig 2 Diagram of reef sequence according to Darwin (table reef added)

or forming complex reef communities in quiet shal low waters that lack the larger reef types fall into the general categories of reef patches, pinnacles, and knolls *See* ATOLL, BARRIER REEF, FRINGING REEF

Because the typical coral reef association (Fig 3) rarely grows with vigor below a depth of 20 m and largely dies out below 100 m, a reef frame thicker than this implies a subsidence of the sea floor or a rise of sea level It was demonstrated by drilling that Eniwetok Atoll has subsided about 1200 m since first reef growth occurred beneath it, this finding confirms the importance of subsidence in the evolution of central Pacific atolls Change of sea level with growth and melting of the Pleis tocene ice sheets is equally important in the ex planation of existing reef features As an added elaboration, organic reefs may also grow upward from or form a veneer over preexisting platforms even inheriting their configuration from preceding topographic forms *See* OCEANIC ISLANDS, SEA LEVEL FLUCTUATIONS

Geographic distribution. Existing coral reefs occur widely at tropical latitudes They are most common in the Pacific and Indian Oceans, but are also found in the Atlantic Ocean and the Red Sea They are uncommon on the western sides of conti nents because of the upwelling of cold water from the depths along these coasts. Coral reefs extend farther north than south and locally range well beyond the tropics because of displacement of the

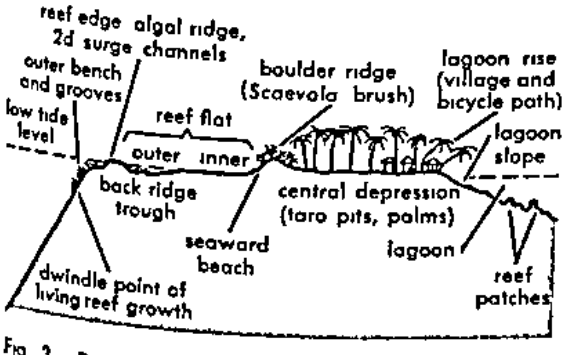


Fig 3 Diagram showing zonation of a Pacific windward reef

controlling 22°C isotherm Calcium carbonate reef structures made by coral and brachiopods are also found in cold and relatively deep water in Scandinavian fiords and the northern Mediterranean The corals that build these reeflike masses are of types not dependent upon the microscopic algal symbionts (zooxanthellae) of the typical reef corals

Geologic range. Coral reefs are known to range from Middle Ordovician to modern times They be came abundant during Middle Silurian time, when they ranged into latitudes now within the Arctic Circle Devonian reefs ranged across central Eu rope and much of central and western North America and Asia Organic reefs, but not coral reefs are prominent Permian features A great change in the coral faunas and their associates took place near the end of Paleozoic time No Early Triassic coral reefs or corals are known, but coral reef associations of modern types are known from Middle Triassic onward and locally make up much of the rock sequence

Economic and human significance. Tens of thousands of people live on Pacific and Indian Ocean islands that are built of reef formations or have reef foundations beneath them In the reef waters and on the islands live animals and plants that provide food shelter, and tools to maintain life and copra for the markets of the world The air bases and harbors at many reef islands provide the only stopovers in broad expanses of water Rich phosphate deposits occur on some elevated reef islands such as Ocean, Nauru, and Angaur The porous nature and organically rich environ ment of reef rock makes it a potential source of petroleum *See* PACIFIC ISLANDS, PETROLEUM GE OLOGY [P E C]

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Coral snake

Any of several species of poisonous snake of the family Elapidae found in the Americas Although they are mostly tropical two species occur in the southern United States These snakes are related to the cobras, and like them, have fixed, grooved fangs They are slender, small headed shiny snakes brilliantly marked with bands of red, yel low, and black They are usually 24 in or less in length, but may grow to 45 in The eastern coral snake, *Micrurus fulvius*, is distinguished by a black

ring around its neck It occurs in the southern Coastal Plain and lower Mississippi Delta from South Carolina into Mexico and northward into Arkansas The western coral snake, *Micruroides euryxanthus* has a red neck ring It ranges from southern Arizona and New Mexico into Mexico

The coral snakes are shy burrowing snakes but if stepped on or handled will bite not strike and chew the bite to facilitate the flow of venom Their venom is highly toxic but their fangs are so short that they are not as dangerous as supposed There is no positive record of any injury to man by the western species About 10–20% of the bites of the eastern species are fatal *See* COBRA SQUAMATA

[J D B]

Corallimorpharia

An order of the subclass Zoantharia or Hexacoral lia These sea anemones resemble corals in their weak musculature capitate (spherically tipped) tentacles and complex nematocysts They do not possess a skeleton however The tentacles are ar ranged in radial rows, not cycles on the disk and the base has no musculature The mesenterial fila ments are without special ciliated tracts The group occurs in shallow water from the temperate zone to the tropics The species are solitary although they may occur in large asexually produced aggre gations Examples are *Corallimorphus* and *Cory nactis* *See* ANTHOZOA

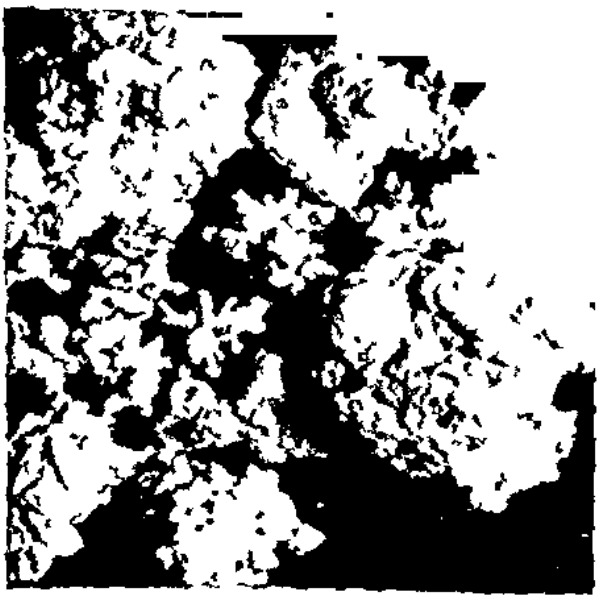
[C H]

Coralline algae

Red algae formerly called Nullipores belonging to the family Corallinaceae They secrete lime within and between the cell walls and make impor tant contributions to the building of limestones and reefs In a number of the Recent atolls of the Pacific coralline algae contribute significantly with the corals to the formation of the reef Coralline algae are commonly preserved as fossil and occur abundantly in rocks ranging in age from Late Cretaceous to Recent Genera commonly rep resented as fossils include *Archaeolithothamnium Lithothamnium Lithophyllum Corallina* Jan a and *Amphiroa* *See* ALGAE FOSSILS ATOLL OR CANIC REEF

[J H S]

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Specimens of coralline algae dredged at a depth of 42 fathoms off the west coast of central Florida (From H R Gould and R H Stewart Continental terrace sed ments in the northeastern Gulf of Mexico in Find ing Ancient Shorelines Soc Econ Paleontologists M n eralogists Spec Publ 3 1955)

Cordaitales

An extensive and for the most part natural group ing of forest trees of the late Paleozoic With in clusion of certain presumed relatives the strati graphic range of the Cordaitales extends from the Upper Devonian to the Lower Triassic The order may be divided into three families Pityaceae Cordaitaceae and Poroxylaceae The degree of re lationship between the three families is quite un certain and the bulk of knowledge and significance of the group resides in the Cordaitaceae abundant remains of which occur in Carboniferous sediment in most parts of the earth

Pityaceae Fossil plants grouped in the family Pityaceae are known only as petrifactions of branches and wood and the generic classification is based on anatomical features such as coni cal structure nodal vascularization tracheary pitting and other features of the secondary wood The range of structural variation among the genera is so great that the family is patently an artificial grouping and yet collectively finds its closest affin ity with the Cordaitaceae among known groups of vascular plants The best known and most wide spread member of the Pityaceae is the genus *Cal lixylon* of Upper Devonian and lowermost Carbon iferous (Mississippian) age *Callixylon* was a for est tree with diameter up to 4 ft or more Stem fragments showing little taper have been found as much as 27 ft in length The wood of *Callix lon* is featured by a pronounced widely spaced clus tered arrangement of the bordered pit pairs on the tracheid walls (Fig 1) The rays of the wood are commonly multiseriate and heterogeneous, dif fering from the wood rays of true *Corda tean* stems Leaves and reproductive structures of *Cal lixylon* are unknown *See* PETRIFACTION

Cordaitaceae The genus Cordaites is the central taxonomic unit of the family Cordaitaceae As is often the case with other groups of fossil plants the various parts or organs of the plant are known under a series of separately designated generic

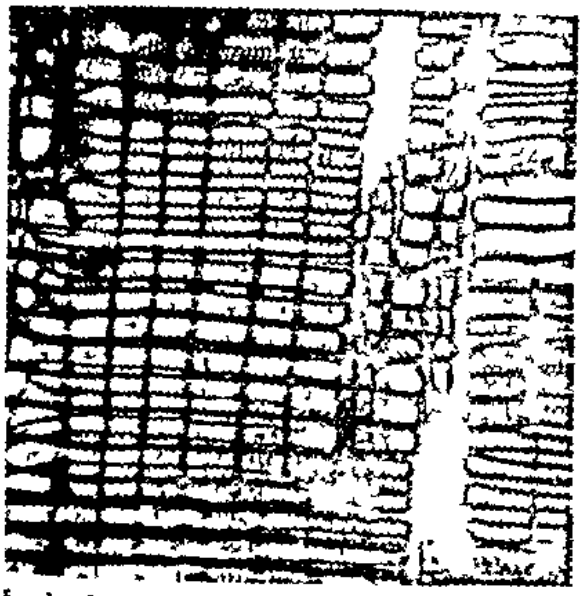


Fig 1 Radial section through secondary wood of *Callixylon newberryi* showing alignment of pit groups on radial walls of tracheids (*Photograph by C A Arnold*)

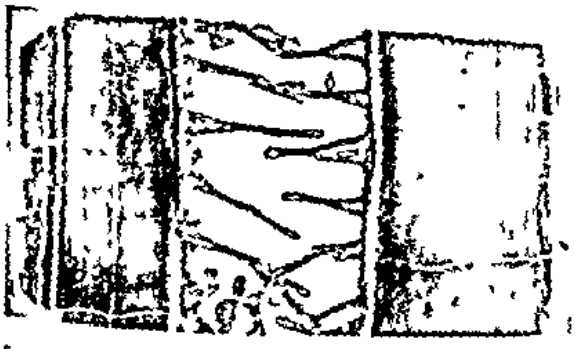


Fig 2 Radial section through stem of *Cordaites transversa* showing pith septations Coal Measures England (*From C A Arnold An Introduction to Paleobotany, McGraw-Hill, 1947*)

categories and binomials This cumbersome taxonomic procedure is a necessary consequence of the sedimentary process whereby different parts of the plant body are separately and disjunctly preserved

Plant tissues The secondary wood of *Cordaites* when it is preserved devoid of pith or cortex is known as *Dadoxylon* It is virtually indistinguishable in basic structure from the secondary wood of conifers of the extant family Araucariaceae The trunks achieved a diameter of 1 meter and the trees probably attained a height of 30 meters or more With preservation of other diagnostic features of the primary tissues such as pith cortex and leaf vascularization cordaitean stems may be placed in the genera *Mesoxylon* or *Cordaites* Pith casts commonly 4-10 cm in diameter are known as *Artisia* and often show external evidence of the septae or diaphragms which usually characterize the internal pith cavities of structurally preserved stems (Fig 2) The leaves of cordaitean trees are all basically similar in design though varying greatly in length from a few centimeters to over 100 cm Apices of the leaves vary in acuteness but the leaves are characteristically linear in shape with numerous parallel veins and are devoid of a mid rib (Fig 3) Internal preservation indicates that the leaves were thick coriaceous and rather heavily cutinized

Reproductive organs The reproductive organs of the Cordaitaceae are quite thoroughly known and are of special interest in their bearing on the evolution of the reproductive structure of the great group of gymnosperms the Coniferales Both pollen bearing and ovuliferous structures were produced in small multibracted florets borne helically inserted in the axils of distinct bracts on lax reproductive axes or as inflorescences (Fig 3) The individual florets as well as the inflorescences as a whole are unisexual Both male organs (stamens) and female organs (ovules) were borne terminally and grouped on the distal apex of the floret, surrounded below by the densely imbricated sterile bracts Pollen grains are ellipsoidal with a circumferential air bladder inside and attached at the inner proximal surface is a spherical grouping one cell thick of prothallial cells A row of spermatogenous nuclei (Fig 4) is occasionally shown within the prothallial mass Histological detail of

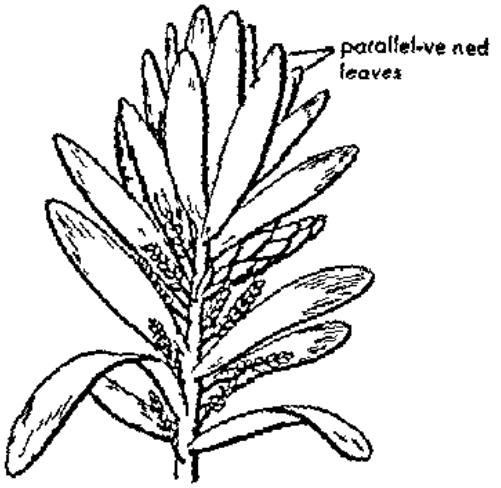


Fig 3 Foliage and inflorescence of *Cordaites* (*After Grand Eury*)

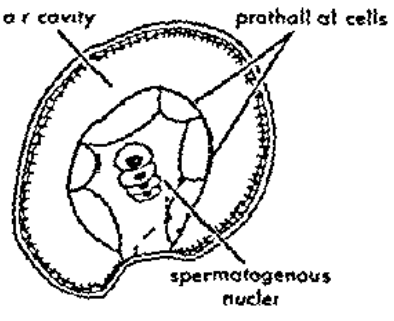


Fig 4 Pollen grain of *Cordaites* (*After R Florin*)

the early stages of ovule development are not known although it is known that the ovules were archegoniate Structurally preserved seeds of cordaitean trees are 1–3 cm long usually ovoid and commonly winged Internal organization closely resembles that of many seed fern seeds of contemporary deposits though less elaborate in structure Coalified compressed remains of cordaitean seeds often appear cordate in outline with a conspicuous broad wing if they are detached from vegetative organs they cannot be distinguished from seeds of seed ferns Cordaitean seeds have been described under the generic categories *Cardiocarpon*, *Mitrospermum* *Cordaicarpus* and *Samaropsis*

Poroxylaceae Remains of plants known from a limited locality in Europe under the generic name *Poroxylon* have been traditionally grouped in the Cordaitales perhaps most appropriately as the family Poroxylaceae The status of the genus is unsatisfactory It is probable that *Poroxylon* is a genus best classified among the seed ferns

The evolutionary significance of the Cordaitales (the Cordaitaceae) lies in their importance in delineating early stages in the phylogeny of the Coniferales The details of this well documented sequence in the evolution of vascular plants are described in the works of Rudolf Florin [E S B]

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Cordierite

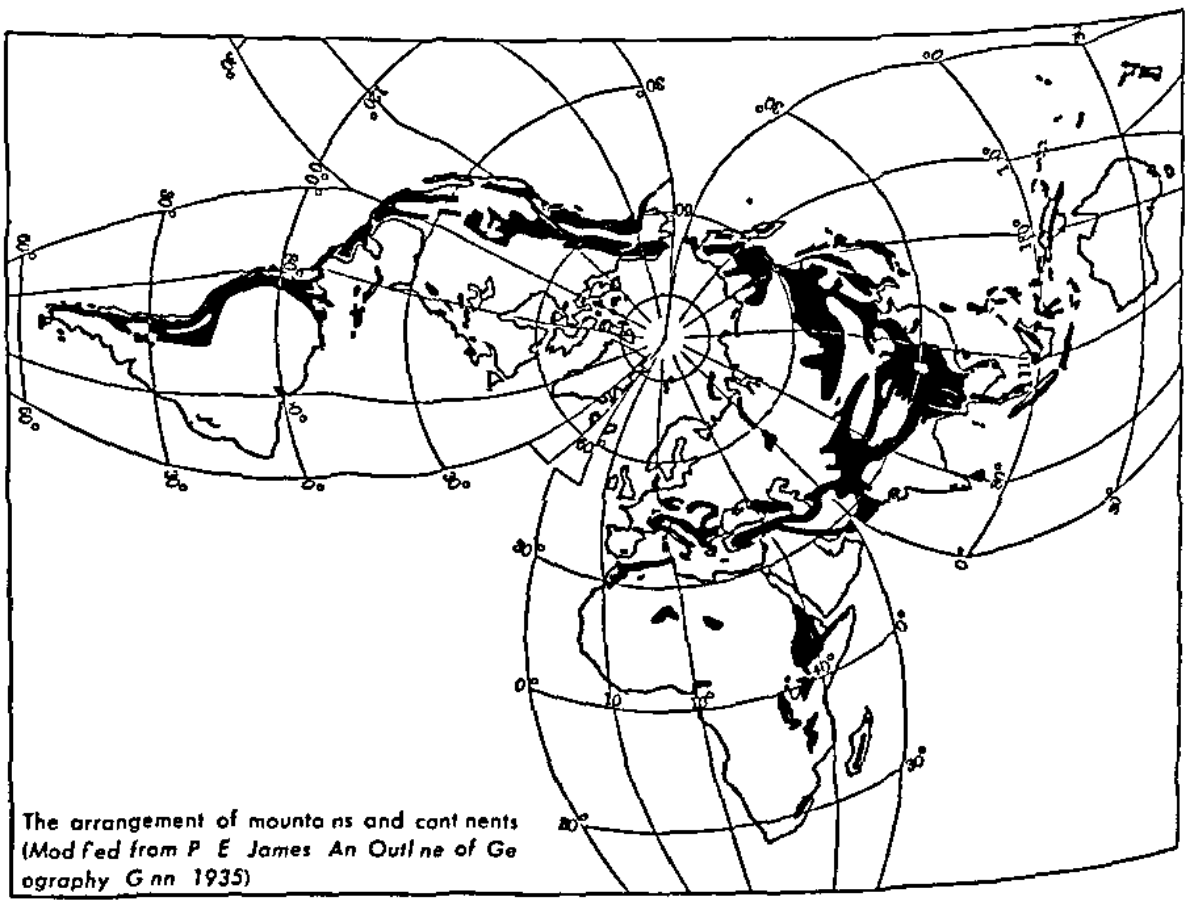
A mineral cyclosilicate composition $Mg_2Al_4Si_5O_{18}$ crystallizing in the orthorhombic system Crystal are short and prismatic pseudohexagonal twinning is common It is frequently massive occurring in imbedded grains resembling quartz It is distinguished from quartz by one direction of poor cleavage and its color which is various shades of blue Some transparent varieties are pleochroic varying from colorless to deep blue depending on the direction of the transmitted light The synonym dichroite is given because of this property Hardness is 7–7½ (Mohs scale) specific gravity is 2.60–2.66 luster is vitreous *See* SILICATE MINERALS

The chemical composition of cordierite is usually close to that given above but ferrous iron and manganese may substitute for magnesium and ferric iron for aluminum Water may also be present. Fresh cordierite is rare and it is usually altered, at least in part to mica chlorite and talc

Cordierite is found in granites granite pegmas in New England Transparent gem material [C S H] come from Ceylon

Cordilleran belt

A master assembly of mountains forming a significant part of a continent All of the mountain ranges, plateaus trenches and intermontane valleys of



The arrangement of mountains and continents (Modified from P E James An Outline of Geography Ginn 1935)

western North America from Alaska to Central America for instance form a cordillera The North American cordillera has a number of divisions called systems each with its own characteristic geologic features

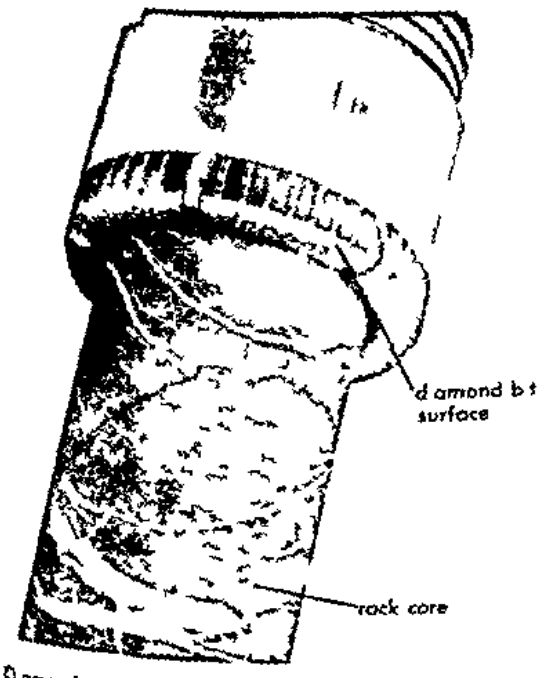
The Andes of South America including the Coast Ranges central plateaus and trenches and main mountain masses form a cordillera However some writers refer to the master assembly as the system and the major divisions as the cordilleras Nomenclature of mountain divisions has not yet become well standardized *See* MOUNTAIN SYSTEMS

Cordilleras are not only a matter of geographic distribution but also of age because they have been built at different times in the geologic past The old mountain systems have usually been worn away by erosion and now constitute regions of low or moderate relief The great cordilleras of the world as generally recognized by geographers are young mountains geologically and as a result generally have high elevations

The cordilleras are generally linear or beltlike in plan and represent zones of massive deformation of the earth's crust The internal architecture of the mountains indicates nearly everywhere compressional deformation in the form of folds of the strata and great overthrust sheets (*see* OROGENY) Erosion is quick to dissect these structures and volcanic vents then commonly break through from deep below and spew out large volumes of volcanic rock over the terrain Some of the highest peaks of a cordillera may be volcanic cones such as those of the Andes of Peru and Chile and the Cascades of Oregon and Washington [A J E]

Core drilling

The *boring* of a hole in the earth by drilling a circular groove and leaving a central core It is usually done to obtain the core as a sample for visual examination and to test its physical and chemical properties but is also done for making the hole itself whenever it is more economical to drill the annular groove and remove the core than to drill the entire cross sectional area of the hole



Diamond drill core and diamond bit

The greatest use for core drilling is in prospecting for mineral deposits It is usually done with a diamond core drill so called because it utilizes the extreme hardness of the diamond to cut the annular groove in rock The cores carved out by the diamond bit hundreds of feet in the earth are brought to the surface as true and unaltered specimens of the rocks and their mineral contents Diamond core drilling is also widely used in civil engineering work to determine the strength of the rocks that must support the tremendous weights of buildings bridges and dams and to determine how expensive it will be to excavate foundations and highway cuts

In shaft sinking by the core drill method and in core drilling other large diameter holes chilled steel shot is used as a cutting medium instead of diamonds Other cutting mediums sometimes used are hard alloy steel teeth sintered carbides and corundum grit *See* BORING AND DRILLING MINERAL PROSPECTING [F C S T]

Core loss

The rate of energy conversion into heat in a magnetic material due to the presence of an alternating or pulsating magnetic field It may be subdivided into two principle components, hysteresis loss and eddy-current loss *See* EDDY CURRENT HYSTERESIS MAGNETIC

Hysteresis loss The energy consumed in magnetizing and demagnetizing magnetic material is called the hysteresis loss It is proportional to the frequency and to the area inside the hysteresis loop for the material used (*see* MAGNETIZATION) Hysteresis loss can be approximated empirically by the expression

$$P_h = K_h f B_{max}^n$$

where K_h is a constant characteristic of the material f is the frequency B_{max} is the maximum flux density and n called the Steinmetz coefficient is often taken as 1 6 although it may vary from 1 5 to 2 5

Most rotating machines are stacked with silicon steel laminations which have low hysteresis losses The cores of large units are sometimes built up with cold reduced grain oriented silicon iron punchings having exceptionally low hysteresis loss as well as high permeability when magnetized along the direction of rolling

Eddy current loss Induced currents flow within the magnetic material because of variations in the flux This eddy current loss may be expressed to close approximation by

$$P_e = K (B_{max} f \tau)$$

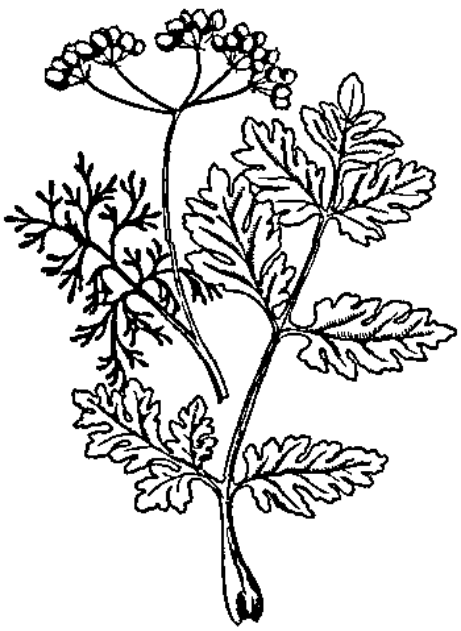
where K_e is a constant depending on the volume and resistivity of the iron B_{max} is the maximum flux density, f is the frequency and τ is the thick

cycle rotating machines core laminations of 0 014–0 018 in are usually employed to reduce eddy current loss

Measured core loss The measured core loss in a rotating machine also includes eddy current losses in solid structural parts such as the frame ventilating duct spacers pole faces and damper windings as well as those due to burrs or other contacts between punchings A number of precautions are taken to minimize these components which become appreciable in large machines Structural parts close to the core including clamping plates I beam spacers dovetail bars and shields may be made of nonmagnetic material Some of these parts may be shielded from the variable flux by low resistance plates or by flux traps of laminated high permeability low loss steel The core punchings are carefully deburred and are coated with a baked on insulating varnish The finished cores are often tested with an ac magnetizing coil to locate and correct any hot spots caused by damage during assembly Pole face losses may be reduced by avoiding excessive slot width to air gap ratios by surface grooving of the poles and by low resistance amortisseur windings *See* ELECTRIC ROTATING MACHINERY [L T R]

Coriander

An ancient flavoring material The plant *Coriandrum sativum* is a strong scented perennial herb about 3 ft tall The small spherical brown fruits



Coriander (Coriandrum sativum) (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

have an unpleasant odor when fresh but are pleasingly aromatic when dried They are used as a flavoring in cookery The oil of coriander is used in medicine and for flavoring beverages *See* SPICE AND FLAVORING UMBELLALES [P D S]

Coriolis acceleration and force

Two alternative concepts which pertain to the difference between the acceleration of motion as referred to and viewed from a coordinate system which does not partake of the earth s rotation (absolute acceleration) and the acceleration of motion as referred to and viewed from a coordinate system fixed on the surface of the earth (relative acceleration) Part of this difference is the centripetal acceleration of a fixed point on the earth s surface toward the axis of rotation of the earth The sum of this acceleration and the true gravitational acceleration (which is directed toward the center of mass of the earth) is equal to the apparent gravitational acceleration (which is observed to act normal to the ellipsoidal surface of the earth) The remainder of the difference between the absolute and relative accelerations depends upon the motion relative to the earth and is called the Coriolis acceleration

The direction of the Coriolis acceleration is perpendicular to the plane formed by the northward directed polar axis of the earth and the direction of motion relative to the earth Its sense is such that if one faces in the direction of this acceleration the smallest rotation required to bring the axis of the earth into coincidence with the direction of relative motion is clockwise The magnitude of the Coriolis acceleration is equal to twice the product of the speed of motion relative to the earth times the angular speed of rotation of the earth about its axis times the sine of the angle between the polar axis and the direction of relative motion If the vertical velocity component is small as it is in the large-scale motions of the atmosphere the horizontal component of the Coriolis acceleration is normal to the horizontal component of relative motion and is directed to the left of the direction of this component on the Northern Hemisphere and to the right on the Southern Hemisphere

The magnitude of the horizontal component of the Coriolis acceleration is then given by twice the product of the speed of the horizontal component of relative motion (or wind) times the angular speed of rotation of the earth times the sine of the latitude Thus it is equal to zero at the Equator

[illegible] reaches a maximum

[illegible] must

be considered in meteorological problems relating to the dynamics of large scale wind currents since its horizontal component is typically as large as any other horizontal force acting

A simple illustration of the Coriolis acceleration is afforded by consideration of the special case of air motion or wind at the poles Suppose that an air parcel crosses the North Pole and moves directly south so that its motion to an observer on the earth is in a straight line This same motion to an observer fixed in space would be curved and would display a continual acceleration toward the east because of the rotation of the meridian down

wh ch the air parcel is moving This acceleration is the Coriolis acceleration

The necessity of considering the Coriolis effect stems from the fact that Newton's second law is valid only when the motions and accelerations are those observed in a coordinate system fixed in space Thus the sum of the forces must be equated to the sum of the Coriolis acceleration and the ac celeration of motion as determined by an observer on the surface of the earth (relative acceleration) It is often most convenient however to think in terms of an equality of the sum of the forces and the relative acceleration alone In this instance the forces must include a fictitious force equal in mag nitude to the Coriolis acceleration and opposed to it in direction This fictitious force is the Coriolis force The alteration in concept from the Coriolis acceleration to the Coriolis force is equivalent to the mathematical device of moving the former from the acceleration side of the equation of mo tion to the force side with a change of sign *See* GEOSTROPHIC WIND GRADIENT WIND

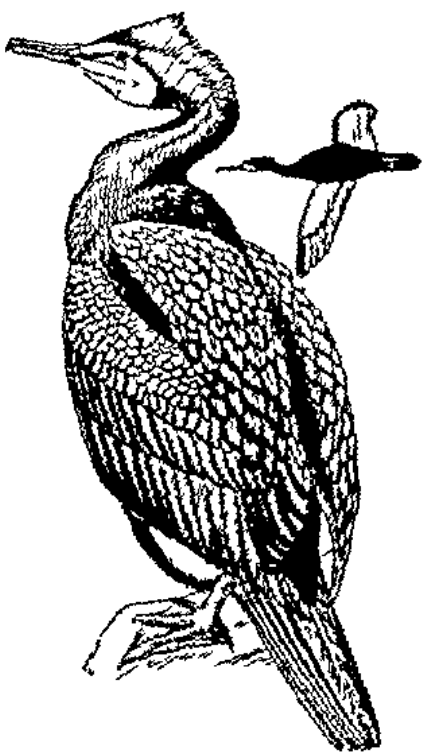
[F S]

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Cormorant

Any of 30 species of the nearly cosmopolitan fam ily Phalacrocoracidae dark colored fish eating b rds of moderate size Five species occur in the United States Cormorants are gregarious and breed in colonies They are found on both fresh and salt water but are primarily marine They have strong, hooked bills with which they catch fish by diving and swimming underwater They are of no economic consequence and catch worthless fish more often than desirable species *See* PELECANI FORMES

[J D B]



The double-crested cormorant, Phalacrocorax auritus length 35 in (From E L Palmer Fieldbook of Natura History McGraw-Hill 1949

Corn

The plant *Zea mays* is the most extensive of all the grain crops in the United States where 60% of the world production is grown Corn requires a warm temperature a good supply of moisture and fertile well drained soils for maximum yields Al though many states grow some corn as shown in Fig 1 the largest acreage is in the eastern half of the United States where average rainfall is 20 or more in per year Within this eastern area the most extensive acreage is planted in Iowa Illinois Indiana Ohio northern Missouri southern Minne sota eastern Nebraska and southern Wisconsin and Michigan This area is generally called the *Corn Belt* The average annual value of $1 599 755 500 in the 10-year period 1945–54 exceeds that for any other crop Although corn is grown in the United States primarily for livestock feed about 10% is used for the manufacture of corn meal starch breakfast cereals sugar oil alcohol and a wide variety of other specialized products In most other countries of the world corn is used primarily for human food

Origin and description From its presumed cen ter of origin in Central America corn has been in troduced into nearly every country of the world However the corn of today is far different from primitive types found in prehistoric tombs in Cen tral America It was cultivated by the native Indi ans in the New England states and survival of the early American colonists was due largely to their use of corn as food Over a long period of evolu tionary development corn may have intercrossed with *Tripsacum* a much branched grassy plant and with teosinte a near relative of corn to produce many diverse types

Botanically corn is a member of the grass fam ily (*see* GRAMINALES) Within the species *mays* there are several distinct subspecies These include *indentata* the dent corns *indurate* the flint corns, *amylacea* the soft or flour corns *saccharata*, the sweet corns *everta*, the popcorns, and *tunicata* the pod corns Each of these six subspecies has the same number of chromosomes (10 pairs) and freely intercross (*see* CHROMOSOME GENETICS REPRO DUCTION PLANT) Dent corns are the most impor tant in the United States In South America the flint corns predominate The soft corns are favored in Central America Mexico and in other countrie where considerable amounts are still ground b hand into corn meal Sweet corn is more exten sively grown in the United States than in othe countries and it is used either canned or eaten o the cob In other countries field corn flour or deni

[illegible] the same purposes as sweet corn in t

[illegible] vely A



Fig 1 Corn for all purposes United States total acreage 1954 78 122 557 Each dot represents 10 000 acres (*U S Dept Commerce*)

ican The pod corns are not of economic impor tance in any country of the world

Varieties and types Corn is a cross pollinated plant largely because the staminate (male) and the pistillate (female) inflorescences (flower clus ters) are borne on separate parts of the same plant (Fig 2) Plants of this type are called monoecious

FLOWER (BOTANY) INFLORESCENCE Natural cross pollination maintains a continuing source of varia tion in genetic constitution As corn was carried by Indians to different environments in North Central and South America, a large array of varieties ulti mately was developed Many of these primitive varieties still exist today in Mexico where special studies have been made to classify them and to de termine their origin and relationships In the early history of the United States when farmers migrated from the eastern states to the new lands in the West they took with them their corn seed (techni cally fruits) In time by both natural and planned selection a large number of varieties and local strains became well established which differ in color of grain ear and plant characteristics and in length of time required to reach maturity Perhaps in no other cultivated crop can there be found so much genetic variability traceable to diversity in species origin and maintained in so plastic a state through countless generations of cross pollination From this pool of germ plasm there have been de rived early maturing dent corns that are well adapted to a frost free growing season of less than



Fig 2 A corn plant in full tassel (above) and silk (below) The tassel produces pollen that is blown by wind to the silks (*Photographs from J W McManigal*)

100 days and, in contrast, corns that grow 12–15 ft tall and require over 200 days for maturity as in certain areas in Guatemala

Corn hybrids The development of varieties and strains of corn made possible the extension of its culture under diverse soil and climatic conditions However modern research methods used for its further improvement led to the present widespread use of hybrid corn *See* BREEDING (PLANT) HETEROSIS Today nearly all of the corn grown in the United States is planted with hybrid seed In many foreign countries the transition from varieties to corn hybrids is now in progress

The hybrid corn in most general use is a double cross produced from a first generation hybrid between single crosses Each of the two single crosses is obtained by crossing two inbred lines Thus a double cross has in its parentage four different inbred parents Inbred lines are developed by controlled self pollination originally using well known varieties as the starting point In the process of inbreeding pollen is transferred by hand to the silks of the same plant which are protected from outcrossing by covering with a parchment bag prior to silk emergence Although self pollination leads to reduction in vigor it also makes possible the development of lines that are genetically pure or homozygous By careful selection and evaluation during the process of inbreeding some lines are obtained that are pure for such desired characters as resistance to lodging (falling over due to weak stalks) diseases and insects Because inbred lines are reduced in yield they must be crossed to restore vigor lost during the inbreeding process Some inbred lines do not produce high yielding hybrids, nor transmit their desirable characters to any high degree of expression Hence many experimental hybrids must be made and tested to find those combinations that excel in all attributes When the proper combinations have been determined seed of the parental inbred lines is increased and quantities of single crossed seed produced by planting the respective inbred parents in isolated fields usually 60 rods away from other corn One parent is detasseled before anthesis (maturity) of the pollen thus becoming the pistillate or female parent Seed produced on ears of the detasseled inbred is single crossed seed The two single crosses used as parents for the double cross are subsequently planted in an isolated plot usually with 6–8 rows of the single cross female parent to 2 rows of the male parent The female parent is detasseled before anthesis and seed produced on this parent from cross pollination by the male parent is double crossed seed Recently genetic means have been developed that permit the incorporation of male sterility transmitted through the cytoplasm into the female parent (*see* CYTOPLASM) These cytoplasmic male sterile plants do not produce viable pollen and hence need not be detasseled When this genetic mechanism to avoid detasseling is used to produce double crossed seed the male parent single cross must possess a genetic factor (or factors) that restores pollen production in the hybrid progeny

Many commercial hybrid seed corn companies utilize these corn breeding methods developed from basic research at colleges universities and the United States Department of Agriculture to produce process and market annually over 10 000 000 bushels of hybrid seed This modern technique of hybrid seed production is a remarkable advance over the older methods of saving seed corn practiced by farmers only 25 years ago Gains to farmers from planting hybrid seed are conservatively estimated as 25% in yield Greater resistance to lodging and greater uniformity in maturity ear height and ear size also made it possible to use mechanization in harvesting the crop (*see* AGRICULTURAL MACHINERY)

Planting The majority of the corn grown in the humid areas is machine planted in rows 38–42 in apart In areas with somewhat limited rainfall corn frequently is listed planted in the bottom of furrows to provide more favorable conditions for retention of moisture (*see* AGRICULTURAL SOIL AND CROP PRACTICES) Contour listing on sloping land is an effective method to reduce soil and water losses *See* SOIL CONSERVATION TERRACING (AGRICULTURAL) On level land the majority of corn fields are planted in check rows with hills spaced 38–40 in apart in the row to permit cross cultivation for weed control However there is now a marked tendency to change from the check row system to a power drop system of planting in which the corn planter without the use of check wires drops two or more kernels 15 30 in apart within the row A third system of planting called drilling consists of dropping a single kernel at 6–12 in spacing within the row Power drop and drilling methods of planting are exclusively used when corn is planted on the contour because cultivation up and down the hill would be undesirable with respect to soil and water loss Rates of planting vary widely depending largely on soil moisture and soil fertility With favorable moisture and fertility stands of 16 000–20 000 plants per acre produce maximum yields Under less favorable moisture and soil fertility stands of 8000–12 000 plants per acre are best

The date of planting corn is determined largely by the date of the last killing frost in the spring This varies from February in the Gulf States to early June in the extreme northern area of the United States Corn seed normally will not germinate in soil at temperatures of 50°F or lower and seedlings make poor growth at temperatures of 60°F Corn seed generally is planted from 2 to 3 in below the soil surface

Cultivation The major objective in corn cultivation is control of weeds Cultivation begins prior to planting so as to kill weeds that have emerged during the early spring The first cultivation often is accomplished with a rotary hoe a machine with curved spikes shortly after the corn seedlings have emerged This machine is operated at a high ground speed (6–8 mph) and requires less power

other cultivation equipment Subsequent cultiva tions are done with a row cultivator, using sweeps or broad shovels to destroy weeds In removing weeds care must be taken to cultivate as closely as possible to plants in the row without damage to corn roots In the second or third cultivation, if such is needed, the corn seedlings are sufficiently large so that soil may be directed toward them to cover smaller weed seedlings Corn is laid by when the plants are 2 2½ ft tall and when they suppress weed growth by shading the ground

Harvesting. In the Corn Belt states nearly all corn is harvested by mechanical pickers from the standing stalks (Fig 3) As previously stated, the use of strong stalked hybrids has been an important factor in the use of corn pickers to harvest the crop Corn can be safely picked and the ears stored in well ventilated cribs when the moisture content of the grain has been reduced by natural drying to 20–22% In recent years there has been an increased use of picker sheller machines and in some areas the corn combine has come into general use When corn is shelled in the field with a moisture content above 14%, it becomes necessary to dry the grain artificially if stored for prolonged periods in large bins In low rainfall areas and when fall temperatures are above and rainfall be low normal corn may become dry enough in the field to permit use of picker sheller or combine without artificial drying *See* AGRICULTURAL SCI ENCE (PLANT) [I J J]



Fig 3 Mechanical picking of corn is now the most common method of harvest (*J C Allen and Son*)

Corn diseases. In the United States about 5% of the potential crop or about 150 000 000 bushels of corn are lost annually from diseases, and it is not uncommon for regions or individual states to sustain losses of 5–10% from a single disease For instance, in 1933 bacterial wilt, *Xanthomonas stewartii*, alone destroyed 45% of all the sweet corn grown in Pennsylvania

Some diseases are conspicuous, such as common corn smut, *Ustilago maydis* (Fig 4), head smut, *Sphacelotheca reiliana*, and downy mildew, *Sclerospora* spp Other diseases, such as root rot, stalk rot (Fig 5), and certain viruses, which cause decay



Fig 4 Corn smut *Ustilago maydis* on various parts of a corn plant (*Univ Minn Agr Expt Sta*)

or general weakening of plants, are not evident until the plants are severely damaged Consequently their economic importance is frequently underestimated

Seedling injury is one of the most common causes of trouble, especially when cold and wet conditions weaken the corn In cold soils the seed often decays and seedlings die before or shortly after they emerge The fungi *Diplodia zeae*, *Fusarium* spp, *Gibberella zeae*, *Penicillium* spp and *Pythium* spp are most commonly associated with seedling injury and may be seed or soil borne (*see* FUNGI) The planting of sound mature and chemically treated seed will help to reduce seedling rot

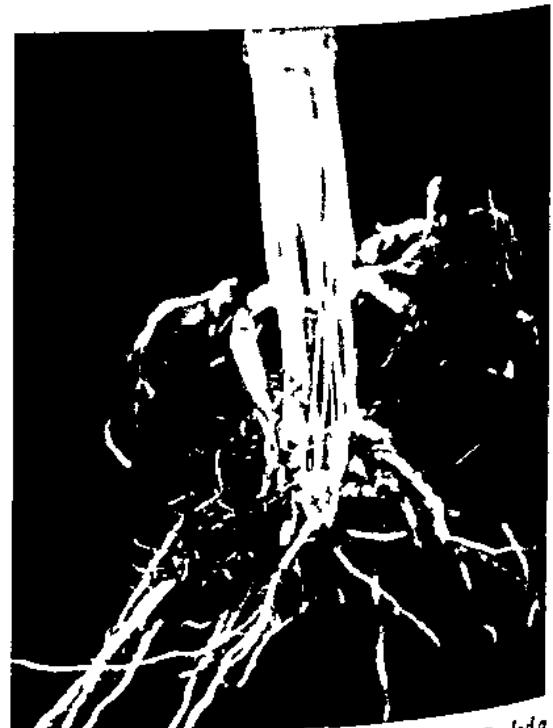


Fig 5 Basal stalk rot of corn caused by *Diplodia zeae* (*Univ Minn Agr Expt Sta*)

There are more than 25 leaf diseases of corn only a few of which are important in the United States Northern leaf blight *Helminthosporium turcicum* is probably the most destructive especially in regions that have heavy dews and abundant rainfall The fungus persists in the fields from one season to another and is spread by wind A similar but less important disease southern leaf blight *H maydis* occurs throughout the southern states Another important foliage disease is the bacterial wilt *Xanthomonas stewartii* If the stalk of a severely affected plant is cut crosswise the bacteria ooze out in sticky yellow droplets from the vascular bundles (*see* VASCULAR BUNDLES) Although the pathogen may overwinter in the seed and in plant debris insects, particularly the corn or brassy flea beetle *Chaetocnema pulicaria*, are the principal agents of dissemination (*see* COLEOPTERA) The initial infection usually occurs through wounds made by the flea beetle and severe epidemics are generally associated with a high population of infested flea beetles

Corn is susceptible to two smuts The common smut, *Ustilago maydis* is by far the most prevalent and destructive Any rapidly growing tissue is susceptible to infection Galls are produced on all above ground parts of the plant and vary in size from headlike structures to galls 6–8 in in diameter The fungus is difficult to combat except by growing resistant varieties

In the United States corn rusts are generally of minor importance but in certain countries of Latin America and of Africa one or both are sometimes destructive Woodsorrel, *Oxalis* spp is the alternate host for the common rust *Puccinia sorghi* however no alternate host is known for southern rust *P polysora* Fairly cool temperatures favor development of the common rust whereas high temperatures favor the southern rust Varieties differ greatly in their susceptibility to the common rust

Stalk rot and ear rots caused by many species of fungi are among the most destructive diseases of corn in the United States Stalk rot causes stalk breakage infected plants yield much less and the quality of the grain is reduced The type of rot varies tremendously depending on the time of infection and the causal pathogen Thus *Diplodia zeae* causes a dry gray ear rot *Gibberella zeae* a conspicuous red rot and *Penicillium* spp a blue green discoloration (Fig 6) The development of disease resistant varieties offers the most practical means of control See PLANT DISEASE PLANT DISEASE CONTROL [J J C]

Processing Corn may be processed for three general purposes animal feed human food or industrial uses For animal feed it may be cracked or ground by a variety of methods including hammer burr or roller mills For human consumption cornmeal is produced by grinding either between millstones or with steel rolls Millstones which grind slowly at low temperature are commonly used by small mills, especially in the South The steel roller system is used by larger corn millers



Fig 6 *Ear rot of corn caused by Gibberella zeae (Univ Minn Agr Expt Sta)*

Four main parts of the corn kernel are hull germ gluten and starch The object of milling is to separate these components which on a moisture-free basis constitute the following percentages of the entire corn kernel hull 6% germ 11% gluten 11% endosperm 70% The products from milling are corn flour cornmeal and feed by products Dent corn either white or yellow is preferred to flinty varieties for manufacturing cornmeal

In processing corn two systems are used dry milling and wet milling

Dry milling Shelled corn is passed over magnetic separators to eliminate foreign material and then through scourers to remove the tip cap from the end of the kernel The cap is often dark and may produce black specks in the finished meal If the shelled corn is higher than 12% moisture it may be dried to about that percentage before cleaning and grinding operations In the process of tempering or conditioning, water is added to toughen the bran before milling The corn needs to be somewhat dry at the start so that moisture added during tempering will loosen the bran and germ Water often is added in stages to bring the moisture content to more than 20% the corn then is allowed to stand several hours Sometimes warm water and steam are used for this purpose before the milling process starts

Degermination is accomplished in a machine which contains a horizontal revolving cone-shaped drum covered with small metal projections This drum is in a housing also studded with metal projections and having small perforations As the corn passes through the machine the bran and germ are to a large extent pulled from the kernel and the endosperm is broken into several large pieces The fine particles of hull and germ pass through the perforations and are thus separated from the endosperm The stock passes to grading reels where the different sized particles are separated From the grading reels the particles are sent to centrifugal aspirators which remove loose bran The various

grades of aspirated corn fragments are gradually reduced to coarse medium and fine grits as they pass between corrugated rolls with sifting and bolting operations in the same sequence as in wheat milling The flow sheet for corn milling though simpler is similar to that of wheat milling

Grits intended for industrial use are generally flaked This is accomplished by steaming the grits before they pass between heavy duty heated rolls operating at approximately the same speed The heat of pressing between heated rolls causes partial gelatinization of the starch

Wet milling Wet process corn milling is used to separate the various components of the kernel for industrial purposes The industrial use of corn to manufacture starch dextrin and dextrose (glucose) uses as much as 100 000 000 bushels per year In addition oil is recovered from the germ and fiber as well as gluten for use in animal feeds Some corn is utilized for industrial fermentations especially in time of warfare when the demand for alcohol for industrial uses often exceeds the supply obtainable from molasses *See* ETHYL ALCOHOL GLUCOSE STARCH

In the wet milling process which uses in excess of 150 000 000 bushels per year clean corn is steeped from 36–48 hours in diluted sulfurous acid solution to loosen the hull and soften the gluten At the end of the steeping period the corn contains from 40 to 50% moisture The wet corn is passed through a special type of attrition mill consisting of studded rotary plates which turn in opposite directions and tear the kernel apart This makes possible the separation of the germ hull and disintegrated endosperm Separation is accomplished by passing the material through long tanks as a slurry Here the germ rises to the surfaces and the particles of endosperm settle to the bottom The settlings are separated from the liquid by passing through reels then they are reground on burr mills to permit the separation of starch gluten and hulls The discharge from the burr mill goes through a series of reels and shakers which permit the starch and gluten but not the particles of hull to pass through the bolting cloth The suspension of starch and gluten flows slowly down slightly inclined flat bottomed troughs called tables The starch settles on the tables while the gluten passes along with the solution In some plants this separation of starch from gluten is accomplished with centrifuges Starch collected from the tables is given a series of washings before it is dried in rotary vacuum driers From there the product can be further processed into corn sugar (dextrose) corn syrup or corn starch

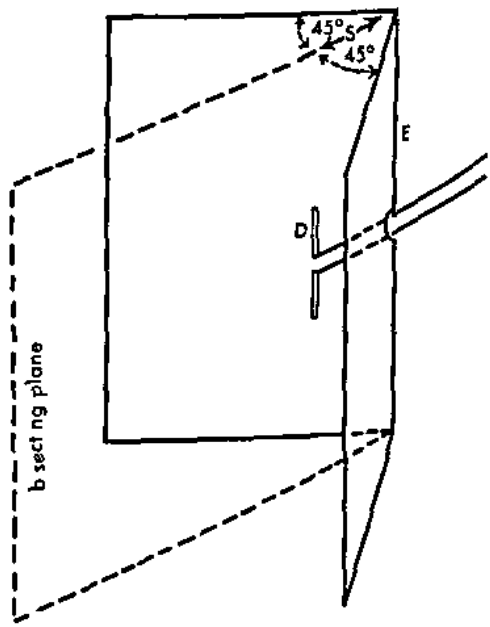
The corn germ is kiln dried preheated and the oil extracted by either pressure or solvent The oil

30% feed material and 3% oil *See* FOOD ENGINEERING [J A SH]

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Corner reflector antenna

A directional antenna consisting of the combination of a reflector comprising two conducting planes forming a dihedral angle and a driven radiator or dipole which usually is in the bisecting plane It is widely used both singly and in arrays gives good gain in comparison with cost and covers a relatively wide band of frequency For a discussion of directional antennas *see* ANTENNA (AERIAL)



Corner reflector antenna

The illustration shows the general configuration for a 90° corner reflector The distance S from the driven radiator D to edge E need not be critical chosen with respect to wavelength for a 90° reflector D may lie between 0 25 and 0 wavelength The over all dimensions of the reflector need exceed 2 wavelengths in order to approximate the performance obtained with very large reflectors Gain as compared with an isotropic radiator about 12 decibels

The reflecting planes may be metal sheets or parallel wires separated by a small fraction of a wavelength and extending in the direction of current flow [J C]

Corona, solar

The outermost extension of the atmosphere of the Sun which is normally visible only at a total solar eclipse The corona consists of gas at a density of about 10^{-15} g/cm^3 (or 10^{-12} atmospheric density) and a normal kinetic temperature between 1 and 2×10^6 °K It is easily observable at an eclipse to a height of 2 3 solar diameters The outer envelope

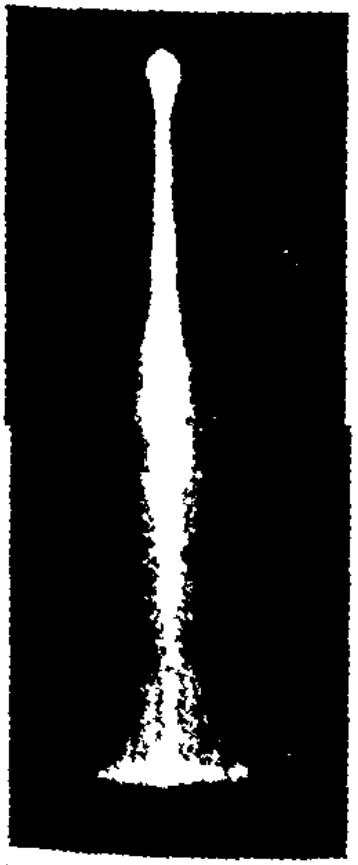
often consists of beautiful radial streamers composed of electrons and protons ejected by the Sun *See* SUN [J W E]

Corona discharge

A type of electrical conduction that generally occurs at or near atmospheric pressure in gases A relatively strong electric field is needed External manifestations are the emission of light and a hissing sound The particular characteristics of the discharge are determined by the shape of the electrodes the polarity the size of the gap and the gas or gas mixture

In some cases corona discharge may be desirable and useful whereas in others it is harmful and attempts are made to *minimize* it The effect is used for voltage division and control in direct current nuclear particle accelerators On the other hand the corona discharge that surrounds a high potential power transmission line represents a power loss and limits the maximum potential which can be used Because the power loss due to i^2r heating decreases as the potential difference is increased it is desirable to use the maximum possible voltage

The shape of the electrodes has a very profound effect on the potential current characteristic If the radius of curvature of the positive electrode is small compared to the gap between electrodes the transition from the dark current region to the field sustained discharge will be quite smooth (*see* DARK CURRENT) The effect here is to enable the free electrons to ionize by collision in the high field surrounding this electrode One electron can produce an avalanche in such a field because each ionization event releases an additional electron which can then make further ionization To sustain the discharge it is necessary to collect the positive ions and to produce the primary electrons far enough from the positive electrode to permit the avalanche to develop The positive ions are collected at the negative electrode and it is their low mobility that limits the current in the discharge For a discussion of ionic mobility *see* ELECTRICAL CONDUCTION IN GASES The primary electrons are thought to be produced by photoionization (see illustration)



Photograph of breakdown streamers in positive point corona crossing from positive point to cathode below (From L B Loeb *Fundamental Processes of Electrical Discharge in Gases* Wiley 1939)

The situation at the negative electrode is quite important The efficiency for ionization by positive ions is much less than for electrons of the same energy Most of the ionization occurs as the result of secondary electrons released at the negative electrode by positive ion bombardment These electrons produce ionization as they move from the strong field at the electrode out into the weak field This however leaves a positive ion space charge which slows down the incoming ions This has the effect of diminishing the secondary electron yield Because the positive ion mobility is low there is a time lag before the high field conditions can be restored Thus the discharge is somewhat unstable

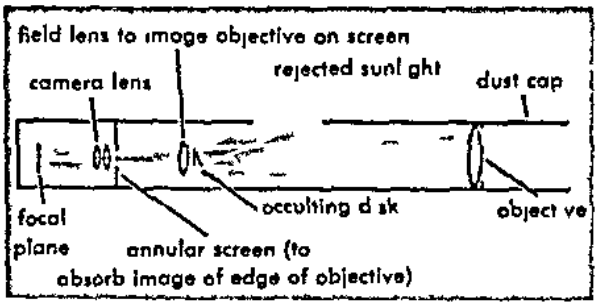
From the preceding it may be seen that the electrode shape is important The dependence on the gas mixture is difficult to evaluate Electronegative components will tend to reduce the current at a given voltage because heavy negative ions have a low mobility and are inefficient ionization agents The excess electron will not be tightly bound however and may be released in a collision The overall effect is to reduce the number of electrons that can start avalanches near the positive electrode Further if a gas with low lying energy states is present the free electrons can lose energy in inelastic collisions Thus it is more difficult for the electrons to acquire enough energy to ionize In electrostatic high voltage generators in pressurized tanks it is quite common to use Freon and nitrogen to take advantage of this effect to reduce corona In a pure monatomic gas such as argon for example corona occurs at relatively low values of voltage

In the potential current characteristic the corona region is found above the dark current region and is field sustained Near the upper end it goes into either a glow discharge or a brush discharge depending on the pressure Higher pressure favors the brush discharge *See* BRUSH DISCHARGE GLOW DISCHARGE

For still higher potential difference breakdown takes place and a continuously ionized path is formed *See* SPARK ELECTRIC. [C H MI

Coronagraph

A specialized astronomical telescope used for the observation of the solar corona The heart of the instrument is the objective which must be as per fect as possible with regard to optical figure and polish the glass must be flawless The presence of



The coronagraph of B Lyot

scratches minute bubbles or dust on the lens prevents successful observation Stray light is further reduced by the occulting disks screens and the re imaging system as illustrated When installed at high altitudes where scattering from dust in Earth s atmosphere is low the Sun s corona can be ob served directly on days of extreme clearness but generally high contrast photographic emulsions and light filters are required for making satisfac tory records [R R M]

Coronatae

An order of the class Scyphozoa which includes mainly abyssal species The exumbrella is divided by a circular or coronal furrow into two parts an upper central disk and a lower coronal part The central disk is usually domelike but in *Peri phylla* it often narrows toward the top The coronal part has gelatinous thickenings or pedalia situ ated on the radii running from the center of the umbrella to the tentacles and the sensory organs The pedalia are separated from one another by clefts running down the radii that are halfway between each tentacle and sensory organ The mouth has four lips There are four groups of gas tral filaments within the central stomach Abyssal forms of this group are dark brown or redd h purple in color The littoral species of *Nausithoe* is reported to show alternation of generations but the life history of abyssal forms remains unknown. *See* SCYPHOZOA [T C]

Corrosion

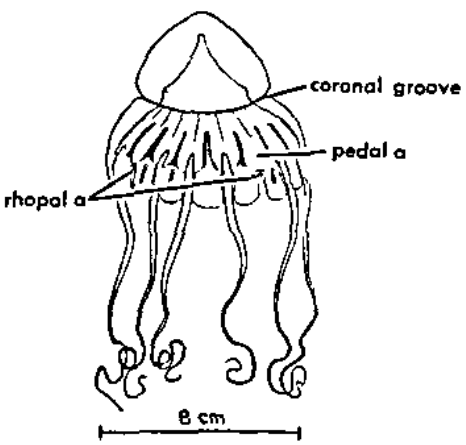
mated at $6 000 000 000 per year This is a large figure but it is not difficult to perceive why the cost is enormous when it is realized that corrosion in varying degrees occurs on all metals alloys and other materials in practically all environments Air and water cause great corrosion damage and they are omnipresent For convenience the causes ef fects and prevention of corrosion can be classified into two main categories according to the environ ment in which corrosion occurs These env ron ments are liquids and solutions on the one hand, and gases on the other

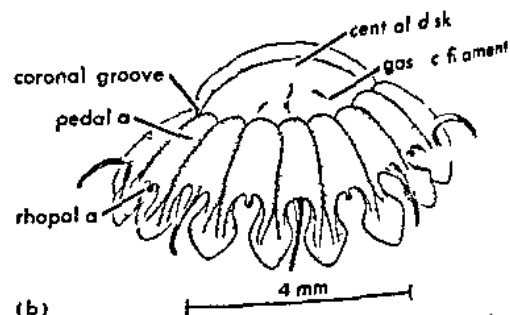
CORROSION IN LIQUIDS AND SOLUTIONS

Corrosion is the result of electrochemical or chemical reaction between a metal and its sur roundings Wet corrosion describes attack by liquids and dry corrosion by gases above the dew point

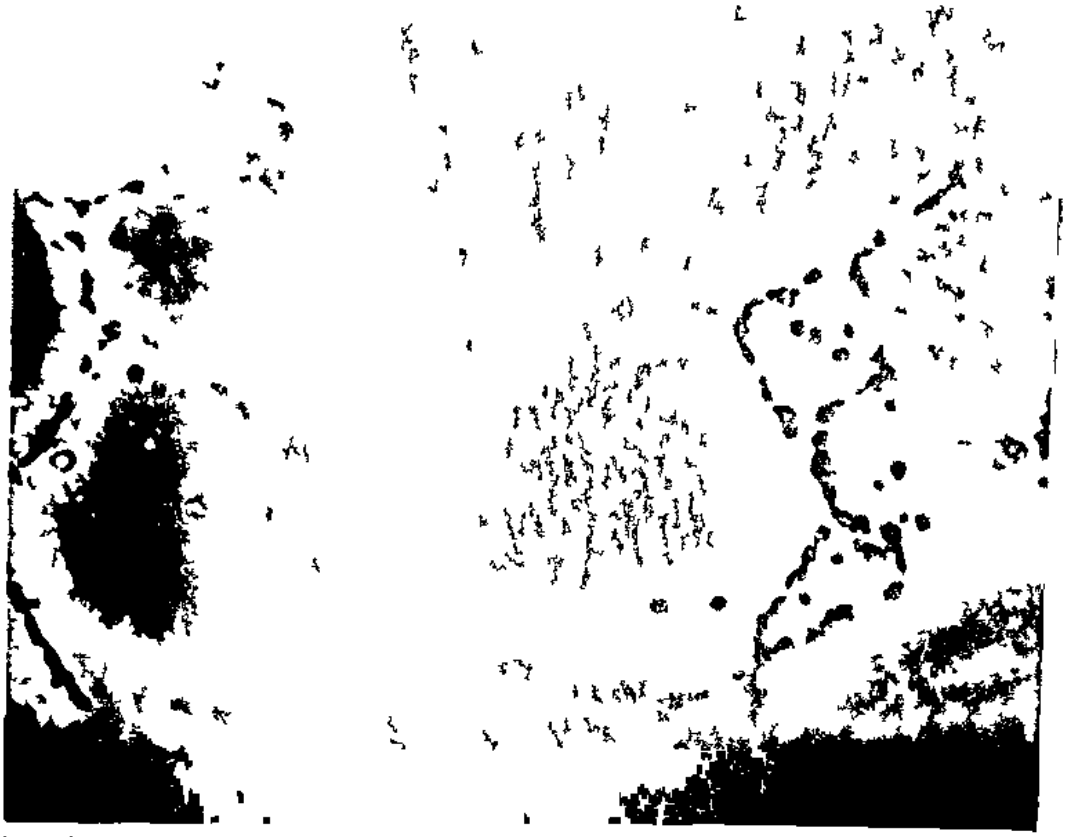
Most corrosion costs are due to corrosion in electrolytes or wet corrosion The basic requ re ments for electrochemical corrosion are (1) anodes and cathodes must be present to form an electro chemical cell and (2) direct current must flow The anodes and cathodes could be close together (local cells) or far apart that is on the same p pe sect on or on two different sections of a pipel ne The current can be self induced or it can be impre sed on the system from an outside source

The anode is the area in which corrosion occurs and in which the current leaves the metal The cathode is the area in which practically no corro sion occurs and in which current enters the metal





Coronatae (a) *Per phylla* (b) *Naus thoe* (From L H *Hyman The Invertebrates* vol 1 McGraw-H ll 19



Even d s but on of ch om m o o o on e an alloy

Pho og aphs by Ba e le Memo al Ins tu e

Leach ng effect of a pa cu a sal on the same ch om um at e eva ed tem pe atu es

Anodes and cathodes can form on a single piece of metal because of local differences in the metal or differences in the environment

Local differences in a given metal can be chemical or mechanical in nature for example impurities such as oxides and other inclusions grain boundaries, orientation of grains differences in composition of the microstructure localized stresses and scratches and nicks Highly polished surfaces are used in special cases Pure and smooth zinc will not corrode in pure hydrochloric acid because anodes and cathodes do not form Yet commercial zinc and hydrochloric acid react rapidly Pure metals are not often used because they are expensive and have relatively low strength

Figure 1 summarizes the requirements for corrosion and can be considered as a basic diagram for wet corrosion of metals and alloys The quantity of current which passes through the cell is directly proportional to the amount of metal that corrodes For example 1 ampere per year equals about 22 lb of steel.

Anything that upsets the scheme shown in Fig 1 might be useful for stopping or minimizing corrosion For example a barrier such as a coating would keep the environment away from the metal Sometimes a layer of hydrogen gas (polarization) forms on the cathode and insulates it thus stopping corrosion

Different metals have different reactivities or tendencies to corrode The familiar electromotive force (emf) series lists elements in the order of decreasing reactivity However the emf series is a poor guide for predicting corrosion behavior of metals and alloys in commercial environments For example chromium is above iron in the series so the addition of chromium to iron should decrease the corrosion resistance of iron Actually this mixture results in the stainless steels whose main advantage is good corrosion resistance This increase in nobility or corrosion resistance is due to passivity which can be simply defined as a condition that causes a metal not to corrode when it should See ELECTROCHEMICAL SERIES

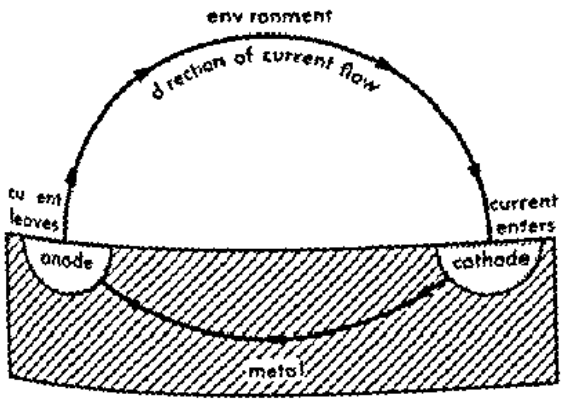


Fig 1 Basic requirements for corrosion by electrolytes

Passivity is usually due to surface films which act as barriers between the metal and its environment On stainless steels the film consists of adsorbed gases or oxides Aluminum is a reactive metal but it is widely used for corrosion applications because of protection by a stable aluminum oxide film Lead resists sulfuric acid because of the formation of a lead sulfate barrier

Types Corrosion may be classified into the eight forms in which it manifests itself The basis for this classification is the appearance of the corroded metal These eight forms are galvanic, uniform concentration-cell pitting intergranular stress dezincification or selective leaching and erosion corrosion

Galvanic corrosion Galvanic or two metal corrosion occurs when two dissimilar metals in contact or otherwise connected electrically are exposed to a corrosive electrolyte Corrosion of the less resistant metal is increased and corrosion of the more corrosion resistant metal is decreased

The following list shows a practical galvanic series for metals and alloys exposed to actual sea water

Galvanic series for sea water
Magnesium and magnesium alloys
Zinc
2S Al (commercially pure)
Cadmium
24 ST Al (4.5% Cu 1.5% Mg 0.6% Mn)
Steel or iron
Cast iron
13% Cr iron (active)
Ni Resist (High Ni cast iron)
18-8 (active)
18-8-Mo (active)
Lead tin solders
Lead
Tin
Nickel (active)
Inconel (active) (80% Ni 13% Cr 7% Fe)
Hastelloy B (60% Ni 30% Mo 6% Fe 1% Mn)
Chlorimet 2 (66% Ni 32% Mo 1% Fe)
Brasses (Cu Zn)
Copper
Bronzes (Cu Sn)
Cupro nickels (60-90% Cu 40-10% Ni)
Monel (70% Ni 30% Cu)
Silver solder
Nickel (passive)
Inconel (passive)
Chromium steel (passive) (11 to 30% Cr)
18 8 (passive)
18-8 Mo (passive)
Hastelloy C (62% Ni 17% Cr 15% Mo)
Chlorimet 3 (62% Ni 18% Cr 18% Mo)
Silver
Titanium
Graphite
Gold
Platinum

The farther apart two metals are in this series the greater is the potential when they are coupled The material higher in the series becomes anodic to the one below it Magnesium and copper would form a bad galvanic couple as far as corrosion is concerned Metals in a given bracket usually do not suffer particularly when in contact with each other

All of the less resistant metals usually become the anode and the more resistant metals the cathode Current flows here in a way similar to the situation shown in Fig 1 The driving force for the current is the potential generated by the electrodes This is the principle of the so called dry battery

Uniform corrosion Uniform corrosion or over all general attack occurs when anodic and cathodic areas keep shifting so that corrosion takes place more or less uniformly over the entire exposed surface The metal becomes thinner and fails

This form of corrosion accounts for most of the destruction of metals on a tonnage basis From the technical standpoint however uniform attack causes the least concern largely because service life can often be quite accurately estimated on the basis of relatively simple corrosion tests The localized form of corrosion often results in an unexpected failure

Concentration cell corrosion This occurs when anodes and cathodes form because of differences in the environment For example a potential difference can be measured between two identical copper electrodes immersed in different concentrations of hydrochloric acid The cells formed because of differences in the environment are called concentration cells This form of corrosion is also designated crevice corrosion gasket corrosion and deposit corrosion It is usually associated with stagnant conditions The most common forms of concentration cells are oxygen cells and ion cells

Pitting This type of corrosion is readily recognized by the presence of pits or holes Pitting is one of the most vicious forms of corrosion and one of the hardest to predict The anodic area remains stationary and corrosion progresses inwardly on one spot Pitting can be considered to be the intermediate situation between no corrosion (complete passivity) and uniform corrosion (entirely active) in that the surface breaks down and corrodes only in relatively small areas

Pitting often starts because of concentration cell effects such as those that occur under a permeable deposit The environment under the deposit becomes exhausted of oxygen or increases in ion concentration But the surrounding metal away from the deposit is exposed to an essentially constant concentration of oxygen or ions The rate of penetration often accelerates because the pit acts as a crevice and thereby increases the concentration cell effect

Intergranular corrosion Localized attack at the grain boundaries of a metal or alloy is called intergranular corrosion The grain boundaries are always anodic and the grains cathodic when this form of corrosion occurs In some cases complete dis-

metal is under stress and exposed to a corrosive environment is called stress corrosion

In most cases the magnitude of the stresses required to cause stress corrosion is high These stresses could be due to applied loads or to residual stresses although failures because of the former

cold working or cold forming and also the locked in stresses resulting from welding In a few cases, plant failures have occurred because of severe thermal gradients in the metal which cause high stresses Tensile stresses are required for cracking

Stress corrosion usually occurs when over all or uniform corrosion is low and often negligible It is somewhat similar to pitting in that active cells develop in the metal which is passive The presence of stress often accelerates this localized attack A crack is initiated and propagates to failure

Two of the earliest and classic examples of stress corrosion are the seasonal cracking of brass cartridge cases and the caustic embrittlement of riveted steel locomotive steam boilers Ammunition became worthless during the wet seasons Boilers exploded because of cracks which started near the rivets or stressed areas

Dezincification Dezincification selective leaching or parting was first observed on brasses The zinc is selectively leached out of the alloy leaving a brittle weak and porous mass It consists predominantly of copper plus copper oxides The obvious mechanism is solution or corrosion of the brass The zinc stays in solution and the copper plates back onto the surface

Dezincification can be readily observed because

arsenic phosphorus and antimony ... the resistance of brasses to dezincification Dezincification can occur uniformly in plugs or in spots

The selective removal of one of the constituents of any alloy falls into the category described here The so called graphitization of cast iron is a misnomer actually the removal or corrosion of iron occurs leaving the graphite network

Erosion corrosion This is a combination of corrosion and mechanical wear effects Many metals and alloys depend upon surface films or corrosion products for corrosion resistance If these surface layers are removed active and rapid corrosion occurs Erosion corrosion is often encountered under conditions of high velocity turbulence impingement and solids in suspension Valves pumps agitators and heat exchange tubes often fail because of erosion corrosion

Corrosion prevention or reduction Methods for combating corrosion can be classified into eight

general categories that cover essentially all corrosion problems Many corrosion problems can be solved by more than one method Sometimes a combination is used In any case the most economical solution to the problem is usually adopted

Alloying Alloying for increased corrosion resistance involves using materials with better resistance to corrosion If steel corrodes copper stainless steel or high silicon iron may be more satisfactory Proper heat treatment for optimum corrosion resistance is also in this classification *See* ALLOY

Cathodic protection This method involves making the structure to be protected the cathode of a cell Cathodic protection can be done by two general methods namely use of sacrificial anodes or impressed currents The most widely known sacrificial anode system is galvanized steel in which the zinc coating is the anode which corrodes preferentially thereby protecting the steel Zinc and magnesium anodes are also widely used

The important point is to have direct current entering the entire surface of the structure to be protected Impressed currents involve passing a direct current from an external source through an anode through the corrosive environment and then to the structure In this case a very corrosion resistant or so-called permanent anode is needed Carbon and 14 5% silicon iron (Duriron) are used for impressed-current anodes Underground pipelines water tanks sea going vessels and piers are examples of structures using cathodic protection

Figure 2 shows a layout for impressed current protection of an underground pipeline in a wet area by means of high silicon iron anodes

Metallic and inorganic coatings Nickel chromium and tin electroplates and fused on glass and enamels can be used to create barriers to separate the metal from the environment *See* ELECTROPLATING OF METALS METAL COATINGS

Organic coatings Paint type materials can act as barriers Proper metal surface preparation such as sand blasting is the most important factor followed by a proper primer for good adhesion and compatibility with overcoats and then by good top coats The use of an expensive paint does not guarantee good protection *See* SURFACE COATING

Metal purification High purity metals are not often used but they solve some problems High purity aluminum which is available at reasonable cost is a good example Contamination and catalytic effects may be involved

Alteration of the environment Often the addition or removal of an ingredient in the environment is beneficial Deaeration is an example of the former and inhibitors for automobile radiators of the latter An inhibitor is anything added to an environment to decrease corrosion In many cases reduction of temperature or solution concentration without substantially affecting the process solves a corrosion problem or permits the use of less expensive materials such as steel *See* INHIBITOR (CHEMICAL)

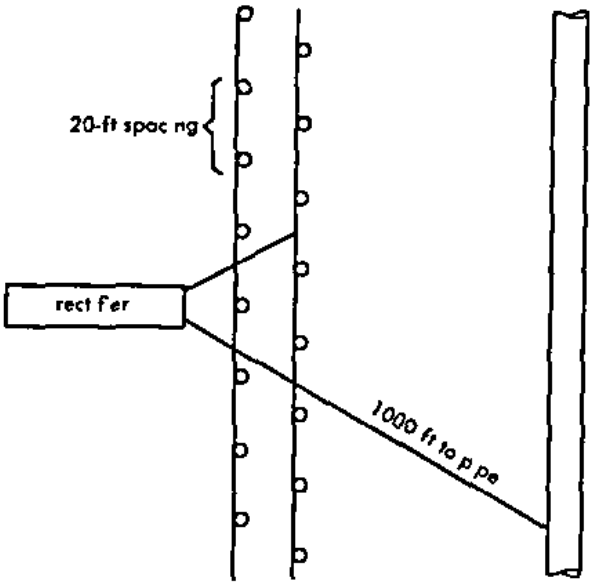


Fig 2 Cathodic protection of underground pipeline with Duriron anodes

Nonmetallic materials Integral or monolithic construction or thick coverings such as sheet linings made of nonmetals can be classed into five general types (1) carbon and graphite (2) ceramics such as stoneware porcelain fused silica glass brick mortars and cement (3) plastics such as phenolics vinyls polyethylenes acrylics epoxies styrenes nylon silicones and fluorinated polymers (4) natural and synthetic rubbers and (5) wood

Design This involves the shape of a structure Life of equipment can be prolonged or corrosion costs reduced through the use of (1) bottom outlets designed to drain completely (2) readily replaceable or interchangeable parts (3) standard lengths of tubing (4) increased thickness in more vulnerable areas (5) a design to prevent crevices or stagnant areas and (6) butt welded instead of riveted joints

One excellent example of design improvement involves offshore drilling platforms in the Gulf of Mexico Early platforms were made with tie rods complicated joints and numerous crevices that were difficult to prepare for coating protection Later designs involve tubular members and streamlined joints with all surfaces readily accessible for coating and repair

Offshore drilling platforms and radar towers are

below the water line (2) Monel sheathing (resistant alloy) at the water line and splash zone (3) organic and other coatings above the splash zone (4) inhibitors in the casing around the piling and (5) efficient design [M G F]

CORROSION BY GASES

Chemical reaction of metals with gases produces

the metal s properties are changed Although cor rosion by gases is similar to corrosion by liquids two important differences are found—in gases the products of corrosion usually remain on the surface and in some systems form a protective film and local electrochemical cell reactions do not occur Four types of reactions are observed (1) The gas is dissolved in the metal as molecules atoms or ions Solution is followed by diffusion in the metal (2) A solid reaction product is formed on the sur face Reaction continues by diffusion of the gas or metal atoms or ions through the surface film (3) A volatile reaction product is formed (4) A liquid reaction product is formed Most corrosion reac tions involve two or more of these types Rapid cor rosion occurs if liquid or volatile corrosion products are formed or if the solid compound is nonadherent (spalling) For these conditions new metal is con tinually being exposed to the gaseous environment

The extent of deterioration of the metal s proper ties depends upon whether the corrosion is uni form or localized A small amount of highly local ized corrosion can change the metal s properties more seriously than a larger amount of uniform corrosion Although corrosion by gases is usually considered to produce uniform films recent work has shown that this is not the case

Thermochemical data can be used to calculate the tendency of a reaction to proceed The final equilibrium state depends upon pressure and tem perature At 25°C and 1 atm pressure the follow ing generalizations can be made All metals react with oxygen except gold most metals react with the halogen gases or with sulfur vapor Many met als react with nitrogen or hydrogen The tendency of metals to react with water vapor carbon dioxide sulfur dioxide and other gaseous compounds is much less than with the gaseous elements

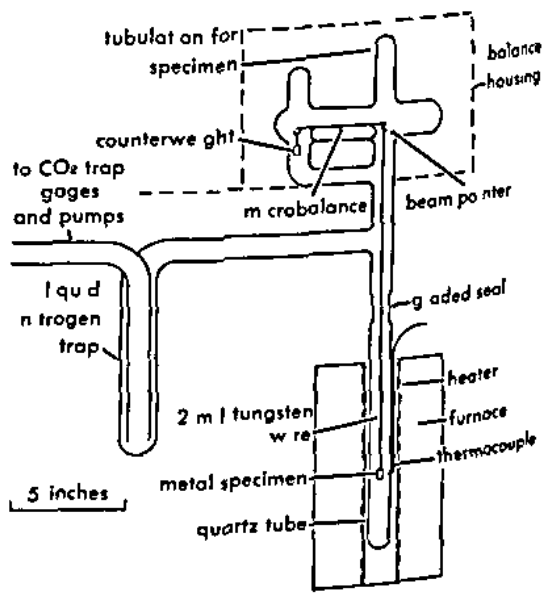
Large amounts of heat are evolved when some of the metals react with oxygen or the halogens When 1 mole of zirconium reacts with oxygen at 25°C 259 kcal of heat are evolved Fine iron and other metals burn in oxygen Smaller heats of reaction are associated with the less reactive metals For example copper reacts with oxygen giving off 37 1 kcal of heat per mole of CuO formed

The rate of corrosion is not determined by the magnitude of the heat or free energy of the reac tion but by kinetic processes such as diffusion Reaction is reduced by the formation of a thin oxide film which limits access of oxygen water vapor and other gases In dry atmospheres at room temperature the oxide film on iron is 15–50 angstroms (A) thick and is invisible (1 A = 10^{-8} cm) Its rate of growth is negligible In humid atmospheres the oxide film breaks down locally with the formation of hydrated oxides called rust In dry atmospheres and at higher tem peratures the oxide film grows in thickness and metal is consumed Protection of metals for these conditions depends upon controlling the rate of growth of the oxide film and upon maintaining adherence of the oxide To achieve good protec tion at high temperatures alloys are used These alloys are designed to give a low rate of reaction good adherence of the oxide low volatility of the metal and oxide and a high melting point

Experimental methods The experimental in vestigation of corrosion reactions by gases involves a study of the following problems (1) rate of corrosion (2) crystal structure and chemical com position of the corrosion product (3) crystal hab t of the corrosion product and (4) mechanism of reaction

The kinetics of corrosion reactions deals with the effects of time temperature pressure and sur face conditions on the rate of corrosion Kinetic studies are important for comparison of metals and for determination of the mechanisms of corrosion Several methods used include (1) change in weight of metal sample (2) change in volume or pressure of the reacting gas and (3) change in thickness of the reaction product Most of the kinetic data have been obtained using weight change methods Because the weight changes may be small sensi tive microbalances are necessary

Weight changes Figure 3 shows a diagram of a vacuum microbalance reaction system The balance is placed inside the reaction system One layer of oxygen atoms on a metal surface of 15 cm^2 can be measured A thin sheet of metal to be tested is sus pended on one end of the balance and a counter weight of the same material from the other Move ments of the balance due to chemical reaction are followed by a micrometer microscope Figure 4 shows the course of the reaction of oxygen with an oxide free iron sample at 25°C An oxide film of 19 A is formed After the initial reaction the rate of reaction is very slow and the oxide film can be said to protect the metal This experiment shows the importance of a thin oxide film in the protec tion of metals Figure 5 shows the time course of the reaction of nickel with oxygen at temperatures



Fg 3 M crobalance apparatus

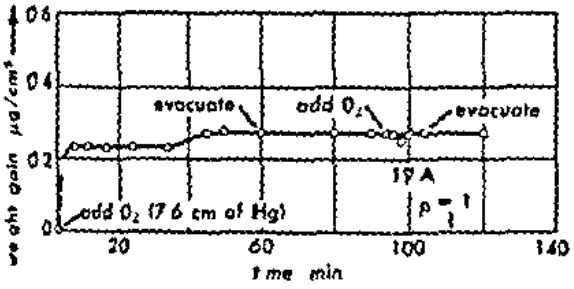


Fig 4 Reaction of pure iron with oxygen at 25°C and stability to high vacuum

of 400–700°C. A rapid initial reaction occurs As the oxide film grows the rate of reaction decreases The oxide film limits the rate of reaction of nickel with oxygen Mathematical equations can be derived to express the influence of time temperature and pressure on the rate of reaction

At some temperature time or oxide thickness a more rapid reaction occurs indicating a change in reaction mechanism This phenomenon for some metals is called breakaway corrosion In many metals, breakaway corrosion is related to loss of adhesion of the oxide layer to the metal Several conclusions concerning the behavior of metals at elevated temperatures can be given First transport of ions and electrons through the film determines the rate of reaction in the initial stage Second adhesion of the oxide to the metal determines the oxidation resistance after the initial stage

Other types of gas metal reactions such as the solubility of gases in metals and the vapor pressure of metals and oxides can be studied with the vacuum microbalance method

Crystal structure The crystal structure of the oxide or corrosion film can be determined by x ray or electron-diffraction analysis For the study of surfaces electron diffraction has been particularly useful High voltage electrons are diffracted by solids much as x rays are However the efficiency of scattering of electrons is 1 000 000 times greater than that of x rays In the reflection method in which the beam is directed to the sample at grazing angle the penetration of electrons is limited to a few layers of surface atoms For this reason electron diffraction is of particular interest for the study of crystal structure of surface films

The table shows the oxides formed by oxidation of iron cobalt nickel chromium and copper between 300 and 700°C Four oxides are formed on iron (three are shown in the table) Transformation in the oxides on iron occurs when the metal is heated or cooled The poor protective properties of oxide films on iron can be related in part to these

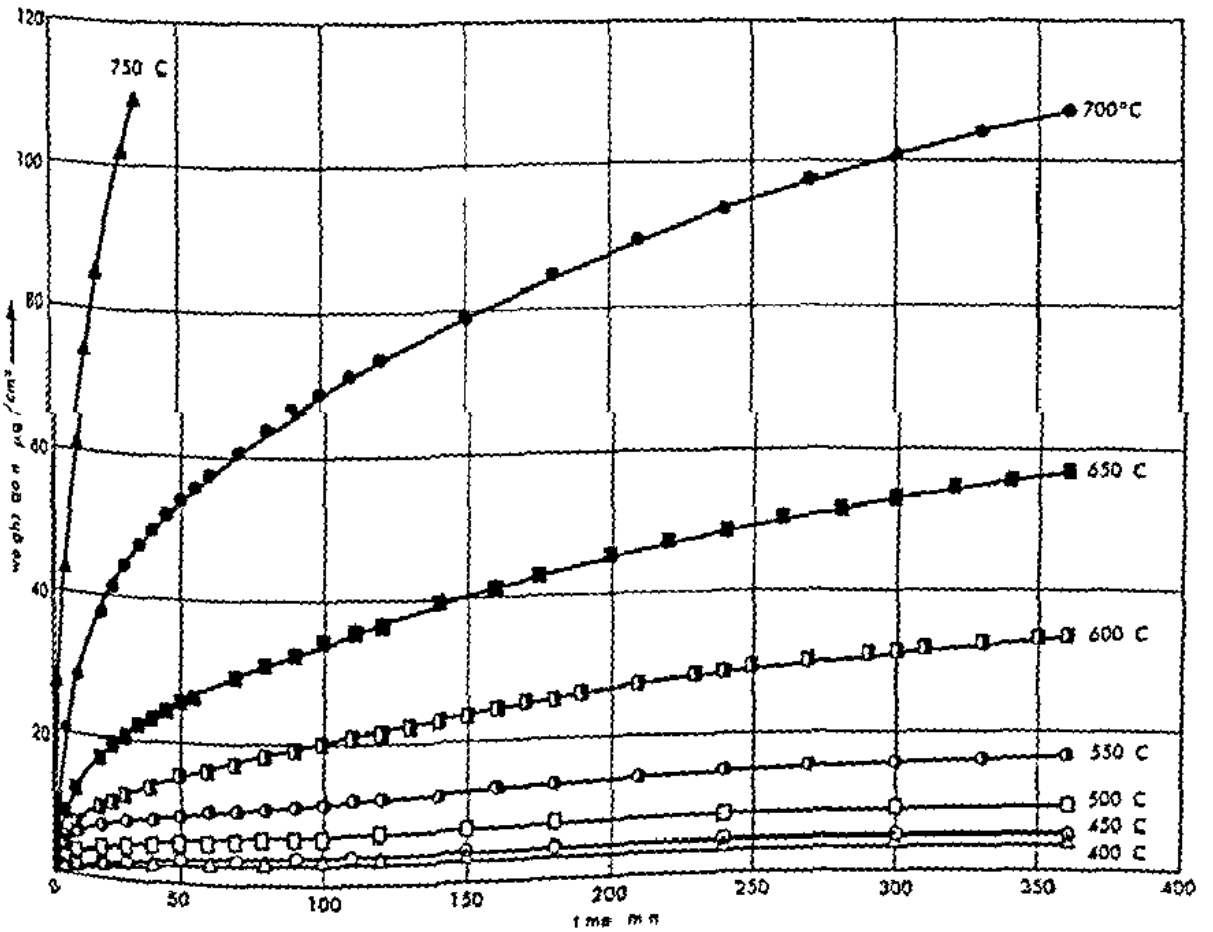


Fig 5 Effect of temperature on oxidation of nickel at 400–750°C (Oxygen pressure is 7.6 cm Hg)

transformation reactions Chromium and nickel form only one oxide over the temperature range The oxide films on these metals have much superior protective properties

Oxide films formed on metals at various temperatures

Metal	200°C	300°C	400°C	500°C	600°C	700°C
Iron	α Fe_2O_3	α Fe_2O_3	Fe_3O_4 + α Fe_2O_3	Fe_3O_4	FeO	FeO
Cobalt		Co_3O_4 + CoO	Co_3O_4 + CoO	CoO	CoO	CoO
N ckel		Ni_2O	Ni_2O	Ni_2O	Ni_2O	Ni_2O
Chrom um		Cr_2O_3	Cr_2O_3	Cr_2O_3	Cr_2O_3	Cr_2O_3
Copper		Cu_2O	Cu_2O	Cu_2O	Cu_2O	

For metals the chemical composition of the cor rosion film can be inferred from the crystal struc ture studies However for alloys it is necessary also to determine the chemical composition This is done by microchemical analyses or by x ray fluo rescence analyses

Crystal habit refers to the size and shape of the crystals in the corrosion film and the relationships of these crystals to the metal From these studies information can be obtained on the mechanism of reaction and the role of dislocations precipitates and grain boundaries in the metal on the corrosion reaction In many systems the localized corrosion product rather than the uniform corrosion product is of primary interest This localized attack occurs in gaseous corrosion as well as in liquid phase corrosion

The crystal habit can be studied by the light and electron microscopes in several ways For thick corrosion layers the metal can be encased in plas tic A cross section of the metal is made and the corrosion layer studied The presence of pores in the oxide layer or of pits in the metal can be ob served For thin films the corrosion layer can be covered by a thin plastic film and removed from the metal by chemical or electrochemical methods

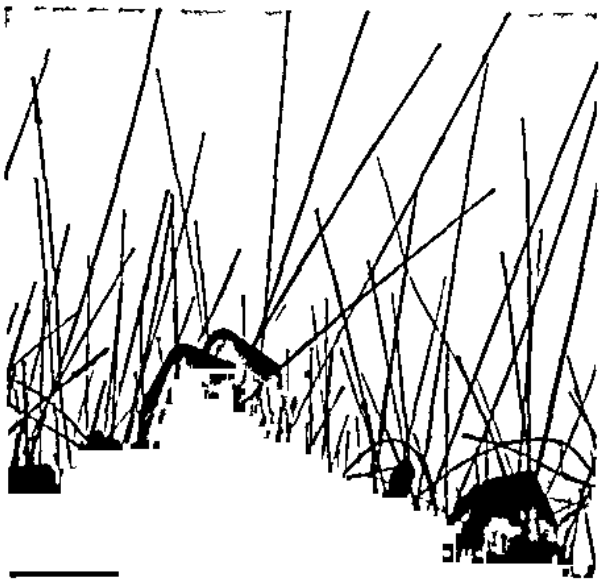


Fig 6 Crystal habit of ox de formed in the oxidat on of Armco iron at 500°C in tank oxygen for 220 hours No applied stress

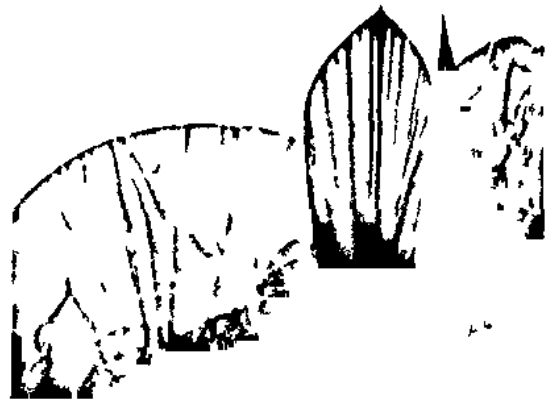


Fig 7 Crystal habit of oxide formed in the ox dat on of 18–8 stainless steel at 600°C in wet oxygen plus a trace of HCl vapor for 138 hours Prestressed to 59 000 psi

t t t. the electron shown y small

crystals on each metal grain

Direct observation of the edges of oxidized speci mens by the electron microscope has shown new and unsuspected crystal habits in the corrosion film Figure 6 shows an electron micrograph of the [illegible] 500°C in oxy [illegible] 000 A [illegible] rface

These results show that gas reacts with met als to form nonuniform corrosion films Chemical reac tion occurs at highly localized areas on the surface These areas are related to substructure factors in the metal such as precipitates dislocations and subgrain boundaries

Effect of stress Stress is another factor of in terest in gaseous corrosion If an austenitic stain less steel wire is prestressed to the elastic lim t and heated to 600°C for 138 hours with wet oxy gen plus a trace of hydrochloric acid a new type of crystal habit occurs Large platelets of oxide are formed This is shown in Fig 7 The platelets are about 100 A thick and grow perpendicular to the surface to a height of 100 000 A and to a length of over 250 000 A Electron diffraction analyses shows the platelets to be single crystals of chro mium oxide

The formations of long oxide whiskers and thin oxide platelets are unusual crystal habits Thermo dynamic considerations would predict the forma tion of crystal shapes with minimum surface area The fact that oxide whiskers and platelets form shows the very important influence of the metal and oxide substructure and stress on gaseous cor rosion *See* CRYSTAL STRUCTURE [E.A.C]

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Cortex, plant

The mass of primary tissue in roots and stems extending inward from the epidermis to the phloem The cortex may consist of one or a combination of three major tissues: parenchyma, collenchyma and sclerenchyma The cortex is bounded, more or less distinctly by the hypodermis (exodermis) on the periphery and by the endodermis on the inside

Cortical parenchyma is composed of loosely arranged thin walled living cells. Prominent intercellular spaces usually occur in this tissue In stems the cells of the outer parenchyma may appear green due to the presence of chloroplasts in the cells (Fig 1) This green tissue is sometimes called chlorenchyma, and photosynthesis probably occurs in it.

In some species the cells of the outer cortex are modified in aerial stems by an irregular deposition of additional wall substances (but no lignin) especially in the corners or angles of the cells This tissue is called collenchyma, and the thickening of the cell walls gives mechanical support to the shoot

Lignified fibers and sclereids, and other lignified cells also occur in the cortex of many plants The tissue composed of such hard walled cells is often referred to as cortical sclerenchyma

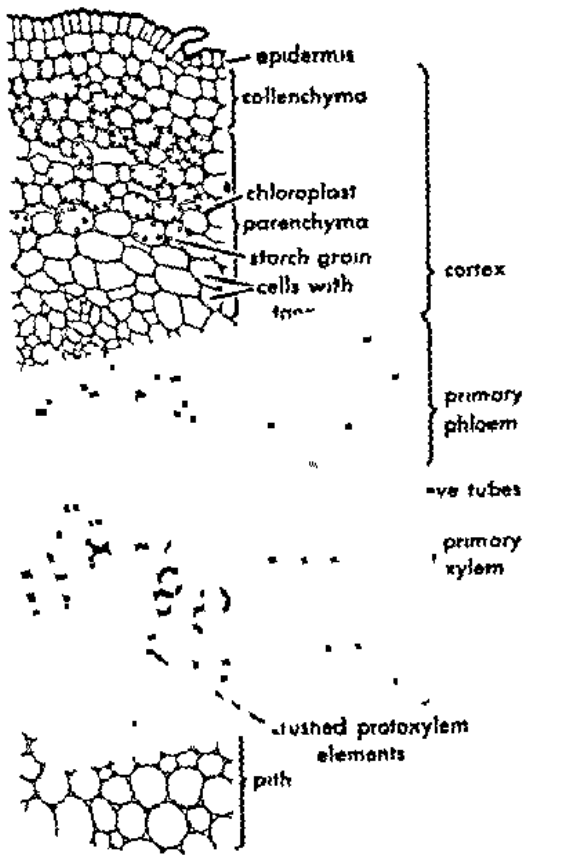


Fig 1 Part of a transverse section of *Prunus* stem showing cortex containing collenchyma and parenchyma the latter with cells containing chloroplasts (chlorenchyma), starch grains, and tannin (*From K Esau Plant Anatomy, Wiley, 1953*)

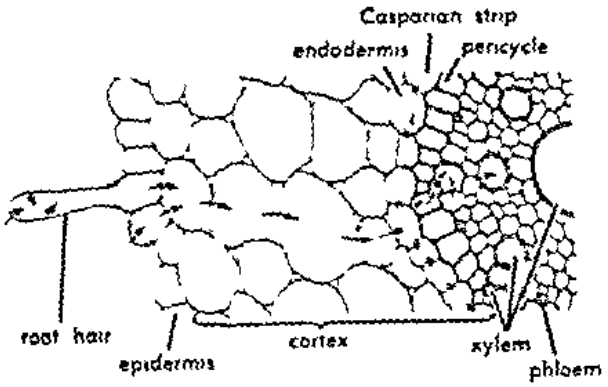


Fig 2 Part of transection of wheat root illustrating the kinds of cell that may be traversed by water and salts absorbed from the soil before they reach the tracheary elements of the xylem The arrows indicate the direction of the movement through a selected series of cells Among these, the living cells are partly stippled The Casparian strip in the endodermis is shown as though exposed in surface views of the end walls (*From K Esau Plant Anatomy, Wiley 1953*)

The cortex makes up a considerable proportion of the volume of the root particularly in young roots where it functions in the transport of water and ions from the epidermis to the vascular (xylem and phloem) tissues (Fig 2) In older roots, it functions primarily as a storage tissue The cells of the root cortex generally are similar in appearance in different plants and they may occur in radial files Histochemical tests however, reveal a variety of cell types within the root cortex

In addition to being supportive and protective, the cortex functions in the synthesis and localization of many chemical substances, it is one of the most fundamental storage tissues in the plant The kinds of cortical cells specialized with regard to storage and synthesis are numerous The histochemical localization of enzyme systems apparently results in a remarkable differentiation of functional cell types

Because the living protoplasts of the cortex are so highly differentiated and specialized, patterns and gradients of distribution of substances occur within the cortex including starch tannins, glucosides organic acids crystals of many kinds, and alkaloids Oil cavities, resin ducts, and laticifers (latex ducts) are also common in the mid-cortex of many plants (*see* SECRETORY STRUCTURES, PLANT)

The outer cortical cells stain heavily with basic dyes a reaction suggesting a high nucleic acid content Also the outer cortex contains sulfhydryl protein peroxidase, cytochrome, neutral fats, and glycosides in higher quantity than the inner cortex Furthermore synthesis and hydrolysis of glucosides and their oxidation products occur in the outer cortex, and to a lesser extent in the inner cortex Starch gradient patterns in roots are most pronounced outside the xylem ridges The part of the cortex opposite the xylem also readily gives a test for sulfhydryl protein with the appropriate indi

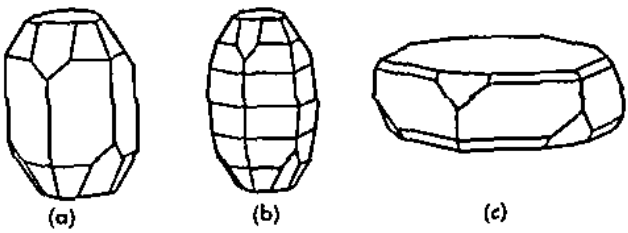
cators In contrast the cortical cells opposite the phloem in some conifer roots develop lignified reticulate thickenings in cells in a radial gradient outward from the phloem *See* COLLENCHYMA, ENDODERMIS HYPODERMIS PARENCHYMA, ROOT (BOTANY), SCLERENCHYMA, STEM (BOTANY)

[D S V F]

Bibliography See PLANT ANATOMY

Corundum

A mineral having composition Al_2O_3 and crystallizing in the hexagonal system Corundum crystals are usually prismatic or in rounded barrel shapes resulting from tapering hexagonal dipyramids (see illustration) There is no cleavage but a rhombohedral parting is common permitting crystals to break into blocks having roughly cubic angles More rarely there is basal and prismatic parting The hardness is 9 (Mohs scale) exceeded in min



(a) (b) (c)

Corundum crystals (a) Prismatic (b) Tapering hexagonal pyramids (c) With rhombohedral facies (*From C S Hurlbut Jr Dana's Manual of Mineralogy 16th ed Wiley 1952*)

erals only by diamond the specific gravity is 4 02 The mineral is transparent to translucent with adamantine to vitreous luster The color is usually brown gray pink or pale blue but may be white green red or deep blue Several gem varieties of corundum are distinguished by the color sapphire is blue and ruby deep red Gem corundum of other colors is frequently designated sapphire with the color indicated as yellow sapphire green sapphire or may be named after other gems with the prefix oriental for example oriental topaz (yellow) and oriental emerald (green) Some corundum has oriented needles of rutile within it resulting in asterism When cut en cabochon an exceedingly finely divided oriented intergrowth shows a 6-pointed star and the gem is called star ruby or star sapphire Since 1904 transparent gem corundum has been manufactured by the Verneuil process and more recently star rubies and star sapphires have been made by the same method *See* GEM GEM MANUFACTURED RUBY SAPPHIRE

stituent in certain syenites nepheline syenites lamprophyric dikes and pegmatites and is a common accessory mineral in crystalline limestones mica schists and gneisses Because of its chemical stability and high hardness it is commonly found as crystals or rolled pebbles in stream gravels and detrital soil Rubies are found in Ceylon only as stream pebbles and in Siam near Bangkok in a clay derived from the decomposition of a basalt Since early times the most famous locality for rubies has been near Mogok in Burma Here some are found in situ in a crystalline limestone but most of them have been recovered from the soil remaining after solution of the limestone *See* IGNEOUS ROCKS, METAMORPHIC ROCKS

Emery has been used for centuries as an abrasive Later corundum was mined for similar purposes in Ontario Canada, Transvaal South Africa, India, Madagascar, and in the United States in Montana North Carolina and Georgia Since the beginning of the twentieth century with the introduction of manufactured abrasives (silicon carbide and artificial aluminum oxide) the mining of corundum has largely ceased *See* ALUMINUM, EMERY

[C S HU]

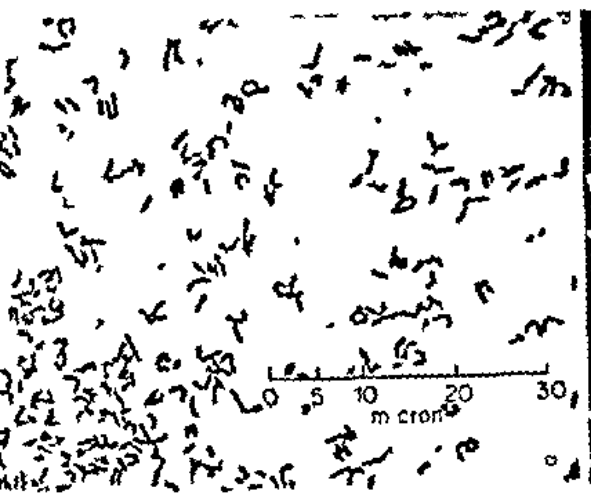
Corynebacteriaceae

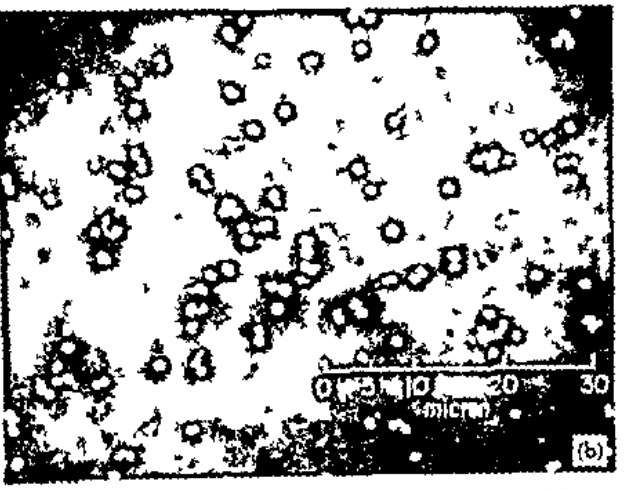
A group of nonsporeforming bacteria of the order Eubacteriales The Corynebacteriaceae are divided into 6 genera One group of genera including *Corynebacterium Listeria* and *Erysipelothrix* is [illegible] Some [illegible] ases [illegible] um. [illegible] idely *Arthrobacter* and *Cellulomonas* [illegible] occurring saprophytes

The microorganisms are characterized by the variable size and shape of their cells At various stages of growth they appear chiefly as irregular often segmented rods with a club- or wedgelike shape but they may vary from quite long filaments to short simple rods or spherical cells Most members show no motility while some are motile having polar or lateral flagella In general the cells are gram positive but some species are partially decolorized more easily than others that is they become gram negative (*see* GRAM'S STAIN)

Oxygen is usually required for growth but some species are microaerophilic that is need ng oxygen but growing best at (or even requiring) reduced oxygen tensions usually less than 10% They may even be anaerobic growing in the absence of oxygen This marked diversity in morphological and physiological characters causes several members of the family to appear as transitional forms difficult to separate from certain other groups of bacteria

Corynebacterium The cells of this genus have characteristic club shapes and when stained often show an irregular, banded coloration with intensely staining bodies known as metachromatic granules Cell reproduction takes place either by binary fission or by multiple division of rods into several short segments After binary fission the daughter cells bend or snap into V K or N shaped figures or small irregular clusters which normally are not





Arthrobacter simplex var (a) Irregular slightly club shaped rods in angular arrangement 2-day-old culture phase contrast (b) Almost spherical cells 9-day old culture n gras n smear (K Gundersen and H L Jensen *Acta Agr Scand* 6 100–114 1956)

in chains Simultaneous germination of short segments may cause the formation of palisade like cell bundles The corynebacteria as a whole produce moderate amounts of acid from various carbohydrates rarely have any proteolytic effect and demand for cultivation a rather rich medium with a number of amino acids and growth factors

The majority of species occur in animals mostly warm blooded Some are harmless parasites but others are important pathogens such as *C diphtheriae* the agent of diphtheria in man *C pseudotuberculosis* which causes chronic lymphadenitis in sheep and *C equi* which causes pyaemia in foals *C equi* often occurs in cervical lymph nodes of swine where it assumes an acid fastness approaching that of *Mycobacterium*

A few anaerobic species, like *C acnes* found in acne pustules show affinities with the genera *Propionibacterium* and *Butyribacterium* (*see* PROPIONIBACTERIACEAE) A number of corynebacteria are parasitic in plants These like *C insidiosum* in alfalfa and *C michiganense* in tomatoes, resemble the animal parasites except that a few of them are motile like *C poinsettiae* and *C tritici* The animal parasites as far as is known are all nonmotile

Listeria and Erysipelothrix The parasitic Corynebacteriaceae include two other genera of a somewhat different character (1) *Listeria*, aerobic organisms with short rodlike motile cells and (2) *Erysipelothrix* microaerophilic nonmotile and with a tendency to form long irregular filamentous cells *L monocytogenes* is found in necrotic infections in man and animals and *E insidiosa* causes among other things erysipelas in swine

Saprophytic Corynebacteriaceae Among the saprophytic Corynebacteriaceae there is a small genus called *Microbacterium* closely related to *Corynebacterium* and included by some authorities in this genus Some species are common in milk and dairy products and they differ from *Corynebacterium* mainly in their pronounced heat resistance being able to survive for 15–30 min at 75°C *See* MILK

A large number of coryneform bacteria are widely distributed in soil and elsewhere The bulk of these organisms are in the genus *Arthrobacter* Morphologically they resemble *Corynebacterium* in a general way but show a greater diversity of cell shape and size with a tendency to form longer sometimes strongly swollen or slightly branching cells These with progressing age usually become very short and almost spherical In addition their mode of cell division seems somewhat different and the gram reaction is often weakly positive or even negative especially in young cells Some species are motile but in contrast to *Corynebacterium* they are often strongly proteolytic (break down protein) and form little acid from carbohydrates Their growth requirements vary greatly some will grow in quite simple synthetic media while others demand numerous amino acids and compounds of the vitamin B complex and still others require unknown growth factors present in soil extract or synthesized by other bacteria A common soil inhabitant is *A globiforme* in which the change from rod to spherical shape was first observed Many incompletely known soil bacteria with irregular rod shaped cells probably belong to this genus The tendency of *Arthrobacter* to show rudimentary budding and branching suggests an abortive mycelium formation that brings these organisms into line with the genus *Nocardia* of the Actinomycetales

A number of *Arthrobacter* like soil bacteria are able to decompose cellulose and are therefore placed in the separate genus *Cellulomonas* *See* BACTERIA TAXONOMY OF EUBACTERIALES SOIL MICROBIOLOGY [H L J]

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Cosmic electrodynamics

The science concerned with electromagnetic phenomena in ionized media encountered in interstellar space in stars and above the atmosphere Because these ionized materials are excellent electrical conductors they are strongly linked to magnetic field lines they can travel freely along but not across the field lines Statistically this linkage tends to equalize the energies in the magnetic field and in the turbulent motion of the ionized material Phenomena treated under cosmic electrodynamics include acceleration of charged particles to cosmic ray energies both in the galaxy and on the surface of the Sun collisions between galaxies the correlation of magnetic fields with galactic structure sunspots and prominences magnetic storms aurora and Van Allen radiation belts

Alfven waves—transverse waves which travel along the magnetic field lines in a manner similar to the way waves travel along a stretched string—are often important *See* GEOMAGNETIC STORM IONOSPHERE MAGNETOHYDRODYNAMICS

[R K M L]

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Cosmic rays

The nuclei of atoms—largely hydrogen—which impinge upon Earth from all directions of space with nearly the speed of light These nuclei with relativistic speeds are often referred to as primary cosmic rays to distinguish them from the cascade of secondary particles generated by their impact against air nuclei at the top of the terrestrial atmosphere The secondary particles shower down through the atmosphere and are found with decreasing intensity all the way to the ground and below It was V Hess s observation of the increasing intensity with height which first established that the particles were of extraterrestrial origin rather than from Earth itself

Cosmic rays are studied for a variety of reasons not the least of which is a general curiosity over the process by which nature can produce such energetic nuclei Apart from this the primary cosmic rays being deflected by the interplanetary and geomagnetic fields are currently used as probes to determine the nature of these fields far out from Earth Cosmic rays have long served as an inexpensive source of high energy particles for the study of nuclear interactions and production of the so called strange particles The initial identification of the positron the μ meson the π meson and certain of the K mesons and hyperons were made from studies of cosmic rays which are still the only source of particles with energies of 100 Bev and higher The observed long flight time of the unstable μ mesons produced by the primary cosmic rays at the top of the atmosphere demonstrates directly the time dilatation of special relativity The effects of cosmic rays on living cells are discussed in a number of other articles for example *see* RADIATION INJURY (BIOLOGY)

Cosmic rays are detected principally by the ionization they produce in the matter through which they are passing The instrumentation for their detection involves cloud chambers ion chambers Geiger Muller counters proportional counters and photographic emulsions used singly or in elaborate combination *See* CLOUD CHAMBER PARTICLE DETECTOR

In the vicinity of Earth the velocities of primary cosmic rays are observed to be isotropically distributed at least to within one per cent, and their intensity is 0 3 nuclei/(cm²) (sec) (steradian) approximately depending somewhat upon the phase of the sunspot cycle and the low energy cut off of the detecting apparatus The mean energy is about 2 Bev/nucleon so that the total energy density is perhaps 4×10^{-13} erg/cm³ to be compared with the energy density of starlight 5.2×10^{-13} erg/cm³

To have energies as low
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not confined just to the solar system but are a phenomenon of at least galactic scale

Atmospheric cosmic rays The primary cosmic ray particles coming into the top of the terrestrial atmosphere make inelastic collisions with nuclei in the atmosphere The collision cross section is essentially the geometrical cross section of the nucleus of the order of 10^{-26} cm² (*see* NUCLEAR REACTION) The mean free path for primary penetration into the top of the atmosphere is given in Table 1 (Division by the atmospheric density in g/cm³ gives the value of the mean free path in cm)

Table 1 Mean free paths for primary cosmic rays in the atmosphere

Atomic number of primary nucleus	Mean free path in air g/cm²
$Z = 1$	60
$Z = 2$	41
$3 \leq Z \leq 5$	32
$6 \leq Z \leq 9$	27
$10 \leq Z \leq 29$	21

When a high energy nucleus collides with the nucleus of an air atom a number of things usually occur The abrupt stopping of the incoming nucleus leads to production of π mesons with positive negative or neutral charge this meson production is closely analogous to the generation of x rays or bremsstrahlung produced when a fast electron is stopped by impact with the atoms in a metal target The mesons like the bremsstrahlung come off from the impact in a narrow cone in the forward direction Anywhere from zero to 30 or more π mesons may be produced depending upon the energy of the incident nucleus The ratio of neutral to charged π mesons is ~0 75 *See* BREMSSTRAHLUNG MESON

A few protons and neutrons (in about equal proportions) may be knocked out with energies which are a significant fraction of that of the *incoming* nucleus. They are called knock on protons and neutrons.

All these protons, neutrons and π mesons generated by collision of the primary cosmic ray nuclei with the nuclei of air atoms are the first stage in the development of the secondary cosmic ray particles observed inside the atmosphere. Since several secondary particles are produced by the collisional *stopping of each primary* the total number of energetic particles of cosmic ray origin will increase with depth even while the primary density is *decreasing*. Since electric charge must be conserved and the primaries are positively charged the *positive particles* outnumber the negative particles in the secondary radiation by a factor of about 1.2. This factor is called the positive excess.

Cascade processes. The uncharged π^0 mesons from the stopping primary nuclei decay into two γ rays with a life of $\sim 5 \times 10^{-15}$ sec. The decay is so rapid that π^0 mesons are not directly observed among the secondary particles in the atmosphere. The two γ rays together have the rest energy of the π^0 about 140 Mev plus the π^0 kinetic energy. They each produce a positron electron pair which cannot have individual mean energies of less than 35 Mev. Upon passing sufficiently close to the nucleus of an air atom deeper in the atmosphere the electrons *and* positrons convert their energy into bremsstrahlung. The bremsstrahlung in turn create new positron electron pairs and so on. This cascade *process* continues until the energy of the initial π^0 has been dispersed into a shower of positrons electrons and photons with insufficient individual *energies* ($\leqq$ 1 Mev) to continue the pair production. The shower then being unable to reproduce its numbers is dissipated by ionization of the air *atoms*. The electrons and photons of such showers are referred to as the soft component of the atmospheric (secondary) cosmic rays reaching a maximum intensity at an atmospheric depth of 150-200 g/cm^2 and then declining by a factor of about 10^2 down to sea level. *See* PAIR PRODUCTION (ELECTRON POSITRON).

Mesons. The π mesons produced by the primary collisions have a life of about 2.5×10^{-8} sec before they decay into μ mesons

$$\pi \rightarrow \mu + \text{neutrino}$$

With a life of this order a π possessing enough energy (> 10 Bev) to experience significant relativistic time dilatation may exist long enough to interact with the nuclei of the air atoms. The cross section for π nuclear interactions is approximately the geometrical cross section of the nucleus and the result of such an interaction is essentially the same as for the primary cosmic ray nuclei already discussed. The low energy π mesons decay into μ mesons before they have time to undergo nuclear interactions.

The μ^2 mesons will not interact with nuclei and are too massive (207 electron masses) to produce *bremsstrahlung*. They can lose energy only by the comparatively feeble process of ionizing an occasional air atom as *they progress* downward through the atmosphere. Because of this ability to penetrate matter they are called the hard component. Their *life* is 2×10^{-6} second before decaying into an electron or positron and two neutrinos. Hence with the time dilatation of their high energy some 5% of the μ mesons reach the ground. Their interaction with matter is so weak that they penetrate deep into the ground where they are the only particles of cosmic ray origin to be found. At a depth equivalent of 300 m of water the μ meson intensity has decreased from that at ground level only by a factor of 2.0 at an equivalent depth of 1400 m it has decreased by a factor of 10^3.

Nucleonic component. The high energy nucleons —the knock on protons and neutrons—produced by the primary particle collisions and a few π meson collisions in the atmosphere proceed on down into the atmosphere with a mean free path of about 60 g cm^2 (same path as for the primary protons). They produce nuclear interactions of the same kind as the primary nuclei though of course with diminished energies. This cascade process constitutes what is called the nucleonic component of the secondary cosmic rays.

Nuclear stars. A nucleus struck by a proton or neutron of the nucleonic component with an energy greater than approximately 300 Mev may have its internal forces momentarily disrupted so that some of its nucleons are free to leave with their original kinetic energies of about 10 Mev inside the nucleus. The nucleons freed in this fashion appear as protons, deuterons, tritons, α particles and even somewhat heavier clumps radiating outward from the struck nucleus. In photographic emulsions the result is a number of short prongs radiating from the point of collision and for this reason is called a nuclear star. When the nucleon energy falls below about 100 Mev star production and further knockons can no longer be produced. At the same time the protons are rapidly disappearing from the cascade because their ionization losses in the air slow them down before they can make a nuclear interaction. The neutrons are already dominant at 3500 m about 300 g/cm^2 above sea level where they outnumber the protons four to one. Thus the final stages in the lower atmosphere are given over almost entirely to neutrons in a sequence of low energy interactions which convert them to thermal neutrons (neutrons of kinetic energy of about 0.025 ev) in a path of about 90 g/cm. These thermal neutrons are readily detected in boron trifluoride (BF_3) counters. The nucleonic component increases its intensity down to a depth of about 120 g/cm^2 and thereafter declines in intensity with a mean absorption length of the order of 200 g/cm^2.

The various cascades of secondary particles in the atmosphere are shown schematically in Fig. 1.

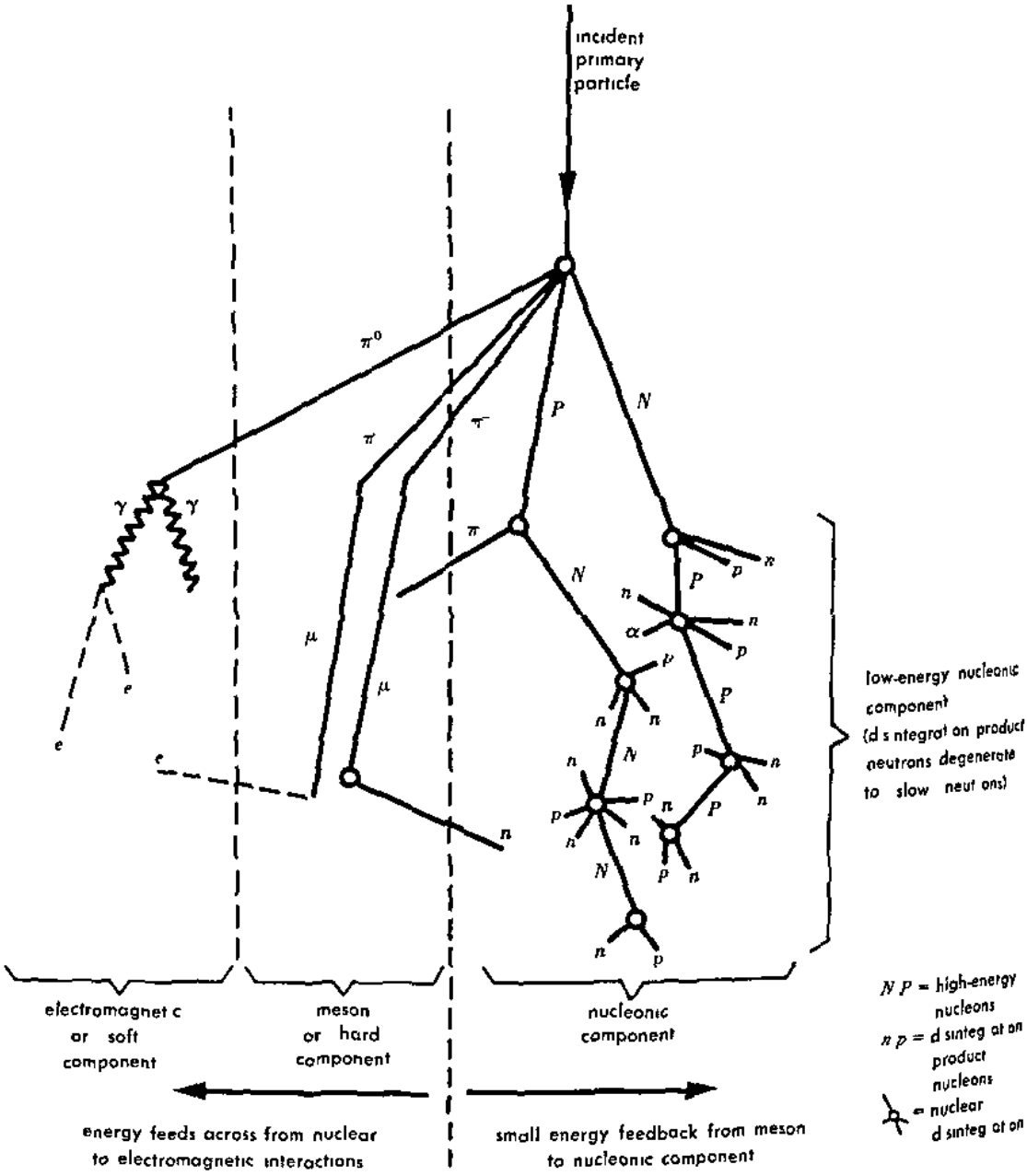


Fig 1 Cascade of secondary cosmic ray particles in the terrestrial atmosphere

Note that about 48% of the initial primary cosmic ray energy goes into charged π mesons, 25% into neutral π mesons, 7% into the nucleonic compo nent and 20% into stars The nucleonic component is produced principally by the lower energy, ~5 Bev, primaries Higher energy primaries put their energy more into meson production Hence in the lower atmosphere, a Geiger counter responds prin cipally to the higher energy primaries ~15 Bev, because it counts the μ mesons and electrons whereas a BF_3 counter detecting thermal neu trons responds more to the low energy primaries This is of particular importance for investigations of the effects of interplanetary and geomagnetic fields on the primary cosmic rays, because the lowest energy primaries are the most drastically affected

Showers The collision of an extremely energetic primary particle say 10^7 Bev, at the *top* of the atmosphere can lead to such a vast cascade of elec trons photons, μ mesons and nucleons *that* widely separated (100 m and more) counters on the ground will record the event simultaneously Such a cascade is called an extensive air *shower* and it is largely by measuring the density and extent of these showers that the extremely high primary energies can be estimated

Geomagnetic effects The geomagnetic dipole (the magnetic dipole caused by Earth's magnet c field) with a dipole moment of 8.1×10^{-5} cgs electromagnetic units has a field density of 0.3 oersteds on the equator Its extension out into space has a characteristic scale equal to the rad u of Earth 6.4×10^3 km Around the equator where

a particle must come in perpendicular to the geomagnetic lines of force to reach Earth particles with momenta less than 10 Bev/c per nucleon are entirely excluded (c is the velocity of light) though at higher latitudes where entry can be made more nearly along the lines of force lower energies can reach Earth Thus the cosmic ray intensity is a minimum at the equator and increases to its full value at either pole to give the cosmic ray latitude effect At sea level the variation with latitude is obviously small ~15% as seen with Geiger counters but it is very large when observed with BF_3 counters amounting to something of the order of a factor of two as shown in Fig 2 for latitudes > 40°

The minimum energy of a particle able to reach the top of the atmosphere at a particular geomagnetic latitude is called the geomagnetic cutoff energy at that latitude and its calculation is an exceedingly complex numerical problem Fortunately for an observer near the ground obliquely arriving secondary particles produced by the oblique primaries are so heavily attenuated by their longer path to the ground that it is usually sufficient to consider only the geomagnetic cutoff for vertically incident primaries which is given in Table 2 for protons

Table 2 Geomagnetic cutoff

Geomagnetic latitude	Vertical cutoff for protons Bev/c
0°	15
±20°	11 5
±40°	5
±60°	1
±70°	0 2
±90°	0

Recent studies of cosmic ray intensity as a function of latitude have shown that the conventional geomagnetic coordinates are unsatisfactory for the

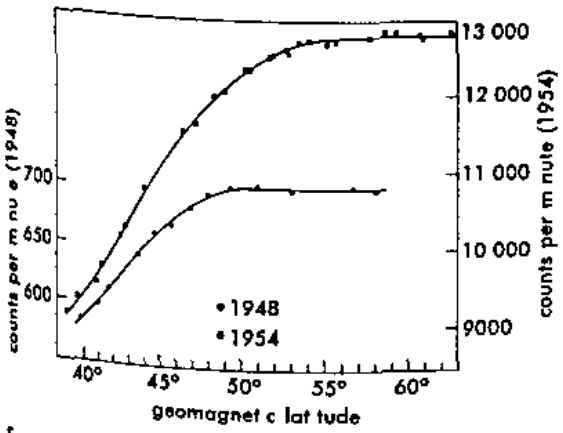


Fig 2 Latitude variation of the neutron component of cosmic rays at 80°W longitude and at a height corresponding to an atmospheric pressure of 22 5 cm of mercury in 1948 when the Sun was active and 1954 when the Sun was deep in a sunspot minimum

oretical determination of the latitude effect and cutoff energies The implication is a permanent distortion of the outer geomagnetic field from the classical magnetostatic dipole

The geomagnetic field at the surface of Earth is observed to be very steady in time varying at most about 1% during geomagnetic storms so that it can be used as a magnetic analyzer for the incoming cosmic rays allowing a determination of the energy spectrum by observing the cosmic ray intensity as a function of latitude

Since the geomagnetic field is directed from south to north above the surface of Earth the incoming cosmic ray nuclei are deflected toward the east Hence an observer finds some 20% more particles incident from the west This is known as the east west effect *See* GEOMAGNETISM

Energy and mass spectrum Above 20 Bev/nucleon the cosmic ray intensity is steady in time to within ±2% and the energy spectrum evidently varies as the −2 7 power of the energy all the way to energies of 10^7 Bev/nucleon or more each of the nuclear species making up the general primary cosmic ray field seems to follow this power law spectrum The relative abundance of cosmic ray nuclei is indicated by the following approximate intensities in nuclei/(cm²)(sec)(steradian) 0 3 for protons 0 03 for α particles 0 002 for carbon nitrogen and oxygen nuclei and 0 0005 for all nuclei with more than 10 protons

Below 20 Bev/nucleon the cosmic ray intensity varies markedly with time S Forbush was the first to show that the cosmic ray intensity was low during the years of high solar activity and sunspot number which follows an 11 year cycle By carefully studying the latitude variation Fig 2 of the cosmic ray intensity observed from various long range and high altitude aircraft flights J Simpson and P Meyer have shown that the cosmic ray energy spectrum varies as shown in Fig 3 during the sunspot cycle In the deep sunspot minimum of 1954 the cosmic rays were present in copious numbers all the way down to 200 Mev continued activity on the Sun (during the years preceding and following 1954) seems to bring about the disappearance of the low energy cosmic rays particularly below ~0 9 Bev where they essentially vanish to produce the low energy cutoff It has further been shown that this 11 year variation with the sunspot cycle cannot be explained by hypothetical geoelectric or geomagnetic effects Presumably when the Sun is inactive one sees the unhindered cosmic rays which evidently fill interstellar space when the Sun is active it sweeps back the cosmic rays with its magnetic field thereby excluding the lower energy nuclei from the vicinity of Earth *See* SUN VAN ALLEN RADIATION

There are of course other fluctuations in the cosmic ray intensity besides this 11 year variation with solar activity For instance the cosmic ray intensity often exhibits recurring changes with a 27 day period and as much as a 15% amplitude This

is attributed to hypothetical active regions on the surface of the Sun which has an approximately 27 day period of rotation

There is also the Forbush type decrease, where the primary intensity around the world may drop in an irregular way as much as 20% in 15 hours, or 8% in 3 hours slowly recovering in the days or weeks that follow Often but not always, the Forbush decrease and geomagnetic storms accompany each other Striking geographical variation is to be seen in the sharper fluctuations during the onset of a Forbush decrease

Origin During the solar flare of February 23, 1956 cosmic rays with a hundred times the normal daily intensity were observed to arrive at Earth from the direction of the Sun Thus it seems obvious that as had long been argued cosmic rays are occasionally produced in solar flares The direct and prompt arrival showed that the region between Earth and Sun must be relatively free of transverse magnetic fields that are stronger than approximately 10^{6} oersted

Following the flare it was found that the particles from the flare were temporarily trapped in the inner solar system The cosmic ray intensity did not immediately drop back to normal with the disappearance of the flare but declined only over periods of many hours It was still above normal 30 hours after the flare Detailed analysis of the observed onset and decay of the flare cosmic rays indicates

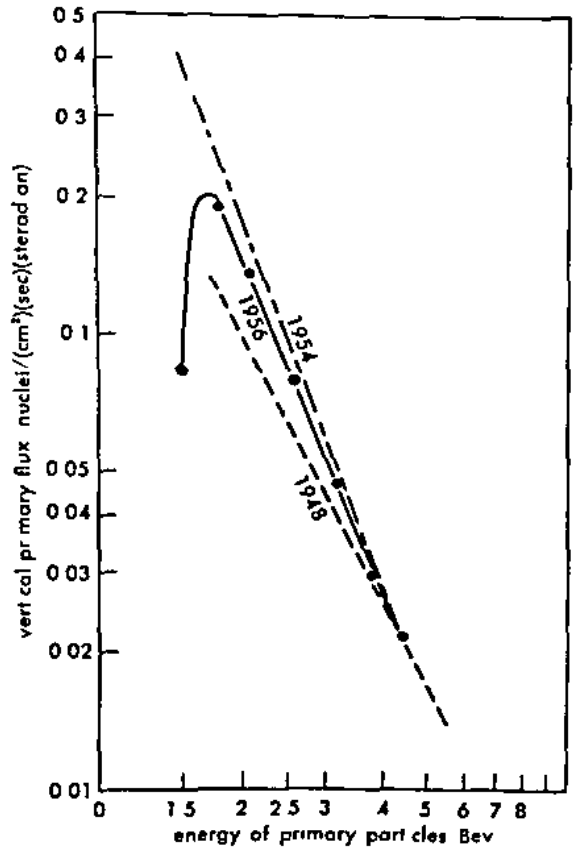


Fig 3 The cosmic ray energy spectrum in 1948 (near solar maximum) in 1954 (solar minimum) and in 1956 (when activity had begun again)

that the inner solar system is enclosed by a thick shell of disordered magnetic field of about 10^{-3} oersted, extending from about the orbit of Mars to the orbit of Jupiter, which seems also to account for the observed 11 year variation

It follows that except during an occasional solar flare most of the cosmic rays do not come from the Sun For if a major portion were of solar origin one would be able to discern the anisotropy caused by their general diffusion outward from the Sun The anisotropy would be some 5% or more judging from the rate at which the particles could diffuse away following the flare

There is a small anisotropy (~0.5%) called the diurnal effect which shows both a solar and a sidereal component, but that is quite another matter The origin of the diurnal effect is not known

If cosmic rays do not come from the Sun then as argued by E Fermi they are from interstellar space filling the arms of the galaxy and perhaps even the galactic halo trapped there by the galactic fields of strength 10^{-5} oersted (The galactic halo is the name given to the extremely sparse and nearly spherical distribution of gas and stars surrounding the Milky Way and other spiral galaxies) Because of the high proportion of heavy nuclei observed to be present the cosmic rays probably can not have traversed more than about 3 g/cm² or 4×10^{6} light years before escaping from the galaxy, otherwise the heavy nuclei would be destroyed by collisions The Fermi mechanism accelerating ions by bouncing them between relatively moving magnetic fields, can be shown to be the only means for accelerating ions in the electrically conducting gases which seem to fill all of space outside cold planetary atmospheres the mechanism tentatively appears to be adequate to account for the observed cosmic rays Presumably cosmic rays get their initial energies in the vicinity of active stars particularly supernovae and are then further accelerated in interstellar space *See* SPACE

Future uses Perhaps the most obvious future use of cosmic rays will follow from their observation with rockets and satellites thus ending the limitations caused by the terrestrial atmosphere Already it is within man's technical ability to map the cosmic ray intensity over the entire Earth in a few days with an orbiting satellite allowing detailed analysis of rapid variations in the outer geomagnetic field and interplanetary field When extensive logging of cosmic ray intensity in outer space is possible, say as far as the Moon altitude latitude effects can be studied The effects on the geomagnetic field of the solar wind the 1000 km/sec gas streaming in all directions outward from the Sun can be investigated Perhaps one may be able to associate fluctuations in the outer geomagnetic field with Fermi acceleration of the sub cosmic ray protons observed by J Van Allen to fill a large portion of the geomagnetic field Once away from Earth it may be possible to map the celestial sphere in the light of the γ rays of π^{0} decay from cosmic ray nuclear collisions in interstellar space *See*

ASTRONOMICAL GEOPHYSICS RADIOACTIVE SPECIFS PRODUCED BY COSMIC RAYS [E N P]

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Cosmochemistry

The branch of science which treats the chemical composition of the universe its origin and evaluation Cosmochemistry is concerned with the mechanism of creation of the elements and nuclides and the present cosmic abundances as deduced from stellar and solar spectroscopy meteorite analysis and theoretical nuclear physics It is also concerned with the chemical aspects of planet formation and the composition of planetary atmospheres and comets Cosmochemistry and geochemistry meet at the stage of the fully accreted Earth The data of cosmochemistry provide important boundary conditions for both cosmological theories and theories pertaining to the composition and evolution of the planet Earth *See* EARTH (AGE OF) ELEMENTS (COSMIC ABUNDANCE) ELEMENTS AND NUCLIDES (ORIGIN) LIFE ORIGIN OF METEORITE [J L K]

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Cosmogony

Study of the origin and evolution of specific astronomical systems and of the universe as a whole

Age of the universe The age of an astronomical system is the time that has elapsed between a specified event in its history and the present For the universe the specified event is the beginning of the cosmic expansion for a star its arrival at the main sequence (*see* STELLAR EVOLUTION) for Earth, the solidification of the crust None of these events nor indeed any appreciable fraction of the history of any astronomical system is a matter of record the time scale of human history is too short for that

Observations of the red shift in the spectra of external galaxies are interpreted as signs of a uniform cosmic expansion According to relativistic cosmology the expansion had a definite beginning in time at which epoch the density of matter was equal to or perhaps even greater than the density of atomic nuclei Because present day astronomical systems could not have existed at the beginning of the expansion the age of the universe must exceed the age of any astronomical system This statement is not a tautology but rather a theoretical prediction and it provides a crucial test of relativistic cosmology for if the steady state hypothesis were correct it would be possible to find astronomical systems older than any assigned limit including the age of the universe as predicted by relativistic cosmology *See* COSMOLOGY

According to the simplest version of relativistic cosmology the age of the universe is equal to two thirds the reciprocal of Hubble's constant (*see* RED SHIFT) This quantity can in principle be determined from observations of distant galaxies The main uncertainty in this determination results from uncertainty about the cosmic distance scale which in recent years has undergone considerable revision The age of the universe as derived from observational determinations of Hubble's constant is probably between 5×10^9 and 5×10^9 years

A much smaller uncertainty is introduced by the choice of a theoretical world model The choice of a model does however affect the meaning of the term 'age of the universe' The crucial point is whether the model is finite or infinite A finite universe is cyclic each cycle consisting of an interval of expansion followed by an equal interval of contraction Because a cyclic universe is reborn at the start of each new cycle its age can quite properly be reckoned from the beginning of the current cycle On the other hand a finite universe can also be said to be ageless in the sense that it has no beginning in time In this respect finite and infinite models differ An infinite universe expands indefinitely from a state of maximum density whose occurrence may be taken to mark the beginning of time (Time can have a beginning in science time is merely a convenient parameter whose possible values correspond in a one-to-one way with possible states of the universe This parameter could possess a semi infinite range of possible values or it could possess an infinite range of values)

Among finite astronomical systems those for which fairly accurate age determinations exist are Earth meteorites and star clusters in our own galaxy

For the methods by which ages are assigned to terrestrial rocks and meteorites *see* EARTH (AGE OF) ROCK (AGE DETERMINATION) They depend on measurements of the abundance of radioactive isotopes and their decay products The oldest ob

[illegible] determined are [illegible] found to be

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The dating of star clusters rests on a theoretical interpretation of their color magnitude (Hertzsprung Russell) diagrams When a star has used up a definite fraction of its nuclear fuel supply it moves off the main sequence of the H R diagram and becomes a red giant By inspecting the H R diagram of a star cluster one can tell which stars have reached this critical stage in their evolution But the time required for a star to use up a given fraction of its nuclear fuel supply can be calculated if its mass and the primeval hydrogen to helium abundance ratio are known The mass is the more important parameter and can be inferred from the color and luminosity which are given by observation By this means ages have been derived for a large number of clusters They range from a few million years for some galactic clusters to 5×10^9 to 6×10^9 years for globular clusters

Age estimates based on dynamical arguments are on a lower level of precision It can be shown for instance that the extent to which the distribution of matter and motion in the galaxy approaches

a state of equilibrium is consistent with an age considerably greater than 10^8 years and considerably smaller than 10^{11} years but it is difficult to derive narrower limits without straining the argument

Although the information about cosmic ages is fragmentary and imprecise it hangs together surprisingly well In particular it is consistent with the conclusion that the oldest astronomical systems were formed near the beginning of the expansion If this conclusion survives the inevitable improvement and multiplication of cosmic age determinations it will greatly strengthen the foundations of relativistic cosmology and cosmogony

Origin of hierarchy structure Nonuniformity is perhaps the most characteristic feature of the astronomical universe Instead of being spread evenly through space matter has convened in a hierarchy of more or less self gravitating systems ranging in diameter from a few kilometers to millions of light years including galaxy clusters multiple galaxies single galaxies star clouds star clusters multiple stars stars planets and satellites

The differences among these systems have led some cosmologists to conclude that the systems were formed in a variety of ways Other investigators however have regarded the hierarchy structure as the embodiment of a tendency towards nonuniformity capable of manifesting itself over a wide range of physical conditions This view has one striking and suggestive piece of evidence in its favor Although the hierarchy spans a range of masses whose extremes differ by a factor of 10^{14} and a range of densities whose extremes differ by a factor of 10^{8} (neglecting planets and satellites whose masses have probably diminished by large factors) the gravitational binding energy per unit mass is not significantly different in galaxy clusters multiple galaxies galaxies multiple stars stars and the solar system Most of these systems have specific binding energies in the range 10^{12}–10^{16} erg/g and the various ranges all overlap (Star clusters however have specific binding energies in the range 10^{10}–10^{12} erg/g)

Because nearly the whole of the observed range of specific binding energies is shown by a single kind of object binary stars it is difficult to avoid the conclusion that the main features of the hierarchy structure admit of a unified explanation in which the specific binding energy plays a key role One such explanation has been attempted by F Hoyle Hoyle's theory is based on two key ideas The first is that a massive cloud of hydrogen contracting under its own gravitation will tend to assume and maintain a temperature close to 10^4°K provided that it is thin enough to be transparent to its own radiation The reason is that near 10^4°K the rate of radiation increases rapidly with increasing temperature and equals the rate at which energy can be supplied by gravitational contraction at about this temperature A cloud that is in equilibrium under its own gravitation and has a temperature of 10^{4}°K will have a specific binding energy of about 10^{12} erg/g which is in the observed range But a cloud that is initially in equilibrium at this temperature will not remain in equilibrium as the cloud contracts because for equilibrium to be maintained the temperature would have to increase The second key idea in Hoyle's theory is one for which no adequate theoretical justification has so far been found Hoyle postulates that a contracting cloud whose tempera

[illegible]

it will occur repeatedly till it results in fragments so dense that they are no longer transparent Then it will stop because in an opaque hydrogen cloud gravitational contraction offsets radiation loss and at the same time keeps the temperature at its equilibrium value Thus the fragmentation process envisaged by Hoyle would result in a hierarchy of clusters with all specific binding energies close to 10^{12} erg/g The smallest fragments which Hoyle identifies with protostars would continue to contract and their specific binding energies would accordingly increase perhaps by a factor of 100 or 1000 but larger systems ought to keep their original binding energies

According to C F von Weizsaecker's theory of the hierarchy structure the primeval galaxies were turbulent gas clouds (whose origin he does not discuss)

In a turbulent fluid the velocity field has a hierarchic structure which may be described somewhat imprecisely in terms of eddies which in turn are defined by the more or less common motion of the constituent fluid particles An eddy is a transient structure which holds together only long enough to travel a distance equal to its own diameter and ends by breaking up into smaller eddies which in turn break up into still smaller ones and so on till finally the kinetic energy that was originally present in the form of organized motion (the motion of the eddy as a whole) has been converted into random motions of gas molecules termed heat This conversion of organized into unorganized motion is the chief function of turbulence The hierarchy of turbulent eddies is the mechanism in which motion becomes progressively more disorganized as it proceeds towards the ultimate molecular chaos

There is an analogy between the hierarchic structure of the velocity field in a turbulent fluid and that of the density field in a galaxy but there is not a definite causal connection This would require the turbulent eddies to become permanent and self gravitating The continual dissolution and reformation of eddies is an essential feature of turbulence but when energy ceases to flow along the hierarchy the fluid can no longer be said to be turbulent Thus the 'freezing' of turbulent eddies implies a decay of the turbulence but not in the usual sense of decay which is characterized by a gradual diminution of the turbulent intensity and of the

size of the eddies that contain most of the turbulent energy The decay process cannot produce self gravitating eddies where none was present to be gin with Thus the analogy with a turbulent fluid attractive as it may seem leads to an impasse Weizsaecker s theory also fails to account for the narrow range of specific binding energies in astronomical systems

Galaxies and galaxy clusters The largest astronomical systems present a special cosmogonical problem because they presumably resulted from the fragmentation of an unbounded distribution of matter rather than a finite cloud

The stability of a uniform infinitely extended medium was discussed qualitatively in 1694 by Sir Isaac Newton who thought that such a medium would break up into self gravitating fragments Sir James Jeans arrived at the same conclusion in 1902 by way of a mathematical argument and derived a criterion relating the mass of the fragments to the temperature and density of the medium He identified the fragments with galaxies (galaxy clusters were unknown at the time) However Einstein s theory of gravitation (general relativity) predicts that a uniform unbounded medium cannot remain static but must either expand or contract In the simplest form of relativistic cosmology it expands indefinitely The expansion prevents the kind of instability contemplated by Jeans In a pressure free universe any spherical volume of gas expands just as it would if it were isolated in empty space

Relativistic world models with nonvanishing values of the cosmical constant have sometimes been considered in connection with the condensation problem (This constant multiplies an additional term in Einstein's field equations whose effect is that of a repulsive force increasing with distance Introduced by Einstein in 1916 to make possible a static solution of the equations it was abandoned by him and by many but not all other physicists and astronomers in 1929 when observations of the red shift in the spectra of external galaxies showed that the universe is not static as astronomers had previously thought) By assigning appropriate values to the cosmical constant it is possible to construct world models that begin by expanding then go through a virtually static phase which can be made arbitrarily long and finally expand again These models are all finite It was suggested by A G E Lemaitre that galaxies condense during the static interlude between the initial and final periods of expansion but it is by no means clear that this can happen The situation is precisely the same in fact as in the simpler world models with a vanishing cosmical constant every spherical volume behaves exactly as it would if it were isolated in empty space

A hypothesis closely related to Lemaitre s is that of Sir Arthur Eddington For any given value of the density there is a critical value of the cosmical constant for which the world model is static This is the model invented by Einstein for the sake of which he introduced the cosmical constant It is unstable in a somewhat special sense If any of the parameters that characterize it change slightly the model ceases to be static Whether it expands or contracts depends upon the nature of the change Eddington suggested that the formation of condensations in an initially uniform Einstein universe would have the effect of such a perturbation and would cause the model to expand This hypothesis has been studied further by others but no definite conclusions have been reached

The problem becomes much more definite if one adopts the steady state hypothesis because the conditions under which new galaxies come into being can be determined at least in principle by observation they are the conditions that now prevail in intergalactic space Of course a complete cosmogonical theory based on the steady state hypothesis would have to explain why these conditions are as they are

Two distinct hypotheses based on steady state cosmology have been put forward According to D Sciama new galaxies form by a process known as accretion in the wakes of mature galaxies moving relatively to the intergalactic medium Every galaxy tends by virtue of its motion and its gravitational attraction to generate a twin which in turn will reproduce itself in a similar manner Thus the process favors the formation of galaxy clusters

Hoyle on the other hand relies on gravitational instability to give rise to distinct clouds that ultimately evolve into galaxy clusters Application of Jeans s criterion leads to a temperature of about $10^{8.5}$°K for the intergalactic medium and Hoyle gives an argument to make this temperature seem plausible He does not however justify his use of Jeans's instability criterion which is certainly as inapplicable to a steady state as to a relativistic universe

The origin of clustering among galaxies presents a curious and important problem Distinct self gravitating clusters undoubtedly exist but there is no reason to believe that all or even most galaxies belong to such clusters It seems more likely that there are usually no clear lines of demarcation between adjacent regions where the concentration of galaxies is higher than average This would mean that galaxies rather than galaxy clusters are to be regarded as the primary cosmic fragments Theory would then need to attribute the clustering of galaxies to a process distinct from the ones by which galaxies and smaller systems were formed On the other hand if one postulates that galaxy clusters were the primary cosmic fragments the problem arises of explaining why they are so ill defined

V Ambartsumian has suggested that some galaxy clusters may not be gravitationally bound but are temporary associations in the act of dispersing This view is based partly upon observational evidence but the observations are not sufficiently secure either to confirm or to disprove it If true it implies that galaxy clusters have an explosive ori

bartsumian and others on the origin of certain star clusters (O B associations)

Origin of stars and star clusters Studies of the colors and magnitudes of stars in clusters show that while considerable differences of age and chemical composition often exist between different clusters all the stars in a given cluster seem to have substantially the same age and chemical composition This resolves the old question of whether star clusters were formed by the gradual accretion of field stars or by star formation in a preexisting self gravitating unit because accretion could not result in clusters with distinct ages and compositions Whether all stars were formed in clusters is still an open question however On the negative side is the observation that only a small fraction of the stars in the galaxy now belong to recognizable clusters On the positive side are three facts (1) the observation that young stars (between 10^6 and 10 years old) are invariably found in clusters most of which will soon disperse either because of their own internal motions or as a result of the differential rotation of the galaxy (2) the fact that many galactic clusters are only just stable against disruption by galactic rotation and will not long remain so and (3) the fact that the oldest clusters in the galaxy are also the ones that could be expected to have survived the longest because they are extraordinarily massive compact and spherical in shape and move in orbits that keep them away from the galactic plane where the disruptive influences are strongest

The problem of star formation must be considered along with the problem of the origin of certain large scale features of galactic structure W Baade has shown that the contents of galaxies can be regarded as a mixture of two relatively distinct populations whose relative proportions vary from one galaxy to another and from place to place in the same galaxy The main criteria for distinguishing between the two populations are age the abundance of metals relative to hydrogen and helium eccentricity of the galactic orbits proportion of matter in the form of stars to matter in the form of gas and dust and degree of concentration to the galactic plane of symmetry Population I is characterized by young objects with high metal content moving in circular orbits with low inclinations to the galactic plane and by a high proportion of gas and dust Population II is characterized by old objects with low metal content moving in highly inclined orbits and orbits of high eccentricity and by the absence or near absence of gas and dust Globular star clusters in our own galaxy and elliptic galaxies are pure population II while the arms of spiral galaxies are defined by population I superimposed on a smooth structureless population II background

Because the mechanism of star formation is not yet understood any attempt to account for the two populations and their properties is necessarily speculative One view that has been put forward (by J Oort W Baade and others) to account for mixed systems like the galaxy postulates continuous star formation in a gaseous cloud that is initially spherical in shape After an initial period of star formation during which population II is laid down, the remaining dust and gas cool and contract in the direction at right angles to the plane of symmetry, contraction in this plane being prevented by conservation of angular momentum Star formation continues in the contracting spheroid and in the disk that ultimately results giving rise to population I This theory accounts for the fact that population I stars are younger than those of population II are associated with gas and dust and have a highly flattened distribution It does not account for the fact of spiral structure nor do star clusters play an essential part in it Finally there is so far no theoretical support for the notion that stars can condense in a self gravitating cloud whose density is a smoothly varying function of position

Young star clusters (10^6–10^7 years old) have attracted special interest because in them star formation has either just ceased or is still going on Regardless of whether the mechanism of star formation is the same in these young clusters as in old ones the results are in some ways unique Many of the clusters are expanding and at such a rate that they must soon dissolve and merge with the general field, some are conspicuously deficient in dwarf stars even when allowance is made for the fact that some of the dwarfs would not yet have had time to contract to the main sequence and most of the young clusters contain a considerable quantity of gas and dust Some writers have suggested that the expanding associations (the term is due to V Ambartsumian) result from nuclear explosions in clouds of 10^3 10^4 solar masses which have attained stellar densities at their centers Although there is general agreement that nuclear reactions are the ultimate source of energy for the expansion of these systems it is also possible that these reactions occur in the interiors of the blue supergiants which are invariably members of associations and which liberate more than enough energy in their lifetime to produce the observed motions

Rotation and angular momentum It follows from the law of conservation of angular momentum that unless galaxies have changed appreciably in size since they were formed which is unlikely their present rates of rotation are not very different from the ones with which they were formed Because the present rates can be either measured or inferred from the observed shapes with fair accuracy one can calculate how much angular momentum the material in a typical star would have had if it had been part of a gaseous protogalaxy This turns out to be about 10^9 times as much as it now possesses which means that in the process of contraction a typical protostar would have expended all but $1/10\,000\,000$ of 1% of its original angular momentum How has this been accomplished? Mass ejection could rid a system of some of its angular momentum but not of 99.9999999% of it Magnetic braking has frequently been suggested for the same purpose but the suggestion has not yet been put

m a definite form At present no satisfactory solu tion for the difficulty is known

The angular momentum difficulty also crops up in different forms in the problems of the origin of double stars and of the solar system

Origin of double stars *It has been estimated* that nearly half the stars in the neighborhood of the Sun belong to binary systems indicating that the origin of duplicity among stars is not to be sought in any unusual combination of circum stances The hypothesis that double stars are formed by encounters among single stars must be rejected on these grounds for the sort of encoun ters that are required (at least three stars must participate the third star being necessary to carry off the energy liberated by the formation of the binary) is far too rare to account for the ob served frequency of double stars

A rotating cloud contracting under its own grav itation will ultimately attain a state in which its self gravitation just balances the centrifugal force due to the rotation Many writers have conjectured that at this stage a cloud whose mass is of stellar proportions might split into two parts and thus form a double star This view derives most of its support from the theory of rotating liquid masses wh ch has been extensively developed by a number of distinguished mathematicians A gaseous cloud will behave like a liquid mass as long as its den sity remains uniform In any real cloud however the density would build up more rapidly at the center than near the edges as the cloud contracted Rather than split in two such a cloud would prob ably tend to shed matter at its equator leaving a th n rotating disk

The fission hypothesis for the origin of double stars encounters other difficulties It is difficult to reconcile with the existence of highly eccentric orbits which are not uncommon and with the ab sence of rotation in components of binary systems If the fission products have managed to get rid of the r angular momentum without undergoing fis s on it is not clear why the original cloud was un able to do so

Origin of the solar system More detailed in formation is available about our planetary sys tem than about any other astronomical system yet we know nothing about any other planetary sys tem not even that one exists This ignorance is the source of two difficulties First it is not known whether planetary systems are as common as for example double stars or whether they are exceed ingly rare No doubt the first hypothesis is more practical than the second because it is more re strictive, but astronomers have not hesitated to put forward theories predicated on exceedingly im probable events such as near collisions between stars and in the absence of statistics on the abun dance of planetary systems such theories cannot be ent rely dismissed

The second difficulty is that of deciding which features of the solar system call for an explana tion and which do not Examination of a hundred planetary systems or even a dozen would separate the essential features from the accidental ones but because only one system is known the task is more difficult A good example is Bode's law This celebrated mnemonic device has been regarded alter natively as a special case of a more general law derivable from stability considerations a conse quence of certain geometrical properties of vortices in a hypothetical solar nebula and an accidental regularity

Generally theories that have contributed most to the present limited understanding of the prob lem have concentrated on explaining in detail spe cific regularities while those that have contributed least have often been concerned with reconciling as many as possible of the observed regularities with an ad hoc hypothesis In the following discus sion specific problems rather than complete the ories will be emphasized

Chemical composition Limited information about the chemical composition of the planets can be derived from their spectra and from data on their masses radii and densities The minor plan ets differ strikingly from the Sun in the abundance of hydrogen and helium relative to the heavier ele ments Whereas hydrogen and helium account for perhaps 98% of the Sun s mass they account for only a small fraction of the mass of the Earth and of the other minor planets In Jupiter and Saturn the proportion of hydrogen and helium is much higher though not as high as it is in the Sun The differences in chemical composition among the planets and between the planets and the Sun do not require the postulate that the material of which the planets were formed differed in chemical com position from the Sun It seems possible to explain them as the result of evaporation of the light gases during the formation of the planets a process that has been studied by Sir James Jeans H N Russell D H Menzel and others

G Kuiper has put forward the hypothesis that the planets have evolved from protoplanets with the same chemical composition as the Sun He has esti mated the masses of the protoplanets by comparing their present composition as derived from spectro scopic evidence combined with data on the present masses and densities with the solar composition

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Sun's mass and because planet building may not have been a perfectly efficient process the mass available for it may have been comparable to that of the Sun This conclusion (an inescapable one

potheses

The evolution of the protoplanets has been stud ied by Kuiper and others who attributed the seg regation of heavy elements to sedimentation Free hydrogen and helium are at first present in the planetary atmospheres but are gradually lost by evapo

ter is for the most part driven out of the solar system by corpuscular radiation from the Sun (which is also the cause of comet tails) but some of it may spiral into the Sun perhaps causing the equatorial acceleration

Angular momentum At present the planets carry 98% and the Sun 2% of the total angular momentum of the solar system Jupiter alone accounts for 60% The division of angular momentum between Sun and planets must have been even more one sided than it is now before the planets lost their light gases The classic difficulty posed by such a division is that of understanding how it could have arisen if all the matter in the solar system had once belonged to a single nebula The nebular hypothesis in any form demands the existence of some highly efficient mechanism for transferring angular momentum from the central part of the nebula to the periphery Magnetic coupling has been suggested as the mechanism but no one has yet shown that magnetic fields of the required kind exist and could be expected to occur in a nebula

A system can gain or lose angular momentum only when acted upon by a torque Through tide-raising force and tidal friction the Moon exerts a torque on the Earth tending to slow its rotation The angular momentum of the Earth accordingly diminishes and because the total angular momentum of the Earth Moon system must remain constant (or nearly so) the distance between the Earth and the Moon increases causing the orbital angular momentum of the Moon to increase at just the rate at which the rotational angular momentum of the Earth decreases Earlier in time the Earth rotated faster and the orbit of the Moon was smaller These considerations provide the starting point of G H Darwin s theory of the origin of the Moon *See* Moon

The Sun would have exerted a considerable torque on the protoplanets during their formative stages which would have tended to make them rotate about axes at right angles to the plane of the solar system and in the same sense as their orbital motion (called the direct sense) But whether direct rotation would in fact have resulted depends upon the amount of angular momentum the protoplanets had to start with and the amount they acquired through the action of the torque Of the six planets whose rotations have been well determined five rotate in the same sense as that of their orbital motion and one Uranus rotates in the opposite sense The axes of the planets with direct rotation deviate from the perpendicular by between 3° and 29° but the axis of Uranus deviates by 98° It is an open question whether this state of affairs is consistent with the above explanation first given by H Poincare for the direct rotations of the planets

Orbits All the planets go around the Sun in the same direction in nearly circular orbits that lie in almost the same plane The explanation of these three regularities has usually been regarded as the main task of a cosmogonical theory Less emphasis has been laid on the departures from these regularities exhibited by the smaller bodies of the solar system Of the planets Mercury (the smallest) and Pluto (the outermost) have the most eccentric and highly inclined orbits The asteroids which are

three regularities

The chief attraction of nebular hypotheses, the first of which was put forward by P S Laplace in 1765 is that they account in such a simple way for the orbital regularities In a rotating nebula the damping of noncircular motions is accomplished by internal friction and the flattening results from the cooling of the gas by radiation In a nongaseous cloud consisting of particles pursuing their individual orbits in the gravitational field of the cloud as a whole without being much influenced by neighboring particles the same effects can be produced by superficially different causes provided that the particles occasionally undergo collisions in which part of their mutual kinetic energy is converted into internal energy Whatever shape the cloud has to begin with it will gradually become lenticular and the particle orbits will gradually become more and more nearly circular The orbital motions will not all be in the same sense but these motions will be preponderantly in one sense which will become increasingly marked as particles moving in the opposite sense undergo collisions lose their kinetic energy, and fall into the center of the cloud Thus the observed orbital regularities do not point unambiguously towards a nebular origin They indicate rather that frictional dissipation and radiation have been important in the evolution of the planetary system

The satellites The general resemblance between the satellite systems especially those of Jupiter and Saturn and the planetary system strongly suggests that they were formed in the same way In particular satellite orbits tend to be circular direct and only slightly inclined to the equatorial plane of the primary The preceding remarks about planetary orbits apply equally well to satellite orbits

Although the innermost satellites in both the Saturn and Jupiter systems have direct circular orbits in the equatorial plane of their primaries the outermost satellites exhibit large departures from this rule However the fragments of a rotating disk must all revolve in the same sense Thus the nebular hypothesis must attribute a separate origin to the retrograde satellites Usually they are believed to have been captured a view that was easier to accept in the days when retrograde orbits were exceedingly rare than it is now when no less than twelve are known

Satellite systems differ from the planetary system in another important respect the distribution of angular momentum Except in the Earth Moon system (which is exceptional in other respects as well), the primary carries the bulk of the angular momentum instead of the satellites This happens partly because the satellite systems are more com-

pact than the planetary system, the distances of the satellites from their primaries measured in units of the radius of the primary, are systematically smaller than the distances of the planets from the Sun measured in units of the solar radius But in addition the planets rotate more rapidly for their densities than the Sun as is evident from their greater degree of flattening This circumstance aggravates the theoretical difficulty presented by the slow rotation of the Sun for if the Sun has somehow managed to get rid of the angular momentum it would be expected to have according to the nebular hypothesis why have the planets not done likewise?

Nature and origin of Saturn's rings J C Maxwell showed that Saturn's rings cannot be solid or liquid but must consist of tiny particles pursuing independent orbits about the planet He also showed that any irregularities in the structure of the rings would tend to be smoothed out in the course of time which explains their regular appearance It has been shown that a satellite with the same density as Saturn would not be stable at the distance of the rings but would be torn apart by tidal forces exerted on it by the planet This first suggests that the rings are composed of fragments of a satellite that was torn apart by tidal forces On the other hand they could also be composed of matter that has been prevented by tidal forces from coalescing into a satellite More knowledge is needed before these conflicts can be resolved [D L]

Cosmology

The branch of astronomy that treats the over all structure of the physical universe Although cosmological speculation is older than civilization modern development dates from the second decade the twentieth century On the theoretical side Albert Einstein s general theory of relativity made possible the first self consistent description of an unbounded self gravitating medium On the observational side studies of stellar population provided convincing evidence that our stellar system is one of many comparable systems (galaxies) sprinkled throughout a region whose known size is limited only by the light gathering and light recording power of astronomical telescopes and accessories *See* UNIVERSE

Cosmological principle Modern cosmological theories proceed from an assumption called the cosmological principle which states that the distribution of matter and motion in the universe is statistically homogeneous and isotropic no average property of the distribution defines a preferred place (statistical homogeneity) or a preferred direction (statistical isotropy) the universe has no center and no axis

Some consequences of the cosmological principle are that in any sufficiently large sample the average number of galaxies per unit volume and the relative proportions of various types of galaxies (spirals ellipticals irregulars) are the same as in any other large sample Similarly the planes of spiral galaxies are randomly oriented in any sufficiently large sample No sufficiently large region can possess an appreciable net angular momentum because this would define a preferred direction in space

A large quantity of observational data bearing on the validity of the cosmological principle exists but to interpret it correctly one must assign a quantitative meaning to such phrases as a sufficiently large sample Failure to do this has led to mistaken assertions that the cosmological principle conflicts with observed facts In reality the cosmological principle sets no limit on the magnitude of departures from strict uniformity and isotropy provided only that such departures have a purely local character when local departures are duly allowed for data strongly support the cosmological principle

Three possible motions Because local irregularities are not of direct interest in cosmology theoretical studies usually refer to idealized models of the universe in which irregularities have been smoothed out In these models the density of matter is constant in space its value being identified with the average density of matter in the actual universe

(3) a spatially uniform expansion In a uniformly contracting or expanding model the relative velocity of any two material particles is proportional to the distance between the particles (A two dimensional analog is the surface of an expanding spherical balloon) The constant of proportionality which has dimensions (time) $^{-1}$ is called Hubble s constant Its value is the same everywhere in space but may vary with time

Dynamical theory provides a means of deciding among the three possible kinds of motion Because Newton s theory of gravitation cannot be applied in a self consistent way to an unbounded uniform distribution of matter a sound theoretical treatment had to await the development of general

he showed that there exists no solution of the field equations of general relativity that is consistent with this assumption Rather than abandon the assumption of a static universe he modified the field equations by adding to them an extra term involving a new constant of nature the so called cosmological constant G A Friedmann on the other hand showed in 1922 that the original equations admit two kinds of nonstatic solutions that

infinitely [illegible]
state at time $t = 0$ at such a rate that the density

varies as $1/t^2$ In this universe Hubble's constant is inversely proportional to time t elapsed since the beginning of the expansion its reciprocal is 1 5t The square of Hubble s constant is proportional to the product of G Newton s gravitational constant and the density Finally ordinary euclidean geom etry holds good and the distribution of matter extends infinitely at all times

The Friedmann model with negative spatial cur vature behaves in much the same way as the Ein stein de Sitter model It expands indefinitely from an initial infinitely condensed state I ut the density falls off faster with time than in the Einstein de Sitter model The reciprocal of Hubble s constant lies between t and 1 5t its exact value depending on the amount of negative curvature for a given value of Hubble s constant density is less than that of the Einstein de Sitter model Finally the model extends infinitely at all times but the geometry is noneuclidean For instance the volume of a sphere of radius r is greater than $4/3\pi r^3$

The Friedmann model with positive spatial cur vature behaves differently from the other two models It does not expand indefinitely but reaches a state of maximum distention (minimum density) after which it begins to contract The contraction phase lasts exactly as long as the expansion phase and ends with the model in its initial state The cycle then repeats On this model the value of t inferred from Hubble s constant is less than on the other two models and the density of matter is greater Finally the model with positive spatial curvature is closed that is its volume is finite and it contains a finite quantity of matter Its two dimensional analog is the surface of a sphere The geometry is noneuclidean the volume of a sphere of radius r being less than $4/3-r^3$

Other models than these three may be con structed by keeping the extra term in the field equations introduced by Einstein to make possible a static solution No good reason for doing this has been advanced

Expanding universe The expanding universe was shown to be a reality by the work of E Hubble whose empirical velocity distance relation was pub lished in 1929 Hubble found that spectral lines of distant galaxies show a systematic red shift which he interpreted as arising from recession the reces sion velocity being related to the red shift by the Doppler formula (*see* DOPPLER FFFECT, RED SHIFT) He also found that the velocity derived in this way was proportional apart from fluctuations that could be averaged out to the distance as estimated by various indirect methods His original value for the constant of proportionality led how ever to a value for the age of the universe that is considerably less than the radiogenic age of the crust of Earth (*see* RADIOCARBON DATING) This dif ficulty remained unresolved for many years until it was removed by a revision of the distance scale on which Hubble s determination was based At present the agreement between observational cos mology and the predictions of the Einstein de Sitter theory is satisfactory

Alternative cosmologies Two alternatives to relativistic cosmology, one proposed by P A M Dirac (1938) the other by H Bondi and T Gold (1948), have attracted attention in recent years. Each rests on a hypothesis that is considered by many people to be esthetically attractive and each conflicts with portions of present day physics, al though not with observational or experimental evidence

Dirac's cosmology has as its point of departure the observation that a dimensionless number of order 10^{39} can be constructed in two completely independent ways from basic physical parameters One way is to form the ratio between the electro static force and the gravitational force exerted by a proton on an electron The other is to express the reciprocal of Hubble's constant in atomic un ts of time Dirac postulates the existence of a relation between these two combinations of physical quan tities that ensures their permanent near equal ity This implies that one of three things is true (1) the atomic constants (strong coupling constants) are not all constant in time or (2) Newton s gravitational constant is not constant in time or (3) the universe is in a steady state Dirac s co- mology develops the consequences of (2)

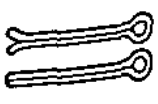
The steady state cosmology of Bondi Gold and F Hoyle rests on the hypothesis that the stat t cal properties of the universe do not change in spite of its expansion Because existing galaxies are co tinually moving away from each other by virtue the expansion the steady state hypothesis requ r that new galaxies must be created all the time o of matter which is itself continuously created Th conflicts with the laws of conservation of energ but the discrepancies are too small to be observabl if they exist The steady state cosmology also pr dicts a relation between red shift and apparer magnitude that is different from the one pred te by relativistic cosmologies The differences lie o the borderline of detectability by present method [D L.

See RELATIVITY SPACE TIME

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Cotter pin

A cotter pin is a split pin (as illustrated) formed by doubling a piece of wire semicircular in cross section to form a loop at one end After in ert on in a hole or a slot in a nut and through a mat ing crosswise hole in a bolt the ends of the p n



Common forms of cotter p n

are separated and bent to hold it in place (*see* NUT) This fastener is not adaptable to q ick as- sembly but is widely used in locations where serv ice inspection is difficult and where failure would be disastrous Cotter pins are similarly used in many other applications to prevent relative rota tion or sliding [P R B.]

Cotton

The plant *Gossypium* of the order Malvales has been used by man in many ways for more than 3000 years Cotton is the most economical natural fiber because of its comparatively low cost of production and low price as a finished product Not only is cotton an important textile when used alone but also when used as a base for some of the man made textile fibers *See* FIBER NATURAL, TEXTILE

Unlike other fibers obtained from plants the cotton fiber is a single elongated cell (*see* EPIDERMIS PLANT) Under the microscope it resembles a collapsed spirally twisted tube with a rough surface The thin cell wall of the fiber has 200–400 natural twists or convolutions per inch The fiber is flat twisted and ribbonlike with a wide inner [illegible] 90% being [illegible] ce of coat



Fig 1 Open boll of cotton ready to harvest

Cultivation and harvesting To mature cotton requires about 200 days of continuously warm weather with adequate moisture and sunlight fro t is harmful and may kill the plant The ground must be thoroughly plowed and the soil pul er zed In the United States usually in March or April carefully selected cotton seeds are planted in rows The plants require systematic fertiliza tion (*see* FERTILIZER, FERTILIZING) When they are about 3 in high they are weeded and thinned The plant begins to bloom in June or July about 4 months after planting Creamy white flowers ap pear first change to a reddish purple in about 2 days and then fall off leaving seed pods that grow to full size by August or September *See* FLOWER (BOTANY) The cotton capsules or bolls mu t be protected against the boll weevil *See* ENTOMOLOGY ECONOMIC FRUIT (BOTANY) SEED (BOTANY)

When fully grown the cotton plant may be 3–6 in height Its wide green leaves partially con eal some of the bolls until they burst and expose ie fleecy white fiber which indicates that the cotton s ready for harvesting Not all cotton bolls open at he same time Only those that have burst are ready or picking Consequently a cotton field must be gone over several times in a single season This is he most expensive operation in growing cotton When the raw cotton is harvested it contains seeds leaf fragments and dirt that must be removed be fore the fiber can be baled Cotton seeds alone const tute approximately two thirds of the weight of the raw cotton when picked *See* MALVALES

[MDP]

Products and processing When the bolls open the fiber and seed or seed cotton is harvested by hand or machines (Fig 1) The fiber or lint as t is then called is separated from the seed by gins The lint is compressed into bales covered w th jute bagging and bound with metal bands for ea e of handling Bales weigh about 500 lb each The seed (except that portion needed for planting the next crop and for other farm uses) is trans ferred from the gins usually by trucks to oil mills for processing After baling the lint is sam pled graded and sold The bales then pass through commercial channels and eventually reach cotton mills where they are broken open and the lint is blended cleaned carded and spun into yarns for many uses In the oil mill processing industry the cottonseed is separated into fuzz or linters hulls oil and cake Each of these products is converted to several subproducts The oil is the mo t valuable product and the cake next in order The oil subproducts are largely used as human food (*see* FAT AND OIL EDIBLE) the cake either as cracked cake or ground meal is used as livestock feed Hulls are also fed to livestock and the linters are con verted into chemical cellulose

Distribution and production The cotton plant is one of the world s major agricultural crops It is grown in all countries lying within a wide band around the earth The limits of this band in the New World are at about 37°N latitude and at about 32°S latitude In the Old World the band spreads northward to 47°N in the Ukraine of the Soviet Union but only to about 30°S in Africa and Australia In addition to the effects of latitude suitability of climate for the growth of cotton is also regulated by elevation wind belts ocean cur rents and mountain ranges As a result of the ef fects of these climatic factors the topography of the land the nature of the soil and the availability of irrigation water when needed cotton culture actually is carried out in an irregular and greatly [illegible] more often

Pakistan eastern China Central is a

World production of cotton for 1939 and 1953–1956*

Continent or country	Production by years thousands of bales				
	1939	1953	1954	1955	1956
North America	11 918	16 536	17 822	15 794	17 277
Asia and Oceania	8 280	8 736	9 725	10 488	10 192
Europe	158	309	367	522	610
Africa	2 637	3 558	3 021	3 175	3 223
South America	2 703	2 727	2 889	2 850	2 836
Soviet Union	3 800	5 000	5 500	5 800	6 300
United States	11 617	15 167	16 402	13 630	14 685
World	29 528	36 906	39 324	38 629	39 168

SOURCE U S Department of Commerce Bureau of the Census *Cotton Production and Distribution* Bull 193 1956
* Year ending July 31 of the year given

River Valley East Africa northeastern and southern Brazil northern Argentina and Peru Within these regions and outlying districts 44 countries report data on cotton production The production for 1939 and 1953–1956 combined in larger geographical units is shown in the table

The increase in cotton production between 1939 and 1953 was more than 7 000 000 bales and between 1953 and 1954 more than 2 000 000 bales However during the 1954–1956 interval there was little change

The rapid increase in production of man made fibers appears to have slowed down world production of cotton since 1954 Man made materials have so expanded the total world supply of textiles that the increased population secures ample wearing apparel and industrial textiles without raising the production level of cotton In 1939 the world's production of man made fibers was equivalent to 5 272 000 bales of cotton in 1953 to 10 537 000 bales of cotton and in 1955 to 12 800 000 bales of cotton

Stimulants to production The United States has made three major contributions to world cotton production These were the development of upland cotton the invention of the saw gin and the development of important knowledge of cotton culture

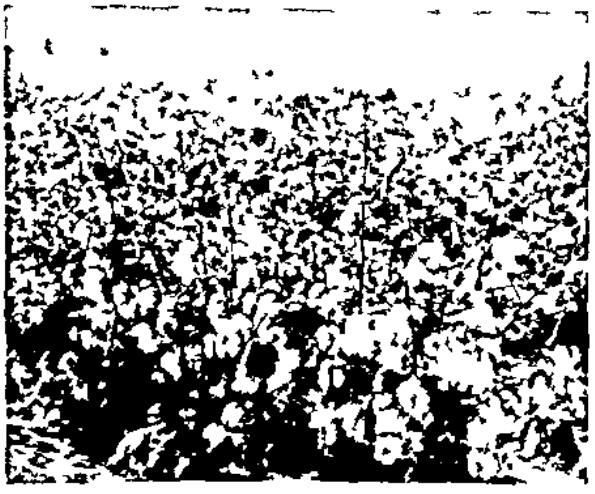


Fig 2 Productive field of open cotton (*K Bilbrey County Agent Mississippi County Ark*)





Fig 3 Ginned seed of upland cotton showing dense and tight covering of short fuzz hairs on seed coat (*J O Ware Journal of Heredity*)

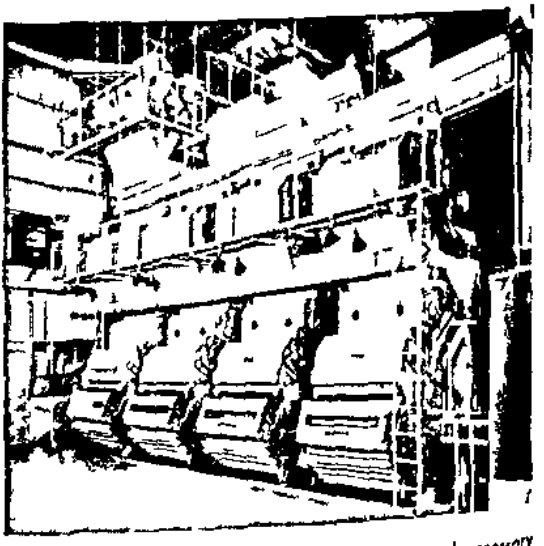


Fig 4 Modern cotton gin four stands and accessory equipment for cleaning and conveying the cotton (*The Murray Company of Texas*)

Upland cotton arose from an annual form of *Gossypium hirsutum* native to the plateaus of southern Mexico This species was introduced into what is now southern United States at different times from the colonial period to the first decade of this century The name Upland is derived from the upland country in southeastern United States commercially The name of its early development as a crop in the American Cotton Belt has been very hardy and productive and versatile in its many uses (Fig 2)

Upland production was handicapped at first by the difficulty of ginning The seed coat has a tight covering of short fuzz hairs (Fig 3) Only saw like teeth can penetrate and remove the longer coat of lint from the seed and leave the fuzz behind with the seed coat undamaged The saw gin incorporating this principle was gradually developed into the modern gin plant (Fig 4)

In the history of cotton culture simple but efficient farm tools were developed and the mule was

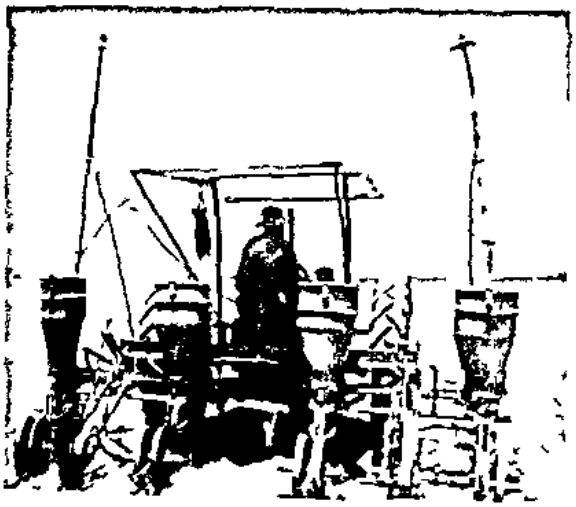


Fig 5 Planting cotton with four-row tractor propelled planter on large farm (USDA)



Fig 6 Two-row cotton-spindle picker in operation (Allis-Chalmers Manufacturing Co)

generally the source of farm power The cotton fields were well tilled, the weeds controlled the cotton carefully picked by hand, and the best seed selected for the next crop However, when mechanical power began to replace animal power the United States quickly mechanized both the cultural and harvesting phases of cotton production (Figs 5 6) Great progress in research plant breeding (Fig 7), technology, and mechanics paved the way for advancements when economic conditions were ready for their adoption Upland cotton and some of the improvements made in handling this crop spread to most cotton growing countries as they began commercial production Upland cotton now provides about 75% of the world supply of raw cotton for factory use

The other 25% of world production is supplied from three other cultivated species *Gossypium barbadense*, *G arboreum*, and *G herbaceum* *G barbadense*, the longest staple type, includes Egyptian Tanguis and Sea Island Egyptian is grown in Egypt and the Sudan, Tanguis in Peru; American Egyptian in southwestern United States, and Sea Island in the West Indies Sea Island cotton formerly was grown on islands and coastal areas of southeastern United States The other two species *G arboreum* and *G herbaceum*, are commonly referred to as Asiatic cottons and include the shortest staple types of cultivated cottons The growth of the former is largely confined to India and China and of the latter to Central Asia, western India, and the Near East Saw gins are not necessarily required for these cottons, they are still largely ginned with roller gins The saw gins usually used for Upland cotton in other countries are simpler and carry less cleaning equipment than those used in the United States Most other countries still employ much hand work in cotton culture, nearly all of the crop is harvested by hand and usually picked carefully by hand

Most commercial cottons are now annuals However in the tropics some races of the regular cultivated species are perennial All cottons at one time were tropical and perennial (*see* ANNUAL PLANTS PERENNIAL PLANTS)

Wild cotton Besides the four cultivated species, *Gossypium* includes about 16 wild and lintless species that are widely scattered and occur mostly in sparsely covered desert and tropical areas of the world All of the wild species may ultimately be of economic interest Some of them already have been used in crosses with cultivated cottons to improve quality values in the latter [JOW]

Cotton diseases. Wherever cotton is grown cotton diseases occur Those of greatest importance in the United States are seedling diseases verticillium wilt boll rot bacterial blight, root knot, root rot and fusarium wilt Losses from all diseases average more than 10% of the total crop in the United States

Seedling diseases are caused by seedborne and soil inhabiting pathogens *Ascochyta gossypii*, *Glomerella gossypii* and *Xanthomonas malvacearum* are seedborne whereas *Rhizoctonia solani* and *Pythium* spp inhabit the soil (Fig 8)

Verticillium wilt is caused by *Verticillium albo atrum* The disease is most severe in the lower Mississippi Valley and in the irrigated areas of the Southwest Infected plants have pale yellow mark

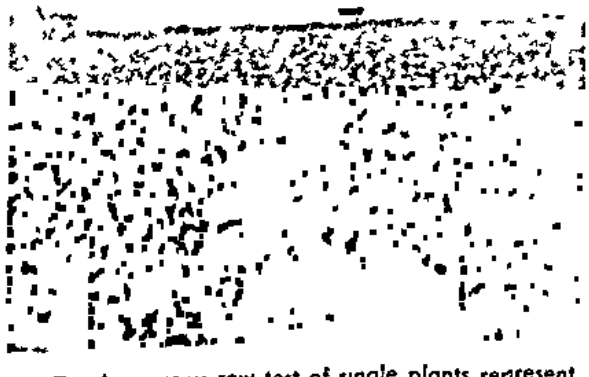


Fig 7 A progeny row test of single plants representing a step in a cotton breeding program (*Arkansas Agricultural Experiment Station*)

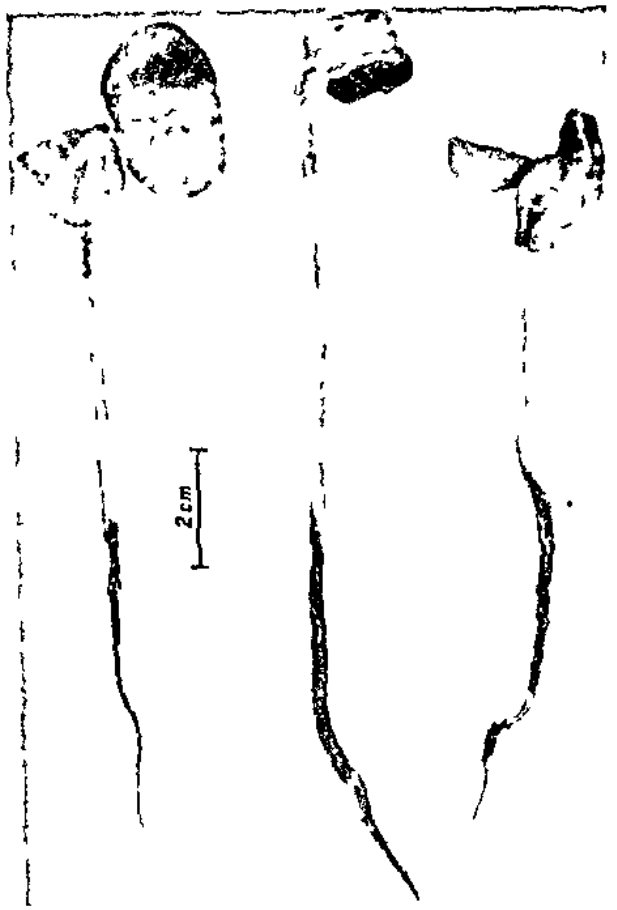


Fig 8 Cotton seedlings affected by *Glomerella*



Fig 9 Verticillium wilt of young cotton plant

ings on the leaves and brown streaks in the woody portion of the stem Verticillium wilt is sometimes difficult to distinguish from fusarium wilt The discoloration produced by verticillium is usually more evenly distributed through the stem and is lighter

thomonas malvacearum, that penetrate uninjured bolls, and secondary invaders *Rhizopus* spp, *Aspergillus* spp, and others that enter through wounds made by the primary organisms or insects Boll rots may destroy or reduce the value of the crop by 10–25% (Fig 10*a*)

Bacterial blight caused by *Xanthomonas malvacearum*, occurs across the Cotton Belt Serious losses may occur if environmental conditions are favorable Angular spots on the leaves and water-soaked spots on the bolls are typical symptoms (Fig 10*b*)

Root knot, caused by the nematode *Meloidogyne incognita acrita*, occurs throughout the Cotton Belt principally on the lighter soils Infested plants are stunted or killed and galls are present on the roots (Fig 10*c*)

lowed by sudden wilting and death of the plants

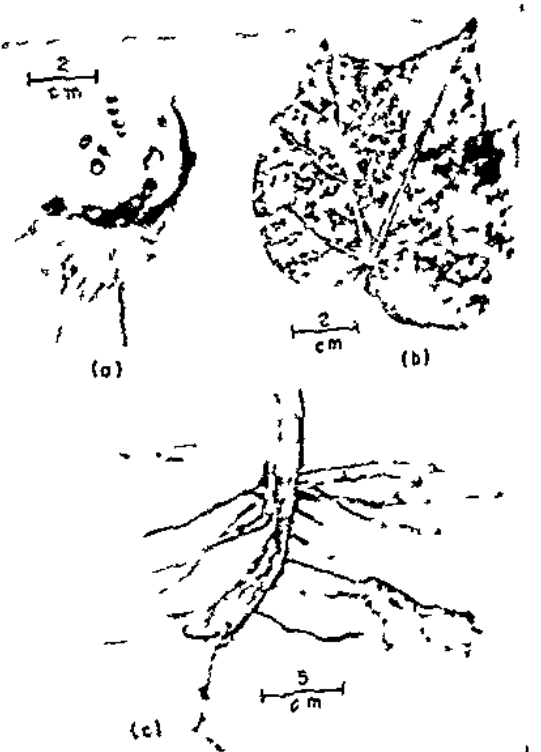


Fig 10 Effect of bacterial blight on various parts of cotton plant (a) Bacterial blight lesions on bolls (b) Bacterial blight lesions on leaves (c) Root knot galls on cotton roots

Fusarium wilt caused by *Fusarium oxysporum f vasinfectum* occurs primarily in the Southeast but it also extends into Texas and Oklahoma Symptoms are stunting of the plants yellowing and wilting of leaves and discoloration of woody portions of the stalk

Minor leaf spot diseases and nutrient deficiencies may reduce yields in localized areas Certain diseases are now being largely controlled by use of resistant varieties seed treatments soil fumigation or cultural practices, others are becoming more widespread and destructive *See* BACTERIA FUNGI PLANT DISEASE CONTROL, PLANT MINERAL NUTRITION OF, ROOT (BOTANY), SOIL MICROBIOLOGY [J T P]

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Cottonmouth

The water moccasin or cottonmouth *Ankistrodon piscivorus* a relatively sluggish heavy bodied pit viper which may grow to 5 ft in length It is present over much of the southeastern United States generally south of the Ohio and Missouri Rivers and from Virginia to the Great Plains

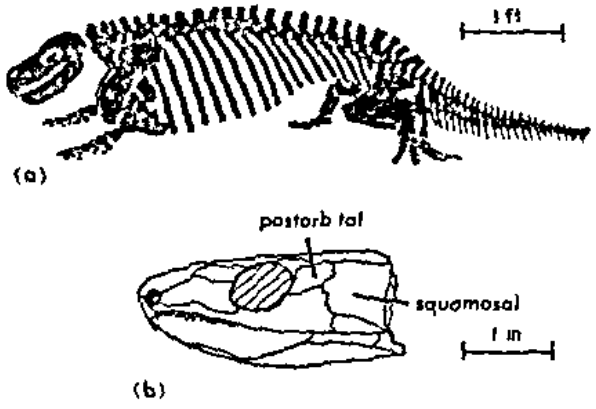
The cottonmouth is a semiaquatic snake which frequents swamps and sluggish streams especially those with heavy vegetative cover It is ovoviviparous, and it eats warm and cold blooded verte-brates

Old adults are black or nearly black the young are brightly marked with white edged bands of dark brown [illegible] The [illegible] mouth revealing the white inner mouth area Although more even tempered than the copperhead or rattlesnake the cottonmouth is highly unpredictable and dangerous *See* SQUAMATA [J D B]

Cotylosauria

The cotylosaurs comprise primitive reptiles usually grouped as an order under the reptilian subclass Anapsida They are called stem reptiles and include ancestors of all more advanced reptiles Association of all primitive reptiles under this single order almost certainly does not represent a natural phylogenetic classification but does provide a convenient horizontal assemblage Cotylosaurs range in age from Late Carboniferous (Paleozoic) to Late Triassic (Mesozoic) *See* ANAPSIDA

Three distinct suborders are generally recognized Seymouriamorpha Captorhinomorpha and Diadectomorpha All have common features of the skeleton such as broad neural vertebral arches but each has its own distinctive osteological features Seymouriamorphs lie very close to the reptilian amphibian border and are classified by some authorities under a separate

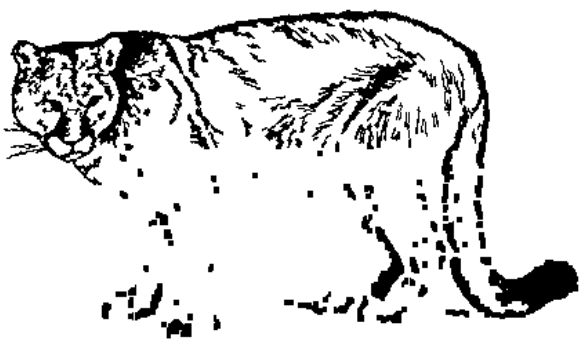


Cotylosaur (a) Skeleton of Diadectes (b) Skull of Captorhinus (From E H Colbert Evolution of the Vertebrates Wiley 1955)

chosauria They were small partially aquatic animals which lived in swamps along coastal margins and on deltas Diadectamorphs probably derived from seymouriamorphs were highly varied small to moderately large clumsy herbivorous animals The turtles (Chelonia) probably arose from this group Captorhinomorphs were more agile superficially lizardlike reptiles and are considered by many to include ancestors of most of the more advanced reptilian groups *See* CHELONIA [E C O]

Cougar

A large tawny to grayish cat *Felis concolor* called panther painter puma and mountain lion It is [illegible]



The cougar Felis concolor; length to 9 ft (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

9 ft including a 3-foot tail and a weight of 200 lb It is a skilled tree climber and hunter of big game [illegible] The [illegible] has been a [illegible] ties in the last few years coincident with the restoration of deer herds The cougar may destroy domestic animals and in rare instances has been known to attack man *See* CARNIVORA [L P G]

Coulomb

The unit of electric charge in the mks system of units The coulomb is defined as that quantity of electricity which in 1 sec passes through a cross section of a conductor in which there is a constant current of 1 amp 1 coulomb = 1 amp sec *See* CHARGE ELECTRIC ELECTRICAL UNITS [R P WI]

Coulomb's law

For electrostatics Coulomb s law states that the direct force F of point charge q_1 on point charge q when the charges are separated by a distance r is given by $F = k_0 q_1 q / r^2$ where k_0 is a constant of proportionality whose value depends on the units used for measuring F q and r It is the basic quantitative law of electrostatics In the rationalized meter kilogram second (mks) system of units $k_0 = 1/4\pi\epsilon_0$ where ϵ_0 is called the permittivity of empty space and has the value $\epsilon_0 = (1/4\pi \times 8\ 98776 \times 10^9)$ coul /newton m^2 $\cong 8\ 85 \times 10^{-12}$ coul /newton m^2 Thus Coulomb s law in the rationalized mks system is

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} \qquad (1)$$

where q_1 and q_2 are in coulombs r is in meters and F in newtons (*see* ELECTRICAL UNITS) The direction of F is along the line of centers of the point charges q_1 and q_2 and is one of attraction if the charges are opposite in sign and one of repulsion if the charges have the same sign For a statement of Coulomb s law as applied to point magnet poles *see* MAGNETOSTATICS

Experiments have shown that the exponent of r in Eq (1) is very accurately the number 2 Lord Rutherford s experiments in which he scattered α particles by atomic nuclei showed that Eq (1) is valid for charged particles of nuclear dimensions down to separations of about 10^{-12} cm Nuclear experiments have shown that the forces between charged particles do not obey Eq (1) for separations smaller than this

The direct force that one charged particle exerts on another is unaffected by the presence of additional charge and in any electrostatic system Eq (1) gives this direct force between q_1 and q_2 under any conditions of charge configuration including that in which intervening and surrounding matter is present and the molecules of the matter are polarized so that their charges contribute to this configuration The total force on any one charge say q_1 is the vector sum of the separate direct forces on q_1 due to q_2 q_3 q_4 and so on each force computed separately by use of Eq (1) as if all other charges were absent

The permittivity ϵ of a medium is defined by $\epsilon = k\epsilon_0$ where k is the relative dielectric constant of the medium The name specific inductive capacity is also given to k *See* DIELECTRIC CONSTANT

If two free point charges q_1 and q_2 are immersed in an infinite homogeneous isotropic dielectric the total force on one of them (say q_1) is given by $F = q_1 q_2 / 4\pi\epsilon r^2$ and the use of ϵ (in place of ϵ_0) takes proper account of the forces on q due to the polarization charges of the dielectric molecules It is only in a few special cases that this latter formulation of Coulomb's law is valid *See* CHARGE, ELECTRIC, ELECTROSTATICS [R P WI]

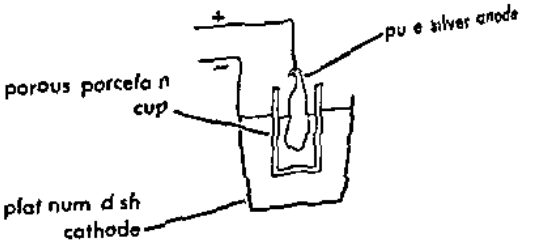
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Coulometer

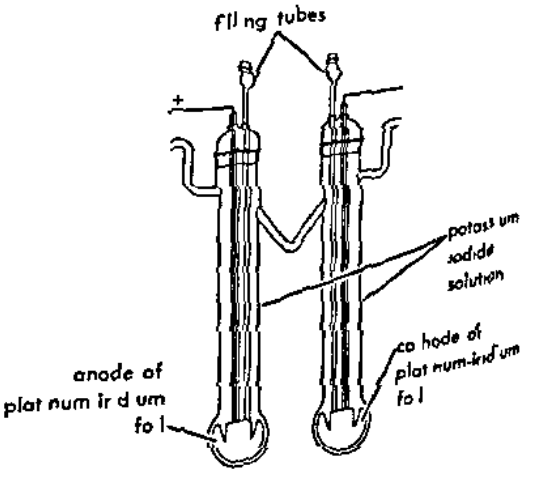
Electrolytic cell for the measurement of quantities of electricity by quantitative determination of chemical changes sometimes called voltameter Coulometers are used for the precise determination of quantities of electricity in standardization procedures and in some electroanalytical measurements

Coulometers are based on Faraday s law which correlates the quantity of electricity consumed by electrolysis with the quantities of substances that are produced or consumed for discussion of Faraday s law *see* ELECTROCHEMICAL EQUIVALENT ELECTROLYSIS

The quantity of substance produced or consumed in a coulometer is generally determined by weighing titration or volume measurements Many electrode reactions have been proposed but only a few proceed with the 100% current efficiency that is required for application of Faraday s law The deposition of silver copper or mercury the electrolysis of water with hydrogen and oxygen evolution and



Silver coulometer



Iodine coulometer

the oxidation of iodide to iodine are the electrode reactions generally selected for coulometers

In the silver coulometer, the quantity of electricity is determined by weighing the amount of silver plated upon the platinum cup cathode during passage of the current One coulomb of electricity will deposit 0 0011180 grams (g) of silver

The passage of 1 coulomb of electricity through the iodine coulometer will liberate 0 001315 g of iodine at the anode [F D]

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Coulometric analysis

That area of electroanalytical chemistry which involves quantitative estimation of materials via measurement of the quantity of electricity required to electrolyze them Primary coulometric analyses are those in which the unknown material is electrolyzed directly Secondary coulometric analyses are those in which a reagent is generated electrolytically in quantity equivalent to the unknown material In both types the amount of material is calculated from the quantity of electricity required to complete the reaction

The basis for coulometric analysis is Faraday's law which may be expressed in modified form by the mathematical statements which follow

$$M = \left(\frac{IT}{nF}\right)_I = \frac{1}{nF}\int_0^T I\,dT$$

In these expressions M is the number of moles of matter electrolyzed I is the current in amperes T is the electrolysis time in seconds n is the number of electrons exchanged per molecule and F, the faraday is 96 492 ± 3 coulombs (ampere seconds)/equivalent (chemical scale) The first form of the equation which is valid only when the current remains constant throughout the electrolysis indicates that the number of moles electrolyzed may be measured in this case by timing the electrolysis The second form of the equation is general and may be used in any case but the evaluation of the integral requires the use of an integrating device or a chemical coulometer

For coulometric analysis the current must be very nearly 100% efficient in bringing about the desired reaction Although Faraday's law is among the most exact relationships known it is often difficult to find experimental conditions under which a given electrochemical reaction will be the only reaction contributing to the current. For this reason there are comparatively few materials which may be determined by primary coulometric analysis Among the techniques used are the electrodeposition of metals electrodissolution of plated metals and metal oxides and electroreduction or electrooxidation of materials which have several soluble oxidation states In some cases where it is not possible to deposit a metal with 100% current efficiency because of simultaneous evolution of hydrogen the deposition may be completed without measurement and the metal then may be dissolved from the electrode coulometrically The electrodes most commonly used are platinum and mercury although many other materials find limited application

Coulometric titrations are analyses at constant current most often of the secondary type in which a titrant is generated electrolytically usually in the solution Among the reagents which may be generated with 100% current efficiency are the ions hydronium (hydrogen) hydroxyl silver(I) copper(I) mercury(I) uranium(IV) and titanium (III) and the elements chlorine bromine and iodine In these titrations some means of end point detection is needed Most of the methods used in ordinary titrations may be used but electrometric methods are most common

Primary coulometric analyses conducted with constant potential on the working electrode are more selective than coulometric titrations because no current flows after the desired reaction is completed making an indicator system unnecessary Because very small amounts of electricity may be conveniently and accurately measured coulometric analyses at constant electrode potential and coulometric titrations are of great importance in trace analysis *See* COULOMETER ELECTROCHEMICAL EQUIVALENT ELECTRODEPOSITION ANALYSIS ELECTROLYSIS TITRATION [C F M]

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Counter, digital

A discrete state device each state of which represents a nonnegative integer and changes to the state representing the next highest integer when given an input signal A radix r counter counts to $r - 1$ and returns to 0 For example a decimal counter goes from 0 to 9 to 0 *See* NUMBER SYSTEMS

An n stage counter consists of n radix r counters connected in such a way that when $r - 1$ is reached at a given stage a carry is generated and counted into the next higher stage

Counters are used in many applications including counting of factory items produced counting of nuclear particles and control of sequencing of digital computer operation Thus there are two generic uses (1) as arithmetic devices for adding unity and accumulating the sum and (2) as means for controlling occurrences of events at successive time intervals in automatic devices such as digital computers

A mechanical counter is a ratchet wheel counter (Fig 1) used in mechanical key driven desk calculators An electronic example is the ring counter Flip flops are arranged as in Fig 2 Assuming only flip flop (0) is on, successive pulses turn on flip flops (1) (2) and so on, only one flip flop of the ring is on at a time Circuit details are omitted With n stages the device of Fig 2 can be used as an n stage decimal counter with the carry signal serving as input to the next higher stage

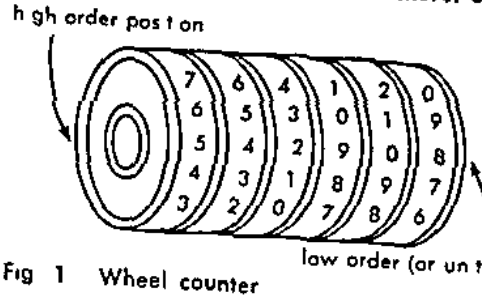
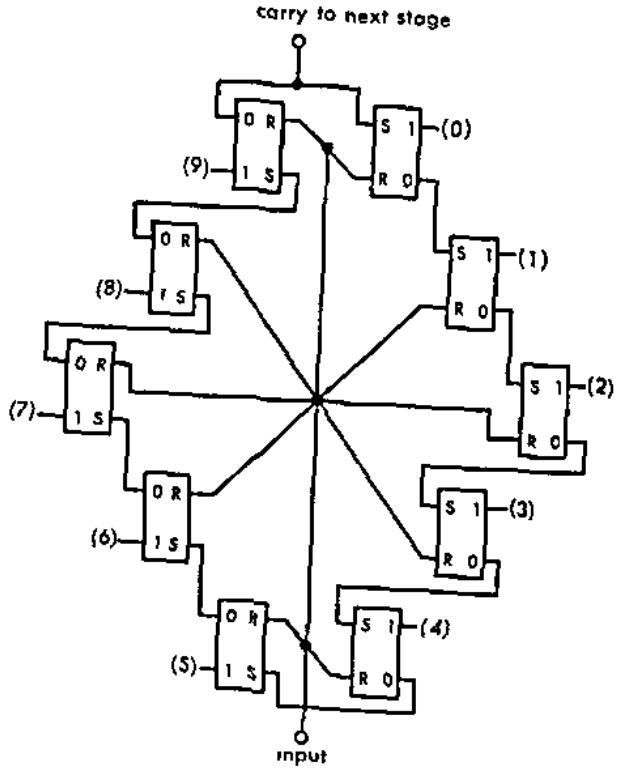


Fig 1 Wheel counter



Fg 2 Ring counter (1 ON 0 = OFF)

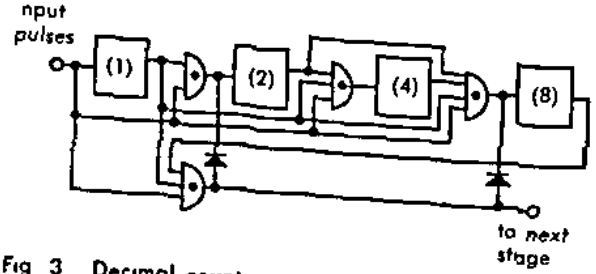


Fig 3 Decimal counter employing 8–4–2–1 code

The output of the flip-flops might also be used as sources of timing signals in the second type of application mentioned *above* For example the timing sequence of an arithmetic execution cycle in a digital computer might be defined by a ring counter of the *above type The main* disadvantage of the ring is excessive use of equipment

A stage of a more economical decimal counter that employs the 8–4–2 1 code is shown in Fig 3 As the input is pulsed flip flops (1) (2) (1 & 2) (4) (1 & 4), (2 & 4) (1 2 & 4) (8) and (1 & 8) operate representing decimal *numbers 1 9* The tenth pulse causes a carry and after a delay (not shown in figure) which is supplied to allow flop (2) to settle *down* (2) (8), and hence entire stage are reset to OFF (zero)

A six bit binary counter arranged as in F without carry or special reset means but with puts provided at each stage could be employe an address counter for the typical digital comp control *See* DIGITAL COMPUTER [R J

Countercurrent mass transfer operatio

A laboratory or industrial operation invol fractionating processes The ultimate purpose the separation of a mixture or solution into components or at least the recovery of a de ir component in a pure or highly enriched state each process at least two phases are present some state of dispersion and are moving in opp site directions (countercurrent) under the infl ence of gravity or mechanical transport Whe density differences between the phases are ur available transport may sometimes be provided b an applied electric field if there is a charge differ ential between phases Gravity transport may con versely produce strong electric fields as in a thundercloud In contrast to batch processes the mass transfer processes are essentially continuous. The entire operation may be regarded as a steady state process in which gradients in concentration are produced as a result of a flow of energy in some form through the materials The processes find ex tensive application in both industrial and labora tory separations For discussions of specific proc esses *see* ABSORPTION CRYSTALLIZATION DISTIL LATION DRYING ELECTROPHORESIS EXTRACTION LEACHING SEPARATION (CHEMICAL AND PHYSI CAL) Between two phases having two or more components the equilibrium condition between phases will result in one phase being rich" the other 'poor' with respect to a chosen component Analysis of a batch at equilibrium allows determination of the degree of enrichment or separat on factor characterizing the particular eq il brium system If the rich phase is isolated and cau ed to undergo separation again into two new phases a further degree of enrichment can occur Co nter current mass transfer processes allow for essentially continuous repetition of the enrichment process

The requirements for countercurrent separation processes are (1) a means for production *of two* phases (2) a means for transport of the two phases either in opposite directions or at least at different velocities in the same *direction* and (3) repeated equilibration between phases during transport In many cases transport of heat is also required

In distillation processes phase separat on is produced by input of heat to a boiler *heat* is transported through the column in the same direct on as the vapor phase In the column *as the eq il* brat on proceeds each new portion of vapor produced is richer in the lower boiling *component and re*ceives an upward component of velocity as it en

ters the vapor phase The poorer liquid phase re turns downward by gravity toward the source of heat until a steady state is attained In practice the maximum separation efficiency is not reached because of continued withdrawal of rich and poor fractions

In extraction or adsorption processes where a component distributes itself between two phases gravity or centrifugal force commonly provides phase transport Fresh pure extractant enters the system at a point which is practically depleted of the desired component undergoes continual en richment during transport and is removed at the point of maximum enrichment

The rate of attainment of equilibrium in phase equilibria is governed by diffusion transport across phase boundaries Because this is a relatively slow process the total area of phase boundaries is kept large by dispersing one phase in the other Signifi cantly each time a molecule enters a phase across its boundary it receives a component of velocity from that phase impressed upon its own thermal motion Ultimately when a steady state exists in an apparatus the concentration gradients between the phases create a diffusion flow equal in rate and opposite to the net rate of transport of molecules by phase motion *See* MASS TRANSFER OPERATION [CEV]

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Counting circuit

One of several types of functional circuits used in switching or digital data processing systems such as dial telephone systems and digital computers The general function of a counting circuit is to re ceive and count repeated current or voltage pulses which represent information arriving from some other circuit within the same switching system or from a source external to the system Counting circuits may be devised with a variety of switching circuit devices such as electromagnetic relays vacuum tubes and transistors *See* SWITCHING CIR CUIT SWITCHING SYSTEMS (COMMUNICATIONS)

The basic requirement of a counting circuit is to detect each incoming pulse and to establish within itself a unique state for each successive appear ance of such a pulse The number of pulses that have arrived can then be indicated to another circuit by an output which reflects the particular state of the counting circuit

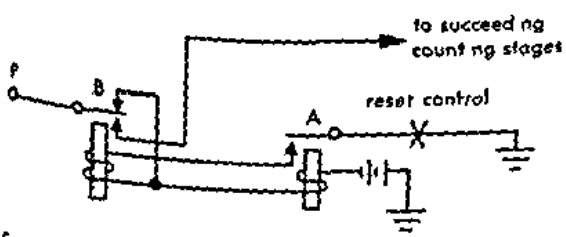


Fig 1 Single pulse relay counter

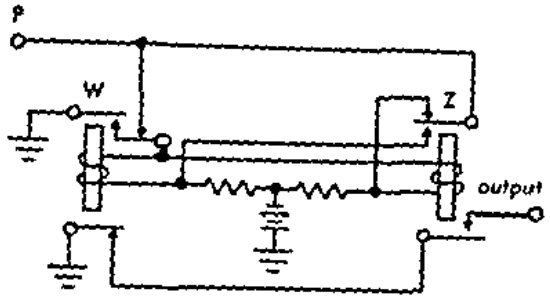


Fig 2 Two pulse relay counter

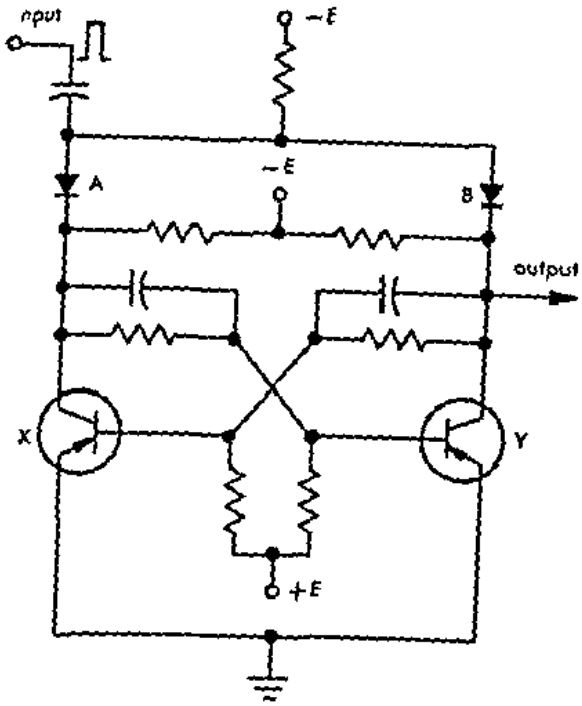


Fig 3 Two pulse transistor counter

Obviously the simplest counter is one that counts a single pulse With electromagnetic relays the counting of a single pulse requires at least two re lay actions one to record the arrival of the input signal and a second to record its disappearance A simple embodiment of such a counter is the re lay circuit of Fig 1

In this circuit an incoming ground pulse on lead P operates relay A The contact of A applies ground to relay B but as long as the input ground is pres ent, B is short circuited and cannot operate When the input ground disappears B operates in series with the winding of A which remains operated The count of one pulse is now completed and the input lead is steered to a succeeding similar circuit stage A number of such stages can of course be cascaded to count a train of pulses

A frequently used counting circuit configuration is a two-pulse or binary counter which recycles or returns to its original state after the second pulse A relay circuit of this kind is shown in Fig 2

In this circuit the first ground pulse on lead P

through the normally closed contact on W How ever at this time only W operates because the in put ground short circuits Z through its normally closed contact When this first pulse disappears W remains operated because of the ground connection through its own closed contact This same ground now operates Z When the second ground pulse ap pears on lead P it short circuits W through Z's closed contact thereby restoring W to normal Z holds operated on the input ground until this ground disappears Thus at the end of a second pulse the circuit is back to normal that is both relays are unoperated The output of this binary counter is a ground which appears during every second input pulse For this reason a binary counter is often referred to as a pulse or frequency divider

Figure 3 shows a transistor type of binary counter If in this circuit the normal (no count) state is designated as transistor Y conducting and X cut off the first positive input pulse will pass through diode A and on to the base of Y causing Y to cut off and X to conduct The second positive input pulse will now pass through diode B to the base of X causing X to cut off and Y to conduct After two input pulses therefore the circuit is back to normal The second pulse causes the out put lead to rise from a negative voltage (Y cut off) to ground (Y conducting) Therefore the binary counter stage produces a positive output pulse for every two positive input pulses thus act ing as a frequency divider

Several single stage binary counters may be connected so that the output of one counter stage acts as the input to the next counter stage A two stage circuit of this type can count four pulses a three stage eight pulses and so on [J MZ]

Couple

A system of two parallel forces of equal magnitude and opposite sense (Fig 1) Forces P at normal distance p constitute a counterclockwise couple C_z (viewed from $+Z$) in the OYY' plane forces Q at arm q a clockwise couple C_x (from $+Y$) in OYZ

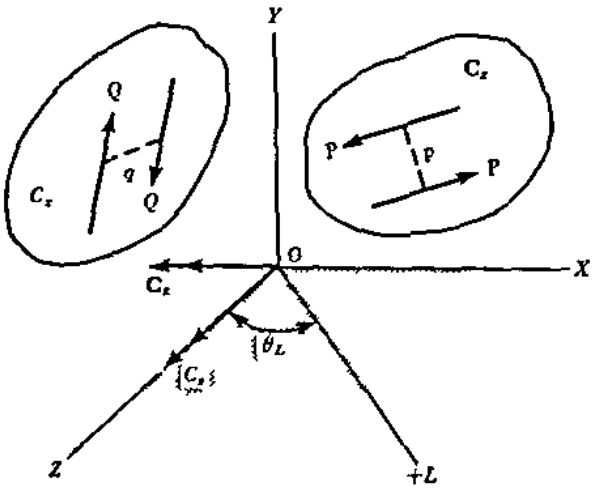


Fig 1 Vector properties of a couple

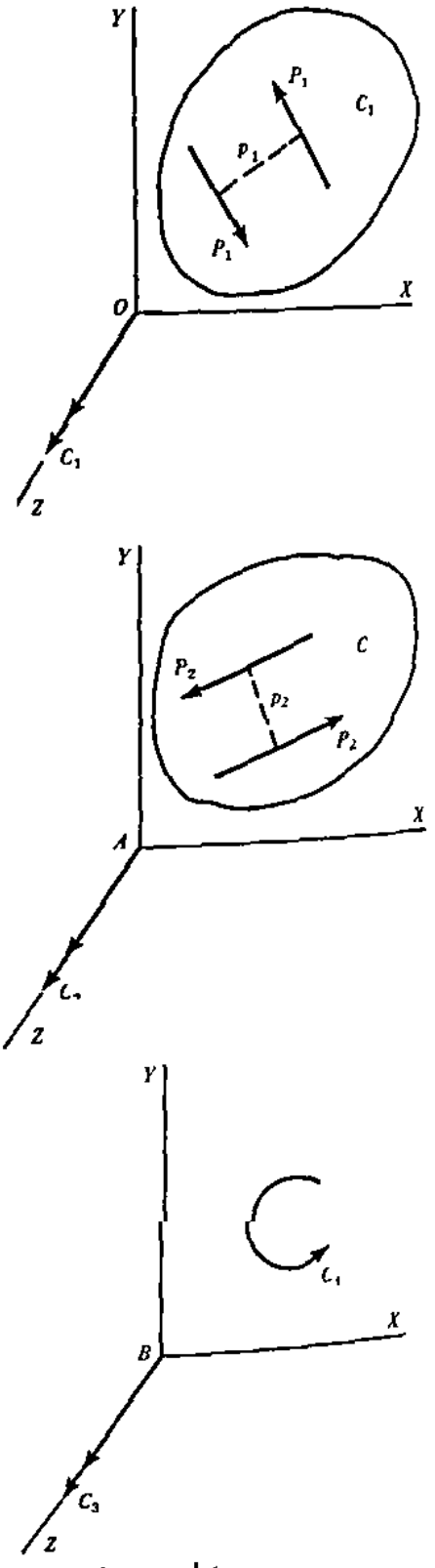


Fig 2 Equivalent couples

Under a couple's action a rigid body tends only to rotate about a line normal to the couple's plane This tendency reflects the vector properties of a couple

Vector properties The total force of a couple is zero The total moment C of a couple is identical about any point (*see* RESULTANT OF FORCES) Ac cordingly C is the moment of either force about

a point on the other and is perpendicular to the couple's plane *See* STATICS

In Fig 1 C_t at the origin for convenience is the moment of couple C_t Its magnitude $|C_t| = +P_p$ Its sense by the convention of moment is $+Z$ Also C of sense $-Y$, represents couple C_t $C_t = +Q$

Scalar moment of a couple The moment of a couple about a directed line is the component of its total moment in the line's direction For example the moment of couple C_t about line L is $M_L = C_t \cos\theta_L = +P_p \cos\theta_L$ Also $M_x = 0$ $M_y = 0$ and $M_z = +P_p \cos 0^\circ = +P_p$

Equivalent couples Couples are equivalent whose total moments are equal In Fig 2 the paired linear forces and the counterclockwise curl represent counterclockwise couples C_1 C and C_3 in parallel planes OXY, AXY, and βXY When their total moments are directed the same $(+Z)$ and their magnitudes $|C_1| = P_1p_1$ $|C_2| = P_2p_2$ and C_3 are equal then $C_1 = C_2 = C_3$ and these couples are equivalent Thus C_1 can represent these or any number of other equivalent couples

[N S F]

Coupled circuits

Two circuits or two meshes are said to be coupled when power can be transferred from one to the other The operation of radio and communication networks depends on the interaction between two or more circuits The operation of alternating current apparatus such as the transformer and induction motor depends on the mutual effect between windings For basic theory of circuits and explanation of terms and concepts used in this article *see* ALTERNATING-CURRENT CIRCUIT THEORY DIRECT CURRENT CIRCUIT THEORY

Coupled circuits are often classified as direct coupled inductive coupled or combination coupled Direct
a comm
ance R_m
common inductance L_m (Fig 1b) called inductance coupling, or a common capacitance C (Fig 1c) called capacitance coupling.

Inductive coupled circuits have a common magnetic flux linking the two circuits as shown in Fig 1d This is also called a magnetic coupling There may also be coupling through electrostatic flux linking the two circuits

Combination coupled circuits have a combination of direct and magnetic coupling as in Fig 1e

The coupled circuits in Fig 1 may be reduced to those shown in Fig 2 where Z_t is the impedance across 1 1 with 2 2' open Z_3 is the impedance across 2 2 with 1 1' open and $Z_m = V_{20}/I_1$ where I_1 is the current in circuit 1 with 2 2 open and V_{20} is the open circuit voltage in circuit 2

The behavior of all coupled circuits follows the same general character The same analysis may be applied Therefore only the magnetic coupling will be discussed

Mutual and leakage fluxes Figure 3 shows two circuits which are inductively coupled to each other With circuit 2 opened at 2 2 a total flux Φ_1 is produced by i_1 in coil 1 and linking N_1 turns This flux Φ_1 may be viewed as consisting of two parts that part which links N_1 turns of coil 1 and not coil 2 is designated as the leakage flux Φ_{11} that part which links N_2 and N_1 is designated as the mutual flux Φ_{21} Thus

$$\Phi_1 = \Phi_{11} + \Phi_{21} \qquad (1)$$

where the second subscript indicates the origin of the flux

Similarly with circuit 1 opened at 1 1

$$\Phi_2 = \Phi_{22} + \Phi_{12} \qquad (2)$$

where Φ_2 = total flux produced by i_2 in coil 2 and linking N_2 turns
Φ_{22} = leakage flux linking N_2 turns
Φ_{12} = mutual flux linking N_1 turns and N_2 turns

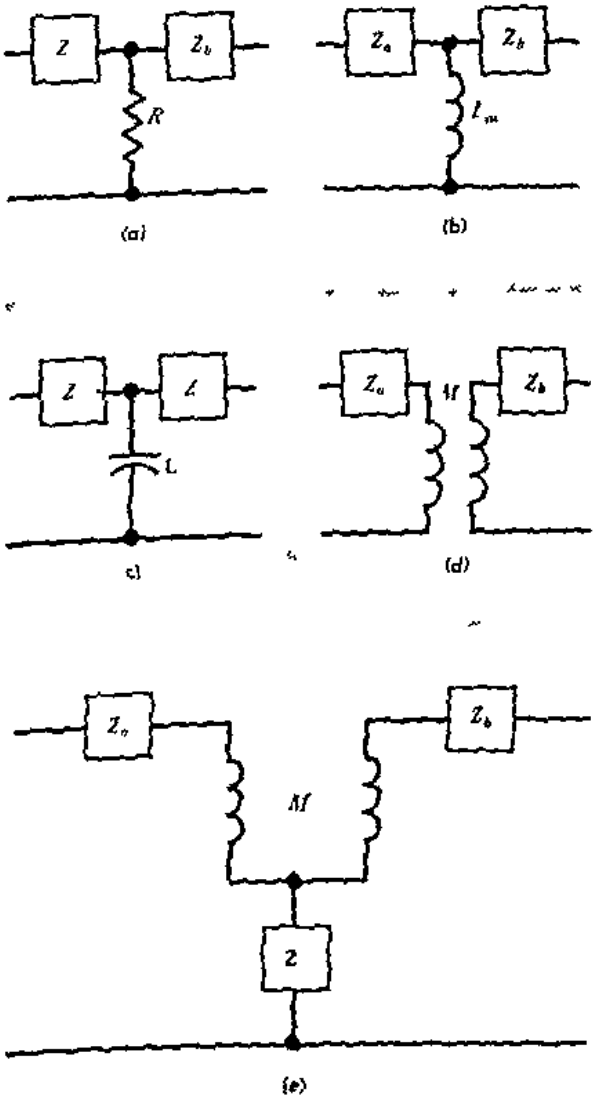


Fig 1 Coupled circuits (a) Resistance coupling (b) Inductance coupling (c) Capacitance coupling (d) Inductive or magnetic coupling (e) Combination

The actual magnetic fields are not so simple as that shown in Fig 3 For example it is not possible to have the leakage flux Φ_{11} linking all the turns in coil 1 nor is it possible to have the mutual flux Φ_{21} linking all the turns in coil 1 and all the turns in coil 2 Actually some flux lines link only a fraction of the total turns of coil 1 and other flux lines link all the turns on coil 1 Thus it may be convenient to consider the leakage flux Φ_{11}

cept may also be applied to Φ_{21} Φ_{22} and Φ_{12}

Self mutual and leakage inductances These inductances are defined as the flux linkages per ampere when the permeability of the surrounding medium such as air is constant Then for Fig 3, the self inductances are

$$L_1 = \frac{N_1\Phi_1}{i_1} \qquad L_2 = \frac{N_2\Phi_2}{i_2} \tag{3}$$

the mutual inductances are

$$M_{21} = \frac{N_2\Phi_{21}}{i_1} \qquad M_{12} = \frac{N_1\Phi_{12}}{i_2} \tag{4}$$

and the leakage inductances are

$$L_{l1} = \frac{N_1\Phi_{11}}{i_1} \qquad L_{l2} = \frac{N_2\Phi_{12}}{i_2} \tag{5}$$

When Φ is in webers and the currents i_1 and i_2 are in amperes L or M is in henries

When the permeability of the surrounding medium is constant

$$M_{21} = M_{12} = M \tag{6}$$

which states that there is only one value of mutual inductance M between two coils in a medium of constant permeability This is true for all sizes shapes and relative positions of the two coils

When the voltages and currents are sinusoidal and under steady state conditions the reactances for the inductances of Eqs (3) (4) and (5) may be stated as follows, where ω the angular frequency equals 2π times the frequency in cycles per second

self reactances

$$X_1 = \omega L_1 \quad \text{and} \quad X_2 = \omega L_2 \tag{7}$$

mutual reactance

$$X_m = \omega M \tag{8}$$

leakage reactances

$$X_{l1} = \omega L_{l1} \quad \text{and} \quad X_{l2} = \omega L_{l2} \tag{9}$$

Coefficient of coupling The coefficient of coupling k is a measure of the magnetic proximity of two coils When all of the flux links both coils (no leakage flux) the coefficient of coupling is one This is the maximum value k can have If the coils are placed a small distance apart so that there will be some leakage flux k is less than unity As the distance is increased indefinitely the value of k becomes smaller, approaching zero as a limit The value of k depends largely on the permeability of the medium

If L_1 and L_2 are the self inductances of two coils and M is the mutual inductance between the two coils the coefficient of coupling is

$$k = M/\sqrt{L_1L_2} \tag{10}$$

In power work the commercial transformers with iron cores of high permeability are close-coupled and may have values of k as high as 0 98 In radio work two circuits are said to be loosely coupled when k is less than 0 5

Voltages of mutual induction Referring again to Fig 3 the voltage of mutual induction in coil 1 is due to the mutual flux Φ_{12} set up by i_2 in coil 2 Since Φ_{12} links the N_1 turns of coil 1 then, by Faraday s law and equations (4) and (6) the magnitude of this voltage of mutual induction is

$$v_{12} = N_1\frac{d\Phi_{12}}{dt} = M\frac{di_2}{dt} \tag{11}$$

Similarly, the voltage of mutual induction in coil 2 due to the mutual flux Φ_{21} set up by i_1 in coil 1 is

$$v_{21} = N_2\frac{d\Phi_{21}}{dt} = M\frac{di_1}{dt} \tag{12}$$

When the voltages and currents are sinusoidal and under steady state conditions Eqs (11) and (12) become

$$V_{12} = j\omega MI_2 \tag{13}$$

$$V_{21} = j\omega MI_1 \tag{14}$$

Solution of coupled circuits As i_1 induces an emf in circuit 2 of Fig 3 and i_2 reacts back on circuit 1 it is necessary to set up two simultaneous Kirchhoff s loop voltage equations in order to determine the values of the currents

The general instantaneous voltage equation for each of the closed circuits is of the form

$$e_g = Ri + \frac{d(N\Phi)}{dt} \tag{15}$$

where $(N\Phi)$ is the total flux linkages of each coil Thus the two loop voltage equations are

$$e_{g1} = R_1i_1 + N_1\frac{d(\Phi_{11} + \Phi_{21} + \Phi_{12})}{dt} = R_1i_1 + N_1\frac{d\Phi_1}{dt} + N_1\frac{d\Phi_{12}}{dt} \tag{16}$$

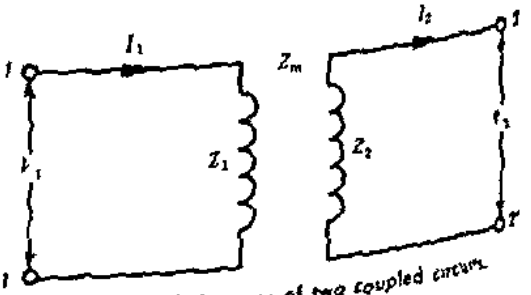


Fig 2 General diagram of two coupled circuits

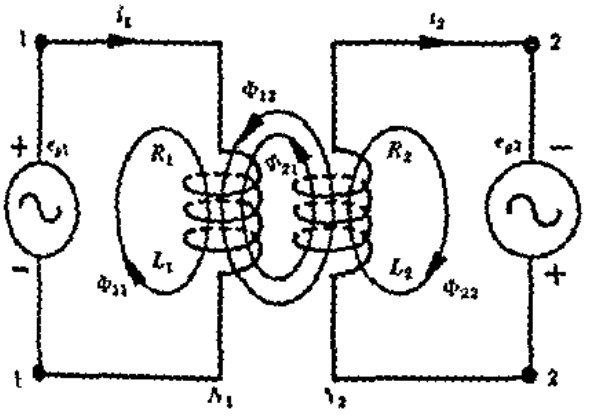


Fig 3 Inductively coupled circuits showing magnetic fields.

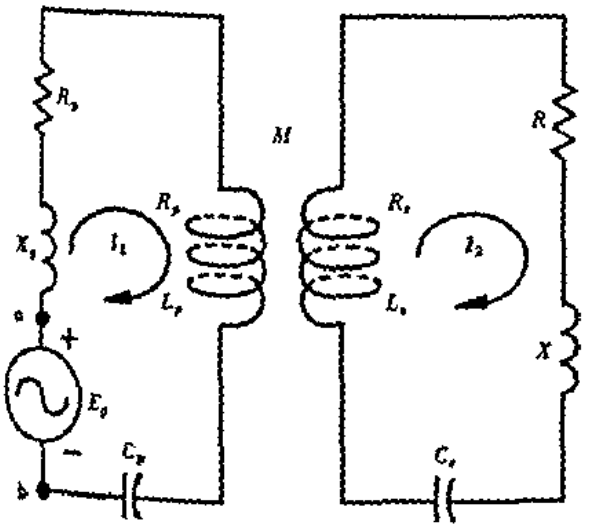


Fig 4 Inductively coupled circuits showing currents voltages and impedances

$$e_{g2} = R_2 i_2 + N_2 \frac{d(\Phi_{22} + \Phi_{12} + \Phi_{21})}{dt}$$

$$= R_2 i_2 + N_2 \frac{d\Phi_2}{dt} + N_2 \frac{d\Phi_{21}}{dt} \qquad (17)$$

Making use of Eqs (3) (4) and (6) (16) and (17) become

$$e_{g1} = R_1 i_1 + L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \qquad (18)$$

$$e_{g2} = R_2 i_2 + L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \qquad (19)$$

The signs of the terms containing M (also called the M terms) depend on the winding senses of the coils and the arbitrary choice of the current senses The following rules are helpful in determining the signs

1 The sign of the M term will be the *same* as that of the L term when Φ_{21} and Φ_{12} are in the same direction as in Fig. 3

2 The sign of the M term will be *opposite* to that of the L term when Φ_{21} and Φ_{12} oppose each other

For sinusoidal quantities and steady state conditions Eqs (18) and (19) may be written

$$E_{g1} = (R_1 + j\omega L_1)I_1 + j\omega M I_2 = Z_1 I_1 + Z_m I_2 \qquad (20)$$

$$E_{g2} = j\omega M I_1 + (R_2 + j\omega L_2)I_2 = Z_m I_1 + Z_2 I_2 \qquad (21)$$

where Z_1 = all impedances in circuit 1 including that of the generator with circuit 2 open circuited

Z_2 = all impedances in circuit 2 including that of the generator (or load) with circuit 1 open circuited

$Z_m = +j\omega M$

Solving Eqs (20) and (21) simultaneously gives

$$I_1 = \frac{E_{g1}Z_2 - E_{g2}Z_m}{Z_1 Z_2 - Z_m^2} \qquad (22)$$

$$I_2 = \frac{E_{g2}Z_1 - E_{g1}Z_m}{Z_1 Z_2 - Z_m^2} \qquad (23)$$

Driving point and transfer impedances In the circuit of Fig 4 where the voltages and currents are sinusoidal and under steady state conditions, the loop voltage equations are

$$E_g = \left[R_p + jX_g + R_p + j\left(\omega L_p - \frac{1}{\omega C_p}\right)\right]I_1 - j\omega M I_2$$

$$= Z_1 I_1 - Z_m I_2 \qquad (24)$$

$$0 = -j\omega M I_1 + \left[R + jX + R_s + j\left(\omega L_s - \frac{1}{\omega C_s}\right)\right]I_2$$

$$= -Z_m I_1 + Z_2 I_2 \qquad (25)$$

where

$$Z_1 = R_g + jX_g + R_p + j\left(\omega L_p - \frac{1}{\omega C_p}\right) = R_1 + jX_1$$

$$Z_2 = R + jX + R_s + j\left(\omega L_s - \frac{1}{\omega C_s}\right) = R_2 + jX_2$$

$$Z_m = +j\omega M$$

Solving Eqs (24) and (25) simultaneously gives

$$I_1 = E_g Z_2 / Z_1 Z_2 - Z_m^2 \qquad (26)$$

$$I_2 = E_g Z_m / Z_1 Z_2 - Z_m^2 \qquad (27)$$

The driving point impedance sometimes called the input impedance at two specified terminals is the ratio of the voltage to current at the two specified terminals For the input terminals a and b in Fig 4 Eq (26) gives

$$Z_{ab} = \frac{E_g}{I_1} = Z_1 - \frac{Z_m^2}{Z_2} = R_1 + jX_1 - \frac{(j\omega M)^2}{R_2 + jX_2} \qquad (28)$$

$$\text{or} \quad Z_{ab} = \left(R_1 + \frac{\omega^2 M^2 R_2}{R_2^2 + X_2^2}\right) + j\left(X_1 - \frac{\omega^2 M^2 X_2}{R_2^2 + X_2^2}\right) \qquad (29)$$

Equation (29) gives a convenient form for studying the effect of coupling The primary resistance R_1 is increased by the amount $\omega^2 M^2 R_2/(R_2^2 + X_2^2)$ and the primary reactance is modified by the amount $-\omega^2 M^2 X_2/(R_2^2 + X_2^2)$ If the conditions are such that both X_1 and X_2 are of the same type of reactances (as both inductive), then

When $$X_1 - \frac{\omega^2 M^2 X_2}{R_2^2 + X_2^2} = 0 \qquad (30)$$

the net reactance of the primary circuit is zero The primary current $\mathbf{I}_1$ is in phase with $\mathbf{E}_g$ and has the value

$$\mathbf{I}_1 = \frac{\mathbf{E}_g}{R_1 + [\omega^2 M^2 R_2/(R_2^2 + X_2^2)]} \qquad (31)$$

The transfer impedance $\mathbf{Z}_t$ is defined as the ratio of a voltage impressed in one part of a network to a current in another part of the network For the circuit in Fig 4, Eq (27) gives

$$\mathbf{Z}_t = \frac{\mathbf{E}_g}{\mathbf{I}_2} = \frac{\mathbf{Z}_1\mathbf{Z}_2 - \mathbf{Z}_m^2}{\mathbf{Z}_m} \qquad (32)$$

The transfer impedance has the dimensions of impedance because it represents the ratio of a sinusoidal voltage to a sinusoidal current If the transfer impedance for the network in Fig 4 is known (its value depends also on the load impedance in Z_2), the secondary current can be found for a given applied voltage that is

$$\mathbf{I}_2 = \frac{\mathbf{E}_g}{\mathbf{Z}_t} \qquad (33)$$

Equivalent circuit In the analysis and solution of some problems it is convenient to replace an inductively coupled circuit (Fig 5*a*) by an equivalent T section (Fig 5*b*) The two are equivalent in the sense that they are represented by the same loop voltage equations (34) and (35)

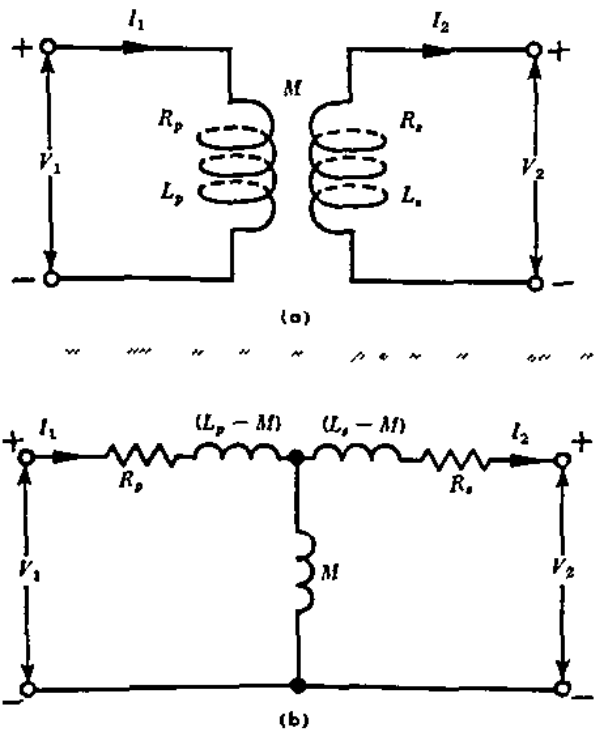


Fig 5 Inductively coupled circuit (*a*) Conventional circuit diagram (*b*) Equivalent T section

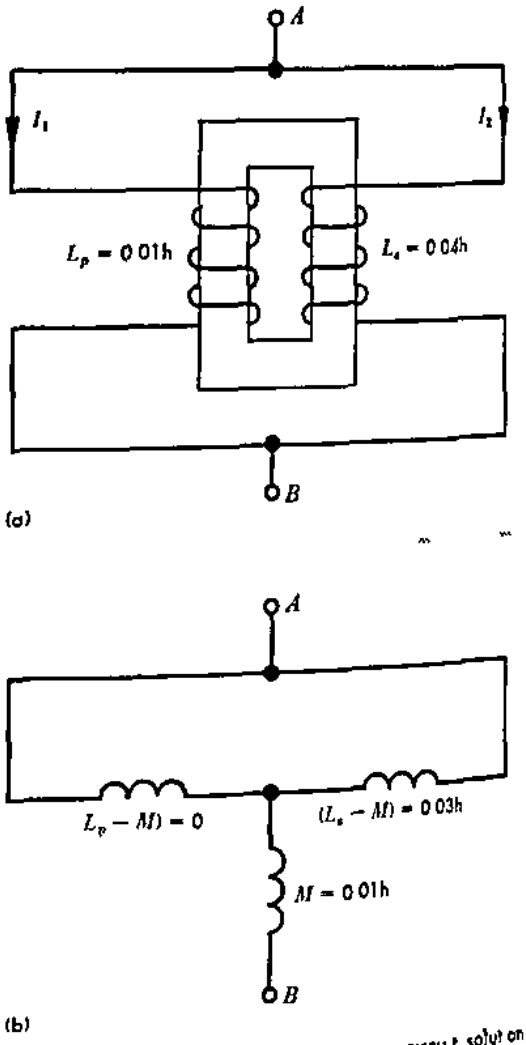


Fig 6 Use of equivalent T section in circuit solution (*a*) Conventional circuit diagram (*b*) Equivalent T section

$$\mathbf{V}_1 = (R_p + j\omega L_p)\mathbf{I}_1 - j\omega M\mathbf{I}_2 \qquad (34)$$
$$-\mathbf{V}_1 = -j\omega M\mathbf{I}_1 + (R_s + j\omega L_s)\mathbf{I}_2 \qquad (35)$$

The use of equivalent T sections for transformers with elements conductively connected together provides a more familiar circuit than an inductively coupled circuit Figure 6*a* shows two coils with negligible resistances The coefficient of coupling k is 0 5 The total inductance between A and B is desired This example illustrates the simplification of solution by the use of the equivalent circuit

The mutual inductance is

$$M = k\sqrt{L_1 L_2} = 0\,5\sqrt{0\,01 \times 0\,04} = 0\,01 \text{ henry}$$

With the aid of Fig 5*b*, the equivalent circuit is shown in Fig 6*b* Since the inductance $(L_p - M)$ = 0, the total inductance between A and B is L_{AB} = 0 01 henry

Equivalent circuit of transformer. Figure 7*a* shows an iron core transformer with a load impedance Z The primary has N_1 turns and the secondary has N_2 turns An equivalent circuit with everything referred to the primary side and neglecting

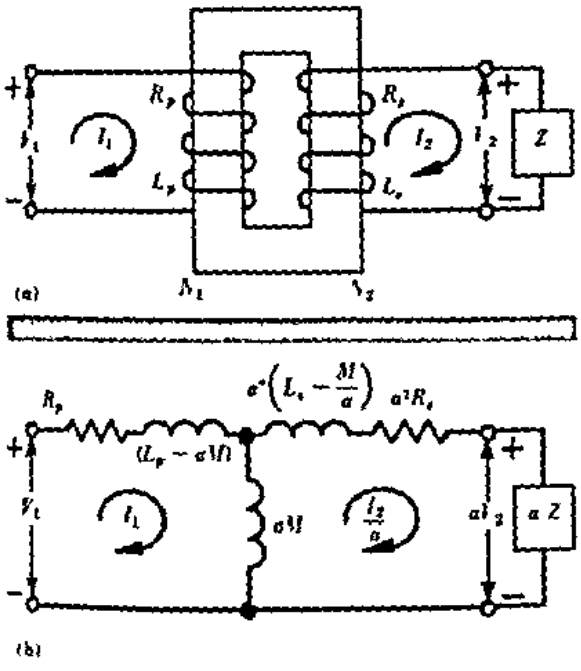


Fig 7 Transformer (a) Convent onal circuit d agram (b) Equ valent circu t

iron losses (iron losses may be included by ex pressing $Z_m = R_m + j\omega M$) is given in Fig 7b They are equivalent in the sense that they have the same loop voltage equations

$$V_1 = (R_p + j\omega L_p)I_1 - j\omega MI_2 \quad (36)$$
$$-V_2 = -j\omega MI_1 + (R_s + j\omega L_s)I_2 \quad (37)$$

The factor a in Fig 7b is necessary to adjust the values of secondary currents voltages and im pedances to the primary circuit For Fig 5b $a = 1$ In the case of good iron core transformers a is usually set equal to the turns ratio N_1/N_2

[K Y T]

Coupling

The mechanical fastening that connects shafts to gether for power transmission often to form long sections of shafting or to connect the shaft of a machine to an external drive Couplings are classi fied with respect to the kind of alignment and the centerline position of the connecting shafts Rigid couplings are used where the axes of the shafts are directly in line flexible couplings where the axes may be at a slight angle and slightly displaced and universal joint couplings for large angularity or large displacement

Rigid coupling The mechanical connection can be rigid for shafts in close alignment or held in alignment without inducing destructive forces in shafts or bearings

For commercial shafting the coupling may be a sleeve with the shafts pressed into each end or it may be a clamping sleeve The sleeve on each shaft end may have an external flange with bolt holes For large power machines shafts are usually forged from billets with flanged couplings shaped integrally on their ends These couplings are bolted together to hold the shafts rigidly hence the shafts must be accurately aligned before assembly

Flange coupling consists of a hub keyed or shrunk to a shaft A larger diameter flange on one end of the hub can be bolted to a mating flange and hub to form a continuous shaft The bolts in the flange are usually countersunk or the flange has a shroud for safety The face of the flange must be checked for trueness on the shaft after assem bly a counterbore fit for a mating projection is necessary to assure alignment of the centers of the two connected shafts The coupling bolts are often fitted into reamed holes in the flanges to distribute the stress when large torques are to be carried

Clamping couplings have split cylindrical ele ments which clamp the shaft ends together by di rect compression through bolts or rings and by the wedge action of conical sections These cou plings are not considered a permanent part of the shaft because they can be removed and reassem bled with hand tools They are generally used on line shafting rather than on the shafting of ma chines

Flexible coupling The mechanical connection for shafts at a slight angle and displaced somewhat and particularly where power machines may set up vibratory forces must be flexible Such couplings are used when alignment is difficult to obtain a nonrigid support makes alignment impossible to maintain or if shaft position changes because of operation

Flexible couplings consist of symmetrical hubs on each end of the joined shafts with a flexible con necting member between This member may take such forms as the floating gear the embedded spring the flexible pin and the flexible disk

Flexible couplings not only provide for lateral and angular misalignment but also reduce the transmission of shock loads and change the vibra tion characteristics and critical speeds of the shafts

Oldham s coupling is the original flexible cou pling and presents the basic principle from which most flexible couplings are derived It consists of two hubs on shaft ends having single radial slots into which fits a floating plate having tongues at right angles on each side This coupling allows kinematic movement to compensate for the lateral displacement of the shafts and also accommodates slight angular misalignment Because the tongues move about in the slots the coupling must be well lubricated and can be used only for low speeds *See* OLDHAM S COUPLING

The geared Fast coupling which is modified from Oldham s uses two interior hubs on the shafts with circumferential gear teeth surrounded by a casing having internal gear teeth to mesh and connect the two hubs Considerable misalignment can be toler ated because the teeth inherently have little inter ference This completely enclosed coupling pro vides means for better lubrication and is thus applicable to higher speeds A similar coupling originated by the Clark Mfg Co and known as the

Clark type consists of a roller chain wrapped around the teeth of two sprockets but it is less ver satile

Spring couplings are flexible couplings with resilient parts The Falk flexible coupling was de veloped by slotting axially the periphery of the two hubs on the shaft ends and threading a continuous steel spring back and forth in hairpin style The Westinghouse Nuttall flexible coupling has a series of coil springs nested tangentially around the flanges of the coupling to transmit torque and al low misalignment in angularity and displacement

Flexible pin couplings use pins as the support for connecting materials between the coupling faces The Ajax flexible coupling has rigid pins from one flange fitting into holes lined with brass bushings and rubber sleeves in the other The Francke coupling uses laminated steel pins be tween the flanges the pins being relatively flexible with one end fixed and the other end free Another coupling uses a leather belt which threads in and out through pins in the flanges to transmit the torque and adjust for misalignment A flexible disk coupling is used between alternate pins on the two flanges to transmit low power it is commonly em ployed on automotive drive shafts The disk may be made of leather or rubber impregnated canvas Most pin couplings have pins set alternately in the two flanges for stability and symmetry They are available in many sizes

Universal joint A flexible coupling for connect ing shafts that have appreciable permanent angu larity is termed a universal joint The initial uni versal joint credited to Robert Hooke was a swivel arrangement by which two pins at right angles al owed complete angular freedom between two con nected shafts However modifications are necessary to transmit constant angular velocity *See* CLUTCH, FLUID COUPLING SHAFTING UNIVERSAL JOINT

[J J R]

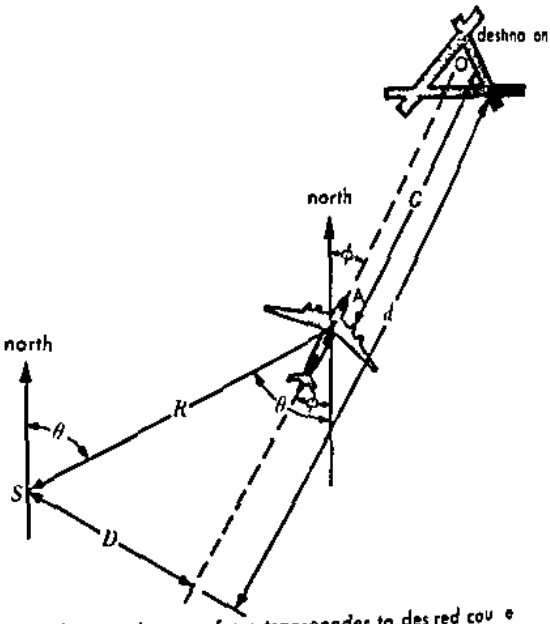
Course line computer

A computer which utilizes positional data obtained from air navigation systems to produce automati cally any straight line course that it is desired to fly within the coverage of the chosen facility

The course line computer utilizing polar coor dinate information is a relatively simple device Two servo driven potentiometers or resolvers de velop voltages which may be compared in a bridge circuit with voltages representing the coordinate of points along the desired course The geometry of this problem is shown in the illustration

With the theta theta computer the problem is more complex since the sources of the two coordi nates are not at the same location The coordinates must be referred to a common reference and re solved before automatic solution is possible

The course line computer operating with hyper bolic data is even more complex It is usually nec essary to resolve the individual readings by digital techniques then convert them to polar coordinates One such computer utilizes the simple expedient of



D—shortest distance from transponder to desired course

R—distance from transponder to aircraft

l—distance from perpendicular to destination

C—distance to go

ϕ—bearing of desired course to destination

θ—aircraft bearing from transponder

The arbitrary-course problem With the facility located at S it is desired to generate courses in any arbitrary direction

printing maps with hyperbolic coordinates Posi tion is indicated on the map by a pen actuated by the output of the hyperbolic line readers Deter mination of the course to be flown is then made by the pilot through the use of a conventional map *See* NAVIGATION SYSTEMS ELECTRONIC. [P C S]

Covellite

A mineral having composition CuS and crystalliz ing in the hexagonal system Tabular hexagonal crystals of covellite are rare, it is usually massive or occurs in disseminations through other copper minerals The luster is metallic and the color indigo blue There is perfect basal cleavage yield ing flexible plates the hardness is 1 5 (Mohs scale), the specific gravity is 4 7 Covellite is a common though not abundant mineral in most cop per deposits It is a supergene mineral and is thus found in the zone of sulfide enrichment as ociated with other copper minerals principally chalcocite chalcopyrite bornite and enargite and is derived by their alteration *See* BORNITE CHALCOCITE CHALCOPYRITE COPPER, ENARGITE [C S H]

Cover crops

Any crop that covers the land for a period of time regardless of its intermediate or ultimate use Two crops crotalaria and the common lupine (bitter blue) are grown only as cover crops because they are toxic to livestock and cannot be used for either hay or grazing (Fig 1)

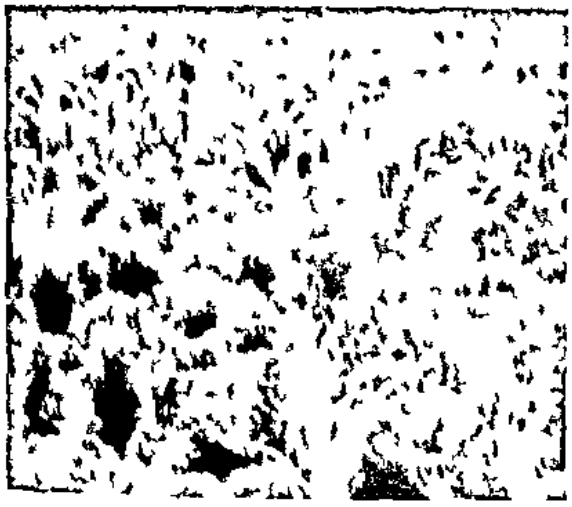


Fig 1 Corn planted in rows in a previously seeded cover crop of blue lupine Soil improvement benefits provided by the lupine subsequently resulted in a significant increase in corn yield (*Soil Conservation Service*)

There are a number of specialized cropping conditions in which grasses sorghums and legumes are used entirely as cover crops and for soil improvement However much larger acreages of small grains annual grasses and legumes that have multiple uses are widely distributed over the southeastern United States Most of these are grazed to some extent cut for hay or harvested for seed With early seeding adequate soil moisture and good fertilization any one or a combination of these uses may be successfully accomplished Under such multiple uses the benefits must be prorated to each use (Fig 2)

Annual winter legumes There is a greatly increasing use of adapted reseeding annual winter legumes for several reasons (1) seed does not have to be bought each year (2) the seeds are in the soil ready to germinate and grow when conditions are favorable (3) no labor or equipment time is required for seedbed preparation and seeding (4) residual fertilizer from the preceding row crop is usually sufficient and (5) lime can be applied at any convenient time as needed

The most widely used reseeding annual winter legumes are caley singleterry or wild winter peas (*Lathyrus hirsutus*) button clover (*Medicago obicularis*) and the vetches Crimson clover is also a widely used winter annual legume In Florida hairy indigo (*Indigofera hirsuta*) is being used successfully as a reseeding annual legume Management must include the termination of grazing prior to seed production to ensure sufficient seed for the next volunteer crop (Fig 3)

The other reseeding winter annual legumes produce a high percentage of hard seed One seed crop every 2 3 years will supply enough hard seed to produce at least two and sometimes three volunteer crops that can be turned under for soil improvement The usual plan consists of planting two or three soil improvement crops to be turned into the soil in preparation for cotton or corn followed by planting of a legume seed crop and finally planting of sorghum sudan or some other short season summer crop for hay or grain

The reliability of volunteer crops from caley peas button clover and vetches is the result of two characteristics the heavy seed crop with a high percentage of hard seed and the size of the seed Caley peas have produced as much as 1 ton of clean seed per acre button clover 500–600 lb of clean seed and vetches 300–500 lb A seed crop can be harvested with assurance that a volunteer crop from the seed will fall to the ground prior to and during the harvesting operations

Farmers are also trying other reseeding annual winter legumes such as ball clover (*Trifolium nigrescens*) and Mike's clover (*T michalianum*) There is a distinct need for other legumes and grasses adapted to the varied soil and climatic conditions in the southeastern states (Fig 4)



Fig 2 Soybeans planted in rows in small grain straw and stubble The straw cover on the soil surface and row furrows laid out on the contour combine to provide an excellent soil and water conservation program (*Soil Conservation Service*)



Fig 3 Hairy indigo volunteering in corn Bahia grass was plowed under in preparing soil for watermelons in spring of 1956 Indigo was seeded in watermelons Corn was planted in 1957 Indigo volunteered as a cover crop in the corn Photo made October 1957 (*Soil Conservation Service*)



Fig 4 Volunteer crop of ball clover, Americus, Georgia April, 1957 (Soil Conservation Service)



Fig 5 Bahia grass turned under in preparing soil for row crops of 1958 Large tonnage of durable crop residue distributed on surface and in plow layer underground (Soil Conservation Service)

Advantages of large seeded legumes The additional plant food found in the larger seeded winter annual legumes enables them to survive more adverse conditions Their habit of producing an upright shoot early helps to get the first true leaves to sunlight through annual weeds or grasses This large seeded characteristic is also a decided advantage when these crops are seeded with adapted perennial summer grasses, such as common Bermuda, Pensacola Bahia, and coastal Bermu cause the add

ally good results have been obtained with larger seeded reseeding winter annual leg used in combination with fescue

Other cover crop combinations. Large ages of perennial grasses, such as Pangola (*taria decumbens*) and Pensacola Bahia (*Pasp notatum* var *Pensacola*) are turned under in p ration for truck crops each year (Fig 5) In is seeded after the truck crops are harvested grass and indigo, if allowed to grow ungr throughout the season, will make a complete co Indigo makes a full seed crop that ensures vo teer stands of the indigo in the grass for a pe of 2–3 years

Effectiveness of cover crops. Early seeding equate fertilization and liming and use of g seed are essential The time of utilization or tu ing determines the total tonnage produced Thi particularly true of the winter annuals A delay 10 days to 2 weeks in the spring will in many ca double the tonnage It also increases the amount nitrogen provided by the legumes for the followi crop The over all effectiveness of the crops f soil improvement is dependent upon the amou and durability of the crop residue produced and i corporated into the soil The adapted perenni grasses and legumes are the best and most econom ical soil improvement crops Field observation throughout the Southeast indicate that 8–12 tons o air dry residue per acre can be expected from turn ing under the adapted perennial grasses A con siderable proportion of this residue is of necessity left on the surface When 2–4 tons of this material are left evenly distributed over each acre of sur face, the infiltration rate of water either by rain fall or applied through irrigation is increased three to four times Such increased infiltration rates can be maintained over longer periods of time Water runoff and soil losses are reduced to a mini mum under such conditions Soil tilth is greatly im proved and crop yields are much higher

The beneficial effects of the adapted perennial grasses can be fully obtained only in two seasons of growth The benefits to both soil and crop yield are very evident for one or two succeeding row crops

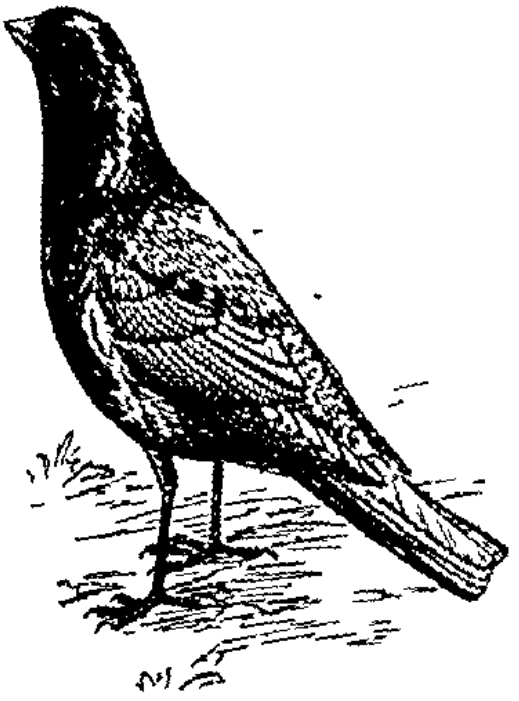
With a combination of adapted reseeding win ter annual legumes and reestablishing adapted per ennial grasses and legumes maximum conservation of soil and economically high yields are ensured

See AGRICULTURAL SOIL AND CROP PRACTICES, GRASS CROPS, LEGUME FORAGES, MANURE, RHIZOSPHERE

[T C M]

Cowbird

Any of several American birds of the family Icteridae, noted for their habit of laying eggs in the nests of other birds Two species are found in the United States Best known is the common cowbird *Molo-*



The cowbird *Molothrus ater* length to 8¼ in (*From* E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

thrus ater which occurs throughout most of the United States The male is the only black bird with a brown head It is further distinguished from the related blackbirds by its smaller size and shorter bill The female is uniformly gray Cowbirds eat both insects and seeds and derive their name from their habit of picking insects from and near cattle *See* PASSERIFORMES [J D B]

Cowpea

A hot weather annual legume of humid climates The stems and leaves are used for livestock forage and cover crops and the seed for food Cowpeas are grown on the poorer soils in the southern half of the United States Many varieties are known, a few with distinctive names but most are grouped according to seed color and shape time of maturity, type of growth and color of pods



Cowpea ducing fruit and seed (*Soil Conservation*

Characteristics and cultivation Cowpeas grow rapidly in hot weather and compete successfully with weeds The earliest varieties mature seed in 6–8 weeks Late varieties do not blossom until the advent of the long nights of autumn Delayed fruiting favors the development of long viny stems which are used for livestock feed

For forage cowpeas seed are sown or drilled at the rate of 1 2 bu of seed per acre either alone or with a small sorghum sudan grass or millet For seed production cowpeas are planted in rows and cultivated Since 1940 cowpeas are no longer planted extensively in corn fields

The acreages annually used for cowpeas have been drastically reduced since 1935 Such crops as soybeans and lespedeza which are better suited for mechanized production have been substituted [P T]

Cowpea diseases Wilt (*Fusarium oxysporum f trachriphilum*) and root knot caused by nematodes (*Meloidogyne* spp) are destructive diseases of cowpeas They are most injurious on sandy soil and often occur together Three parasitic races of the fungus causing wilt are recognized Mississippi Crowder is a vegetable type cowpea highly resistant to Race 1 wilt and tolerant to Races 2 and 3

Bacterial canker (*Xanthomonas vignicola*) attacks the stems and leaves Cowpea varieties that are resistant to canker include Iron Brabham Victor Groit New Era and Brown Sugar Crowder

Numerous leaf spots occur on cowpeas as minor diseases These include zonate spot (*Aristastoma aeconomicum*) target spot (*Corynespora cassiicola*) and bacterial spot (*Cercospora cruenta Phyllosticta phaseolina Cladosporium vignae* and *Pseudomonas syringae*)

Fungi that rot the pods are *Choanephora cucurbitarum* and *Botrytis cinerea*

Diseases that attack the roots and basal portion of the stem are sclerotial blight (*Sclerotium rolfsii*) charcoal rot (*Macrophomina phaseoli*) sore shin (*Rhizoctonia solani*) and cotton root rot (*Phymatotrichum omnivorum*)

Cowpea mosaic a virus disease is characterized by chlorotic leaves and stunted growth It is one of the few plant virus diseases reported to be transmitted by a beetle (*Ceratoma trifurcata*) *See* LEGUME FORAGES PLANT DISEASE [R W J]

Cowper's gland

Two small structures that lie on either side of the membranous urethra in the male mammal. They are also known as bulbourethral glands They contribute a mucoid secretion to the seminal fluid but otherwise their function is unknown

Each gland measures about 4–9 mm in size and gives rise to a 30–40 mm duct which passes through the urogenital triangle to enter the urethra at the base of the penis

In the male embryo the Cowper's glands appear earlier than the prostate in the form of solid epithelial buds They later develop into tubular

grapelike clusters of cells whose secretory activity is most marked during sexual life *See* REPRODUCTIVE SYSTEM [E C ST]

Coxsackie virus

A large group of the enterovirus family It produces various human illnesses, including aseptic meningit[illegible]

[illegible] newborn mice Inapparent infections can be induced in adult mice, chimpanzees, and cynomolgus monkeys. Some strains especially A7 produce severe central nervous system lesions in monkeys Several strains (B1 5 A9) grow well in tissue culture Coxsackie group A and group B viruses differ in their effects on suckling mice, those of group A produce widespread myositis in skeletal muscle whereas group B viruses produce necrosis of embryonic fat pads (brown fat) At least 24 antigenically distinct types in group A are now recognized and five in group B *See* CULTURE TISSUE

After incubation for 2–9 days, during which the virus multiplies in the enteric tract, clinical manifestations appear which vary widely

Diagnosis is by isolation of virus in tissue culture or infant mice Stools are the richest source of virus Neutralizing and complement fixing antibodies form during convalescence and are also useful in diagnosis *See* ANTIBODY, COMPLEMENT FIXATION TEST, NEUTRALIZING ANTIBODY

Coxsackie viruses have world wide distribution Infections occur chiefly during summer and early fall often in epidemic proportions Spread of virus like that of other enteroviruses is associated with family contact and contacts among young children *See* ANIMAL VIRUS [J L M]

Coyote

A predatory carnivore *Canis latrans*, closely related to the dog found from Central America northward throughout the western United States as far as Alaska especially in treeless areas In recent years the coyote has extended its range eastward and has been reported from every state in the United States, although it is not common in the East

The adult is about 4 ft long usually pale brown grizzled with gray and black and has a white belly

Although it has been as diligently hunted as the wolf [illegible] coyo[illegible] carr[illegible] domestic animals They are often erroneously called wolves *See* CARNIVORA [J D B]



The coyote Canis latrans length about 4 ft including tail (From E L Palmer, Fieldbook of Natural History, McGraw Hill 1949)

Crab

Any member of the section Brachyura order Decapoda, class Crustacea phylum Arthropoda Certain species of crab are of considerable economic importance Seven or more species appear in the commercial catch in the United States which has an averag[illegible]

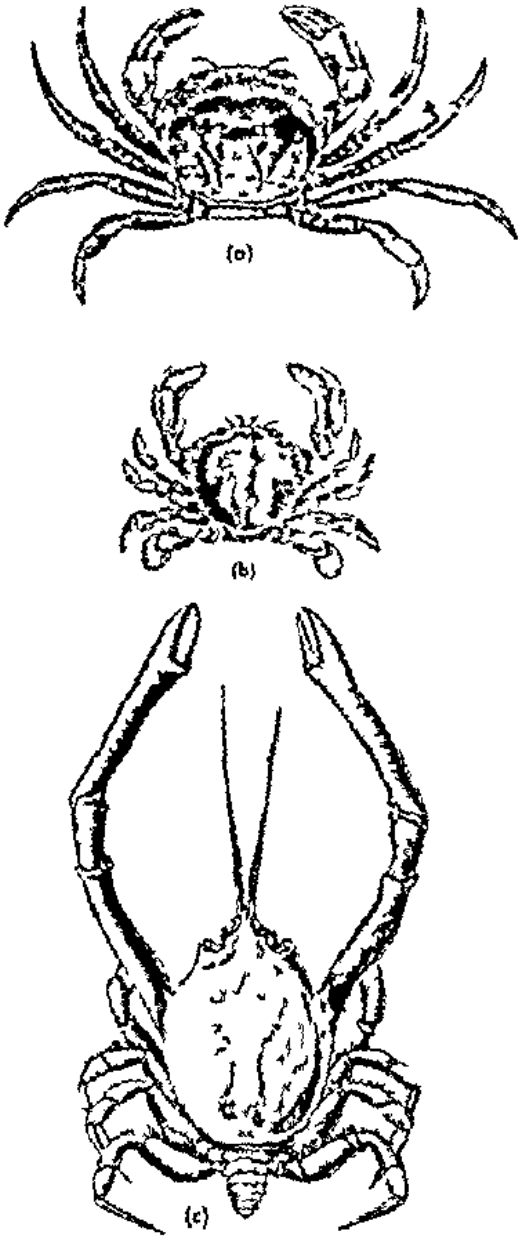
areas and consists almost entirely of one species, the blue crab, *Callinectes sapidus* The principal Pacific species is the Dungeness crab *Cancer magister*, the Alaskan harvest comes chiefly from the Alaskan king crab *Paralithodes camtschatica* Other crabs are important in the food cycles of a host of marine and seashore animals and many are used for fish bait

Crabs are readily distinguished from related animals by the short, broad cephalothorax and small abdomen which is usually bent under the cephalothorax Males have a very narrow abdomen that fits into a groove on the underside of the cephalothorax and has rudimentary appendages. Females have a broader abdomen and four pairs of biramous abdominal appendages which are used to carry the eggs As in the other decapods (crayfish lobsters), there are five pairs of walking legs the first of which is modified into the pincers, or chelipeds In all other fundamental anatomical features, crabs are similar to crayfish

Most crabs are marine although there are fresh water and land forms There is a common fresh water species in southern Europe Several kinds of land crabs live in the tropical and semitropical regions one of which the common land crab of the West Indies and Bermuda *Cardiosoma guanhumi*, has frequently been found in Texas

Blue or soft shelled crab The blue crabs of the Chesapeake Bay area are both soft and hard shelled When the crab molts its new shell is soft for a short time, thus the crab in this stage is known as the soft shelled crab

Blue crabs inhabit salt or brackish water from Cape Cod to South America They live close to shore in the summer, but move to deeper water in winter Average adult males have a carapace about 2½ in long and 6–7 in wide the females are somewhat smaller and have smaller claws. Like most other crabs the blue crab eats both plant and animal food and appears to favor decaying animals



(a) The common shore crab *Carcinus maenas* (b) The swimming crab *Polybius henslow* (c) The masked crab *Corystes cassivelaunus* (From P M Duncan ed Cassell's *Natural History* vol 6 Cassell)

Each summer two lots of 1 000 000–5 000 000 eggs are produced by the female and are carried on the underside of her abdomen until they hatch The free swimming young gradually transform into the adult pattern They require 3 years to reach maturity

The fiddler crab The strange little fiddler crab of the genus *Uca* abounds on all coasts of the United States and is readily identified by the square carapace and the great development of one claw usually the right on the male One Atlantic Coast species *Uca minax* occurs some distance away from salt water and may be found in fresh water

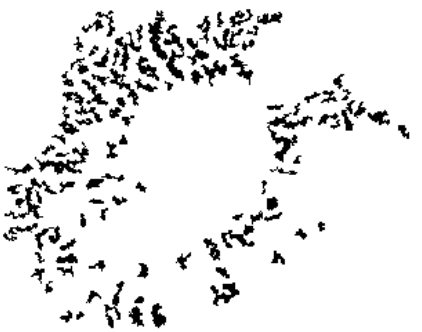
The shell width of most fiddler crabs is less than 2 in These crabs abound at the water's edge and frequently dig burrows where they retire to eat food pellets rolled from organic material The male courts the female with elaborate movements of the claw and with the claw frequently leads a female into a burrow

Hermit crab Hermit crabs *Pagurus* sp are usually less than 1 in long and have a much larger and softer abdomen than other crabs There are about 100 species of hermit crab several of which live in shells of snails in the sea and on land Some dwell in trees Hermit crabs are known for their pugnacity fighting much of the time but retreating quickly into the shell at the approach of larger animals One of the most frequently cited examples of symbiosis is the peculiar relationship between some hermit crabs and sea anemones The anemones attach themselves to the back of the crabs thus providing protection for the crabs while gaining transportation to food in return

King or horseshoe crab The king crab or horseshoe crab *Limulus polyphemus* is not a true crab but belongs to the class Merostomata subclass Xiphosura The carapace is horseshoe-shaped and arched with a wide unsegmented abdomen There are four living species and several fossil forms The telson is prolonged as a spine and there are large movable spines on the carapace There are six pairs of legs on the carapace and six pairs of platelike appendages on the abdomen King crabs can walk on the bottom with the legs and they swim by flapping the abdominal plates They live in shallow water and are found all along the Atlantic Coast of the United States Some attain a length of 2 ft See CRAYFISH DECAPODA (CRUSTACEA) MEROSTOMATA [J D B]

Crab nebula

Formerly classified among the planetary nebulae the Crab nebula is the most remarkable gaseous nebula in the sky (see illustration) It consists of of an amorphous mass which radiates a continuous spectrum surrounded by a mesh of filaments that radiate a bright line spectrum Spectroscopic observations and direct photographs taken over an interval of many years show that the Crab nebula is expanding at a rate of 1150 km sec in the line of sight and 0".235 per year perpendicular to the line



Crab nebula em its strong radio waves

of sight From these data a distance of 1030 *parsecs* was obtained with the result that the dimensions of the nebula are 1 78 × 1 20 parsecs

This nebula has been identified as *the remnant* of a supernova which appeared *in* A D *1054 and* reached an absolute magnitude *of about* −*16* The Crab nebula is a *strong radio-frequency* source whose radiation cannot be produced by a thermal source (*see* RADIO ASTRONOMY) The optical light is polarized and *the only mechanism* that can account for the total emission is *synchrotron* radiation The required magnetic field *is about* 10^{-4} oersted The energy of the electrons *cannot have* been derived from the original explosion or from processes *near a central star* Presumably the electrons are *accelerated* by hydromagnetic waves *within the nebula* The magnetic field of the nebula must be of *the force free type* and the currents are believed to flow in the region of the filaments (*see* MAGNETOHYDRODYNAMICS) The filaments which have a *total mass about 0 1* that of the Sun are presumably low temperature *and high density* regions in an otherwise hot gas [L H A]

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Crabapple

The crabapples of commerce represented by such varieties as *Martha Hyslop* and Transcendent are hybrids *between Malus baccata* (Siberian crabapple) and *Malus domestica* (cultivated apple)

Trees may grow to 40 *ft and* are especially hardy At one time the fruit of the crabapple was esteemed *because of* its high pectin content and its usefulness in *jam and jelly* manufacture (*see* PECTIN) With *the introduction* of commercial pectin preparations demand for *the crabapple* has declined sharply Except for its use as a pickled product there *is little commercial* interest in this fruit

Twenty or more species *of Oriental flowering* crabapples *some of* which produce edible fruit of indifferent quality are *listed* by nurserymen *See* APPLE FRUIT (BOTANY) FRUIT (TREE) FRUIT (TREE) DISEASES [H B T]

Cracking

thermal or by catalytic methods As *a result* of the increased demand for gasoline *and intermediates* relative to that for heavier fractions cracking *processes* have become of major importance in the economic utilization of petroleum

Thermal cracking *This is a* process in which carbon-to-carbon bonds are severed by *the action* of heat alone It consists essentially in the heating of any fraction of petroleum to a temperature at which substantial thermal *decomposition* takes *place followed by* the cooling condensation and physical separation of the reaction products Although many variations have been invented in most common practice a feedstock boiling higher than gasoline is pumped at inlet pressures of 75–*1000* psig through steel tubes so placed in a furnace as to allow gradual heating of the oil to temperatures in the range of 800–1050°F The flow rate is controlled to provide sufficient time for the required cracking to lighter products to take place the time may be extended by subsequently passing the hot products through a reaction chamber that is maintained at a high temperature To achieve optimum process efficiency part of the overhead product boiling higher than gasoline ordinarily is returned to the cracking unit to recycle for further cracking (see Fig 1)

Crude oils differ in their compositions both in molecular weight and molecular type of hydrocarbon As refiners must make products in harmony with market demand they often need to alter the molecular structure of the hydrocarbons The

tic heating oils as well as [illegible] weight olefins needed for the manufacture of synthetic gasolines chemicals and polymers

Beginning in 1912 thermal cracking proved for many years to be eminently suitable for this purpose During the period 1920-1940 more efficient automobile engines of higher compression ratios were developed These engines required higher octane number gasolines and thermal cracking operations in the United States were expanded to meet this need Advantageously thermal cracking reactions produce olefins and aromatics leading to gasolines generally of higher octane number than those obtained by simple distillation of the corresponding crude oils The general nature of the hydrocarbon products and the basic mechanism of thermal cracking is well described by the free radical theory of the pyrolysis of hydrocarbons. *See* PYROLYSIS

In the early 1930s the petrochemical industry began its growth olefinic gases from thermal cracking operations especially propylene and butylenes were used as the chief raw materials for the production of aliphatic chemicals Simultane-

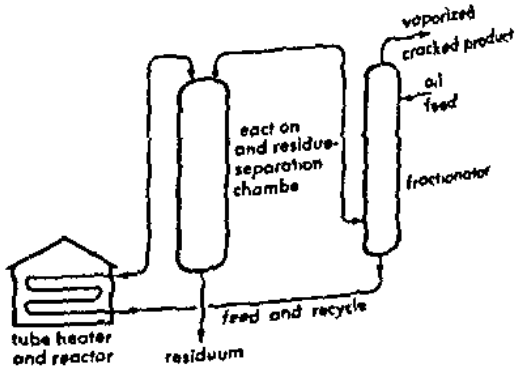


Fig 1 Thermal cracking unit

ou ly practical catalytic processes were invented for polymerizing propylene and butylenes to gaso line components and for dimerizing and hydroge nating isobutylene to 'isooctane' (2 2 4 trimethyl pentane) the prototype 100-octane fuel Just prior World War II the alkylation of light olefins ith isoparaffins to produce unusually high octane soline components was discovered and exten ely applied for military aviation use These de lopments resulted in intense engineering efforts bring thermal cracking operations to maximum ficiency as exemplified by a number of commer al processes made available to the industry

However since World War II, thermal cracking s been largely supplanted by catalytic cracking th for the manufacture of high octane gasoline d as a source of light olefins It is still used dely for the mild cracking of heavy residues to duce their viscosities and for a final cracking of e oils derived from catalytic cracking

Concurrently with cracking reactions which ver carbon to carbon bonds polymerization and articularly condensation reactions take place rming new carbon to-carbon bonds via free radi l mechanisms This results in the production of gher molecular weight hydrocarbons represented heavy cracked residual oils and ultimately coke hese reactions frequently accompanied by loss of drogen cannot be avoided in thermal cracking owever by selection of operating conditions and quipment the refiner can exercise a choice be ween the production of a liquid residue or of solid ke

Since carbon to hydrogen bonds are also severed the course of thermal cracking two hydrogen oms can be removed from adjacent carbon atoms a saturated hydrocarbon producing molecular drogen and an olefin This reaction prevails in hane and propane cracking to yield ethylene and opylene respectively Methane cracking is a que case wherein molecular hydrogen is ob ned as a primary product and carbon as a co-oduct. These processes generally operate at low essures and high temperatures and in some cases ze regenerative heating chambers lined with ebrick or equipment through which preheated fractory pebbles continuously flow Such condi ons also favor the production of aromatics and olefins from normally liquid feedstocks and are plied commercially to a limited extent despite latively low yields of the desired products

Catalytic cracking This is the major process ed throughout most of the world oil industry for e production of high octane quality gasoline by e conversion of intermediate and heavy petroleum illates to lower molecular weight products Oil ated to within the lower range of thermal crack g temperatures (850–1025°F) reacts in the pres ce of an acidic inorganic catalyst under low pres ures (10–25 psig) The catalyst induces a mode of drocarbon decomposition differing considerably om that of thermal cracking and which greatly ters the relative proportions of the individual hydrocarbons making up the cracked products A gasoline of much higher octane number is obtained a principal reason for the widespread adoption of catalytic cracking All nonvolatile carbonaceous materials are deposited on the catalyst as coke and are burned off during catalyst regeneration the only product boiling above gasoline is gas oil

In contrast with thermal cracking residual oils normally cannot be processed as much more coke is deposited on the catalyst and inorganic compo nents of these oils will contaminate the catalyst Feed tocks usually are restricted to distillates boil ing above gasoline however limited operations on residual feeds are practiced especially with the use of modified catalysts

Catalytic cracking as conceived by Eugene J Houdry in France reached commercial status in 1936 after extensive engineering development by American oil companies In its first form the proc ess used a series of fixed beds of catalyst in large steel cases Each of these alternated between oil cracking and catalyst coke burning at intervals of about 10 min and had suitable provision for heat and temperature control

Successful operation led to major engineering developments and the goals of much improved efficiency enlarged capacity and ease of operation were achieved by two different systems One em ploys a moving bed of small catalyst pellets or beads traveling continuously through the oil crack ing vessel and subsequently through a regeneration kiln this process has two commercially engineered embodiments the Thermofor (TCC) and the Hou driflow processes which are similar in general proc ess arrangements (see Fig 2) In the other system called the Fluid catalytic cracking process a finely divided powder catalyst is transported between oil cracking and air regeneration vessels in a fluidized state by gaseous streams in a continuous cycle This system employs the principle of balanced hydrostatic heads of fluidized catalyst between the two vessels Catalyst is moved by injecting heated oil vapors into the transport line from the regen erator to the reactor and by injecting air into the transport line from the reactor stripper to the re

In both the moving bed and fluidized systems the circulating catalyst provides the primary source of heat for the cracking reaction The coke de-posited on the catalyst during cracking is burned at controlled air rates during regeneration the heat of combustion is converted in large part to sensible heat of the catalyst which in turn supplies the endothermic heat of cracking in the reaction vessel

Gasoline of 90–95 research octane number with out lead is rather uniformly produced by catalytic cracking of fractions from a wide variety of crude oils, compared with 65–80 research octane number via thermal cracking the latter figures varying with crude oil source About 1955 the demand for

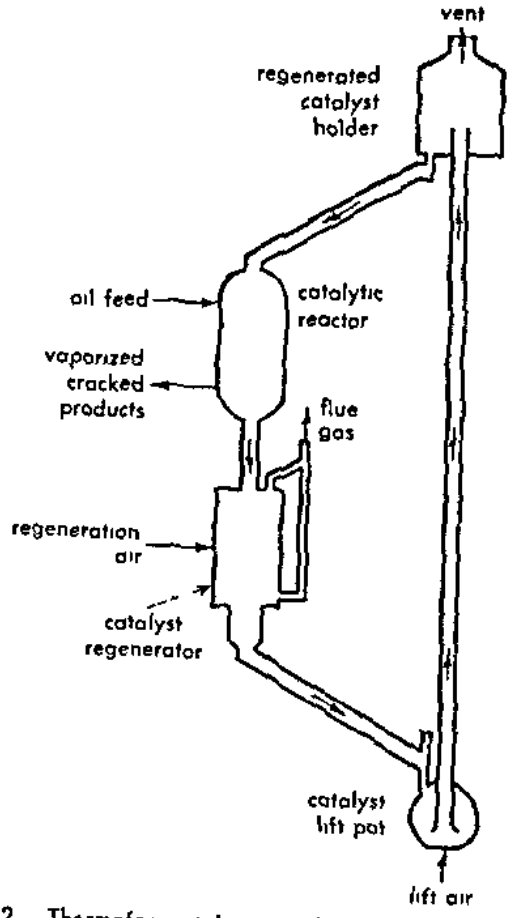


Fig 2 Thermofor catalytic cracking unit

very high octane rating gasolines for American automobile engines reached the point that octane quality required augmentation by the catalytic reforming of straight run gasolines, consequently, gasoline from catalytic cracking is no longer the controlling component in the manufacture of high octane motor fuel

The primary objective of catalytic cracking is the production of maximum yields of gasoline concordant with efficient operation of the process At the same time large amounts of normally gaseous hydrocarbons are produced including propylene and butylenes, which are in great demand for the same purposes as specified in the case of thermal cracking Isobutane and isopentane are also produced in large quantities and are valuable for the alkylation of olefins as well as for directly blending into gasoline as high octane components

The other chief product is the material boiling above gasoline designated as catalytically cracked gas oil It [illegible] ant to fur [illegible] aromatics [illegible] or blended with straight run and thermally cracked distillates of the same boiling range for use as diesel and heating oils Part of the heavier portion is recycled with fresh feedstock to obtain additional conversion to lighter products The remainder is withdrawn for use as a cutter stock for blending with residual oils to reduce viscosity, or else subjected to a final step of thermal cracking

To account for the differences between the product composition obtained by catalytic and thermal cracking, the mechanism of cracking over acidic catalysts has been investigated intensively In thermal cracking, free radicals are reaction intermediates, and the products are determined by their specific decomposition patterns In contrast, catalytic cracking takes place through ionic intermediates designated as carbonium ions (positively charged free radicals) generated at the catalyst surface Although there is a certain parallelism between the modes of cracking of free radicals and carbonium ions, the latter undergo rapid intramolecular rearrangement reactions prior to cracking This leads to more-highly branched hydrocarbon structures than those from thermal cracking and to important differences in the molecular weight distribution of the cracked products Furthermore the cracked products undergo much more extensive secondary reactions in the presence of the catalyst

The catalytic cracking mechanism also favors the production of aromatics in the gasoline boiling range, these reach quite high concentrations in the higher boiling portion This characteristic together with the copious production of branched aliphatic hydrocarbons especially in the lower boiling portion, is largely responsible for the high octane rating of catalytically cracked gasoline

Cracking catalysts must have two essential properties (1) a chemical composition capable of maintaining a high degree of acidity preferably as readily available hydrogen ions (protons) and (2) a physical structure of high porosity (high surface area) Mechanical durability is also necessary for industrial use The catalysts most commonly employed commercially are synthetic silica alumina gels, and natural clays of the montmorillonite or kaolinite groups that have been treated with inorganic acids During use these catalysts gradually lose their porosity, are contaminated by trace metallic constituents present in most feed

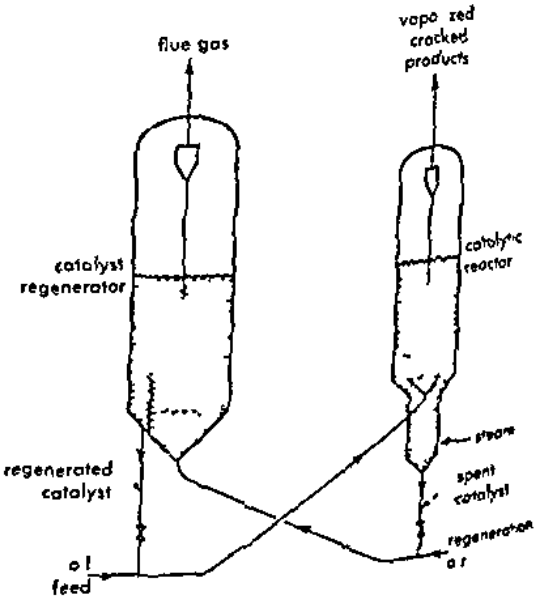


Fig 3 Fluid catalytic cracking unit

stocks, and undergo mechanical attrition To compensate fresh catalyst is added and part of the total catalyst in the unit is withdrawn at periodic intervals, thereby maintaining the quality of the catalyst at a steady level *See* ALKYLATION AROMATIZATION ISOMERIZATION PETROLEUM PROCESSING REFORMING (PETROLEUM REFINING) TUBE STILL HEATER [B S G]

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anberry

: cultivated cranberry *Vaccinium macrocarpon* the plant order Ericales a native of the bogs northeastern North America Two related spe s with smaller fruit occur across the northern t of the United States as well as in Europe and a. The latter are trailing woody evergreen es, growing naturally in peat bogs

Cranberry roots which lack root hairs will live merged in water for an extended period which kes possible the common practice of flooding to e ent winter injury and frost damage and to ntrol certain insects and weeds In the Northwest e m lder winters make protection by flooding un cessary and sprinklers provide irrigation as well effect ve protection against both frost and high mmer temperature

Propagation The cranberry is propagated by t ngs Prunings are scattered over the ground nd disked or punched in by hand The prunings en produce roots and develop into a commercial rop Cranberry bogs or marshes are carefully laid ut on the level with ditches designed to provide lood water if needed or to drain off excess water n important cultural factor is the use of 2–3 in f sand over the peat The sand restricts weed growth and prevents heaving of the substrate dur ng frosty periods cracking of the soil during dry ea her and rapid radiation of heat which results o less damage from frost on sanded bogs It is cus omary to resand by applying an additional ½ in every 3 years

The important cranberry producing states are Ma sa husetts Wisconsin Washington New Jer sey and Oregon with a few plantings in other northeastern states Annual production frequently exceeds 100 000 000 lb In 1956 the value of the cra berry crop was $10 121 000

Harvesting In the eastern states harvesting is done with toothed scoops which comb the berries from the vines In Wisconsin the bogs are flooded the berries then float facilitating scooping and re ult ng in less waste of fruit On the West Coast one type of picking machine operated on dry v nes, combs the berries loose and delivers them nto a box Another reel type machine scrapes the berr es from flooded vines after which they are floa ed to a central point and scooped into boxes

Few cranberries are consumed as raw fruit The major part of the crop is home cooked or processed into cranberry sauce Commercial plantings may be productive almost indefinitely some have been in production for 100 years Unlike the other berry crops cranberries are not adapted to the home garden *See* ERICALES FRUIT GROWING (SMALL) [J H CE]



Cranberry *Vaccinium macrocarpon*

Crane (zoology)

Any of 14 different species of the family Gruidae A single genus with two species occurs in the United States



The sandhill crane *Grus canadensis* length to 4 ft (From E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

Among the rarest of all living birds is the whooping crane *Grus americanus* At no time in recent years have as many as 50 individuals been known and this remnant has survived only because they are under the strictest protection They nest in summer in remote parts of western Canada and winter near Aransas Texas

Because of its more extensive Holarctic breeding range the sandhill crane *Grus canadensis* has maintained its population fairly well

In many localities herons and egrets are called cranes *See* CICONIIFORMES HERON [J D B]

Crane hoist

A mobile construction machine built principally for lifting loads by means of cables A crane hoist consists of three principal elements (1) an undercarriage on which the unit moves (2) a cab or house which envelops the main frame and which contains the power units and controls and (3) a movable boom over which the cables run and to which miscellaneous working attachments are connected (*see* EXCAVATOR) A crane is usually typed according to its undercarriage

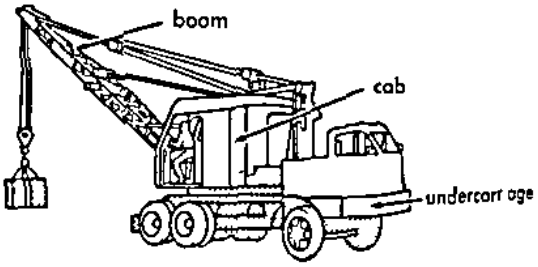
The crawler crane is a self propelled unit mounted on continuous tracks similar to those on army tanks This crane is ideally suited for work on soft ground where wide distribution of weight is more important than rapid mobility

The truck crane is a unit consisting of a crane house and boom mounted on a truck chassis as illustrated Originally assembled by contractors from crawler crane and truck parts the truck crane has for years been manufactured and sold as a unit Although the truck crane is difficult to move on soft or slippery ground it is highly mobile on a firm footing and is easily moved over roads and highways

The wheeled crane is a recently developed modification of the mobile cranes of the early 1900s Whereas the early machines were towed about on steel wheels the modern wheeled crane is self propelled and rides on a rubber tired chassis that is an integral part of the unit Power for transport is provided by the same engine that is used for hoisting and the wheels are controlled from the crane cab

The rail or locomotive crane is mounted on a railroad flat car or a special chassis with flanged wheels for use on standard or special gage tracks Rail cranes may be of either the towed type or self propelled For transport over long distances both types are pulled by locomotives often as part of a freight train

The floating crane has a barge or scow for an undercarriage It is used for water work and for work on waterfronts and generally lacks its own motive power being towed from place to place by tug boats On a job site it is moved short distances by means of cables attached to anchors set some distance off the four corners of the barge Most floating cranes are powered by steam For the land cranes however in which size and weight are prime

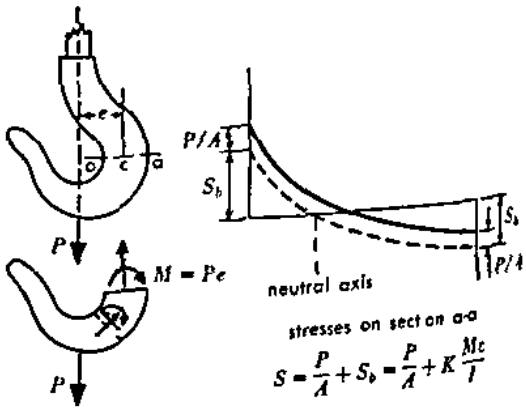


Typical truck crane (*Link Belt Co*)

considerations in over the road transport power is usually supplied by internal combustion engine operating on either gasoline or diesel fuel Cranes used exclusively for pile driving are however frequently driven by steam or air *See* HOISTING MACHINES [E M Y]

Crane hook

A hoisting fixture designed to engage a ring or link of a lifting chain or the pin of a shackle or cable socket The critical section is normal to the load line and is subjected to combined normal force and bending moment Assuming uniformly distributed normal force the stress at any point is found by adding the normal stress to the bending stresses computed by Winkler s formula or the corrected straight beam relation (Fig 1) For well-designed



P = load
e = eccentricity to centroid of section a-a
A = area of section a-a
M = moment
I = moment of inertia of section a-a about axis through centroid
S = stress
K = coefficient of end restraint
c = distance from centroid to extreme fiber on tension side
$S_b = K\frac{Mc}{I}$

Fig 1 Crane hooks

sections the maximum tensile and compressive stresses would be nearly the same Hooks used for light loads as on sheave blocks for fiber rope are usually made of circular stock *See* CURVED BAR

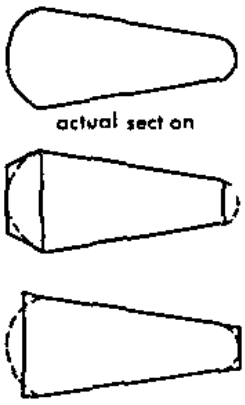


Fig 2 Approximations to shape of a crane hook

Crane hooks have a small radius of curvature and a trapezoidal section that is rounded at the inside and outside surfaces by circular arcs (Fig 2) Bending stresses are greatest at the concave boundary of the hook the section is made wider on the inside Although stresses can be found by integration they are more conveniently determined with sufficient accuracy by approximating the section with a circumscribed or averaging trapezoid

[W J KR]

Cranial nerve

Any one of the twelve pairs of nerves which arise in the brain stem of reptiles birds and mammals and pass to peripheral structures through openings or foramina in the skull Nerves XI and XII are not found in cyclostomes fish or amphibians They are traditionally numbered by Roman numerals I to XII even though one is not a true nerve and others are composite in structure

Olfactory nerve The olfactory nerve (I) is actually a group of about twenty small olfactory cells which lie in the respiratory mucosa in the roof of the nose Their fibers pass upward through the ethmoid bone and synapse with the secondary neurons of the olfactory bulbs The special sense of smell is thus transmitted to olfactory centers primarily in the forebrain where appropriate relays are established with other centers

Optic nerve The optic nerve (II) consists of three layers of special nerve cells in the retina of the eye The deepest layer consists of light sensitive rods and cones the middle layer of bipolar cells while the most superficial layer is composed of ganglion cells Fibers from the last layer converge to form the optic tracts which pass back to the brain through openings in the posterior portions of each orbit

Oculomotor nerve The oculomotor nerve (III) is composed primarily of motor fibers which innervate four of the six muscles of the eyeball namely the superior inferior and medial rectus and the inferior oblique In addition this nerve furnishes autonomic fibers to the ciliary and pupillary sphincter muscles within the eye

Trochlear nerve The trochlear nerve (IV) supplies motor innervation to the superior oblique muscle of the eyeball

Trigeminal nerve The trigeminal nerve (V) is composite that is both sensory and motor fibers occur Its three great branches the ophthalmic maxillary and mandibular nerves indicate the areas from which sensory impulses are received in response to heat pain touch and so forth These branches enter the skull through foramina to converge on the trigeminal or semilunar ganglion which contains the cell bodies of these sensory fibers Secondary fibers pass impulses into the brain to appropriate sensory centers

The second portion of the trigeminal consists of motor fibers which innervate the muscles of mastication Although it is anatomically distinct and functionally different from the trigeminal nerve in its early course from the pons these motor fibers later blend with the sensory fibers of the mandibular nerve between the ganglion and the muscles of mastication

Abducens nerve The abducens nerve (VI) is primarily motor and supplies fibers to the lateral rectus muscle of the eyeball It has a particularly long and tortuous course both in the skull and in the orbit and is therefore subject to more damage from disease or injury Loss of function produces the inability to turn the eye laterally It should be noted that there is an intricate relationship between the oculomotor trochlear and abducens nerves as well as other brain centers which permit the complex movements of the eyeballs

Facial nerve The facial nerve (VII) is a composite nerve The motor elements are special in that they supply all the muscles of expression from the scalp to the subcutaneous platysma muscle of the neck region Damage to these motor components produces a wide range of visible loss of function including the familiar facial or Bell's

Cranial nerves in vertebrates

Number	Name	Origin	Function
I	Olfactory	Olfactory lobe	Sensory
II	Optic	Optic lobe	Sensory
III	Oculomotor	Floor of mid brain	Motor
IV	Trochlear	Floor of mid brain	Motor
V	Trigeminal	Side of *medulla*	Mixed
VI	Abducens	Side of medulla	Motor
VII	Facial	Side and floor *of medulla*	Mixed
VIII	Aud tory (acoust c)	Side of medulla	Sensory
IX	Glossopharyngeal	Side of medulla	Mixed
X	Vagus (pneumogastric)	Side and floor of medulla	Mixed
XI	Accessory	Floor of medulla	Motor
XII	Hypoglossal	Floor of medulla	Motor

Special sensory fibers of the facial nerve receive impulses from the taste buds of the anterior two thirds of the tongue

The facial nerve also includes autonomic fibers which innervate the lacrimal submaxillary and sublingual glands

Auditory nerve The auditory or acoustic nerve (VIII) is composed of two major sets of nerve fibers Those of the cochlear nerve are sensory for hearing originating in the spiral ganglia of the inner ear The other set comprise the vestibular nerve also sensory which receives impulses from the semicircular canals of the ear thus playing a role in the maintenance of equilibrium

Glossopharyngeal nerve The glossopharyngeal nerve (IX) is mixed and contains both sensory and motor components It supplies autonomic innervation to the parotid gland and also contains special sensory fibers for the perception of taste from the posterior one third of the tongue In addition other general sensory fibers from the region of the upper pharynx are carried by this mixed nerve

Vagus nerve The vagus nerve (X) has both sensory and motor fibers Some of the important structures supplied with motor fibers include the larynx pharynx trachea heart stomach small intestine liver pancreas and kidneys as well as the [illegible]

well as a few taste fibers from the back of the tongue

Accessory nerve The accessory nerve (XI) is purely motor but consists of two parts the spinal and the accessory portions The spinal portions emerge from the upper segments of the spinal cord enter the skull through the base of the brain and then leave again They pass outward through the jugular foramen to innervate the sternomastoid and trapezius muscles of the neck The accessory portion indicates an area where the nerve is temporarily joined by fibers from the vagus which then rejoin the vagus after the accessory nerve leaves the skull

Hypoglossal nerve The hypoglossal nerve (XII) is motor to the muscles of the tongue and damage is reflected in paralysis to one or both sides depending on the extent of the injury

Other components Other components for certain of the cranial nerves have been described but in most cases are either unimportant or not accepted by everyone The cranial nerves to a large extent are analogous to the spinal nerves in their general arrangement

Although the courses of the cranial nerves have been extensively studied outside the brain their connections and interrelationships within the brain have defied complete analysis These central connections are fairly well mapped in certain cases [illegible]

nuclei to reflex patterns and projection to higher centers of motor or sensory regulation and recognition *See* NERVOUS SYSTEM [EGST]

Craniata

A major subdivision of phylum Chordata comprising the vertebrates the cyclostomes to mammals Its most distinctive characteristic is the cranium, or brain box that houses the brain A column of separate articulated vertebrae not present in myxinoids and hardly represented in petromyzontids extends from the cranium to the end of the tail supporting the body and sheltering the nerve cord within neural arches on the vertebrae Adjacent to the cranium is a series of paired visceral arches that support the gill region of aquatic vertebrates [illegible]

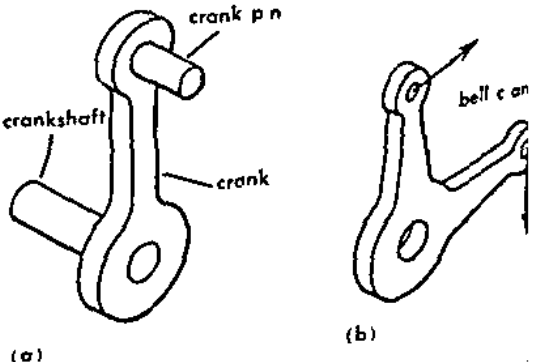
of the larynx in mammals [ITS]

Cranium

That portion of the skull which encloses the brain The cranium is also known as the brain case The cranium of cyclostomes and elasmobranchs is cartilaginous The cartilaginous cranium (chondrocranium) has no differentiating structures such as sutures and is a single structure The cartilaginous cranium is replaced by bones in the higher vertebrates The bones comprising the adult cranium vary in number among the various groups of vertebrates as well as within the groups There is a reduction in the number of bones from fish to mammals with eight bones comprising the human cranium These are the occipital two parietals the frontal two temporals the ethmoid and the sphenoid [EGST]

Crank

In a mechanical linkage or mechanism a crank is a link that can turn about a center of rotation The crank's center of rotation is in the pivot usually the axis of a crankshaft that connects the crank to an adjacent link A crank is arranged for complete rotation (360°) about its center how



Cranks (a) for changing radius of rotation and (b) changing direction of translation

ever, it may oscillate or have intermittent motion A bell crank is frequently used to change direction of motion in a linkage [ESF]

Crappie

Either of two species of North American freshwater sunfishes of the family Centrarchidae, the black crappie, *Pomoxis nigromaculatus*, and the white crappie, *Pomoxis annularis* These similar



The black crappie, *Pomoxis nigromaculatus*, length to 1 ft (*From E L Palmer, Fieldbook of Natural History* McGraw Hill 1949)

species are silvery olive fish, marked with many irregular green to blackish spots, typically paler and arranged in vertical bars in the latter species Crappies are highly prolific and voracious fish which, when they become established in ponds and small lakes frequently crowd out more desirable species They are fair food fish and provide considerable sport to anglers *See* PERCIFORMES

[JDB]

Crayfish

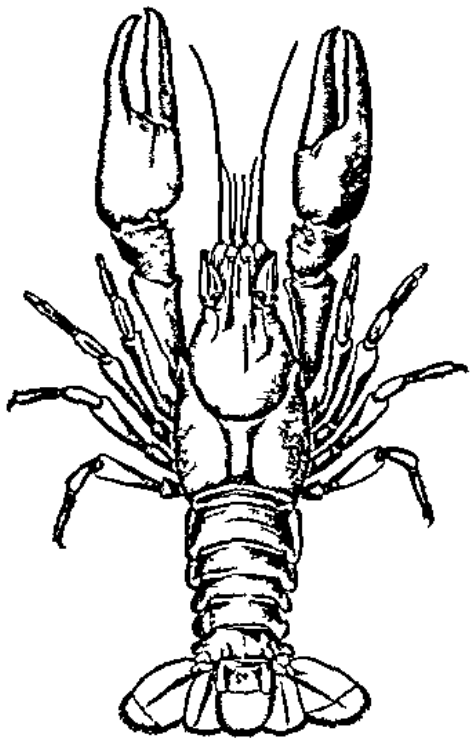
Any member of the family Astacidae, order Decapoda class Crustacea phylum Arthropoda Crayfish are locally known by a variety of names most common of which are crawfish crawdad and crawdaddy In a few localities they are called crabs

Distribution. The crayfishes are found in fresh water over much of the Northern Hemisphere There are 135 different species in North America *as well as numerous subspecies The subfamily* Astacinae, represented by 5 species of the genus *Astacus*, all occur west of the Continental Divide, except for one which ranges eastward into the upper Missouri River basin The subfamily Cambarinae abounds east of the Rocky Mountains and has 130 recognized species and many subspecies Best known is the large genus *Cambarus*

A number of species of crayfish dwell in caves, especially in the southern United States These animals are without pigment and are blind They are also smaller than the other species, have reduced pincers, and slender bodies and antennae The antennae and other appendages are highly modified as tactile organs

Importance. Crayfish are of great importance in the aquatic food chain, being utilized as a [illegible] food by many fishes They are the preferred food of such important fishes as the smallmouth bass, yellow perch, and rock bass They are also the primary food of the snapping turtle and a favorite of the raccoon Crayfish are used extensively for fish bait In the vicinity of New Orleans they are also used for human food in substantial quantities, but elsewhere are of no particular importance as a food animal They are marketed by the thousands for study as a type species of the Arthropoda and used in nearly all introductory biology and zoology classes in high schools and colleges

Characteristics. Crayfish show well the chitinous exoskeleton, jointed paired appendages, and hemocoel characteristic of the phylum Arthropoda The head and thorax are fused into a single piece, the cephalothorax The distinctly segmented abdomen is divided into 6 somites and terminates in a flattened piece, the telson which with the modified last pair of appendages (uropods), forms an effective swimming organ Each segment (5 in the head, 8 in the thorax, and 6 in the abdomen) bears a pair of appendages modified from the primitive biramous or two-branched pattern There are 2 pairs of antennae, the smaller anterior pair is usually called antennules These are followed by the chewing mandibles, 2 pairs of wafer thin maxillae, and 3 pairs of maxillipeds for food handling Posterior to the maxillipeds are the chelipeds, or pincers, and 4 pairs of more generalized walking legs. On the abdomen are 5 pairs of swimmerets, followed



Crayfish, *Cambarus bartoni*, length 1–5 in (*From E L Palmer, Fieldbook of Natural History, McGraw Hill, 1940*)

by the uropods The first 2 pairs of swimmerets are modified as a copulatory organ in the male and as egg carrying devices in the female The last three pairs of swimmerets are close to the primitive pattern for the appendages The modification of the crayfish appendages is an often cited example of serial homology showing how the basically simple primitive structure has become serially modified into many forms for different purposes

Opposing sets of muscles the extensors and flexors control the body movements and the appendages They are especially powerful in the abdomen where they make up the bulk of the section

The digestive system The mouth is followed by a short esophagus leading into a large stomach The stomach is subdivided into a large cardiac portion and a smaller pyloric region The cardiac stomach contains the gastric mill where 2 lateral teeth and 1 medial calcified tooth work together to grind the food The intestine is straight and simple opening into the ventral anus A simple pair of digestive glands sometimes called livers open by separate ducts off the midgut

Food consists of almost any available plant or animal such as insects worms snails algae and rooted plants When present in small ponds in abundance they can be destructive to rooted plants through cutting them down and to all other life through muddying the water

Excretion is accomplished by a pair of green glands lying near the base of the second pair of antennae and opening by means of pores through the basal segment of that appendage

The nervous system The nervous system consists of a dorsal brain or supraesophageal ganglion connected with a ventral subesophageal ganglion by a pair of nerves the circumesophageal connectives and a double ventral nerve cord with segmental ganglia giving off branches at each segment In addition there is a visceral nervous system arising from the brain and circumesophageal connectives to supply the pyloric stomach and adjacent visceral organs

The circulatory system The circulatory system is of the open or hemocoelic type the blood is pumped from a dorsal heart to 7 arteries which distribute blood throughout the body There are no veins but rather blood spaces the blood entering the heart through 3 pairs of slits or ostia

The respiratory system Respiration is accomplished by a series of gills arranged in 2 rows (3 in *Astacus*) on either side of the cephalothorax and covered by a hinged plate the branchiostegite Water enters the respiratory chamber from the rear and is moved by the rowing action of the bailer a modification of the second maxilla

Sexual reproduction Sexes are separate The

hatch in 5–6 weeks into young resembling the adult They remain attached to the mother for several more weeks or until they have started their first molt The young molt several times in the first season and generally reach a length of about 2 in by the time they are 1 year old Crayfish usually live 3 5 years

Like all other arthropods the molting process properly called ecdysis is a critical period The entire exoskeleton down to the finest detail is shed at this time The freshly molted animal is the vulnerable soft shell stage so much favored for fish bait but the new exoskeleton hardens into the typical hard covering in a few hours All growth must take place during the soft shell interval *See* DECAPODA (CRUSTACEA) [J.D.B]

Creatine creatinine

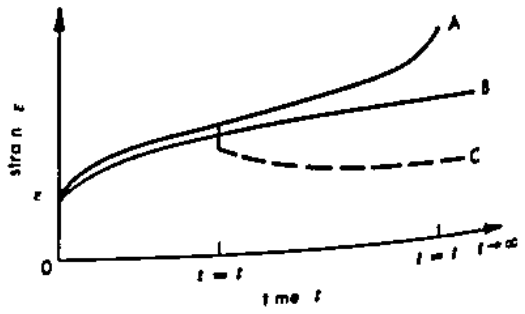
An important nitrogenous extractive of muscle Creatine is formed from the amino acid glycine to which the amidine group of arginine and the methyl group of methionine have been added Ninety eight per cent of the creatine in the body occurs in muscle mainly as the phosphate in which form it has a significant physiological function Its only known metabolic transformation is a nonenzymatic irreversible conversion to creatinine its cyclic anhydride Creatinine is excreted in urine at a very constant rate in normal adults in proportion to the total amount of creatine in the body the daily turnover rate of which is about 1 6% *See* AMINO ACIDS MUSCULAR SYSTEM URINE [H.H.M.]

Creep of materials

A time dependent strain of solids caused by stress (*see* STRESS AND STRAIN) Virtually all solid materials creep to some degree when subjected to stress Several materials which are of technological importance because of their creep properties are metals concretes plastics and bitumens

[illegible] importance in such [illegible] relaxa[illegible] creep [illegible] strain excessive sagging of long span cables by creep strain weakening of prestressed concrete beams by stress relaxation and excessive deformation of machine components due to creep deformation at elevated temperatures

The factors affecting creep rate and time to rupture (which may be minutes or years) are (1) ma



Typical creep curves

ternal properties, (2) temperature, (3) stress intensity, and (4) stress-temperature history

Curves A and B in the figure illustrate typical creep curves of materials subjected to sustained stress They show continued deformation with time over and above the immediate strain ε_0 caused by the initial application of stress Curve A depicts a material having an initially high strain rate region (primary creep), followed by a constant strain rate region (secondary creep) terminated by an accelerated strain rate region (tertiary creep) resulting in rupture at time t_r Curve B shows another kind of creep curve which does not have clearly defined creep regions and does not necessarily have to result in rupture The dashed curve C shows the action of partial creep recovery if the stress is removed at time t_1

Generally, an increase in temperature or an increase in stress causes the creep rate to increase and the time to rupture to decrease Intermittent changes or cycling in the state of stress or temperature generally have the effect of decreasing the overall creep deformation as compared to a state of steady stress and temperature

The phenomenological explanation of the creep mechanism varies with each material as do the creep curves Creep in polycrystalline metals is due to several causes such as slip in the atomic lattice due to atomic dislocations slip between grain boundaries and slip along parallel macroscopic glide planes The creep rate is higher in general for fine grained than for large grained crystals Creep in metals is often accompanied by a metallurgical change of recrystallization Curve A is typical of many metals under tensile stress For further information on creep of metals *see* METAL, MECHANICAL PROPERTIES OF

Creep in concrete is due to a combination of the effects of deformation of the internal voids, flow of the cement water paste crystalline slip in the aggregates and the flow of water out of the cement gel The creep rate decreases as the cement paste hardens with time Curve B is typical for concrete under compressive stress *See* PRESTRESSED CONCRETE

Creep (cold flow) in polymer plastics and bitumens is due basically to the slipping of the molecules over one another Materials with molecules having large dipole moments have a lower creep rate than those having small dipole moments

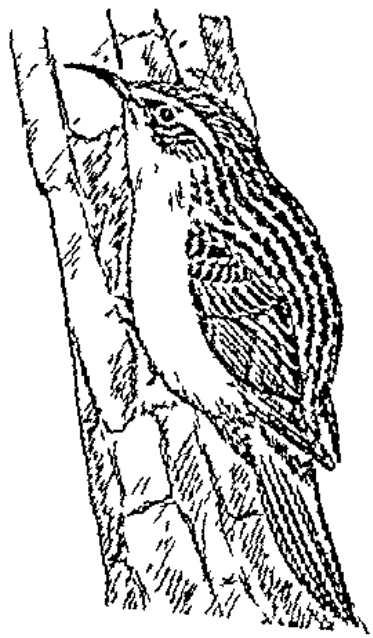
Relaxation is a term often associated with creep When a stressed solid is so constrained that deformation is prohibited or limited creep manifests itself by a reduction in stress intensity (relaxation) In complex structural systems the relaxation process redistributes the stresses so that generally regions of high stress level are reduced and regions of low stress level are increased

For information on related phenomena, *see* PLASTICITY, RHEOLOGY [W.Z.]

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Creeper

Any member of the perching bird family Certhidae There are seven species which are found in the Holarctic, Oriental and Australian regions Only one species *Certhia familiaris*, the brown creeper lives in the United States This is a small brown and gray striped bird with a downcurved bill and a long stiff tail It creeps up tree trunks in a spiral ascent scanning the crevices of the bark for food Because of its habits and color pattern, it is easy to *overlook* It nests in summer in the Holarctic coniferous forests and winters as far south as the Gulf Coast *See* PASSERIFORMES [J D B]



The brown creeper, Certhia familiaris length 5¾ in (From E L Palmer, Fieldbook of Natural History, McGraw Hill, 1949)

Creosote

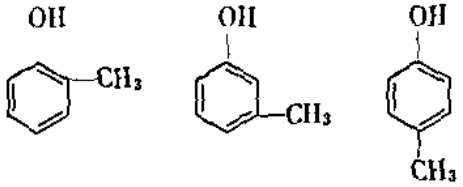
A distillate of either coal tar or wood tar Hard wood creosote usually made from beechwood is an oily distillate appearing between 200 and 220°C It has medicinal uses and its active fractions are mainly cresol and guaiacol It is an expectorant with value in the treatment of bronchitis and an external antiseptic widely used in medicine and dentistry

Coal tar creosote, or creosote oil, is a mixture of more than 160 chemical compounds, it is distilled between 400 and 450°C It is used in the manufacture of lampblack, but primarily in wood preservation Pilings, telegraph poles, floor blocks, and some building lumber are pressure-impregnated with the substance and are then almost immune to

attack by fungi termites and shipworms Lesser impregnations (of lower effectiveness) are achieved by soaking dipping and brushing *See* COAL CHEMICALS CRESOL [G CO]

Cresol

One of the three phenols that have methyl groups (CH_3) ortho meta and para respectively to the hydroxyl group on the ring of carbon atoms



o Cresol *m* Cresol *p* Cresol

They are produced by refining coal tar or the cracked naphtha from petroleum *p* Cresol is made synthetically by two processes analogous to the benzenesulfonate and cumene peroxidation processes for the production of phenol Creosote oil a crude material containing the cresols is used as a wood preservative Mixtures of the cresols (cresylic acid) are used in the manufacture of resins plastics and tricresyl phosphate (a plasticizer hydraulic fluid and a gasoline and lubricating oil additive) The cresols are also used as disinfectants and as ore-flotation agents *p* Cresol is converted to 2 6 di *tert* butyl *p-cresol* (TBPC) an antioxidant used to protect petroleum products foods and rubber from deterioration on exposure to air *See* PHENOL [R B C]

Cress

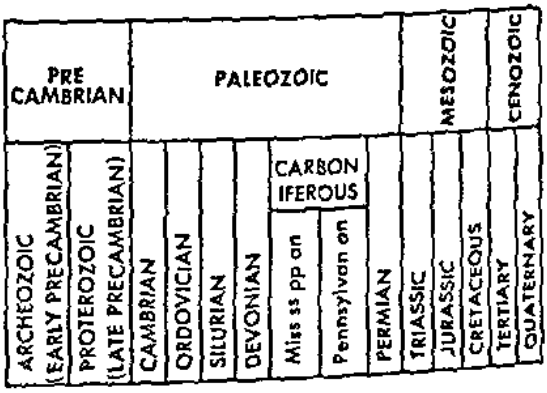
A prostrate hardy perennial crucifer of European origin belonging to the plant order Papaverales Water cress (*Nasturtium officinale*) is generally grown in flooded soil beds and used for salads and garnishing Propagation is by seed or stem cuttings High soil moisture is necessary Leafy stems are cut usually 180 days after planting Virginia is an important producing state

Garden cress (*Lepidium sativum*) is a cool season annual crucifer of western Asian origin grown for its flavorful leaves Propagation is by seed and leaves are harvested approximately 2 months after planting

Upland or spring cress (*Barbarea verna*) is a biennial crucifer of European origin grown and harvested similarly to garden cress but of lesser commercial importance *See* PAPAVERALES VEGETABLE GROWING [H J C]

Cretaceous

The latest system of rocks or period of the Mesozoic Era It includes that part of the earth's history from about 125 000 000 to 70 000 000 years ago —the time of the greatest flooding of the earth s surface It was also the time of extensive chalk deposition over much of the Northern Hemisphere hence the origin of the term *terrains cretaces* by d Omalius d Halloy in 1822 The Cretaceous bounded below by the Jurassic and above by the Tertiary, marks the rapid rise and spread of deciduous trees over the landscape Its close was marked by the withdrawal of the seas from the continents and by the extinction of the dinosaurs flying reptiles and huge marine reptiles as well as the ammonites and certain other groups of marine mollusks that had been so conspicuous throughout the Mesozoic Era



Paleogeography Much of the earth s present land surface was submerged by shallow seas during the Cretaceous Areas that were most extensively and frequently flooded include Europe northern most Africa Madagascar northern India Japan the western margin of North and South America Mexico and the Gulf coastal plain of the United States and the western interior of the United States and Canada Two seas covered much of Europe most of the time A Northern sea extended from the British Isles eastward across Germany [illegible] Tethys covered and pe and [illegible] northernmost Africa The Tethys sea also crossed Asia as a belt through Turkey the Persian Gulf area West Pakistan the Himalayan region Assam Burma and Sumatra The Tethys is believed to have been moderately deep whereas the Northern sea and the vast Western Interior sea of North America were much shallower

Broad climatic belts were present in the Cretaceous Most workers recognize two belts a southern Mediterranean or Tethyan belt and a northern or boreal belt The Mediterranean belt extending from Central America eastward across southern Europe and northern Africa to India and the East Indies was characterized by much deposition of limestone and other calcareous rocks Characteristic fossils include large thick shelled gastropods certain ammonites and sessile bivalves known as rudistids which formed reefs The boreal belt was characterized by an extinct group of squids known as belemnites certain bivalves (such as aucellas) and numerous ammonites Temperatures were warmer than at present and probably more uniform Palms grew as far north as Alaska and Greenland

Subdivision The Cretaceous is divided into two epochs Lower Cretaceous and Upper Cretaceous

Epoch	Stage	Source of name
Upper Cretaceous	Danian	Danish Latin for Denmark
	Maestrichtian	Maastricht Netherlands
	Senonian	Sens France
	Turonian	Touraine France
	Cenomanian	Cenomanum Latin for Mans France
Lower Cretaceous	Albian	Aube France
	Aptian	Apt France
	Neocomian	Neocomum Latin for Neuchâtel Switzerland

These are subdivided into stages whose names derive from localities in western Europe where the Cretaceous was first studied intensively The Neocomian and Senonian are commonly divided into the following substages

Senonian
- Campanian (Champagne France)
- Santonian (Saintonge France)
- Coniacian (Cognac France)

Neocomian
- Barremian (Barreme France)
- Hauterivian (Hauterive France)
- Valanginian (Valangin France)
- Berriasian (Berrias France)

The Danian is a controversial stage Many authorities believe that it should be excluded from the Cretaceous and that a very early Tertiary assignment is more correct

Lower Cretaceous During Early Cretaceous time three seas—Tethys Northern and Russian—covered much of Europe The Tethys submerged the northern part of Morocco Algeria and Tunisia southern and eastern Spain southern France Italy Albania western Greece and Yugoslavia and parts of Switzerland Austria Hungary Romania Bulgaria and Turkey The Northern sea an arm of the Arctic or Boreal Ocean extended through the present North Sea area and flooded the eastern part of England and much of northern Germany and Poland The Russian sea was at first an arm of the Boreal Ocean and later an extension of the Tethys sea Limestone and marl were the dominant sediments formed in the Tethys whereas marl clay shale and sandstone characterize the sediments of the Northern and Russian seas

The fauna of the warm Tethys sea differed considerably from that of the cooler Northern and Russian seas In southeastern France thick masses of limestone (Urgonian limestone) were formed by the accumulation of large foraminifers (orbitolines) corals stromatoporids bryozoans rudistids and large gastropods (nerineas) The cephalopods in the deeper parts of the Tethys were dominantly the rather smooth ammonites (phylloceratids lytoceratids) and flat belemnites The shallow Northern sea contained a more varied pelecypod fauna and very ornate ammonites Aucellas and distinctive forms of ammonites were featured in the cool Russian sea

During the Neocomian the Tethys and Northern seas may have been connected by a strait through Poland West of this possible strait was a land mass covering the southern half of Germany western Czechoslovakia Belgium northern and western France northern Spain and all but parts of the eastern edge of the British Isles In some areas along the margins of this land mass deltaic deposits of sandstone and clay accumulated The largest area of deltaic sediments was in a lowland covering part of Belgium northern France and southern England Here these nonmarine rocks known as the Wealden Beds contain fossil plants freshwater gastropods and pelecypods and dinosaurs known as iguanodons During the Aptian the Wealden area sank below sea level and the Tethys and Northern seas were connected by a strait through northern France and southeastern England The land mass centering in southern Germany was reduced to an island known as the mid European island which persisted throughout Cretaceous time (Fig 1)

The Russian sea was a south trending gulf of the Boreal Ocean during the early part of the Neocomian Later in the Neocomian the sea extended southward and merged with the Tethys During the Aptian the sea was closed off from the Boreal Ocean and became a narrow northeastern arm of the Tethys sea

The Albian seas were very extensive in Europe The Northern sea spread eastward across southern Russia and merged with the Russian sea The mid European island was reduced in size The Northern sea transgressed westward too and submerged most of England where the Gault clay famous for its abundant and exceptionally well preserved fossils was deposited Glauconitic clay marl and sand [illegible] of Albian

Cretaceous a seaway extended northeastward through the present Mozambique Channel to the Persian Gulf This sea encroached upon the western part of Madagascar and the eastern margin of Africa In southeastern Saudi Arabia this sea merged with the Tethys

Asia The Tethys seaway through the Himalayan area of northern India seems to have persisted throughout the Early Cretaceous Nonmarine strata totaling as much as 12 000 ft thick were deposited in northwestern and west central China during the Neocomian Nonmarine rocks also characterize the [illegible]

European Tethys The Albian is represented by conglomerates sandstones and shales and marks an extensive transgression of marine waters

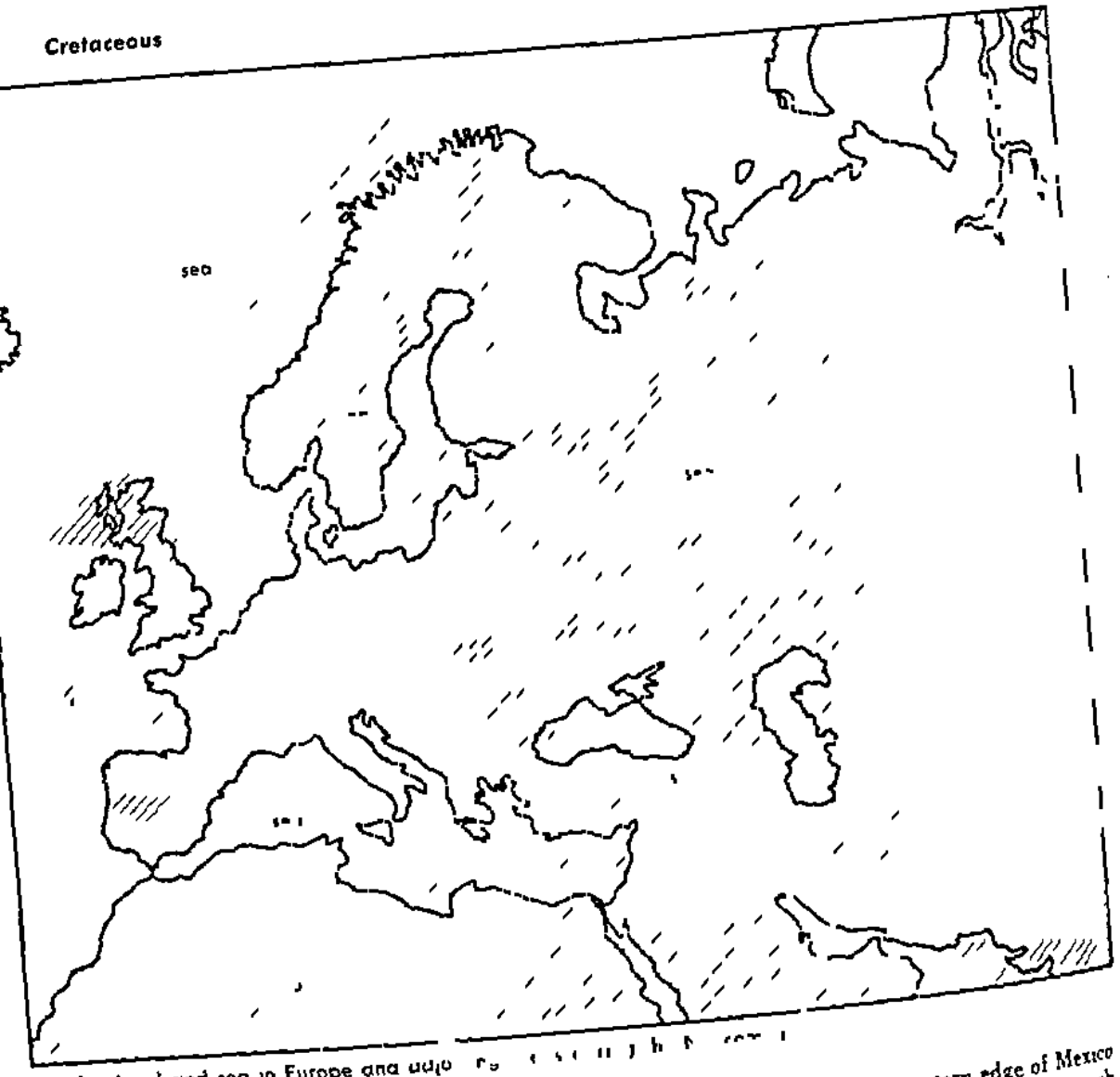


Fig 1 Land and sea in Europe and adjo

Australia Australia was above the sea during the Neocomian The eastern central part was a low land in which fluviatile and lacustrine deposition took place In the Aptian and Albian this lowland area was invaded by shallow marine waters which submerged about a third of the continent and di vided it into two or three large islands

North and South America Along the Pacific Coast of North America many thousands of feet of shale sandstone and conglomerate of marine ori gin reveal the encroachment of the Pacific Ocean onto the continent The rich ammonite faunas of California show the presence of all the stages of the Lower Cretaceous Pacific waters also trans gressed upon the western part of South America Marine Aptian limestone shale and sandstone in northern Colombia and Venezuela suggest a strait connecting the Pacific and Atlantic Oceans The area of the present Caribbean Sea was probably l contained numerous volcanoes f the

Ocean During tended from Arizona south through Sonora and thence southeast along the western edge of Mexico as far as the latitude of Mexico City A much smaller peninsula extended from Texas south into Coahuila Central America and the southwestern part of Mexico were above sea level The Pacific and Atlantic Oceans were united by means of a narrow passage west of Mexico City Near the shores coarse clastic sediments were formed whereas farther east away from the shore limestone and marl accumulated During the Aptian and Al bian the Mexican sea spread widely crossed the Coahuila peninsula and submerged the Gulf Coastal area of the United States as well as south western Texas and southern New Mexico and Ari zona Limestone was formed in central and eastern Mexico but near the shore in Sonora a thick se quence of limestone shale agglomerate and lava was deposited

Neocomian rocks are not known with certainty in the western interior of the United States In Al berta and British Columbia nonmarine deposits with many important beds of coal formed during this time Nonmarine rocks of Aptian and early Albian age are widely distributed over the western

interior of the United States and Canada During middle Albian time an arm of the Arctic Ocean covered northern Alaska and the Mackenzie River area and advanced southeastward across northeastern British Columbia most of Alberta and Saskatchewan and southwestern Manitoba About the same time marine waters spread north from the Gulf Coastal area and inundated Kansas Nebraska the Dakotas and the eastern halves of New Mexico Colorado Wyoming and Montana to merge with the Canadian sea This vast seaway thus split North America into two land masses Sandstone and dark noncalcareous shale characterize the sediments

Nonmarine deposition occurred in Virginia Maryland and Delaware during the Neocomian and Albian In West Greenland nonmarine rocks also accumulated during the Early Cretaceous East Greenland was partly submerged in the Neocomian and Albian

Upper Cretaceous The great transgression of the seas in Europe which began in the Aptian and Albian reached its peak during the Late Cretaceous The mid European island was further reduced in size and most of the British Isles was submerged An arm of the Northern sea extended eastward across Poland to Russia The Tethys sea still covered the Mediterranean area but spread widely and merged with the Northern sea through wide straits in France Romania and in the region of the Caspian Sea

Cenomanian deposits of the Northern sea are typically glauconitic clay sandstone and sandy marl near the shores and glauconitic chalk marly chalk and marl farther from the shores Sediments formed in the Tethys sea area ranged from sandstones and conglomerates near the shores to rudistid limestones or shales and sandstones with oysters During the Turonian marly chalk was deposited in much of the Northern sea and marls sandstones and rudistid limestones in the Tethys The Senonian of the Northern sea area is characterized by white chalk with flint nodules in France the British Isles Denmark and northernmost Germany Farther south in Germany sandy marl and sandstone were deposited near the mid European island In the northern part of the Tethys sea the Senonian rocks display many facies In southwestern France marly limestone rudistid limestone and sandy limestone are typical In southeastern France the upper part of the Senonian consists of brackish water lacustrine and fluviatile beds In Italy Yugoslavia Albania and Greece rudistid limestones mark the Senonian Rocks of Maestrichtian age are not as widespread as those of the Senonian The beds are largely tuffs in the Netherlands and Belgium chalks and greensands in southwestern France chalks in northern Germany and marly and sandy beds farther south near the mid European island *In southeastern France the Maestrichtian* is represented by a continental facies of lacustrine marls lignites and sandstones The Danian also has a very restricted distribution The type Danian of Denmark is limestone with abundant hydrocorals bryozoans and mollusks The Danian is represented by marine limestone in southwestern France and by nonmarine rocks in southeastern France Continental formations also feature the Danian of Spain and Portugal

Africa During the Cenomanian the Tethys sea spread southward over the Sahara and deposited marls and marly limestones with oysters echinoids and some ammonites Sandstone shale and limestone of marine origin are present in Nigeria and north of there in the eastern part of French West Africa This suggests the probability that the Tethys sea and the Atlantic Ocean were connected through the Sahara thus dividing Africa into an eastern and a western land mass A seaway still existed through the Mozambique Channel to Western Pakistan and Cenomanian sediments were deposited in western Madagascar and in places along the east coast of Africa Limy sediments continued to form in North Africa during the Turonian Nigeria the eastern part of French West Africa and the Atlantic coastal part of French Equatorial Africa were submerged as well as the western part of Madagascar and the eastern part of South Africa The Tethys sea continued to cover the northern edge of Africa from Morocco to Egypt during the Maestrichtian Chalk and marl were deposited in Morocco and Algeria Shale sandstone and coal beds formed in Nigeria and in Angola marls and limestones In North Africa the Danian is represented by marine beds with numerous nautiloids

Australia and Asia Most of Australia was above the sea during Late Cretaceous time Chalk chalky clay and greensand of Senonian age are present along the westernmost part of the continent

The Himalayan seaway across the northern border of India persisted through the Late Cretaceous In addition the east coastal area of India was submerged

Cenomanian and Turonian times were marked in Japan by crustal unrest and by a regression of marine waters from parts of the area Coarse sediments are common The Senonian was a time of marine transgression and shale and fine grained sandstone were the dominant rocks formed In the Maestrichtian a regression of the seas occurred and coarse clastic sediments were again common

North and South America North America was extensively flooded during the Late Cretaceous The pattern of the seaways established by the great Albian transgression was followed throughout most of the later Cretaceous During the Cenomanian Turonian and Senonian stages Pacific waters invaded much of Alaska Oregon and California and deposited shales sandstones and conglomerates Marine rocks of Senonian or Maestrichtian age are found along the west coast of parts of British Columbia *The Pacific Ocean also encroached upon* the western margin of South America and laid down mostly shales in the Cenomanian limy in the Turonian and shale and sandstone

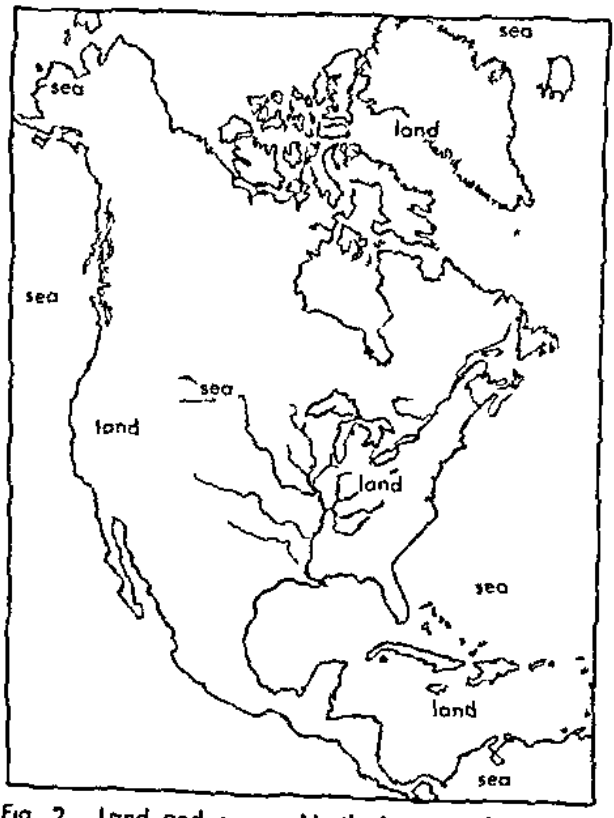


Fig 2 Land and sea in North America during the Turonian

Senonian Part of Central America and much of the present area of the Caribbean Sea was probably land with many active volcanoes An arm of the Pacific Ocean crossed northern Colombia and Venezuela and merged with the Atlantic

The Gulf Coastal region of the United States and most of Mexico were under water during the Cenomanian Only the Sonoran peninsula and the westernmost edge of southern Mexico were emergent Limestone and marl were the commonest rocks formed Carbonate deposition continued through the Turonian

In the early Cenomanian the sea seems to have withdrawn from the great seaway established during the Albian through the western interior of the United States and Canada In the late Cenomanian marine waters again filled this low area and united the Gulf of Mexico with the Arctic Ocean The seaway spread somewhat during the early Turonian and at one time its width reached from central Utah to western Iowa Limestones and marls were formed over most of this region in the early Turonian but sandstones and noncalcareous shales in the later Turonian reflected rising mountains in western Utah (Fig 2)

During the early Senonian the Mexican Western Interior sea was gradually reduced in size as mountains formed to the west Near the western shore thick deposits of shale and sandstone accumulated with thick coal beds in some areas Chalky beds were deposited farther east Later in the Senonian carbonate deposition almost ceased in the western interior of the United States and sandstone and shale was the rule By the late Maestr the sea had completely withdrawn from the and fluviatile deposition occurred to the enc Cretaceous These latest Cretaceous rocks are usually assigned to the Danian have yiel markable horned dinosaurs

Along the Atlantic Coastal Plain of the States nonmarine deposition occurred dur Cenomanian and in the early Senonian L the Senonian and in the Maestrichtian A waters transgressed upon the continent dep marl clay, and sand from central South C northeastward through New Jersey

The Cenomanian and Turonian are knc Greenland only from a very small area in the of the east coast The Senonian rocks are widespread and are represented by marine on the east and west coasts [

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Cretinism

A type of mental deficiency caused by hypoth ism an endocrine malfunction It is occasic endemic (peculiar) to specific geographic gions The incidence of the sporadic type is mated at 1 in 10 000 of the general popul (1 in 100 mental deficients), while the enc type may attain a proportion of 2% of the ge population in the region where the incident endocrine unbalance is high

The cretin usually seems normal at birth bu the sixth month growth and bone developmen retarded and there is a marked increase in we If the condition is untreated there is a typ apathy, slowness of motion protrusion of ton and puffiness of features along with delay in velopment of adaptive behavior (see BEHAV ONTOGENY OF) The adult cretin is a dwarf a shuffling waddling gait a large round head black wavy hair The genitalia are delayed in velopment although ultimately they attain nor size The cretin also has misshapen hands feet, protruding abdomen and flabby skin. Sc confusion with other deficiency types is possi particularly with the Mongoloid in childhood

The common signs of hypothyroidism are to observed in the cretin Pulse and respiration slow and temperature is two or three degrees bel normal Voracious eating results in fat deposit rather than increased energy and most cret exhibit generalized muscular weakness A ma edly subnormal basal metabolic rate (BMR) usual The BMR is between 20 and 50% of t normal

The degree of mental defect of this group vari and is to some extent influenced by medical tre men Some cretins are severe but most are mo erate and from the educational point of vie trainable Their social behavior is marked by the

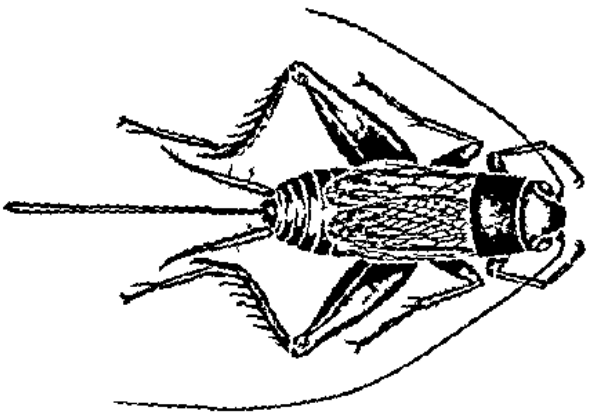
happy good natured and somewhat mischievous demeanor Occasionally they are shy or actually afraid in groups of people

Treatment is by the thyroid compound thyroxin and usually must be continued throughout life If treatment is not continued a relapse will occur When an optimum dose is given the typical physical condition is altered In the young child this change may be rapid and marked but if treatment is delayed until adulthood the change may be slight or unobservable In some cases in the young there is corresponding change in social and intellectual behavior However if treatment is begun much later than the first year it will not effect any great change in the degree of mental defect

Cretinism generally is considered to be caused by congenital pathology of the thyroid gland However there is some evidence of familial involvement (*see* HUMAN GENETICS) The cretins who fail to respond to medication may represent cases of such familial involvement *See* MENTAL DEFICIENCIES THYROID GLAND [M C K]

Cricket

This name is usually restricted to insects of the family Gryllidae order Orthoptera There are orthopterans in other families however which are sometimes called crickets



The field cricket Gryllus assimilis over-all length about 1 in (From E L Palmer Fieldbook of Natural History McGraw-Hill 1949)

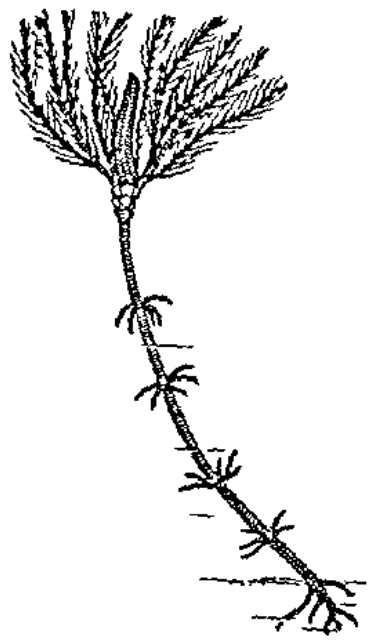
The Gryllidae are readily recognized by their flat backs and when winged by the manner in which their wings lie flat on their backs rather than tentlike as they do in the closely related grasshoppers and katydids Most species are black although the delicate tree crickets are whitish or pale green Crickets are virtually world wide in distribution For the most part they are of little economic importance although when abundant they can damage crops and in houses they will damage clothing There is some commerce in crickets for fish bait the animals being specially reared for this purpose

In China the keeping of crickets as pets and as fighters is an ancient custom Capable fighters which are common field crickets are highly prized and large sums are often wagered on cricket fights Several other species are caged as singers

The wingless hump backed camel crickets are actually long horned grasshoppers They are grayish to light brown and frequently occur in abundance in caves although they are also found in other habitats *See* ORTHOPTERA [J D B]

Crinoid

A member of the class Crinoidea phylum Echinodermata There are about 800 living species and perhaps 5000 fossil forms which are much better known than the living animals Most dwell in the deep sea although some of the stalkless forms are found in shallow water *See* ECHINODERMATA FOSSILS



A simple attached crinoid of the class Crinoidea

Crinoids were abundant in Paleozoic times and many limestone deposits consist mainly of fossil crinoids their fossilized stalks are the best known of all fossil animal remains (*see* PALEONTOLOGY)

Living crinoids are called sea lilies or feather stars The sea lilies, including about 80 species live attached to the bottom by a long slender stalk which supports the body or calyx The calyx bears five arms which are branched and which bear pinnules similar to the barbs on a feather There is a tube foot system but no madreporite Food consists of plankton and detritus Many crinoids are brightly colored in red white green yellow or brown

The feather stars are similar and stalked when young but break loose from their stalk to become free-living They move primarily by pulling themselves along with their arms *See* CRINOIDEA [J D B]

Crinoidea

A class of radially symmetrical Pelmatozoa in which the body is flower shaped and is either carried at the tip of an anchored stem as in sea lilies

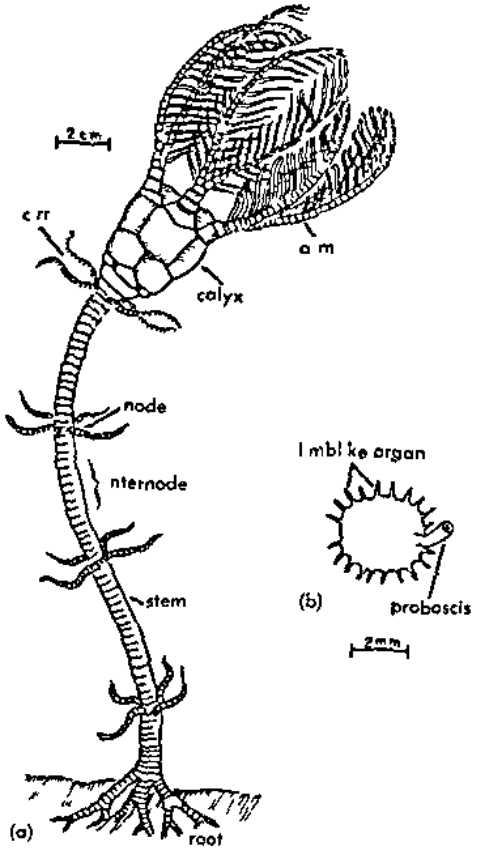


Fig 1 (a) Schematic diagram of crinoid (b) *Myzostoma*

or is free in the adult stage as in feather stars Their flowerlike appearance is the result of the circlet of arms which range like petals around the brim of a cup shaped structure termed the calyx

Crinoids are the only group of Pelmatozoa to survive the Paleozoic and consequently are of great importance in the interpretation of fossil remains of other Pelmatozoa They resemble most closely the extinct Blastoidea but differ from them in having the ring of arms and in the disposition of the ambulacral grooves

Discovery Stem joints of fossil sea lilies were collected by ancient Celts and occur in tumuli In the middle ages in England they were known as St Cuthbert s beads Later when complete fossils were excavated they were regarded as petrified plants (*Encrinites*) When recognized at last as echinoderms it was still supposed that crinoids were extinct and it was not until 1821 that J S Miller first recognized living crinoids as such

There are now some 540 living species known and of these 75 are stalked forms Over 5000 fossil species have been described representing 750 genera All living crinoids are referred to one subclass the Articulata on which this article is mainly based There are also three other subclasses known only from fossils *See* ECHINODERMATA FOSSILS

Small species may be no more than 3 cm across the arms, the largest known forms (from the Okhotsk Sea) reach 1 meter (m) across Feather stars are brilliantly colored because of the presence of conjugated carotenoids (*see* ECHINODERMATA) These may be yellow green purple or red The arms may be banded with concentric zones of color or contrasted black melanoid pigments may occur together with white zones Sea lilies are less vivid often red or purple although bright yellow and green forms occur

No crinoids are of direct economic importance to man because none are used for food nor do they appear to be eaten by other animals None are venomous

Ecology Crinoids occur in all seas except the Black and the Baltic They prefer quiet waters and abound in tropical shallow lagoons In deeper waters they are widespread even under the polar ice shelves They do not seem to inhabit the deepest trenches although *Bathycrinus* occurs down to 9700 m in the Kurile Trench and to 8210 m in the Kermadec Trench however F Madsen (1954) points out that most hauls in deep water have been made from mudbanks which do not favor sedentary suspension feeders One half of the stalked forms and one sixth of the feather stars are known from below 1000 m Crinoids need well aerated water which contains an abundance of suspended food particles and they prefer a hard uneven bottom which provides a grip for the cirri but forms with very long cirri live over mud bottom

The peculiar parasite *Myzostoma* occurs on crinoids usually as an ectoparasite It has a rounded

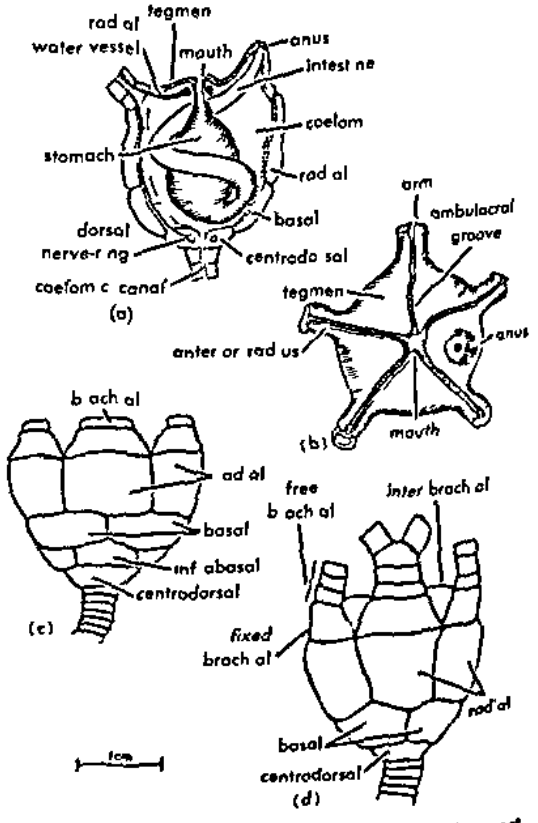


Fig 2 Calyx anatomy (a) Dissection in lateral aspect (b) Calyx from adoral aspect (c) Dicyclic calyces (d) Monocyclic calyces

body bordered by a fringe of limblike organs and a protrusible proboscis which is used to extract food from the ambulacral grooves It is thought to be a polychaete Other parasites include snails flatworms copepods and ostracods Deep sea ophiuroids may adhere to the arms and cryptozoi cally colored shrimps sometimes lurk among the arms *See* ANNELIDA

MORPHOLOGY

Calyx In development the theca becomes the skeleton of the calyx and first forms two horizontal whorls of plates with 5 plates in each whorl Those of the lower whorl are termed basals those of the upper orals The orals turn into 5 valves guarding the mouth Later another whorl of 5 plates appears between the first two whorls and these are termed radials they support the arms A calyx with this structure is said to be monocyclic If a further ring of plates should develop below the basals they are termed infrabasals and the calyx is said to be di cyclic These distinctions are used in classification The upper surface of the calyx is termed the teg men The mouth usually lies near its center and the anus lies in one of the interradii termed the posterior interradius The freely movable arms usually 5 in number occur around the margin of the calyx From the 5 radial corners of the mouth run the 5 ambulacral grooves they cross the teg men and then each one ascends its corresponding arm

Each of the 5 arms is usually subdivided by 1 or more forks producing from 10–30 branches or in extreme cases up to 200 The arms are built up of brachial ossicles usually arranged in single series (uniserial arm) but sometimes in double series (biserial arm) These characters are used in classi fication In existing crinoids the arms usually carry lateral appendages resembling the brachioles of earlier Pelamatozoa these are called pinnules Their function is to capture food and also to bear the reproductive glands Pinnules near the mouth are often specialized in various ways and provide characters used in classification

The stem is attached to the aboral pole of the calyx It may be long and slender with rootlike or gans attaching it to the sea floor or it may carry regular whorls of appendages termed cirri ar ranged in rings of 5 at points termed nodes They are attachment organs anchoring the animal if the stem becomes detached Feather stars discard the stem early in life assuming a free living mode of existence In their case the cirri are all attached in a conspicuous cluster at the aboral pole on a plate termed the centrodorsal The terminal joint of a cirrus often is claw shaped Feather stars crawl with the aid of cirri and anchor themselves from time to time The number of cirri and the number of joints in each cirrus provide taxonomic charac ters

Muscular system The muscular system is made up chiefly of intersegmental muscle fibers between the ossicles of the stem the arms the pinnules and

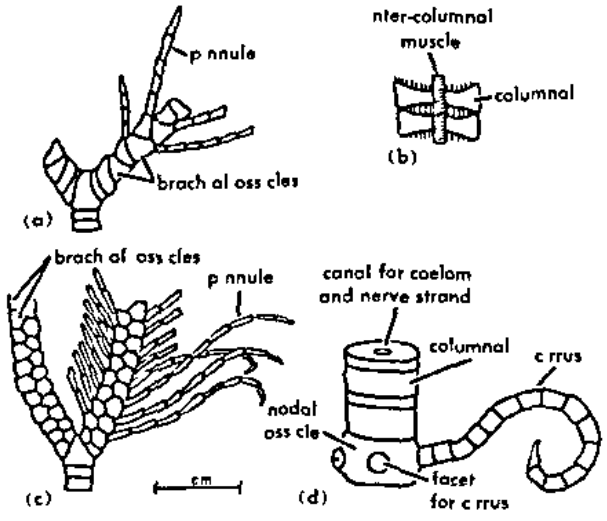


Fig 3 Stem and arm anatomy (a) Uniserial arm (b) Stem in vert cal section (c) B serial arm (d) Stem ossicles

the cirri These can be flexed and extended Stalked crinoids are normally sedentary but some such as *Metacrinus* can swim actively with the long stem trailing behind Feather stars are mainly swim mers but the heavier types such as the Comasteri dae and Tropiometridae crawl on the bottom They can all use the cirri to hold them in a crevice pro tected from surf and a favored spot will be occu pied by an individual for weeks at a time

Coelom A perivisceral coelom forms the body cavity in the calyx The viscera are suspended in it Aging individuals develop calcified sheets of meso derm between the gut and the body wall the tra beculae The coelom extends into the stem as a canal sometimes also into the arms and the shape of the canals is of taxonomic significance

Water vascular system The water vascular sys tem has the general structure for the phylum namely a ring vessel and radial vessels The radial vessels in this class enter the arms and send branches into the pinnules The tube feet develop at intervals on either side of the ambulacral groove and its branches the tube feet lack suckers and are termed tentacles they serve partly for respira tion and partly for feeding by lashing to and fro to produce food currents along the ambulacral grooves to the mouth There is sometimes a madre porite near the mouth but usually there are a num ber (5 200) of separate hydropores on the tegmen leading into the coelom The ring canal replenishes its fluid via several canals which open from it into the coelom

A poorly developed system of irregular blood sinuses known as the hemal system may develop

Alimentary system The mouth opens into a short buccal cavity An esophagus leads into the large stomach from which the intestine doubles back toward the tegmen to open at the anus Saccu lated digestive glands occur on the intestine Cri noidea feed on minute plankton organisms and detritus which they catch on the feathery arms and

transfer to the mouth by ciliary action along the grooves A paralytic toxin is released by the pinnules and serves to narcotize small plankton organisms in the vicinity It is evident that similar feeding mechanisms must have occurred in cystoids and blastoids, and probably in all the fossil Pelmatozoa

Nervous system. The nervous system corresponds to the general type for the phylum, but is distinguished by the greater development of the aboral nerve ring in the centrodorsal plate from which aboral radial nerves enter the arm The nerves are deep seated having lost their connection with the ectoderm In the absence of clear evidence of special sense organs it is inferred that the nerve endings themselves are the receptor organs Thus, although eyespots have not been discovered some feather stars will avoid direct sunlight Taste and tactile functions are probably performed by papillae on the ambulacral tentacles

Reproduction The sexes are separate but seldom differ in external aspect The gonads lie on the pinnules as numerous small testes or ovaries The eggs usually develop on the pinnules until the larva has been formed This is a vitellaria It later becomes attached by one end to some foreign body such as a hydroid or alga grows a stem, and assumes the form of a miniature sea lily In feather stars, the stalked phase is temporary A few Antarctic species are known to be viviparous, such as *Isometra vivipara* in which the young are retained in special pouches In *Notocrinus* the young are nourished with albumin secreted by the marsupium Under unfavorable conditions or during handling, crinoids cast off their arms tegmen and alimentary canal Regeneration occurs within a few weeks *See* ARTICULATA (ECHINODERMATA), CAMERATA, FLEXIBILIA, INADUNATA, PELMATOZOA, REGENERATION (BIOLOGY) [H B F]

Critical constant

If a gas is cooled to a low enough temperature and then compressed it can be liquefied For each gas, there is a characteristic temperature above which it cannot be liquefied, no matter how great is the applied pressure This temperature is called the critical temperature, T_c The pressure required to liquefy the gas at this temperature is called the critical pressure, p_c and it is of course, the highest vapor pressure the liquid can exert The volume occupied by one mole at T_c and P_c is called the critical volume V_c T_c, p_c, and V_c are usually referred to as the critical constants of the gas They vary widely from substance to substance and are well below room temperature for the permanent gases such as oxygen and nitrogen and well above it for compounds such as water and ammonia

Above the critical temperature the distinction between a vapor and a liquid disappears and the critical temperature may be found by observing the minimum temperature at which the meniscus disappears when a sealed tube containing some of the liquid is heated *See* GAS, LIQUID [T C W]

Critical constants of typical gases

Formula	T_c, °K	p_c, atm	V_c, ml/mole
He	5 2	2 26	57 6
H_2	33 3	12 8	65 0
N_2	126 0	33 5	90 2
O_2	154 3	49 7	74 5
CO_2	304 2	73 0	95 7
H_2O	647 2	217 7	45 0
Hg	1823	200	45

Critical mass

That amount of fissile material (U^{233}, U^{235}, or Pu^{239}) which permits a self sustaining chain reaction (*see* CHAIN REACTION, NUCLEAR) The critical mass ranges from about 950 g of U^{235} or a smaller amount of Pu^{239} for dissolved compounds through 16 kg for a solid metallic sphere of U^{235}, and up to hundreds of tons for some power reactors It is increased by the presence of such neutron absorptive materials as admixed U^{238}, aluminum pipes for flow of coolant, and boron or cadmium control rods It is reduced by a moderator, such as graphite or heavy water, which slows down the neutrons, inhibits their escape and indirectly increases their chance to produce fission *See* FISSION, NUCLEAR, REACTOR PHYSICS [J A W]

Croaker

The common croaker, *Micropogon undulatus* a member of the family Sciaenidae It is an abundant marine fish which is found from Cape Cod to Texas, but is more common from the Carolinas southward and in the Gulf of Mexico It is a compressed, brassy colored fish, marked with dark spots and bars It frequents vegetated areas in shallow water Most croakers weigh 1 lb or less They produce a characteristic croaking or drumming sound They are a good sport and food fish and take the hook readily, most of the commercial catch, however, is with seines In addition to the common croaker, there are four other species in the genus none of which is commercially important *See* ACTINOPTERYGII [J D B]

Crocco's equation

A relationship between vorticity and entropy gradient for the steady flow of an inviscid compressible fluid Crocco's equation pertains to isoenergetic flow, which is a common type of flow where the total energy, or stagnation enthalpy, of the fluid per unit mass is constant throughout the fluid The equation is

$$\mathbf{v} \times \boldsymbol{\omega} = -T \operatorname{grad} s$$

where $\mathbf{v}$ is the fluid velocity vector, $\boldsymbol{\omega} = \operatorname{curl} \mathbf{v}$ is the vorticity vector, T is the fluid temperature and s is the entropy per unit mass of the fluid Thus entropy gradients can only occur at right angles to $\mathbf{v}$ and $\boldsymbol{\omega}$ An irrotational flow is one where $\boldsymbol{\omega} = 0$ throughout the flow, and it follows from Crocco's equation that it must also be an isentropic flow that is, one with constant entropy throughout (*see*

LAPLACE'S IRROTATIONAL MOTION) An example of a steady inviscid isoenergetic flow that is rotational and hence nonisentropic is that behind the curved shock wave at the nose of a blunt body traveling at supersonic speeds the flow is uniform and isentropic ahead of the shock wave but because the entropy rise through the shock depends on the inclination of the shock front to the oncoming stream, the flow is nonisentropic behind the curved shock. *See* FLUID-FLOW PRINCIPLES

[A E BR]

Crocodile

A name applied both to the true crocodiles and to all of the order Crocodilia which includes the alligators caimans and gavials All species of the order are large heavy bodied semiaquatic reptiles They are covered with an armor of thick epidermal scutes those on the back and belly are reinforced by dermal bones for greater protection They have a long powerful compressed tail which they use as a weapon The heart is 4-chambered but the systemic and pulmonary blood is mixed to some degree by an arterial junction just above the heart They are cold blooded Crocodilians like mammals have their teeth set in sockets They are found in the warmer parts of the world The eggs are 2 5 in long and are covered with a limy shell From 20 to 50 eggs are deposited in heaps of decaying vegetation and guarded by the female until



The crocodile *Crocodylus* sp length to 30 ft (*From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd London*)

they hatch Some species brood the eggs to protect them from excess heat and help the young dig out of the nest when they hatch

The true crocodiles occur in scattered areas around the world They are represented by one species in the United States the American crocodile *Crocodylus americanus* which is occasionally found in southern Florida Best known are the Nile crocodile *C niloticus* and the estuarine crocodile *C porosus* of the South Pacific both are dangerous to man The latter species may reach a length of 33 ft although this is exceptional The true crocodiles have relatively narrow snouts and the fourth tooth of the lower jaw is visible when the jaw is closed *See* ALLIGATOR CAIMAN CROCODILIA

[J D B]

Crocodilia

An order of the class Reptilia which are large voracious aquatic species and which include the alligators caimans crocodiles and gavials The group has a long fossil history from late Triassic times and its members are the closest living relatives of the extinct dinosaurs and the birds The 21 or 22 living species are found in tropic areas of Africa Asia Australia and the Americas one form the salt water crocodile *Crocodylus porosus* has traversed oceanic barriers from the East Indies as far east as the Fiji Islands The order is distinguished from other living reptiles in that it has two temporal foramina an immovable quadrate a bony secondary palate no shell a single median penis in males socketed teeth a four chambered heart and an oblique septum that completely separates the lung cavities from the peritoneal region

Morphology Certain of these unique features and other salient characteristics of the Crocodilia are intimately associated with their aquatic life The secondary palate composed of medial expansions of premaxillary maxillary palatine and pterygoid bones divides the mouth cavity into two separate regions The area above the bony palate forms an air passage extending from the external nostrils at the tip of the snout posteriorly to near the orbital region The lower space retains the usual functions of the mouth and is bordered above by the secondary palate and below by the lower jaw A special pair of fleshy flaps are found at the posterior end of the mouth cavity and form a valvular mechanism which separates the mouth from the region where the air passage opens into the throat (Fig 1) This complex arrangement allows crocodilians to breathe even though most of the head is under water or the mouth is open holding prey or full of water Inasmuch as these great reptiles are extremely active when submerged and may remain under water for considerable periods the increased efficiency of respiration provided by the oblique septum is an obvious adaptation The significance of the four chambered heart also lies in its contribution to rapid cellular respiration through an increased efficiency of circulation Interestingly all three of these structural characteristics are also found in mammals although differing in detail The

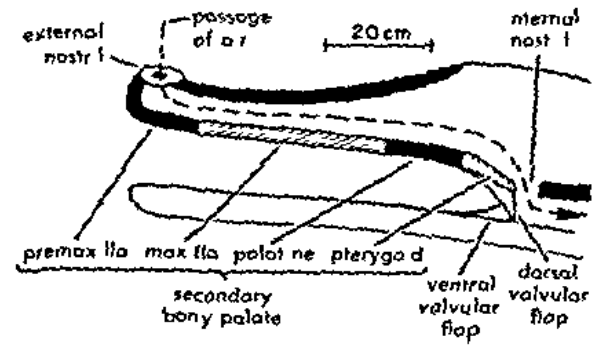


Fig 1 Sagittal section of crocodilian head to show secondary palate and associated structures

Crocodilia, however, are not closely related to any of the reptiles that ultimately gave rise to the mammal stock Other aquatic adaptations include valvular external nostrils that are closed during immersion, a recessed eardrum that can be covered by a skin flap under water, webbed toes, and a long, compressed muscular tail that propels the crocodilian through the water with strong lateral thrusts In addition, the eyes adapted for nocturnal activity by a vertically elliptical pupil and the nostrils are mounted in raised areas of the head so that the animal may see and breathe without exposing much of its body above water

Feeding Crocodilians are all carnivorous and prey upon insects, mollusks fishes and mammals Usually only the larger adults attack terrestrial prey, which is usually caught at the water's edge and after being grasped in the powerful jaws is dragged down to be drowned Crocodilians are extremely vicious reptiles, and are as dangerous as sharks among aquatic organisms The jaws numerous sharp teeth and the habit of twisting and rolling under water after the prey is seized, all contribute to their bad reputations Even on land they are imposing creatures especially when utilizing the muscular tail as a weapon Single lateral swipes with this appendage can inflict serious damage when administered by large specimens

Reproduction During the breeding season male crocodilians set up territories on land which they defend against intruders of the same species During this period their loud roars are frequently heard at night Fertilization is internal and the hard shelled eggs are deposited in excavations in the sand or in large nests of decaying vegetation depending upon the species In some forms at least the female guards the nest, and several females may take turns in protecting a communal nest It has been reported that when the young hatch the female may liberate them from the nest and lead them to the nearest water The method of locomotion on land is by progression on all fours with the belly and head held off the ground and the tail dragging behind In the water, movement is produced by lateral undulations of the tail and the forelimbs are held flat against the sides of the body

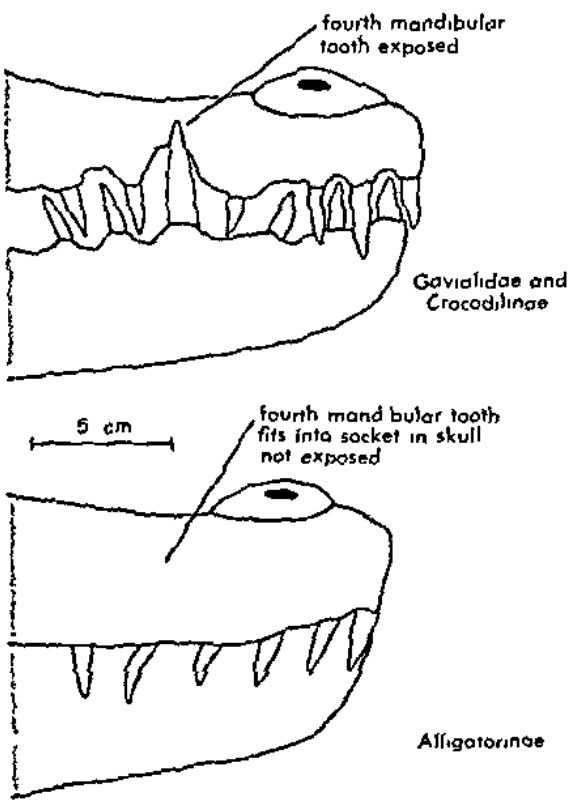


Fig 2 Lateral view of crocodilian snouts

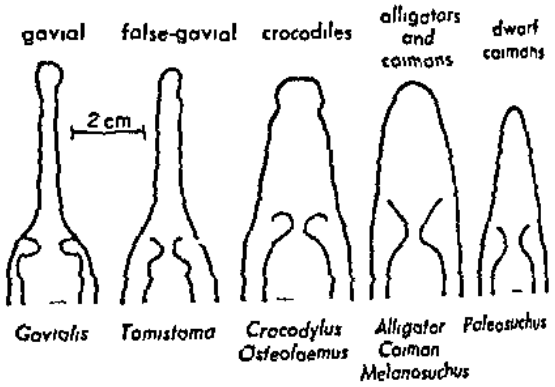


Fig 3 Dorsal view of crocodilian heads

Classification. The living species are placed in two families and eight genera The family Crocodylidae contains two subgroups the true crocodiles Crocodylinae, including the genera *Crocodylus*, found in all tropic areas *Osteolaemus*, in central Africa, and the false gavial, *Tomistoma* in [illegible] hai China, the *Caiman*, from Central and South America, and *Melanosuchus* and *Paleosuchus* of South America The gavial, *Gavialis gangeticus* of India and north Burma is the only living member of the family Gavialidae Crocodiles differ most obviously from alligators and caimans in head shape and in the position of the teeth, although other technical details also separate them (*Fig 2*) The gavial differs from all other living forms in its extremely long and narrow snout which is armed with 27 or more teeth on the upper jaw and 24 or more on the lower jaw Even the false gavial *Tomistoma*, which resembles the gavial in head shape has no more than 21 teeth on the upper jaw and 20 on the lower

Biology. The smallest living crocodilians are the dwarf crocodiles *Osteolaemus*, and dwarf caimans *Paleosuchus*, which attain a maximum length of 4–4½ ft Several species vie for the place as the largest members of the group Authentic records of 20 or more feet are known for the American alligator *A. mississippiensis*, the salt water crocodile *C. porosus*, the American crocodile *C. acutus* the Orinoco crocodile *C. intermedius* and the gavial *G. gangeticus* Probably the maximum size is attained by *C. porosus* at about 24 ft although both the

American and Orinoco crocodiles are almost this large These giants are rather uncommon and most individuals even of these large species are about 10–12 ft in length

Without question the most dangerous of all crocodilians, at least as far as humans are concerned is the moderate-sized mugger *C palustris* of southern Asia which averages about 10 ft and reaches a maximum of 13 ft in length All the larger species are of considerable importance as sources of skins for the commercial leather industry The American alligator once the principal source of hides and pet shop alligators is now protected in Florida Most commercial leather and pet alligators are now taken in Central and South America most commonly from one of the members of the genus *Caiman See* REPTILIA [J M S]

Crocodilia fossils

Crocodilians first appear in deposits of Late Triassic or possibly Early Jurassic age in North America and South Africa *Protosuchus* from Arizona was a small armored reptile 80 cm long not greatly different from Triassic thecodonts Its flattened skull roof slightly elongate coracoid rodlike proximal carpals and pubis forming only a small portion of the border of the acetabulum indicate that it was a true crocodile *Nothochampsa*, from South Africa had a similar skull and *Erythrochampsa* from

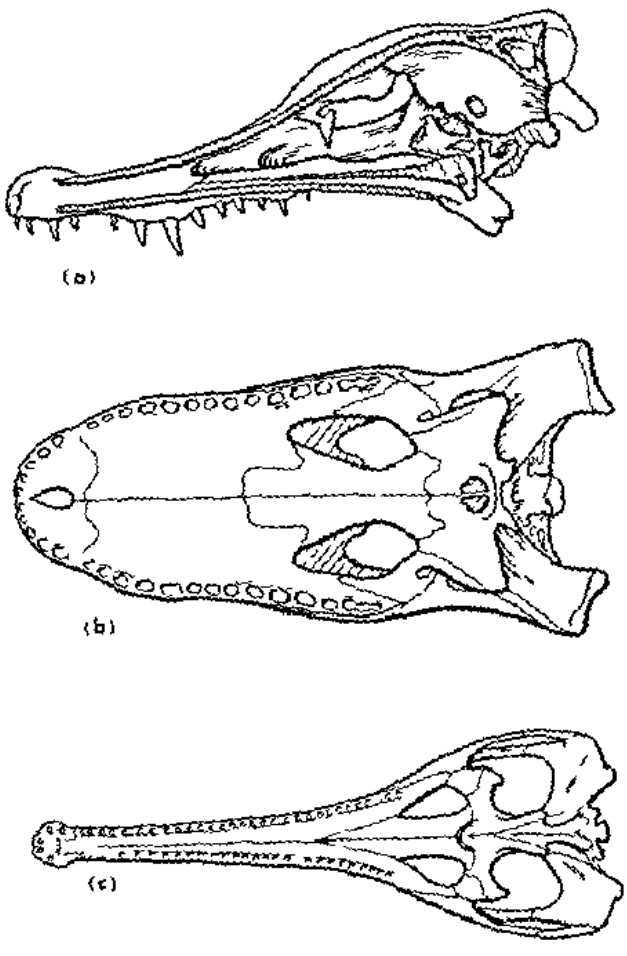


Fig 1 (a) Longitudinal cross section of a crocodile skull to show nasal passages (b) Palate of *Alligator* skull nasal opening at rear of pterygoids (c) Palate of a mesosuchian *Steneosaurus* narial opening between palatines (a b after Deslongchamps c after Andrews)



Fig 2 Skull of teleosaur

slightly later deposits of that country had an equally characteristic pelvis These genera are commonly placed in a primitive suborder Protosuchia The extent of their secondary palates is unknown

Most Mesozoic crocodilians differ from surviving members of the order in the less extensive development of the secondary palate and in having platycoelous vertebrae (in which the centra are shallowly concave at each end) The internal nares or choanae are elongate openings between the palatines and pterygoids (Fig 1) The best known fossils are remains of specialized marine crocodiles Teleosaurs such as *Mystriosaurus* and *Steneosaurus* (Fig 2) were long-snouted completely armored animals with webbed toes These were confined to the Jurassic Smooth skinned *Metriorhynchus* and *Geosaurus* of the Jurassic and Early Cretaceous had lost the armor and developed paddlelike feet and even a small tail fin *Hyposaurus* of the Cretaceous foreshadowed the gavials

Fresh water deposits of Late Jurassic and Cretaceous age have yielded remains of primitive crocodiles such as *Goniopholis* with broader flatter heads which may include ancestors of both alligators and crocodiles Many genera have been named often from fragments

In South America the mesosuchian crocodiles developed a side branch with narrow deep skulls and compressed bladelike teeth suggestive of the carnivorous dinosaurs It is thought that the cretaceous *Baurosuchus* and Eocene *Sebecus* (Fig 3) were more terrestrial and predaceous than typical crocodilians at least they lack the flattened heads and usual aquatic specializations of the order

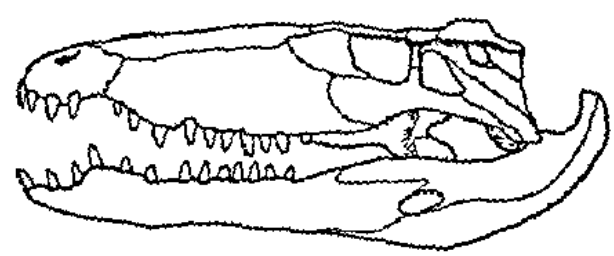


Fig 3 Skull of *Sebecus*, an Eocene mesosuchian from South America (After E H Colbert)

Eusuchia or modern crocodiles with a fully developed secondary plate and procoelous vertebrae (centra concave anteriorly and convex posteriorly) appear late in the Cretaceous and have continued to the present day in the tropics The largest known crocodile *Phobosuchus* whose skull was 2 m long and whose body length has been estimated at 15 m lived during the Cretaceous and may have preyed on dinosaurs *Thoracosaurus* was a long snouted forerunner of the false gavial *Tomistoma* in the Late Cretaceous and Eocene of both North America and Europe Ancestors of the alligators *Allognathosuchus* and *Diplocynodon* are known from the Paleocene and Eocene Specimens indistinguishable from *Crocodylus* abound in the Eocene and are foreshadowed by the Cretaceous *Leidyosuchus*

Crocodilians formerly were much more widely distributed in temperate latitude than today abundant paleobotanical evidence confirms a warmer climate in mid latitudes at this time It seems probable that the restriction of crocodilians to the tropics was a direct result of cooling climate in the late Cenozoic *See* CROCODILIA *see also* ARCHOSAURIA [J T C]

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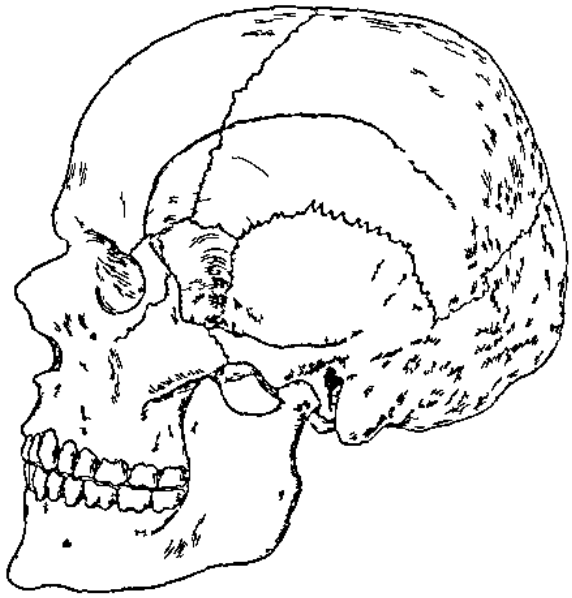
Crocoite

A mineral with the chemical composition $PbCrO_4$ Crocoite occurs in yellow to orange or hyacinth red monoclinic prismatic crystals with adamantine to vitreous luster it is also massive granular Fracture is conchoidal to uneven Hardness is 2 5 3 on Mohs scale and specific gravity is 6 0 Streak or color of the mineral powder is orangish yellow It fuses easily

Crocoite is a secondary mineral associated with other secondary minerals of lead such as pyromorphite and of zinc such as cerussite It has been found in the mines in California and Colorado [E C T C]

Cro Magnon man

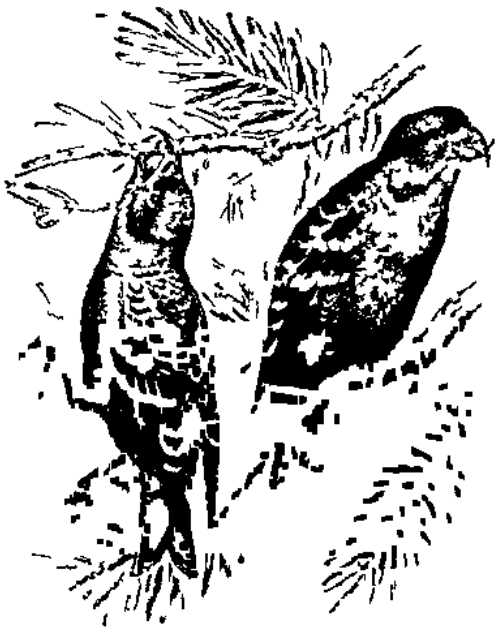
A term which refers generally to the fossil representatives of *Homo sapiens* of the upper Paleolithic archeological period of Europe or the end of the Pleistocene from about 35 000 B C to about 8000 B C Cro-Magnon man was large in skull size and of tall stature but fully modern in form and Caucasoid in racial nature Specifically the name Cro-Magnon refers to skeletons of at least three individuals from the Cro Magnon rock shelter at Les Eyzies Dordogne France found in 1868 by L Lartet and H Christy The Cro-Magnon type long headed but broad faced includes other skeletons of the period having the same features By casual extension the name has been used for all men of this period although some are slightly different being narrower faced and longer headed for example the Combe-Capelle and Lautsch skulls which are earlier than the Cro-Magnons proper *See* FOSSIL MAN [W W H]



Skull of a Cro-Magnon male (*From M F Ashley Montagu An Introduction to Physical Anthropology 2d ed Charles C Thomas 1951*)

Crossbill

A sparrowlike bird belonging to the genus *Loxia* family Fringillidae characterized by a bill which is crossed at the tip There are three species two of which are found in the United States Their principal food is the seeds of conifers the crossed



The crossbill *Loxia curvirostra* length to 6½ in (*From P Martin Duncan ed Cassell's Natural History Cassell & Company Ltd*)

bill is peculiarly modified for opening conifer cones The crossbills nest in the Holarctic coniferous forests and are only infrequently found far from them in irregular winter migrations The male red crossbill *L curvirostra*, is an orange red to brick red bird with brownish wings and tail The male white-winged crossbill *L leucoptera* is pink or rosy with black wings and tail and two prominent white wing bands The females of both species are dull-colored birds See PASSERIFORMES

[J D B]

Crossopterygii

A superorder of the subclass Sarcopterygii composed of the lobefin fishes or choanate fishes The lobefins differ from the other superorder the Dipnoi or lungfishes in having a palatoquadrate which is not fused with the cranium conical teeth that are adapted to predation and not coalesced into plates and premaillae maxillae and dentary which are well developed bearing strong marginal tooth rows

Crossopterygians appeared first in the Lower or Middle Devonian at which time they were well separated from the contemporaneous lungfishes and actinopterygians In body form they bore marked similarity to the lungfishes but later these groups diverged Two orders are distinguishable the Osteolepiformes with four families which were abundant in fresh waters of the Late Devonian and Carboniferous but died out before the end of the Paleozoic and the Coelacanthiformes which appeared in Late Devonian and has a single surviving species Crossopterygians gave rise probably in the Late Devonian to the earliest amphibians the progenitors of the other tetrapods See COELACANTHIFORMES SARCOPTERYGII

[R M B]

Crossover network

A selective network used to divide the audio frequency output of an amplifier into two or more bands of frequencies The frequency separation is employed to feed two or more loudspeakers each operating in a restricted frequency band and thereby operating more efficiently and with less distortion Most crossover networks used in high fidelity audio systems are designed for crossover frequencies somewhere between 400 and 2000 cycles

These networks consist of coils and capacitors connected to provide a low pass filter for feeding the low frequency woofer a high pass filter for feeding the high frequency tweeter and perhaps a band pass filter for feeding a middle-frequency range speaker At the crossover frequency the power outputs of the two filters are equal The crossover network is often connected between the secondary winding of the output transformer and the voice coils of the loudspeakers See LOUDSPEAKER SOUND REPRODUCTION SYSTEMS, ELECTRICAL

[J M R]

Crosstalk

A term originated for the sound produced at a receiving terminal of one voice-frequency circuit by speech signals carried by one or more such circuits The term is used commonly for the induction of signals in one circuit from a neighboring circuit It is also used for cross modulation See DISTORTION (ELECTRONIC CIRCUITS)

Crosstalk is unwanted and it impairs service to a degree determined by the tolerance of the receiving system or the listener and by the frequency of occurrence and duration of high ratios of crosstalk to normal signal intensity If crosstalk causes loss of presumptive secrecy the condition is intolerable

Two paralleling circuits in east west direction between terminals $E_1 - W_1$ and $E_2 - W_2$ are shown in Fig 1 Signals impressed at E_1 will induce crosstalk in the $E_2 - W_2$ circuit Resulting crosstalk at E_2 is called near-end and that at W_2 far end

Crosstalk coupling refers to the unwanted transmission path between reference points on the disturbing and disturbed circuits and is measured either in crosstalk units (cu) or in decibels (db) The value in cu is 10^n times the square root of the ratio of receiving end to sending end power with a specified frequency of the power source For a single frequency measurement a crosstalk (coupling) of 1000 cu means a current ratio of 0 001 for equal sending and receiving impedances A 60 db loss measures this same ratio For special purposes a derived figure of 90 minus the coupling loss in db identified by the symbol *dbx* is used There are near end and far-end couplings and these may include the complication of reflection effects Refer

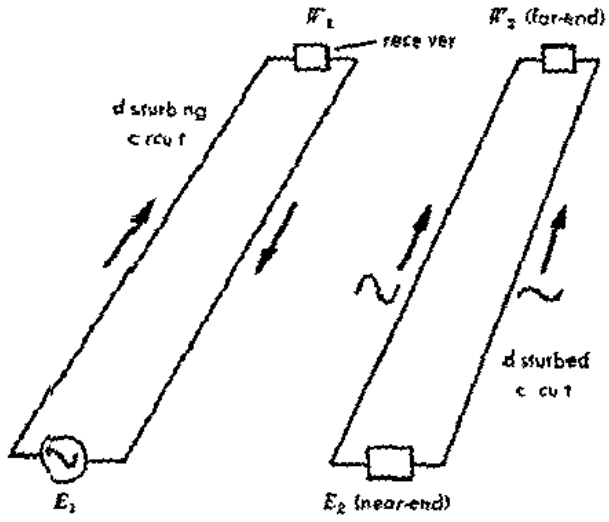


Fig 1 Crosstalk arising in a short section of two parallel circuits The conductor closer to the disturbing circuit has a larger crosstalk voltage than the farther conductor and the voltage is effective at E_2 and W_2 terminals

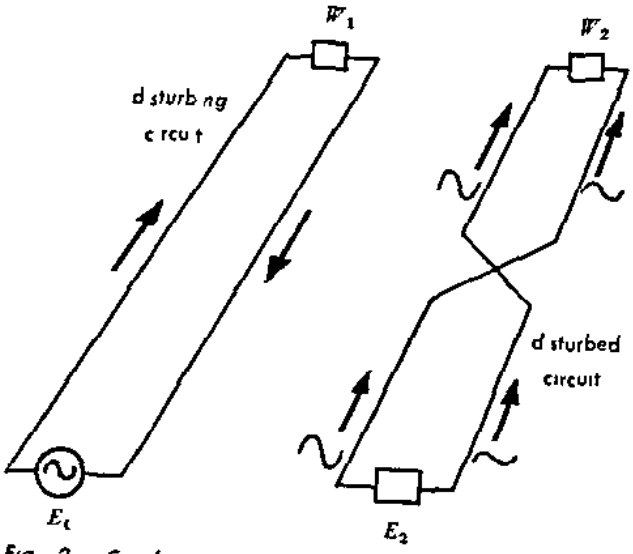


Fig 2 Single transposition of circuit If wires are transposed so that each is the closer conductor for an equal distance the total crosstalk voltages for the two wires will be made nearly equal and their difference will be reduced

ring again to Fig 1 if there were an impedance mismatch between the terminal and line at E_2 some power would be reflected here to travel back to W_2 giving a reflected near end power to combine with the normal far end crosstalk power

The mutual impedances of closely spaced paralleling wire circuits supply coupling links among them Since these impedances are almost wholly reactive coupling values in cu tend to increase linearly with frequency The importance of crosstalk coupling and its control was therefore greatly increased by the development of the carrier method for multiplexing communication transmission lines which employs higher frequencies

With open wire circuits coupling control is effected most practically by transposing (interchanging) positions of the wires of each pair in accordance with a systematic pattern seeking to oppose the coupling of one interval by that of another A simple example of the effect of transposition is shown in Fig 2 The design of patterns to accomplish a satisfactory result for all pair combinations is a specialty calling for a high order of skill and ingenuity Coupling between two pairs involves the effect of another circuit or circuits called a tertiary and there always is at least one tertiary in the form of all wires in multiple to ground The reaction between a pair and the tertiary path may create a series of absorption peaks (high losses) in a pair's transmission frequency characteristic—an added problem for the designer Coupling studies are useful in other than strict crosstalk applications

Near end coupling involves to-and fro transmission at finite velocity and where the coupling is large no practicable transposition design can reduce it to values satisfactory for operation at the carrier frequencies in general use Howe open wire lines far end coupling is controlle effectively by the transposition method Th est frequency consistent with acceptable op is determined by the practical precision with spacings between wires can be maintaine near end limitation is circumvented by emp independent adequately segregated transm paths for the two directions so that with du caution against reflection effects only far en pling will be involved

Control of coupling among insulated t pairs compacted within the metallic sheath cable is the same in principle as for oper lines The transposition effect is manufac into a cable by using different pitches of twi closely spaced pairs Remaining coupling ca reduced by the installation at intervals of s adjustable coupling units The higher dimens stability of the cable structure permits a fina sult superior to open wire

Crosstalk can result from other than indu relations among wire circuits For example the carrier method of multiplexing interchan coupling can arise through imperfect functior of modulating amplifying or frequency selec apparatus at terminal or intermediate points

Peculiarly useful with telephony an effective vice that reduces crosstalk is the compandor wh compresses the volume range of speech signals fore they are impressed upon the line and expa this to its original naturalness at the other e

tensified along with speech but its presence masked The effect of equipping telephone circui with compandors approximates that which woul result from increasing coupling losses 20 db

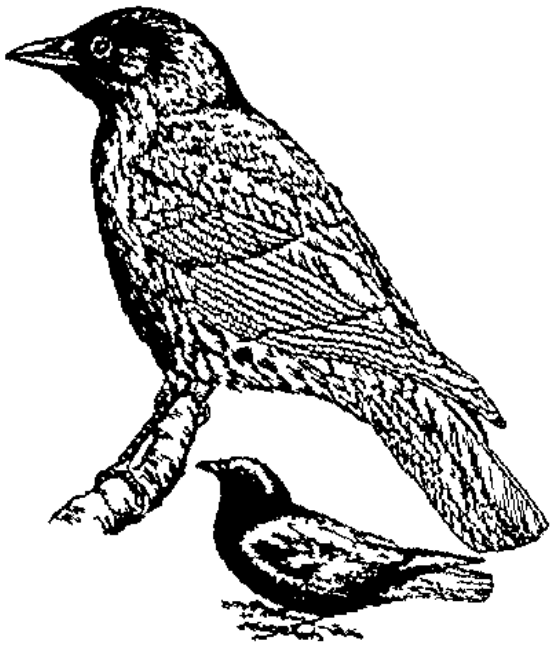
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Crow

Any of 32 species of birds of the genus *Corvus* a widely distributed and well known group Of the five species in the United States two are known as ravens and three as crows All are black or mainly black and relatively large ranging from 16 to 26 in in length The common crow *C brachyrhynchos* is known for its large winter flocks its wary habits and its cawing call Crows are often looked upon as harmful enemies of man but their over all role in nature is probably about as much helpful as harmful They are active predators on duck eggs in the Canadian prairie duck breeding areas and control is necessary

The fish crow *Corvus ossifragus* is primarily a tidewater bird found from New England to Texas



The crow *Corvus brachyrhynchos* length to 21 in (From E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

It is smaller than the common crow and has a short nasal call which is easily recognized *See* PASSERIFORMES [J D B]

Crushing and pulverizing

The reduction of materials such as stone coal or slag to a suitable size for their intended uses such as road building concrete aggregate or furnace firing Crushing and pulverizing are processes in ore dressing needed to reduce valuable ores to the fine size at which the valueless gangue can be separated from the ore These processes are also used to reduce cement rock to the fine powder required for burning to reduce cement clinker to the very fine size of portland cement to reduce coal to the size suitable for burning in pulverized form and in many other processes to prepare bulk materials for industrial handling

Equipment suitable for crushing large lumps as they come from the quarry or mine cannot be used to pulverize to fine powder so the operation is carried on in three or more stages called primary crushing secondary crushing and pulverizing The three stages are characterized by the size of the feed material the size of the output product and the resulting reduction ratio of the material Where the product size should be more uniform than the output from a crushing stage the product is screened

Reduction in size is accomplished by five principal methods (1) crushing a slow application of a large force (2) impact a rapid hard blow as by a hammer (3) attrition a rubbing or abrasion (4) sudden release of internal pressure and (5) ultrasonic forces The last two are not in common use

Table of crushing specifications

	Feed in	Product in	Reduction ratio	Equipment used
Primary crushing	27 12	9–4	3 1	Jaw gyratory cone
Secondary crushing (one or two stages)	9–4	1 ¼	9 1	Hammer mill, jaw gyratory cone smooth roll and toothed rolls
Pulverizing	1 ¼	60 mesh 325 mesh	60 1	Ball and tube coal hammer attrition ball race and roller mills

Crushing All the crushers used in primary and secondary crushing operate by crushing as defined above except the hammer mill which is largely impact with some attrition

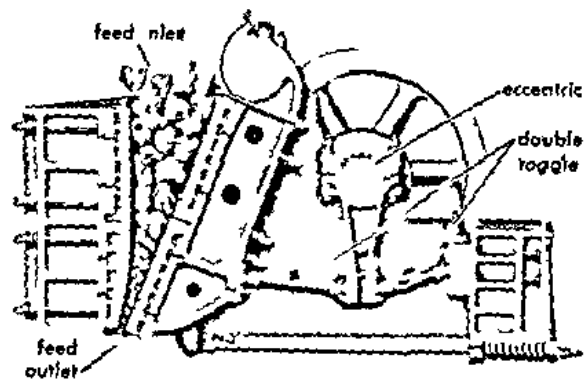
Primary crushers The Blake jaw crusher using a double toggle to move the swinging jaw is built in a variety of sizes from laboratory units to large sizes having a feed inlet 84 by 120 in (Fig 1) Large units have a capacity of over 1000 tons/hr and produce a 9 in product The Dodge jaw crusher uses a single toggle or eccentric and is generally built in smaller sizes

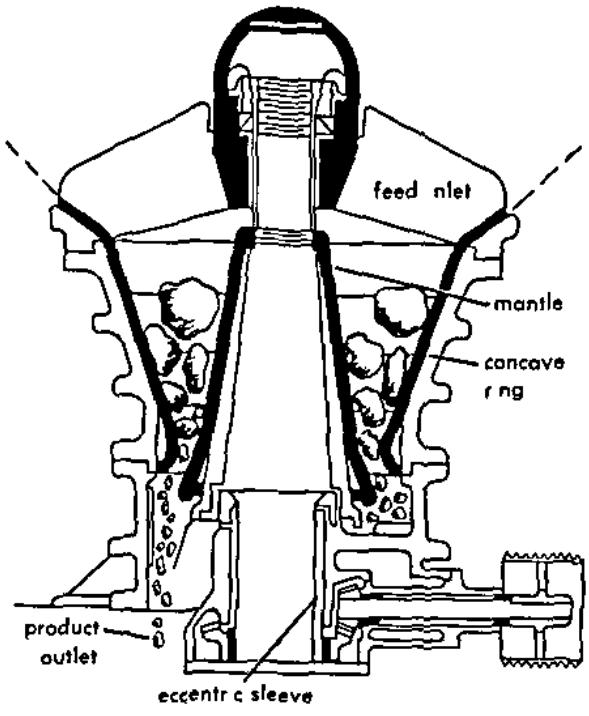
The Gates gyratory crusher has a cone or mantle that does not rotate but is moved eccentrically by the lower bearing sleeve (Fig 2) A 42 by 134 in crusher has a capacity of 850 tons/hr crushing rock from 27 to 8 in

The Symons cone crusher also has a gyratory motion but has a much flatter mantle or cone than does the gyratory crusher (Fig 3) The top bowl is spring mounted It is used as a primary or secondary crusher

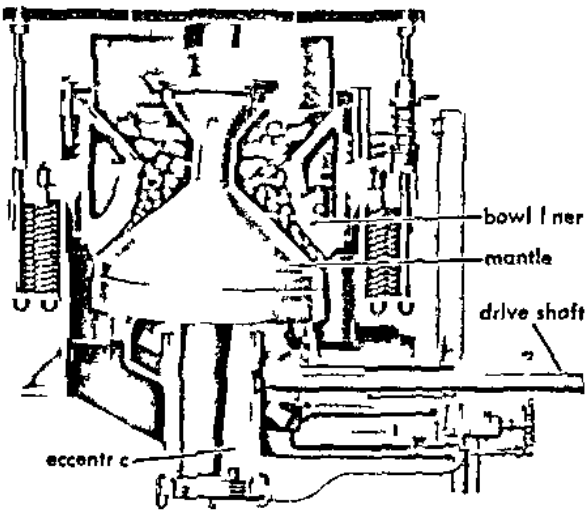
Angle of nip is the largest angle that will just grip a lump between the gyratory mantle and ring between the smooth jaws of a jaw crusher or between the pair of smooth rolls Depending on the material it is 8–48° but 32° is commonly used

Secondary crushers The single roll crusher and the double roll crusher have teeth on the roll sur





F g 2 Gyratory crusher Gates type (*All s Chalmers Co*)



F g 3 Symons cone crusher (*Nordberg Co*)

face and are used mainly for coal (Fig 4) Single roll crushers 36 in in diameter by 54 in long have a capacity of 275 ton/hr crushing run-of mine coal to 1¼ in ring size Smooth rolls without teeth are sometimes used for crushing ores and rocks

The hammer crusher is the type of secondary crusher most generally used for ore rock and coal (Fig 5) The reversible hammer mill can run al ternately in either direction thus wearing both sides of the hammers (Fig 6*a*) A hammer mill 42 in in diameter by 82 in long crushes 300 ton/hr of coal to ⅓ in for coke oven feed The ring coal crusher is a modification of the hammer mill using rings instead of hammers (Fig 6*b*)

Pulverizing In open circuit pulverizing the ma terial passes through the pulverizer once with no removal of fines or recirculation

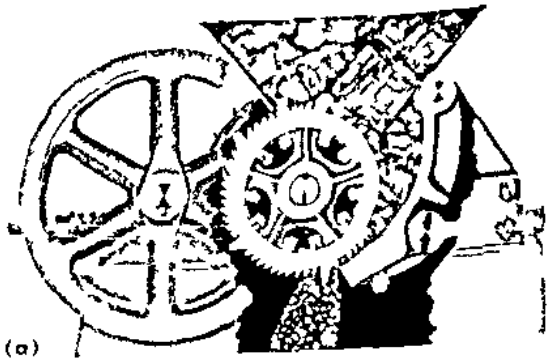
In closed circuit pulverizing the material d s charged from the pulverizer is passed through an external classifier where the finished product is re moved and the oversize is returned to the pulverizer for further grinding

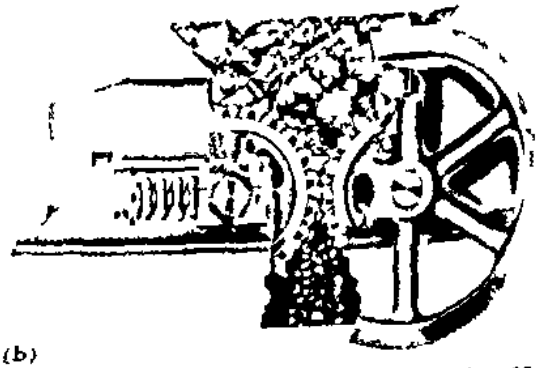
Ball and tube mills rod mills hammer mills and attrition mills are pulverizers operating by impact and attrition In ball race and roller pulverizers, crushing and attrition are used

Buhrstone pulverizer The Buhrstone pulverizer is one of the oldest forms of pulverizers a few still operate in flour and feed mills The pulverizing is done between a rotating lower stone and a floating upper stone which is restrained from rotating. Modern pulverizers use tumbling or rolling action instead of the grinding action of such earlier mills. For example smooth double rolls are used for pul verizing flour and other materials

Tumbling pulverizers There are two principal classes of tumbling pulverizer Both consi t of a horizontal rotating cylinder containing a charge of tumbling or cascading steel balls pebbles or rods If the length of the cylinder is less than 2 3 d am eters it is a ball mill If the length is greater than

ing operation





F g 4 Roll crusher (*a*) With single roll and spr ng loaded breaker plate (*b*) With two rolls one spr ng loaded (*L nk Belt Co*)

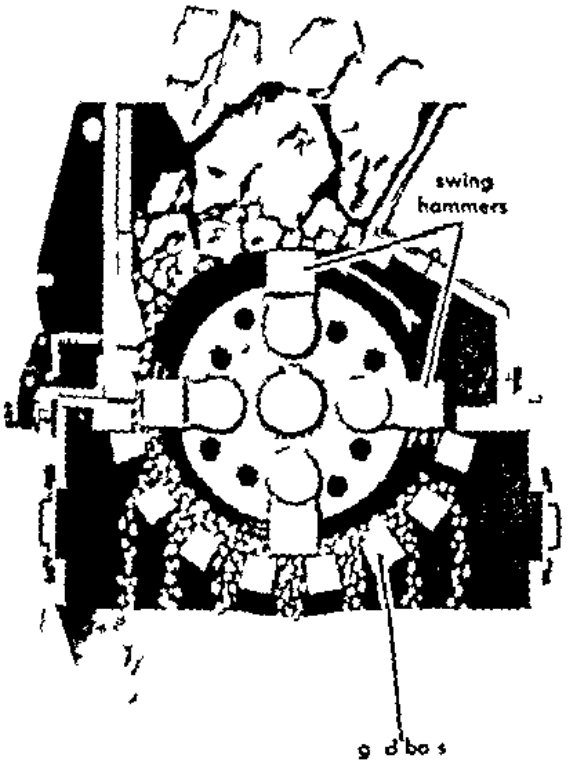


Fig 5 Hammer crusher (Jeffrey Co.)

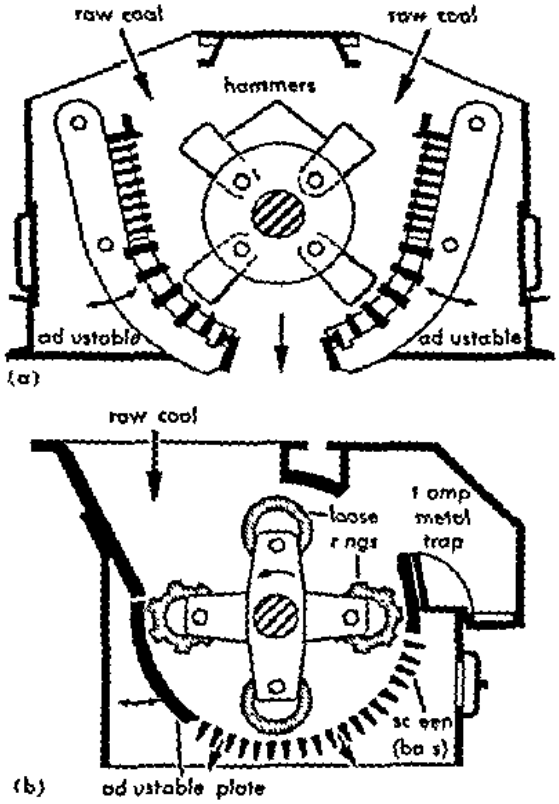


Fig 6 Coal crusher (a) Hammer-mill type (b) Ring type (Penna Crusher)

Ball mills charged with large steel balls 2 3 in in diameter are often used as preliminary pulverizers in series with a tube mill in open circuit (Fig 7a) The Krupp mill is a preliminary ball mill which discharges the material through a screen which forms the cylindrical surface

Pebble mills use balls and liners of quartz for application where contamination of the product with iron would be detrimental For products coarser than 6 mesh steel rods are sometimes used instead of balls

In some cement plants and many mining operations ball tube rod and pebble mills operate wet water being added with the feed and the product being discharged as a slurry Rake or cone type

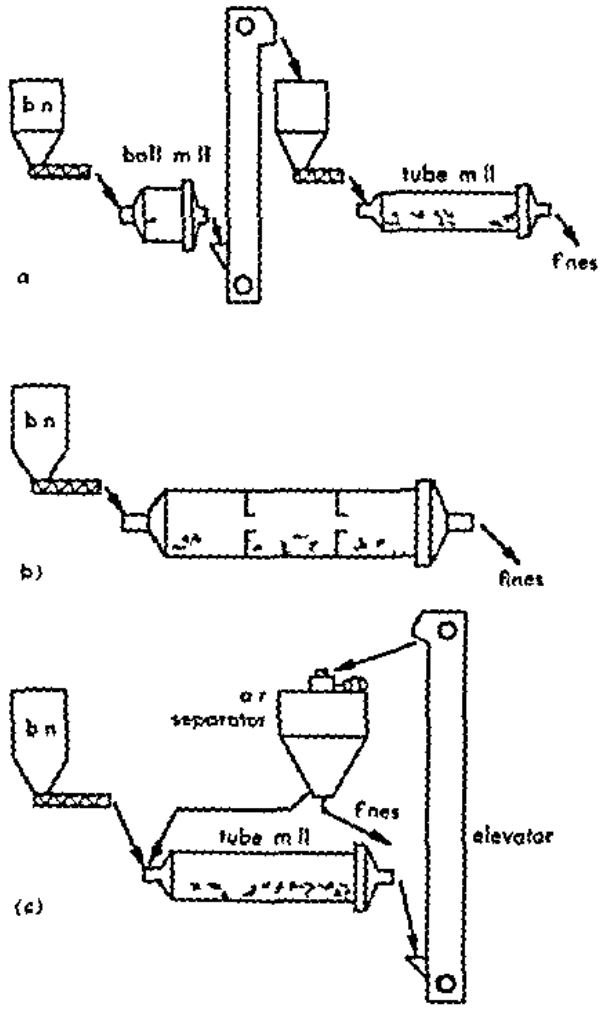


Fig 7 Pulverizers (a) Open circuit with preliminary ball mill stage followed by the mill (b) Open circuit three compartment tube mill (c) Closed circuit tube mill with air separator

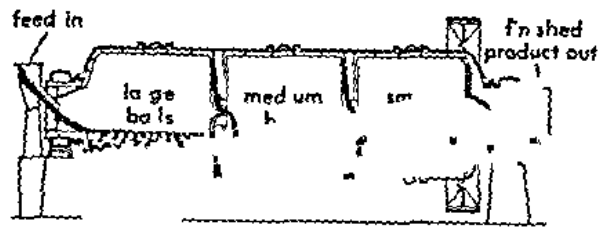


Fig 8 Three compartment tube mill pulverizer (Hardinge Co Inc)

classifiers are used in closed circuits that employ wet grinding

Tube mills for fine pulverization are used extensively in open circuit or as compartment mills or as closed circuit mills (Fig 7)

A three compartment grate discharge tube mill has larger balls in the first medium size balls in the second and smaller balls in the third compartment (Fig 8)

Cascade pulverizers are another form of tumbling pulverizer they use the larger lumps to do the pulverizing The Aerfall pulverizer is built in diameters up to 16 ft Feed is 12 in to 18 in lumps and the unit is airswept with an external classifier A few steel balls are sometimes used but not over 2½ % of the volume

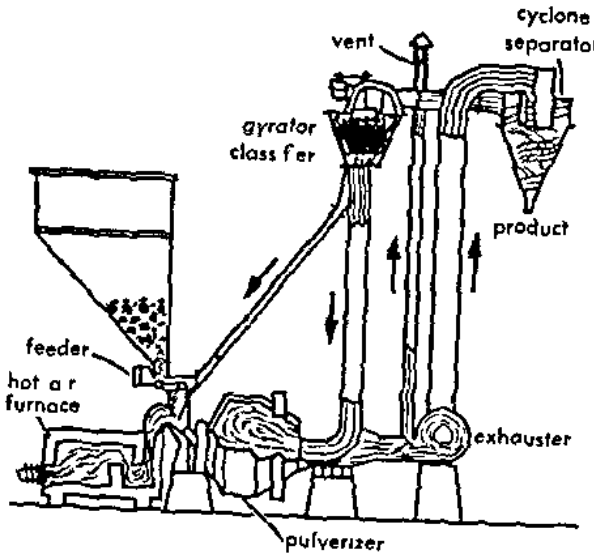


Fig 9 Conical ball mill pulverizer in closed circuit with classifier (*Hardinge Co Inc*)

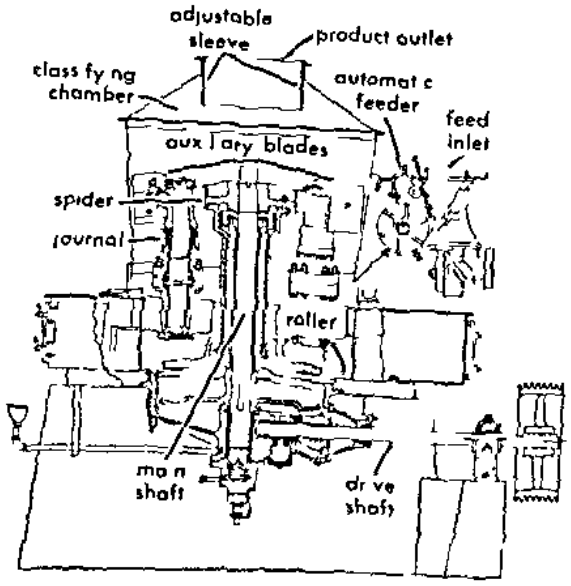


Fig 10 Pendulum roller pulverizer (*Raymond Pulverizer Division Combustion Engineering Co*)

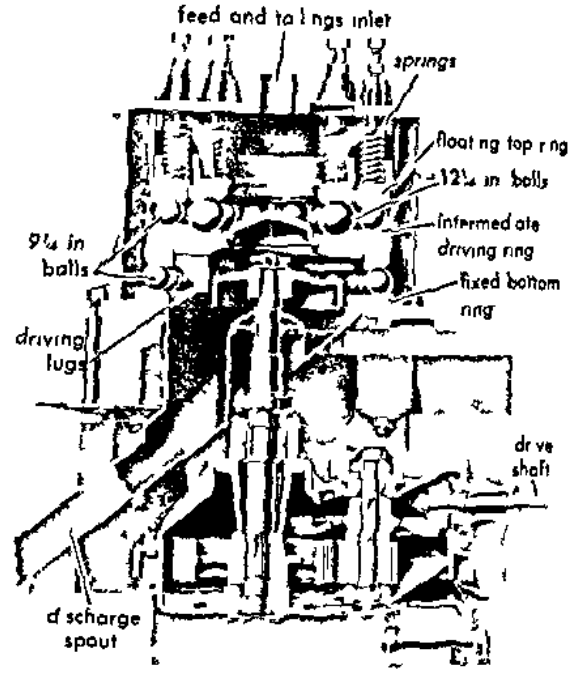


Fig 11 Ball race rock pulverizer for use in closed circuit (*Babcock and Wilcox Co*)

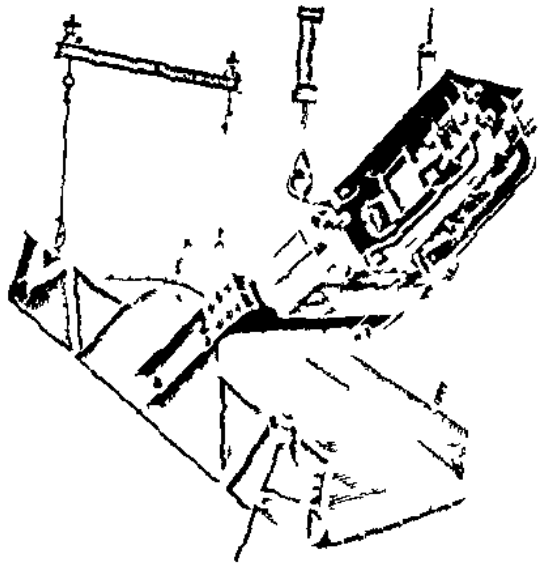


Fig 12 Vibrating screen classifier (*Jeffrey Co*)

The airswept conical ball mill is used in closed circuit with an external air classifier (Fig 9) The conical shape of the mill classifies the balls keeping the large balls at the feed end where they are needed to crush the larger lumps and the smaller balls at the small discharge end where the material is finer This conical ball mill is also used extensively in open circuit in rocks and ores

Roller pulverizers The airswept pendulum roller pulverizer has rollers pivoted from a rotating spider on a vertical shaft the centrifugal force of the rollers supplies the pressure between rollers and ring Hot air enters below the rollers and picks up

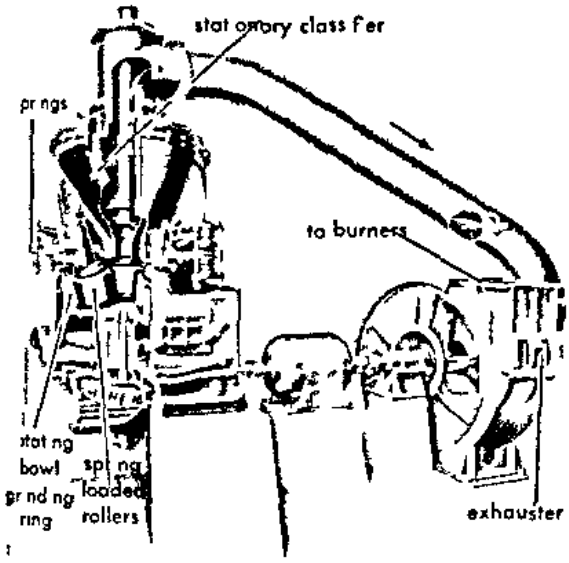


Fig 13 Medium speed bowl mill coal pulverizer (*Combustion Engineering*)

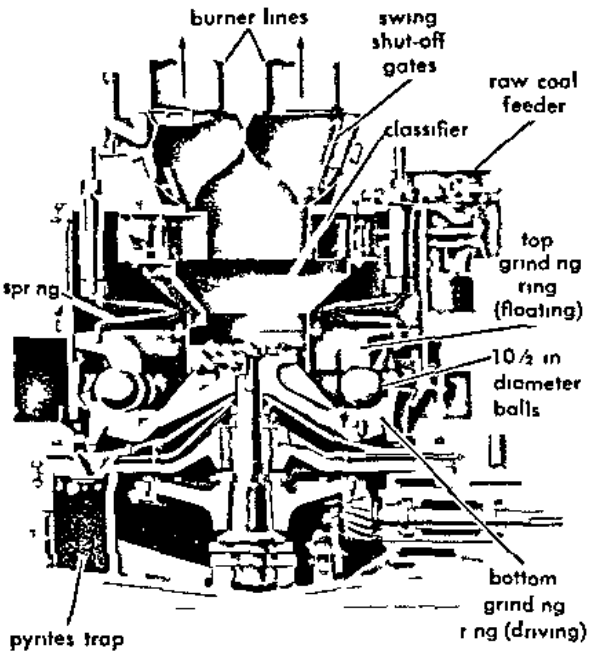


Fig 14 Medium speed ball race coal pulverizer (*Babcock and Wilcox Co*)

the fines The rotating rollers and spider provide a centrifugal classifying action which returns the oversize to the pulverizing zone For higher fineness a rotating classifier is added in the top housing (Fig 10)

The ball race pulverizer uses large steel balls between races (Fig 11) The bottom race is fixed the intermediate race is rotated through driving lugs and the top races are restrained from rotating by stops and are loaded by the springs The material flows by centrifugal force from the cente ward through the 12¼ in and 9¼ in balls A ball race unit in closed circuit with an air separator is used for pulverizing cement rock

Screening Material is separated into desired size ranges by screening For products 2 in or larger, an open end perforated cylindrical rotary screen is used It is on a slight inclination and the undersize goes through the holes and the oversize passes out through the open lower end

For finer products from 2 in down to fine powder passing through a 200-mesh sieve shaking or vibrating screens of woven wire are used

Shaking screens have either an eccentric drive or an unbalanced rotating weight to produce the shaking Vibrating screens have electric vibrators (Fig 12) They are often hung by rods and springs from overhead steel giving complete freedom to

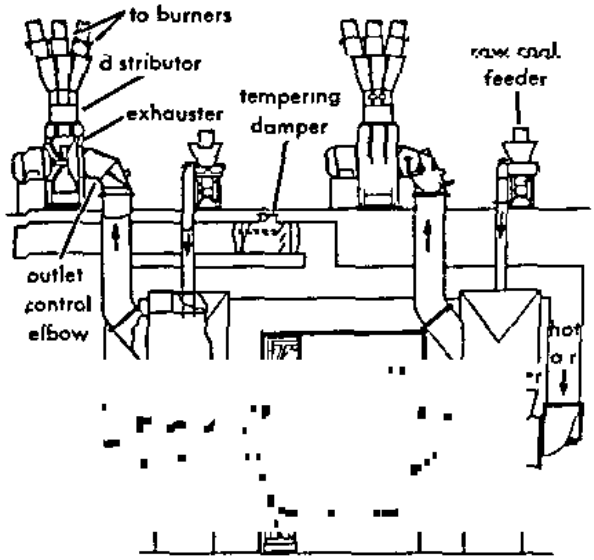


Fig 15 Slow speed coal pulverizer ball mill type (*Foster Wheeler Corp*)

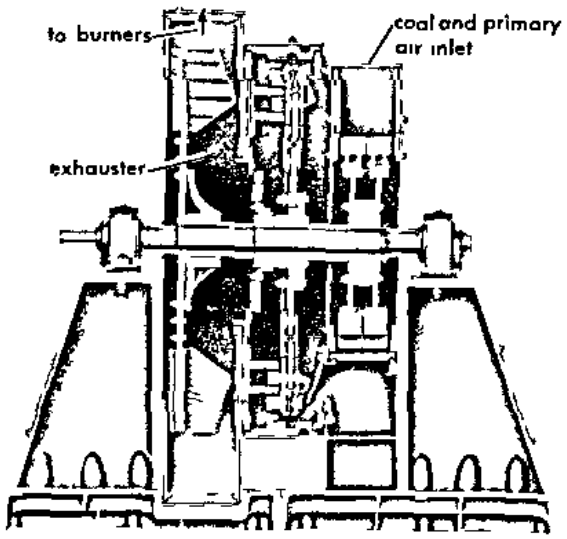


Fig 16 High-speed coal pulverizer (*Riley Stoker*

vibrate In some applications the screen is double decked thus producing three sizes of product

Direct fired pulverizers for coal Most modern large coal fired furnaces are fed directly by the pulverizer the coal rate being regulated by the rate of pulverizing Air at 300–600°F is supplied to the pulverizer to dry and preheat the coal In a bowl type medium speed pulverizer the springs press the pivoted stationary rolls against the rotating bowl grinding ring crushing the coal between them (Fig 13) The self contained stationary cone classifier returns the oversize to the pulverizing zone

The medium speed pulverizer of the ball race type uses closely spaced 10½-in diameter balls between a lower rotating race and a floating top race (Fig 14) The single coil springs restrain the top race and also apply the pressure needed A stationary cone classifier is used This pulverizer operates under pressure using a blower on the clean inlet air instead of an exhauster on the coal laden outlet air

Slow speed pulverizers of the ball mill type have classifiers and return the oversize for regrinding on both ends (Fig 15)

High speed pulverizers usually incorporate multiple stages such as a preliminary hammer mill and a secondary pulverizing stage A built in exhaust fan exhausts the fuel and air from the unit (Fig 16) [R M H]

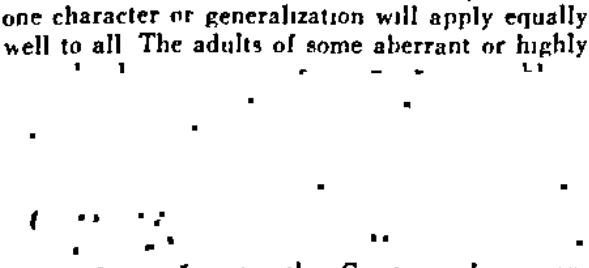
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Crustacea

A class of animals with jointed feet and mandibles in the subphylum Mandibulata of the phylum Arthropoda Although the term Crustacea (meaning animals with crustlike shell) originated with M Brisson (1756) P Pennant (1777) was the first post Linnean author to employ it as a class name

Everyone has seen if not eaten some species of crustacean such as the shrimp prawn crab or lobster (Fig 1) However there are many more with less common vernacular names such as the water fleas beach fleas sand hoppers fish lice wood lice sow bugs pill bugs barnacles scuds slaters and krill or whale food

The Crustacea are one of the most difficult animal groups to define because of their great diversity of structure habit, habitat and development No one character or generalization will apply equally well to all The adults of some aberrant or highly



Hexapoda or Insecta the Crustacea have segmented chitin encased bodies, articulated appendages, mouthparts known as mandibles during some stage of their life however modified they may be for cutting, chewing piercing sucking or licking and two pairs of accessory feeding organs the maxillae In Crustacea the first pair are the maxillulae, the second the maxillae One or the other pair of maxillae is sometimes vestigial or lacking

The Insecta have one pair of antennae whereas the Myriapoda have none The Crustacea differ from these two classes in typically having two pairs of antennae, the first pair, or antennules and the second pair, the antennae proper The latter moreover, are almost always functional at some stage of every crustacean's life although they disappear in the sedentary adult barnacles and in some lower shrimplike forms In some of the same forms the antennules may also become reduced or vestigial

TAXONOMY

Although all questions regarding the subclasses of the Crustacea have not been resolved eight subclasses are currently recognized These are listed in what is believed to be the order of their evolutionary relationship in the classification scheme which follows See articles on each group

Class Crustacea
- Subclass Cephalocarida
- Subclass Branchiopoda
  - Order Anostraca
  - Order Lipostraca
  - Order Notostraca
  - Order Conchostraca
  - Order Cladocera
- Subclass Ostracoda
  - Order Myodocopa
  - Order Cladocopa
  - Order Podocopa
  - Order Platycopa
- Subclass Mystacocarida
- Subclass Copepoda
  - Order Calanoida
  - Order Harpacticoida
  - Order Cyclopoida
  - Order Notodelphyoida
  - Order Monstrilloida
  - Order Caligoida
  - Order Lernaeopodoida
- Subclass Branchiura
  - Order Arguloida
- Subclass Cirripedia
  - Order Thoracica
  - Order Acrothoracica
  - Order Ascothoracica
  - Order Apoda
  - Order Rhizocephala
- Subclass Malacostraca
  - Series Leptostraca
    - Superorder Phyllocarida
      - Order Nebaliacea
  - Series Eumalacostraca
    - Superorder Syncarida
      - Order Anaspidacea
      - Order Bathynellacea

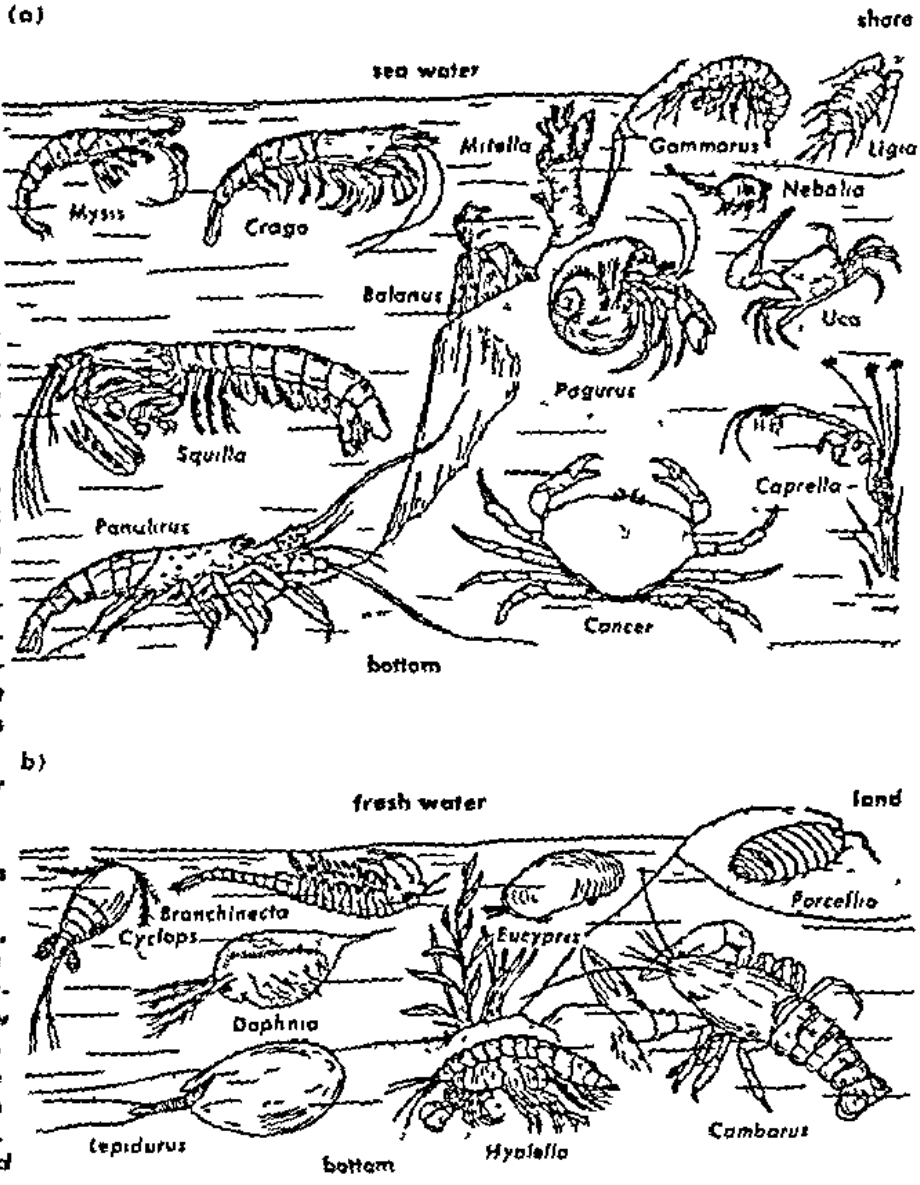


Fig 1 (a) Some marine forms of Crustacea in their respective habitats, mostly reduced but not to same scale Subclass Cirripedia, Order Thoracica *Mitella*, goose barnacle *Balanus*, acorn barnacle Subclass Malacostraca, Order Nebaliacea *Nebalia* Order Mysidacea *Mysis*, opossum shrimp Order Isopoda *Ligia* Order Amphipoda *Gammarus*, sand hopper; *Caprella*, "skeleton shrimp" Order Stomatopoda *Squilla* Order Decapoda *Crago*, shrimp, *Panulirus*, spiny rock lobster *Pagurus*, hermit crab, *Cancer*, edible crab, *Uca*, fiddler crab (b) Some fresh-water Crustacea in their characteristic habitats Some enlarged, others reduced, but not to same scale Subclass Branchiopoda, Order Anostraca *Branchinecta*, fairy shrimp Order Notostraca *Lepidurus* Order Cladocera *Daphnia*, water flea Subclass Ostracoda, Order Podocopa *Eucypris* Subclass Copepoda, Order Eucopepoda *Cyclops* Subclass Malacostraca, Order Isopoda *Porcellio*, sow bug (on land), Order Amphipoda *Hyalella* Order Decapoda *Cambarus* crayfish (From T I Storer and R L Usinger *General Zoology*, 3d ed McGraw-Hill, 1957)

Superorder Pancarida
  Order Thermosbaenacea
Superorder Peracarida
  Order Spelaeogriphacea
  Order Mysidacea
  Order Cumacea
  Order Tanaidacea
  Order Isopoda
  Order Amphipoda
Superorder Eucarida
  Order Euphausiacea
  Order Decapoda
Superorder Hoplocarida
  Order Stomatopoda

GENERAL MORPHOLOGY

The true body segments, the somites or metameres are usually somewhat compressed or depressed (Fig 2) Rarely are they circular rings The somite's dorsum or upper side is the tergum or tergite, the lower or ventral surface the sternum or sternite, and either lateral portion the pleuron or epimeron When prolonged or extended downward to overhang the attachment of the biramous appendages, of which one pair is a part of every typical crustacean somite the structure is termed the epimeron Between the embryonic anterior or prostomial element and the telson at the posterior end the linear series of somites making up the body of a crustacean are more or less distinctly organized into three regions or tagmata the head, thorax and abdomen (Fig 3) Where regional organization of the postcephalic somites is not clearly marked they collectively form the trunk The somites are variously fused with one another in diagnostic combinations in different groups of the Crustacea

Head region. The head region of the simplest type is found in the characteristic crustacean larva, the nauplius When the nauplius hatches it has only three pairs of appendages, the antennules, antennae and mandibles which correspond to the three fused somites of the primary head of the lower Crustacea In more advanced forms, and

vibrate In some applications the screen is double decked thus producing three sizes of product

Direct fired pulverizers for coal Most modern large coal fired furnaces are fed directly by the pulverizer the coal rate being regulated by the rate of pulverizing Air at 300–600°F is supplied to the pulverizer to dry and preheat the coal In a bowl type medium speed pulverizer the springs press the pivoted stationary rolls against the rotating bowl grinding ring crushing the coal between them (Fig 13) The self contained stationary cone classifier returns the oversize to the pulverizing zone

The medium speed pulverizer of the ball race type uses closely spaced 10½-in diameter balls between a lower rotating race and a floating top race (Fig 14) The single coil springs restrain the top race and also apply the pressure needed A stationary cone classifier is used This pulverizer operates under pressure using a blower on the clean inlet air instead of an exhauster on the coal laden outlet air

Slow speed pulverizers of the ball mill type have classifiers and return the oversize for regrinding on both ends (Fig 15)

High speed pulverizers usually incorporate multiple stages such as a preliminary hammer mill and a secondary pulverizing stage A built in exhaust fan exhausts the fuel and air from the unit (Fig 16) [R M H]

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Crustacea

A class of animals with jointed feet and mandibles in the subphylum Mandibulata of the phylum Arthropoda Although the term Crustacea (meaning animals with crustlike shell) originated with M Brisson (1756) P Pennant (1777) was the first post Linnean author to employ it as a class name

Everyone has seen if not eaten some species of crustacean such as the shrimp, prawn crab or lobster (Fig 1) However there are many more with less common vernacular names such as the water fleas beach fleas sand hoppers fish lice, wood lice sow bugs pill bugs barnacles scuds slaters and krill or whale food

The Crustacea are one of the most difficult animal groups to define because of their great diversity of structure habit habitat and development No one character or generalization will apply equally well to all The adults of some aberrant or highly specialized parasitic species are not recognizable as crustaceans and evidence of their kinship rests on a knowledge of their life histories Virtually every form of marine animal life as well as a number of fresh water animals have their crustacean parasites

ages, mouthparts known as mandibles during some stage of their life however modified they may be for cutting chewing piercing sucking or licking and two pairs of accessory feeding organs the maxillae In Crustacea the first pair are the maxillulae, the second the maxillae One or the other pair of maxillae is sometimes vestigial or lacking

The Insecta have one pair of antennae whereas the Myriapoda have none The Crustacea differ from these two classes in typically having two pairs of antennae, the first pair, or antennules and the second pair the antennae proper The latter moreover, are almost always functional at some stage of every crustacean's life, although they disappear in the sedentary adult barnacles and in some lower shrimplike forms In some of the same forms the antennules may also become *reduced or vestigial*

TAXONOMY

Although all questions regarding the subclasses of the Crustacea have not been resolved eight subclasses are currently recognized These are listed in what is believed to be the order of their evolutionary relationship in the classification scheme which follows See articles on each group

Class Crustacea
- Subclass Cephalocarida
- Subclass Branchiopoda
  - Order Anostraca
  - Order Lipostraca
  - Order Notostraca
  - Order Conchostraca
  - Order Cladocera
- Subclass Ostracoda
  - Order Myodocopa
  - Order Cladocopa
  - Order Podocopa
  - Order Platycopa
- Subclass Mystacocarida
- Subclass Copepoda
  - Order Calanoida
  - Order Harpacticoida
  - Order Cyclopoida
  - Order Notodelphyoida
  - Order Monstrilloida
  - Order Caligoida
  - Order Lernaeopodoida
- Subclass Branchiura
  - Order Arguloida
- Subclass Cirripedia
  - Order Thoracica
  - Order Acrothoracica
  - Order Ascothoracica
  - Order Apoda
  - Order Rhizocephala
- Subclass Malacostraca
  - Series Leptostraca
    - Superorder Phyllocarida
      - Order Nebaliacea
  - Series Eumalacostraca
    - *Superorder Syncarida*
      - Order Anaspidacea
      - Order Bathynellacea

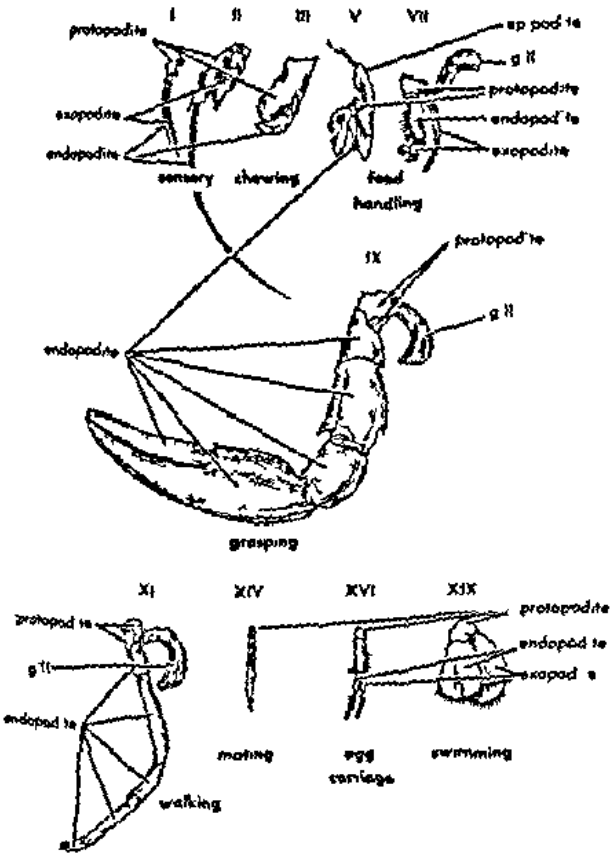


Fig 4 Crayfish appendages of the right side in ventroposterior view (some omitted) showing structural differentiation to serve various functions (From T I Storer and R L Usinger General Zoology 3d ed McGraw Hill 1957)

When the metastoma is bilobed the lobes are called paragnatha each of which may have a movable distal portion but in no sense do these or other armatures of the paragnatha represent appendages In the alimentary tract three regions are recognizable the foregut midgut and hindgut The anterior part of the foregut or stomodeum is esophageal in nature whereas the posterior and greater part is modified as a stomach gullet or gizzard The mechanical preparation of food occurs here because this region (called the gastric mill) contains chitinous ridges or teeth and setae for the trituration and straining of food The midgut or mesenteron in most cases is provided with several ceca or diverticula which produce digestive secretions and serve as organs for the absorption of food When these ceca are present in considerable number they become organized into a sizeable gland the *hepato-pancreas* or liver of higher Crustacea The hindgut or proctodeum is the rectal portion which terminates with few exceptions in the anal opening on the underside of the telson

Circulatory system Most crustaceans have a heart perforated by openings or ostia which admit venous blood from the pericardial sinus in which it is located The heart may be elongated and tubular and extend through the greater part of the body but generally it is a more compact organ It pumps blood through an arterial system or through connecting sinuses or lacunae within the body tissues Some lower Crustacea do not have a heart and the muscular movements of the animal or its alimentary tract circulate the blood through the body cavities or sinuses The blood of the great majority of the crustaceans is bluish because it contains the respiratory pigment hemocyanin A few crustaceans have red blood as a result of the presence of erythrocruorin *See* RESPIRATORY PIGMENTS

Respiratory system Crustacea have appropriately been described as water breathing insects of the sea for the vast majority are aquatic arthropods They take up oxygen by means of gills the general body surface or special areas of it Some of the few species that have become more or less terrestrial in their habits have developed modifications of their branchial apparatus such as villi ridges or water-retaining recesses which when sufficiently moist enable them to breathe air Some sow or pill bugs have special tracheal developments in their abdominal appendages for the same purpose

Nervous system The nervous system is distinctly arthropodan in character A supraesophageal ganglion somewhat larger than the other ganglia is considered to be the brain It is connected by circumesophageal commissures to a double ventral nerve chord with segmentally arranged ganglia These become reduced in number and in the short tailed crabs form a large ganglionic mass centered in the thorax

Organs of special sense The organs of special sense are the eyes, the antennules and antennae or feelers in a very real sense The antennules have also sense of taste of a kind and organs of equilibration, the statocysts in their basal segments Although crustaceans may not hear in the accepted sense they must be sensitive to sound waves and vibrations for many have stridulating or sound producing mechanisms on appendages or on somites overlapping one another on the carapace which produce snapping clicking rasping or rubbing noises Crustacea have setae variously located on their bodies which are sensitive to various external stimuli

Glands and glandular systems Those glands recognized as definite excretory organs are the maxillary and antennal glands in the adult crustacean They are located in the cephalon and rarely are both present at the same time The antennal gland is best developed in the *Malacostraca* It is often called the green gland and opens externally on the underside of the coxal segment of the antennal peduncle Many crustaceans especially deep sea forms have phosphorescent or luminous organs. The barnacles and some other crustaceans have cement glands This may also be true of tube building species which construct their homes of extraneous materials Those species that produce encysted or drought resistant eggs have other glands of special secretion The most intensively studied

crustacean gland is the sinus gland of the eyestalks This gland is part of a neurosecretory system producing hormones which control color change and pattern the molting cycle oogenesis and the development of eggs within the ovary See ENDOCRINE MECHANISMS

Reproductive system The sexes are separate in most Crustacea and usually can be differentiated from each other by secondary sex characters. Chief among these characters are the size and shape of the body appendages or both and placement of the genital apertures Hermaphroditism is the rule in the sessile Cirripedia (barnacles) in isolated cases in the lower crustaceans and in certain parasitic forms Parthenogenesis (eggs developing and hatching without prior fertilization) occurs frequently in some of the lower crustaceans such as the Branchiopoda and Ostracoda which have what might be called an alternation of generations The parthenogenetic generations (and there are usually very many of them in succession) alternate with a generation produced by fertilized eggs See METAGENESIS PARTHENOGENESIS

In shrimps of the genus *Pandalus* protandric hermaphroditism has been observed This is a reversal of sex in the individual or in the species On the basis of careful studies species of *Pandalus* reach maturity as males in the second year of their life cycle but become female in their third year and function as females This phenomenon is not confined to this one genus It has been noted in at least four other crustacean genera and probably occurs in more It has long been known to occur in certain mollusks

The eggs of most crustaceans are carried attached to the female until hatched Some females develop brood pouches in which the young are retained for a time A nutrient secretion which sustains the young until they are released is produced in some species having a brood chamber Penaeid shrimp and a few of the lower Crustacea deposit their eggs in the medium in which they live in some cases attaching them to aquatic vegetation

Development The nauplius larva is characteristic of Crustacea (Fig 5) Its oval unsegmented body has three pairs of appendages indicative of three embryonic somites These are the antennules which are uniramus in the nauplius the biramous antennae and mandibles Besides subserving other functions such as sensory and feeding all three are the organs of locomotion of this free swimming larva Their basal portions the gnathobases are modified to serve as masticatory organs and for passing food to the mouth with its relatively large labrum There is a single dorsal median naupliar eye composed of three closely united similar parts which form a relatively simple compound eye and a frontal organ probably sensory evidenced externally by a very minute pair of projections This frontal organ seems to persist in the form of anterior sensory cells in the Branchiopoda as setae in the Copepoda and as papillae even in the late larval stages of some Malacostraca

The integument of the upper surface of the nauplius body has the appearance of a dorsal shield as in most crustaceans Typical as this first larval stage may be it does not appear in all crustaceans It is common in the lower forms, but in many of the higher forms it occurs during development in the egg and the young are hatched as a different and more advanced larva or as in many Malacostraca in a form similar to the adult Life histories vary from the simple to the complex within the different groups of Crustacea Only the euphausiid and penaeid shrimps among the Malacostraca hatch as nauplii (Fig 6) Following the naupliar stage whether it is passed in the egg or not very remarkable larval stages follow in some groups the free swimming cypris larvae of barnacles the phyllosomae of the spiny lobsters, the erichthus and alima larvae of the mantid shrimps and the zoeae and megalopa of crabs

Molting (Ecdysis) Because of its tough chitinous or calcified exoskeleton a crustacean cannot grow without molting This process involves several steps one of preparation which includes some degree of resorption of the old cuticle the formation of a new temporarily soft and thin one within it and the accumulation and storing of lime salts in the hepato pancreas or as lenticular deposits (gastroliths) one of which occurs on either side of the stomach or gizzard in certain forms such as crayfishes and lobsters The preparatory period is less involved in the thinly chitinous forms The act of molt follows The old shell or cuticle splits at strategic and predetermined places permitting the crustacean within already enclosed in new but still soft exoskeleton to withdraw There is little question but that a temporary absorption of water enables the animal to split or crack his housing Upon withdrawal of the entire animal absorption of water again rapidly takes place with a pronounced increase in body size The chitinous lining of the stomodeum and proctodeum as well as the endophragmal skeleton are shed along with the exoskeleton In this postmolt period the crustacean is quite helpless and if unsheltered is at the mercy of its enemies It is in the soft shelled stage immediately after molting that the Fast Coast blue crab *Callinectes* becomes a much sought after sea food delicacy The tender new cuticle is reinforced rapidly by the resorbed chitin and hardened by whatever reserves of lime salts the animal may have stored supplemented and extended by the far more plentiful supplies in solution in the sea which may be absorbed or ingested by the growing crustacean Molting or ecdysis takes place quite frequently in the larval stages when growth is rapid but becomes less frequent as the animal ages Hormones from the sinus gland play an important [illegible] mark[illegible]imize [illegible]ough injury and hemorrhage it is [illegible] injury or loss to an enemy The appendage is cast off or broken at the fracture or breaking plane This

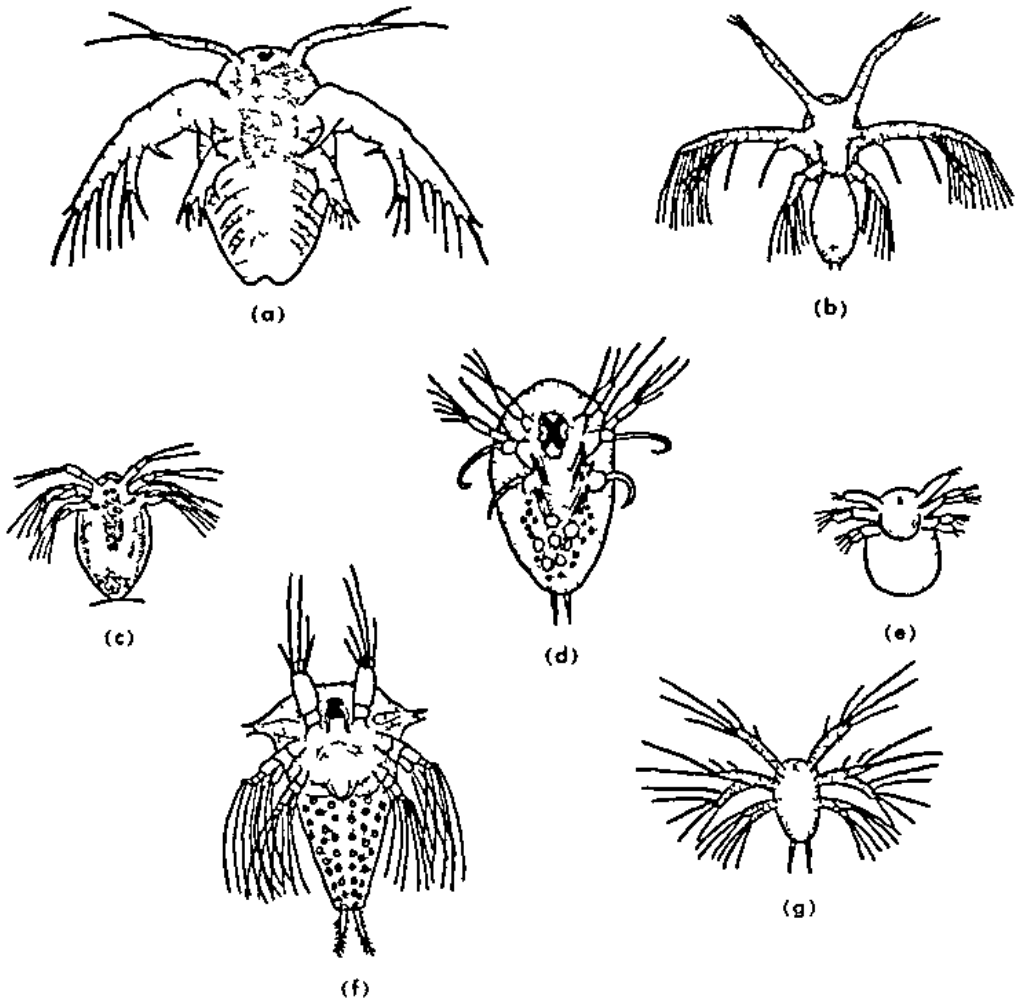


Fig 5 Nauplii of (a) *Apus cancriformis* (b) *Branchinecta occidentalis* (c) *Lernaeocera branchialis* (d) *Haemocera danae* (e) *Meganyctiphanes norvegica* (f) *Sacculina carcini* (g) *Penaeus setiferus* Enlarged but not to same scale (*From R E Snodgrass Crustacean Metamorphoses vol 131 No 10 Publ 4260 Smithsonian Institution 1956*)

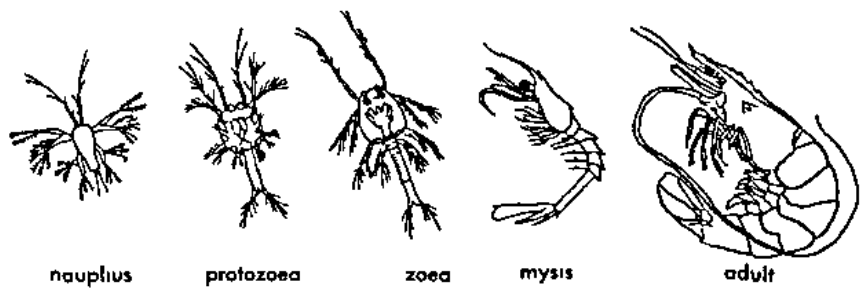


Fig 6 Life history of *Penaeus* Some stages enlarged others reduced but not to same scale (*From T I Storer and R L Usinger General Zoology 3d ed McGraw Hill 1957*)

sacrifice enables the victim to escape This plane runs through the basipodite in all crabs and all but a few lobster species and in some other Malacostraca It is thought by many however to represent the line of juncture of the basipodite and ischiopodite in the pereiopods and chelipeds which in these forms are usually fused The break in other crustaceans with completely jointed pereiopods occurs between the unfused basis and ischium At the fracture plane there is an infolding of epidermal tissue forming a double walled diaphragm with a small medial opening for the passage of nerves and blood vessels This is so designed that severance of the limb will occur at that place The proximal wall of that diaphragm prevents undue loss of body fluids or laceration of tissue and at the same time facilitates the speedy closure of its foramen with quickly clotting blood

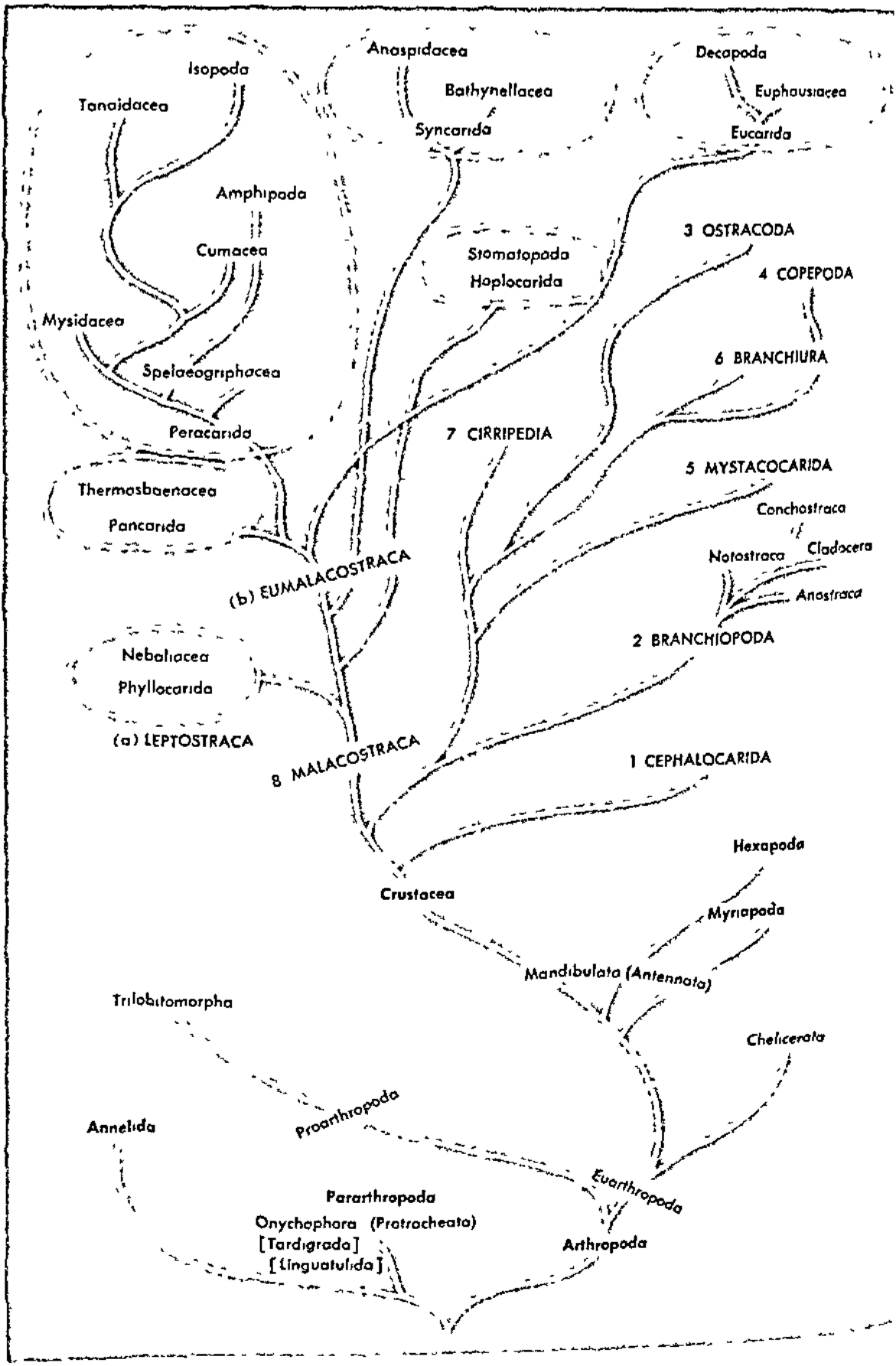


Fig 7. Phylogenetic chart of the Arthropoda (*Courtesy T. Monod*)

Even more remarkable is the fact that crustaceans by voluntary muscular contraction can part with a limb which may be injured *See* AUTOTOMY

Crustacea also have the ability to regenerate lost parts Although the regenerated parts are not always the same size as the original in the first molt after injury increase in size in successive molts soon restores a lost limb to virtually its former appearance During the regenerative stages among alpheid shrimps and lobsters which generally exhibit marked dimorphism in the chelipeds when the major chela is lost the minor one often may take on more or less the character of the former major chela Then the chela replacing the lost one assumes the habitus of the former minor chela during successive molts *See* REGENERATION (BIOLOGY)

PHYLOGENY

The geologic history of crustaceans dates from the earliest fossiliferous rock formations the Cambrian estimated to be about 350 000 000 years of age Many lower forms of crustaceans have been discovered in those strata including some thought to be distantly related morphologically to present day Malacostraca but the state of preservation especially of the appendages of these early fossils leaves much to be desired It is not unlikely that because of their small size and fragility many crustaceans of bygone ages never did become recognizably fossilized Interest in the hypothetical ancestral crustacean has been greatly stimulated by the discovery of the small forms for which the subclasses Cephalocarida and Mystacocarida were recently established (Fig 7) *See* CEPHALOCARIDA MYSTACOCARIDA

An intensive study of the crustaceans which are quite diverse both structurally and biologically raises a much discussed question as to the monophyletic or polyphyletic origin of the subclasses

BIONOMICS AND ECONOMICS

Crustacea are ubiquitous They live at almost all depths and levels of the sea in fresh waters at elevations up to 12 000 ft in melted snow water and in the deepest of the sea's abysses more than 6 miles down, and waters of 0°C (32°F) temperature They live on land trees and mountains although most of these species must descend to salt water areas again to spawn their young Some live in strongly alkaline waters and others in salt water which is at the saturation point still others in hot springs with temperatures of 55°C (131°F)

All crustaceans of sufficient size are eaten by man somewhere in the world None properly prepared have proved to be poisonous so far as is known Myriads of small fry are the sustenance of larger aquatic animals chiefly fish and whales

Crustacea are of all sizes ranging from copepods ¼ in long to huge spider crabs of Japan which span 12 ft from tip to tip of the laterally extended legs Individuals of the giant xanthid crab of Australia have been recorded weighing 20–30 lb and the American lobster the heaviest so far known tops all crustaceans at 44¼ lb

Most crustaceans are omnivorous and essentially scavengers Many are filter feeders and screen particulate life plankton and organic detritus from the waters in which they live others are largely carnivorous still others vegetarian Among the vegetarians are the grazers of the ocean meadows which convert the microscopic plant life (diatoms) into flesh and food for larger animals which in turn are harvested as food for man Annual production figures and imports for the United States in recent years show that crustacean fisheries and markets involved more than 500 000 000 lb valued at nearly $200 000 000 [WLS]

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Crux

The Southern Cross in astronomy is the most celebrated of the constellations of the far south The four principal bright stars of the group form the figure of a cross giving the constellation its name in contradistinction to the Northern Cross of Cygnus (*see* CYGNUS) in the north which is larger and more distinct having a bright star to mark its center The brightest star in Crux is Alpha Crucis at the foot of the cross which has received the artificial name Acrux This is a navigational star The star at the top of the cross is Gamma Crucis sometimes called Gacrux The line joining these two stars points approximately toward the South Celestial Pole *See* CONSTELLATION

Cryogenic engineering

A branch of engineering specializing in [illegible] operations at very low temperatures [illegible] gineers combine competence in the [illegible] of low temperature physics and [illegible] bility in conventional branches [illegible] as mechanical chemical and [illegible] sions of other aspects of low[illegible] ogy *see* CRYOGENICS *Liquefaction of the Gases* LOW TEMPERATURE THERMOMETRY

Nuclear, military, and space [illegible] ing the early 1950s the [illegible] mission supported an extensive [illegible] at the cryogenic engineering [illegible] tional Bureau of Standards at Boulder Laboratories and elsewhere directed toward the [illegible] large scale production [illegible] niques for liquid hydrogen [illegible] number of materials [illegible] also investigated The [illegible] tempt to solve the [illegible] associated with the use of liquid hydrogen

An important military application of cryogenics has been the development of oxygen breathing apparatus for crews of high altitude long range aircraft By storing oxygen as a dense liquid in light weight well insulated containers from which it can be vaporized as needed significant weight reductions are effected over the older method of high pressure low density gas storage in heavy steel cylinders The need for liquid oxygen to fill these containers has led in turn to the development for the military services of portable oxygen generators in a wide range of sizes for installation at air bases and on ships

Cryogenic engineers have also been active in the missile field Because the specific impulse of a rocket is inversely proportional to the square root of the molecular weight of the exhaust gases low molecular weight fuels are obviously highly desirable These however are all cryogenic liquids Improvement in rocket performance has therefore required the concurrent development of (1) large scale gas liquefaction plants for hydrogen oxygen fluorine and other gases (2) large scale storage and transport facilities (3) high capacity and high pressure pumps (4) more efficient thermal insulation (5) lightweight missile fuel tanks and (6) control and other specialized valves and fittings for cryogenic fluids

Because of its low molecular weight hydrogen will be used as the propellant in the first nuclear rockets New and unusual problems in cryogenic engineering are certain to arise because the hydrogen must be stored and delivered to the nuclear reactor as a liquid liquid hydrogen temperatures are appreciably lower than those encountered using other cryogenic fluids such as liquid oxygen and finally additional difficulties arise with nuclear rockets because of the presence of a high radiation flux from the reactor

Chemical engineering applications Gases employed in the chemical industry usually require extensive pretreatment because their source is most often a gas mixture—either the atmosphere natural gas or a by product stream from some other chemical operation In consequence the components must first be separated then purified Both these processes involve cryogenics Depending upon the mixture one or more of the following low temperature techniques must be used fractional distillation scrubbing or most recently selective adsorption This latter technique has proved particularly applicable for the separation and purification of the noble or inert gases

Of all industrial gases oxygen is produced (by separation from air) in the largest quantity In 1959 the estimated production in the United States was 10^{11} ft^3 about 50% of which was used by the steel industry The chemical industry uses about 25% the missile industry about 20% with welding and medical therapy accounting for the remainder In the chemical industry oxygen is used in partial or direct oxidation processes to make other chemicals such as ammonia methanol and ethylene oxide Nitrogen also obtained from the fractional distillation of air is used in the production of ammonia (and hence fertilizer) for blanketing hazardous chemical storage areas with an inert atmosphere for purging and in liquid form for purification of other gases with extremely low boiling points such as hydrogen by scrubbing The rare gases argon neon krypton and helium which are becoming increasingly useful in industry are obtained as a mixture from air separation plants and are then further purified by low temperature adsorption *See* ATMOSPHERIC GASES PRODUCTION OF

Metal industry applications Metallurgical applications for pure gases are increasing as new alloy steels are created and as the production of hitherto rare or seldom refined metals is undertaken in order to meet the unusual demands of the nuclear and the space age Oxygen nitrogen argon and hydrogen all of which are produced cryogenically are the gases most commonly used In order to meet the growing demand for oxygen economically on site generators have been developed to supply the gas from plants constructed adjacent to the user and piped over the fence *in quantities* up to 500 tons per day (Previously liquid oxygen was transported to the consumer from a large centrally located air separation plant) Some of the smaller plants are even automatically controlled requiring only periodic visits from maintenance personnel The liquid produced is stored in large insulated tanks from which it is pumped and vaporized ac

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The former includes jet piercing in which a high velocity jet flame made by burning kerosine and

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are removed and enrichment of both the air blast in blast furnaces and the air feed to the end burners of open hearth furnaces The higher temperatures obtained in the last mentioned application lead to increased reaction rates and hence to an increased daily output per furnace In refining processes oxygen speeds up oxidation of carbon phosphorus sulfur and other impurities in electric and open hearth furnaces thereby increasing capacity by 25% Finally the availability of tonnage quantities of oxygen led to the development of so-called oxygen converters in which oxygen under pressure is blown upon the surface of a molten charge of iron and scrap steel *Impurities* present in the melt are rapidly oxidized to produce steel more cheaply and much faster than by the open hearth method yet of comparable quality *See* STEEL MANUFACTURE

High purity nitrogen is used in strip steel annealing prior to tin plating For purging molten metals of undesirable dissolved and entrained gases and also to provide extremely pure inert at

mospheres for the preparation of reactive metals such as titanium and silicon a noble gas is required and for this purpose argon is most frequently selected Hydrogen is used for certain special annealing processes and may find increasing application in the direct reduction of ores

Solid state memory and switching devices. The first commercially successful application of the phenomenon of superconductivity came in 1953 47 years after its discovery in the form of an electrical circuit element called the cryotron In this device the destruction of the superconducting state by a magnetic field activates a new type switch There have since appeared several other elementary superconducting circuits which can be combined to produce binary memory elements switching devices and multivibrators for high speed computers The small space requirements negligible power inputs and high reliability of these units combine to promise significant advantages over other types of computer components although to date recovery time limitations have precluded their use in the very high speed machines *See* CRYOTRON

Solid state amplifiers These devices are molecular high gain low noise level microwave amplifiers called masers When a paramagnetic crystal is cooled to 4 2°K or lower energy stored in the crystal can be released by a weak incident signal of the appropriate resonance frequency If the crystal passes on more energy than it receives from the input signal it operates as a microwave amplifier When the sensitivity of an electromagnetic detection system is limited by thermal noise for example radioastronomy use of the maser has proved particularly significant *See* MASER

The cryopump A D Little Inc has developed a new high speed vacuum pump for specialized applications capable of producing an extremely low ultimate vacuum and requiring less power than conventional diffusion type pumps The principle employed is well known lowering the pressure within a gas tight enclosure by freezing out condensible gases on a cold surface In the cryopump a low temperature refrigeration unit circulates helium at 20°K through coils in plate condensers upon which the gas to be pumped condenses One application for this pump has been found in large environmental simulation facilities such as high altitude wind tunnels Because of the reduced power consumption of the cryopump other industrial applications may be anticipated

Transportation and storage of gases Gases whose critical temperatures lie below ambient temperature and which therefore are not liquefiable by pressure alone have conventionally been transported and stored in heavy walled steel cylinders at high pressures In the case of hydrogen for example about 140 lb of steel must be used to contain each pound of gas at high pressure In contrast current cryogenic technology yields a corresponding weight ratio of only 11 for liquid containment Although this ratio is not quite so small for heavier gases the dead weight savings are still sufficient to justify liquid storage of nitrogen and oxygen in almost all large-scale industrial operations Methane is now being liquefied and shipped across the Atlantic Ocean in a specially insulated tanker of 32 000-barrel capacity Progress toward similar liquid usage with the gases of lower boiling point such as hydrogen and helium has been retarded by the lack of a sufficient number of large liquefaction plants and a suitable thermal insulation for the container without which long term storage or transport of these volatile liquids would be impractical Both these impediments have now been removed Large-scale hydrogen liquefaction plants are in operation in strategic locations throughout the country large helium plants are under construction and several new super insulations have been developed which are capable of reducing liquid boil off losses to almost negligible proportions

Because the stored liquid is usually required by the consumer as a gas at ambient temperature and sometimes at high pressure effective exploitation of the concept of liquid storage has required the concurrent development of cryogenic pumps and vaporizers for all the liquids in question. This in itself was a difficult engineering feat requiring the solution of numerous low temperature bearing seal and lubrication problems

Isotope separation The increasing demands of atomic energy programs both fission and fusion for large quantities of the separated hydrogen isotopes have led to renewed interest in that isotope separation scheme for deuterium which from the beginning had been recognized as the most efficient namely low temperature distillation This method had been passed over during the war because of the belief that alternative processes required less development and had a higher probability of success Recent advances in cryogenic engineering and several pilot plant investigations demonstrated the feasibility of the distillation method for deuterium separation and led to the construction of major production facilities of this type in the Soviet Union West Germany France and Switzerland Besides being the most economical the distillation method requires the least time to reach equilibrium involves the smallest capital investment and extracts the largest fraction of deuterium from the feed gas *See* DEUTERIUM, ISOTOPE SEPARATION (STABLE ISOTOPES)

High magnetic fields In the vanguard of both applied and basic physics higher magnetic fields than can presently be produced are of immediate interest Oddly enough the applications in these two areas also occur at extremes of the presently accessible temperature scale The former relates to the problem of plasma containment by a magnetic field in controlled thermonuclear reactions in the latter a high field is used to orient nuclei at very low temperatures *See* MAGNETOHYDRODYNAMICS

Because of saturation effects fields higher than about 30 000 oersteds must be produced by circulating electric currents rather than by a

tional iron core electromagnet The power dissipation within solenoids producing high fields at ordinary temperatures is so excessive however that the practical limitation on steady high field production is removal of the heat generated within the winding If the magnet is cooled its resistance decreases and so proportionately does the power By operation of a solenoid at 20°K for example the same fields can be obtained as at ambient temperature with a power reduction of 100–1800 depending upon the purity of the conductor With very high fields some of this advantage is lost by magnetoresistance and obviously the refrigeration costs must also be considered Nevertheless a careful analysis shows that refrigerated solenoids have significant economic advantages over the conventional type [E F H]

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Cryogenics

The science of producing and maintaining very low temperatures Prior to World War II scientific research at very low temperatures was carried out at only a few specialized laboratories because of the large amount of time and money required for the construction operation and maintenance of the necessary gas liquefaction and associated facilities Beginning in the prewar years however recognition of the economic advantages of applied cryogenics in certain industrial processes initiated a rapid expansion of both the scientific and industrial aspects of low temperature technology For example liquid helium which in 1939 was available in fewer than one dozen laboratories throughout the world is now a readily available refrigerant in most large research institutes Similarly many prewar experimental applications of cryogenic engineering such as tonnage oxygen plants to produce pure oxygen for metallurgical processes are now in common use In the vanguard of industrial cryogenics is the development of hydrogen and helium liquefaction plants capable of producing large quantities of these liquefied gases for both industrial and military use

Production of low temperatures From a practical standpoint any given object may be cooled to and maintained at a low temperature most simply by placing it in thermal contact with a suitable liquefied gas held at a constant pressure The temperature ranges available using baths of liquefied gases are given in the table In principle a liquefied gas can be used to provide constant bath temperatures from its triple point to its critical point In practice (except for certain special applications) the normal boiling point is the usual upper limit of the useful temperature range for any given gas Bath temperature is varied by changing the pressure above the liquid by means of a pump and

Selected physical constants of low temperature liquids

Liquid	Triple point		Boiling point, °K	Critical point	
	Temp °K	Pressure atm		Temp °K	Pressure atm
Helium 3			3 2	3 3	1 2
Helium 4			4 2	5 2	2 3
n Hydrogen	14 0	0 07	20 4	33 2	13 0
n Deuterium	18 7	0 17	23 7	38 4	16 4
n Tritium	20 6	0 21	25 0	42 5*	19 4*
Neon	24 6	0 43	27 1	44 7	26 9
Fluorine	53 5	<0 01	85 0	144 0	51 0
Oxygen	54 4	<0 01	90 2	154 8	50 1
Nitrogen	63 2	0 12	77 4	126 1	33 5
Carbon monoxide	68 1	0 15	81 6	132 9	34 5
Argon	83 8	0 68	87 3	150 7	48 0
Propane	85 5	<0 01	231 1	370 0	43 0
Propene	87 9	<0 01	226 1	365 0	45 6
Ethane	89 9	<0 01	184 5	305 4	48 2
Methane	90 7	0 12	111 7	191 1	45 8

* Calculated

throttle valve Within the above mentioned range any desired bath temperature is maintained by holding constant the pressure above the liquid the pumping rate is adjusted to remove precisely the amount of gas vaporized by heat leak to the bath liquid As may be seen from the table liquefied gases do not exist over the entire temperature [illegible] at which it is practicable 55°K

With few exceptions toxic explosive or very costly liquefied gases are not used as temperature baths Finally, because heat leak cannot be excluded entirely all baths of liquefied gases will eventually boil away unless replenished periodically

If the accessible temperature range is to be extended or if temperatures attainable with difficulty using liquefied gases are to be realized more conveniently other methods of cold production are clearly required Two alternative procedures which have been effectively employed are the use of refrigerators and for the attainment of extremely low temperatures the technique of adiabatic demagnetization Refrigerators can in principle be designed to produce and maintain a predetermined temperature at any point along the temperature scale For refrigerators operating cyclically the low temperature produced is not constant because of the periodic withdrawal of heat from the low temperature reservoir When however the working substance changes phase in the low temperature reservoir its specific heat becomes infinite and the reservoir temperature remains constant Such refrigerators are essentially liquefiers and the low temperature reservoir is simply a liquid bath in which the boil off liquid is continuously replenished

Very low temperatures may be produced by the process of adiabatic demagnetization or paramagnetic cooling in which a magnetized electronic or

nuclear paramagnetic substance is thermally isolated and then demagnetized Because of the unavoidable heat leak into substances cooled by this process the extremely low temperatures so obtained are always nonsteady Isothermal experiments using this technique are therefore impossible In many cases however the rate of temperature increase can be made so exceedingly small that quasi-isothermal measurements are practicable See LOW TEMPERATURE THERMOMETRY

Principles of cold production The same basic principles of refrigeration may be used to explain gas liquefaction the periodic temperature reduction of the refrigerator working substance and the adiabatic demagnetization process Cold production is obviously related directly to the concept of temperature which in turn is intimately connected with a quantity defined as

$$\int (C/T)\, dT$$

where C is the specific heat of the substance being cooled This quantity known as the entropy S is a measure of the intrinsic thermal disorder associated with the substance in question At absolute zero the entropy of every substance in internal equilibrium is zero (see THERMODYNAMIC PRINCIPLES) Entropy is increased either by the introduction of thermal energy or by appropriately varying some other parameter upon which S depends Between temperature and entropy a conjugate relationship obtains such that provided parameters such as pressure or volume are held constant a change in T results in a change in S of the same sign The significance of S for low temperatures lies in the fact that there exist idealized processes called isentropic (or constant S) which result in the maximum possible decrease in T for a given spontaneous parametric change Because an isentropic process must be both adiabatic (thermally isolated) and reversible in practice it can be only approximated Nevertheless the isentropic process provides a criterion against which the efficiency of any actual process may be gaged From Fig 1 in which the variation of S with T for an idealized substance is shown at two different constant values of a thermodynamic parameter such as the magnetization it may be easily seen that an isentropic parameter change from $A \rightarrow B$ produces the maximum reduction in T (Spontaneous processes which result in a decrease in S with the indicated parameter change are impossible)

In addition to the isentropic process described above irreversible and hence less efficient processes also exist which are capable of lowering the temperature of the substance to which they are applied Although the temperature drop for the same parameter change is for an irreversible process always less than that obtained from a reversible isentropic change the former is often selected for actual applications This is because refrigerating machines based upon an irreversible cycle possess under certain circumstances numerous practical advantages over those based upon the theoretically more efficient process The cooling achievable by an irreversible process is represented on Fig 1 by a path such as $A \rightarrow C$ (Under certain conditions it is even possible in an irreversible process to produce for the same parameter change a heating instead of a cooling as shown by the path $A \rightarrow C'$)

Cooling of a gas In applying the above principles to a gas, let parameters X_1 and Y_2 be the constant pressures P_1 and P_2 with $P_2 < P_1$ Then if the gas is expanded isentropically with the performance of external work (as in the driving of a turbine or piston expansion engine) one obtains the maximum cooling as shown by the path $A \rightarrow B$ Actually the temperature drop is somewhat less than the ideal because of frictional losses An irreversible expansion of the gas from $P_1 \rightarrow P_2$ for example through a throttle valve, would result in a lesser temperature drop such as that given by the path $A \rightarrow C$ Obviously the latter process is more amenable to practical realization because it involves no moving parts at low temperatures

Adiabatic demagnetization If in Fig 1 the parameter curves are assumed to represent two different but constant magnetizations of a paramagnetic material I_1 and I_2 with $I_2 < I_1$ and if initially the specimen is magnetized to a value I_1 at a temperature corresponding to that given by point A then an isentropic demagnetization of the specimen to I_2 will result in the temperature drop $A \rightarrow B$ In

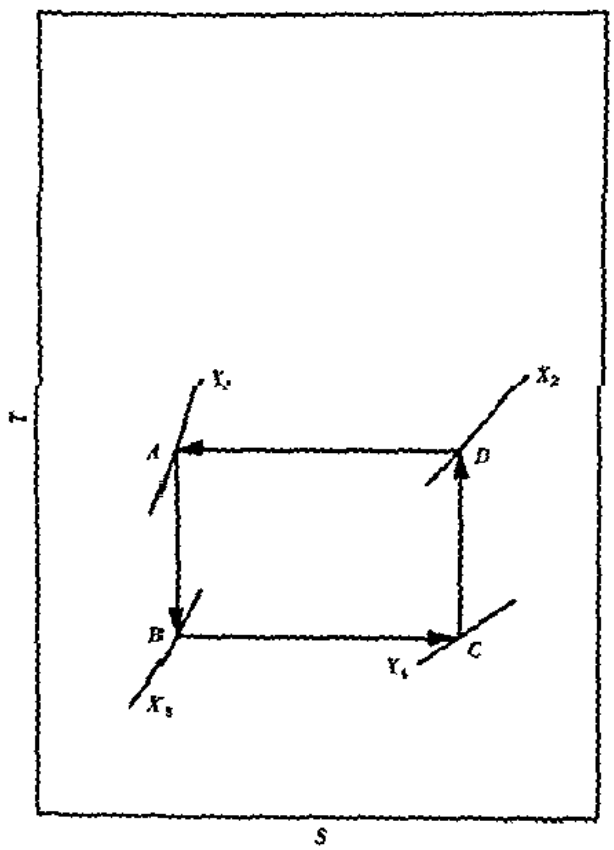


Fig 1 Variation of the entropy with temperature for two different constant values of a thermodynamic

practice this is accomplished by thermally isolating the magnetized paramagnetic before reducing the magnetic field and the associated specimen magnetization After the low temperature T_B has been reached experiments may be carried out on the paramagnetic material itself if that is the object of interest or alternatively a second substance can be thermally connected with the paramagnetic and cooled by it to some intermediate temperature dependent on the relative heat capacities of paramagnetic and sample This technique makes it possible to carry out measurements at 2.0×10^{-5} degree above absolute zero *See* DEMAGNETIZATION

Cooling by refrigeration If a suitable working substance is caused to undergo repeatedly one of the cooling procedures described above a lower than ambient temperature may be maintained indefinitely Machines capable of carrying out such processes are called refrigerators and the closed sequence of states through which the working substance passes is called the refrigeration cycle All reversible refrigeration cycles have the same efficiency the maximum possible One such cycle called a Carnot cycle is illustrated in Fig 2 First a suitable substance showing a large change in S with both T and some other parameter such as the pressure is cooled isentropically $(A \rightarrow B)$ It is then allowed to absorb heat isothermally $(B \rightarrow C)$ by further changing the parameter as required to maintain constant temperature Following this a second isentropic process $(C \rightarrow D)$ is carried out by thermally isolating the working substance and reversing the parametric change adiabatically During this step the working substance heats until it reaches the temperature of the hot reservoir whereupon thermal contact is made between the working substance and hot reservoir The net heat extracted from the low temperature reservoir as well as the work done in circumventing the cycle is then transferred $(D \rightarrow A)$ isothermally to the hot reservoir by further parameter changes until the working substance has returned to its original state and the cycle is ready to repeat As may be seen in Fig 2 this sequence is represented by a rectangle on a T S diagram Actual refrigerators approach the efficiency of the Carnot cycle but cannot exceed it

An application of the above principles is provided by the recently developed magnetic refrigerator the low temperature reservoir of which operates at about 0 2°K The high temperature reservoir consists of a liquid helium bath held at 1 2°K The cycle is essentially that shown in Fig 2 in which a paramagnetic salt is carried through the indicated sequence of isentropic and isothermal changes In order to carry out adiabatic and isothermal changes at will a so-called heat switch is required In the magnetic refrigerator this switch between the working substance and the heat reservoirs consists of a lead wire the thermal conductivity of which can be changed by one or two factors of 10 when it is caused to pass from its superconducting to its "normal" state

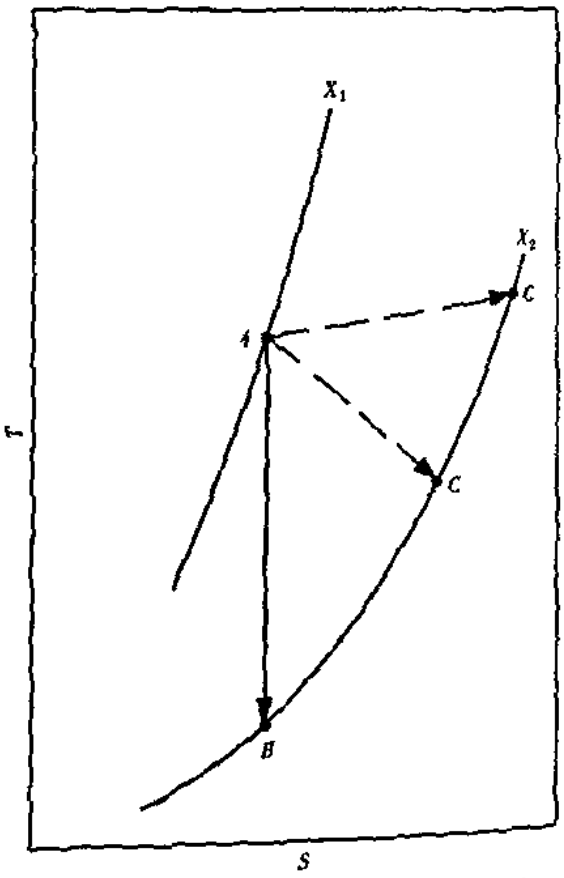


Fig 2 An ideal refrigeration cycle on a temperature entropy (T S) diagram

At higher temperatures a gas may be used as the refrigerator working substance The cycle is then located between two isobars on the T S diagram with the cooling phase occurring during the expansion of the compressed gas Whether or not a reversible expansion is the objective of any given design depends upon the importance of such factors as reliability required simplicity of operation and efficiency For certain applications in which the refrigeration must be supplied at a constant low temperature a portion of the gas is allowed to liquefy in the cold reservoir The absorption of heat then occurs by evaporation of the liquid at constant pressure and hence constant T If the heat absorption can occur over a range of low temperatures however the refrigeration is usually supplied directly by the expanded cold gas

Although the refrigerators discussed above are based upon conventional refrigeration cycles it should be remembered that any heat engine run in reverse constitutes a refrigerator An example of a refrigerator utilizing a cycle quite different from the ones discussed above is the Notelco air liquefier developed in 1954 In this device heat is absorbed and rejected to the heat reservoirs isothermally during expansion and compression of a gaseous working substance (hydrogen or helium) while the cooling and heating phases of the cycle can be considered to occur at either constant pressure or constant volume with the aid of a regenera

tor or heat accumulator The result is a highly efficient refrigerator

Liquefaction of gases In order to reduce the temperature of a gas and eventually liquefy it any one of several procedures may be followed The most frequently used are cooling the gas at constant pressure that is constant parameter by subjecting it to a series of progressively colder refrigerator reservoirs or allowing the gas itself to constitute the refrigerator working substance until it has cooled sufficiently to liquefy partially then continuing the process with the addition of make up gas while simultaneously withdrawing the liquid formed per cycle *See* LIQUEFACTION OF GASES

Maintenance of low temperatures Having once produced a temperature lower than ambient it may be maintained indefinitely (provided the region itself contains no heat sources) if flow of heat to the cooled region can be prevented Because no perfect thermal insulators exist the problem resolves itself practically into minimizing the flow of heat to the refrigerated region Devices designed to provide low temperature environments in which operations may be carried out under controlled conditions are called cryostats

Heat flows irreversibly from a high to a low temperature zone by three different mechanisms radiation convection and conduction Although several of these often operate simultaneously it is usually possible to reduce the contribution of all but one to negligible proportions Radiative heat losses are decreased by surfacing the cold region with material of the lowest possible emissivity Because emissivities of 0 02 are practically attainable a suitably coated surface can be made to reflect 98% of the radiant energy incident upon it Radiation heat leak may be further diminished by the use of similarly surfaced radiation shields located between the hot and cold surfaces Finally the temperature of the hot radiating surface may often be reduced by cooling it to some temperature intermediate between ambient and the low temperature in question by some relatively inexpensive refrigerant By the use of one or more of the above techniques the heat leak from radiation can almost always be reduced to negligible proportions

Heat leak from convection is also relatively easy to eliminate either by evacuation of the space between the hot and cold surfaces to a very high vacuum or by packing this intervening space with an insulating material such as a foamed plastic or a suitable powder The gas is thus effectively displaced or localized sufficiently to prevent convection In addition the efficiency of a powder insulation is often enhanced significantly by evacuating it to a few microns pressure

Conduction along the solid supports piping necessary openings and the insulation itself constitutes the remaining mechanism by which heat can flow to the refrigerated region As a general rule all connecting material between hot and cold surfaces should have the lowest possible thermal conductivity the smallest cross sectional area and the longest length consistent with the imposed requirements of mechanical stability

Finding an optimum solution to any given problem requires an analysis of all the factors contributing to the heat leak Beginning with the largest the various heat leaks are minimized successively Under these conditions it frequently happens that a less than optimum but also less expensive material can be specified for a particular component when its fractional contribution to the total heat leak is small *See* ATMOSPHERIC GASES PRODUCTION OF CRYOGENIC ENGINEERING HELIUM INSULATION HEAT LOW TEMPERATURE PHYSICS REFRIGERATION [E F H]

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Cryolite

A mineral with chemical composition Na_3AlF_6 Although it crystallizes in the monoclinic system cryolite has three directions of parting at nearly 90°, giving it a pseudocubic aspect Hardness is 2½ on Mohs scale and the specific gravity is 2 95 Crystals are usually snow white but may be colorless and more rarely brownish reddish or even black The mean refraction index is 1 338 approximately that of water and thus fragments become invisible when immersed in water Cryolite associated with siderite galena and chalcopyrite was discovered at Ivigtut Greenland in 1794 This locality remains the only important occurrence

Cryolite was once used as a source of metallic sodium and aluminum but now is used chiefly as a flux in the electrolytic process in the production of aluminum from bauxite *See* ALUMINUM [C S HU]

Cryosar

A two terminal semiconductor switching device which operates at very low temperatures The thyratronlike characteristic of this device is the result of the avalanche ionization of normal semiconductor impurity centers (donors and acceptors) which at the low temperature of operation are no longer thermally ionized (*see* SEMICONDUCTOR) It has a relatively high impedance because only a moderate amount of current can be drawn in the conducting state before overheating occurs with an attendant rise in voltage The operating temperature is the liquid helium range

Typical characteristics show a breakdown voltage of 3 volts and a sustaining voltage of 1 volt The nonconducting impedance is of the order of 10 megohms and the maximum current in the conducting state is about 1 millamp for devices of normal size Under suitable conditions of load and voltage overdrive it is possible to switch the device in a few millimicroseconds It is possible to obtain the device with a breakdown voltage either

equal to the sustaining voltage or much greater as the application requires [L P HU]

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Cryotron

A switching device based on the magnetic control of superconductivity Superconductivity is a sud den and complete disappearance of electrical re sistance at temperatures near absolute zero For each of the 23 superconductive elements and the unlimited number of superconductive compounds and alloys there is a superconductive transition temperature in zero magnetic field Niobium be comes superconducting at 9 2°K lead at 7 1°K vanadium at 5 1°K tantalum at 4 4°K tin at 3 7°K aluminum at 1 2°K titanium at 0 4°K and hafnium at 0 35°K *See* SUPERCONDUCTIVITY

If the temperature is held below the transition temperature for a superconductor its resistance is zero and will remain zero as a magnetic field is applied—until that field reaches a critical in tensity Above this intensity the normal resist ance returns If the field is lowered the resistance disappears Raising and lowering the magnetic field thus controls the resistance of the material by causing it to shift from its superconducting state to its normal conducting state and back without changing the temperature If the operat ing temperature is lowered the magnetic field in tensity required to reach the normal conducting region is raised For each of the materials which becomes superconducting there is a temperature about 0 2°K below the zero field transition tem perature which allows operation with rather small magnetic fields between 2000 and 8000 amperes per meter For tantalum this temperature is about 4 2°K Tantalum has been used in many of the early cryotron experiments because 4 2°K is the boiling point of helium at a pressure of one atmosphere and is therefore the temperature of most storage tanks for liquid helium At 4 2°K experiments do not require sealing of the lead in wires and pumping of the helium vessel

Operation The wire-wound cryotron (Fig 1) consists of a straight piece of wire ¼ to 1 in in length over which a single layer control winding is wound A current in the control winding pro duces a magnetic field which controls supercon ductivity in the central wire The central wire is analogous to the plate circuit of a vacuum tube and the control winding is analogous to the con trol grid In this case however the plate resistance is zero in the cutoff region and rises rapidly as grid current cutoff is reached

The control winding is made of a superconduct ing wire such as niobium or lead which has a rela tively high transition temperature At the tempera ture used the control winding remains a super conductor at all times and would remain so even in magnetic fields much more intense than those being used to control the central wire Therefore

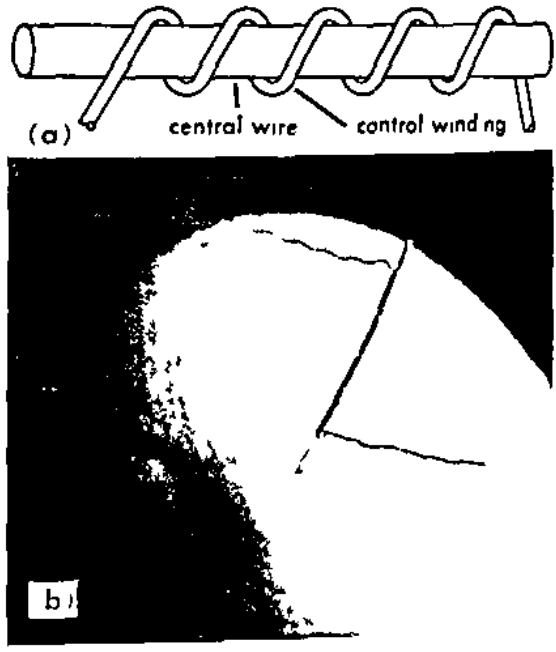


Fig 1 Wire wound cryotron (a) Schemat c. (b) Ac tual photograph Tantalum gate wire is 0 009 in and carries 1 amp when superconduct ng Control w nd ng is 0 003 in niobium wire Control current required to destroy superconductivity in gate wire is 300 ma

there is no resistance in the control winding A magnetic field once established needs no further energy for its support, the control current is main tained against zero back voltage In nearly all cryotron circuits the interconnecting wiring is similarly superconducting at all times

The magnetic field due to the control winding is along the axis of the central wire and the self field of the central wire is perpendicular to the axis so that the two fields add vectorially in space quadrature The central wire is switched from superconducting to normal conducting state when the total field strength exceeds the critical val ie for the material and temperature used Figure 2 shows this critical value called threshold field strength as a function of temperature for niol ium tantalum, and lead

Since the change of conducting state is deter mined by total field strength the cryotron has an interesting property as an electronic component control is independent of the sign of the control current and depends only on the magnitude Fur thermore when the gate circuit (central wire) is superconducting current can flow in either direc tion whereas it is resistive to current in either direction when it is normal conducting Both of these properties are also characteristic of electro mechanical relays Cryotrons can easily be de signed to carry a maximum current when the gate is superconducting of larger magnitude than the current required in the control winding to make the gate resistive

Applications The application of cryotrons is not restricted to digital devices but this field has acute

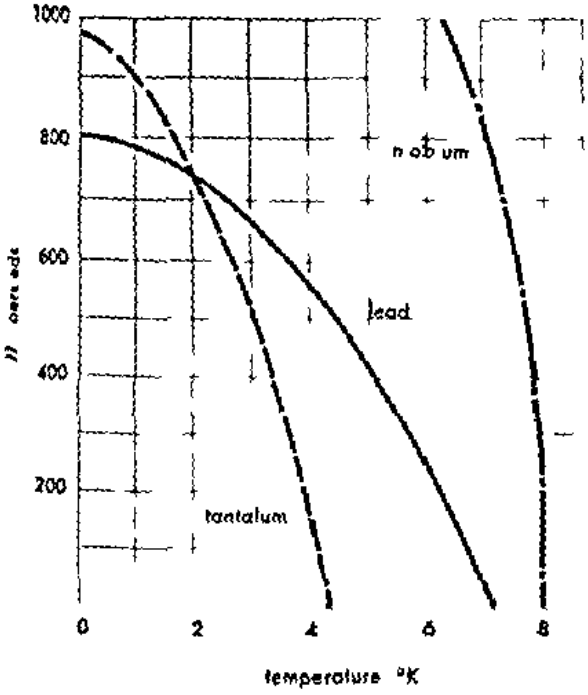


Fig 2 Threshold field strength of niobium tantalum and lead as a function of temperature (From A Van der Ziel, Solid State Physical Electronics Prentice Hall 1957)

needs for large numbers of fast small reliable components and the cryotron development shows promise of fulfilling these needs On the other hand cryotrons would be impractical in many applications because of the requirement that they operate in liquid helium The field of digital devices where very large numbers of components are often needed in a single assembly appears to be the application for which cryotrons hold the greatest practical promise The digital flip flop a typical computer circuit will therefore be described

A cryotron flip flop consists of two cryotrons each having its gate circuit in series with the control circuit of the other as in Fig 3 The two resulting paths are in parallel If the current is established in one of the two paths that current makes the alternate path resistive Current in one path then will continue to flow indefinitely in that path

Two additional cryotrons can be added to the circuit one in series with each branch as in Fig 4 in order to place the flip flop in the desired state A pulse on one of the two input cryotrons momentarily places a resistance in that side Both sides are then resistive and the current divides between them Since one side of the circuit has a resistance inserted by the input cryotron the current chooses the other side Once the current builds up in the other side it makes the side on which the input cryotron is being pulsed resistive and therefore the pulse in the control winding of the input cryotron can be removed the current will continue in the new path

Two more cryotrons can be added to the circuit as in Fig 5 for sensing the state of the flip flop Placed with their control windings each in series with one of the two sides of the flip flop one of the read out cryotrons is resistive and the other is superconductive The gate circuits are joined and a read out pulse is applied at the junction The read out pulse will choose one path or the other depending on the state of the flip flop

Any number of input cryotrons can be added in series with those already described to set the flip flop to one state or the other Connected as such they are logical OR gates any one of them acting alone can set the flip-flop Similarly additional cryotrons can be added with their gate circuits in parallel with the control winding of the input cryotron already described behaving as logical AND circuits The flip-flop set current is bypassed by one or more of the parallel gates unless all of them are resistive Additional read out cryotrons can be added in series with those already described Since their control windings are superconducting the additional cryotrons do not add any resistance to the flip-flop The additional inductance increases the L/R time constant of the circuit however lengthening the transition time between states

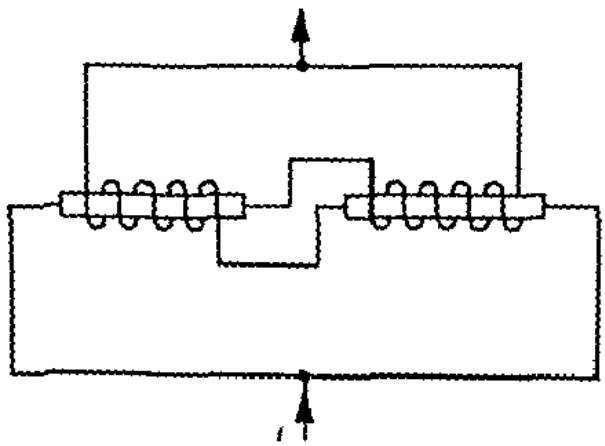


Fig 3 Simple cryotron flip flop

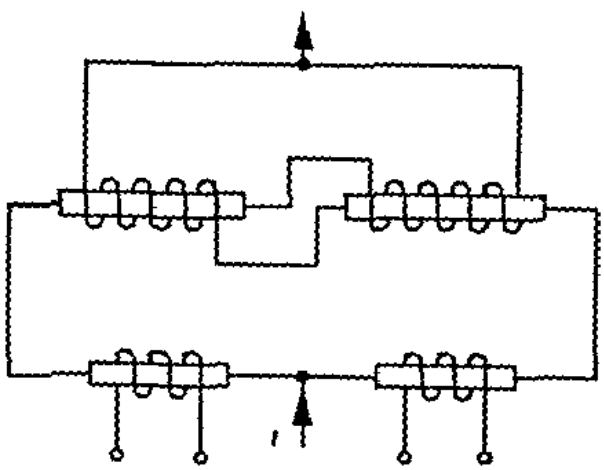


Fig 4 Flip-flop with input control (read in) cryotrons

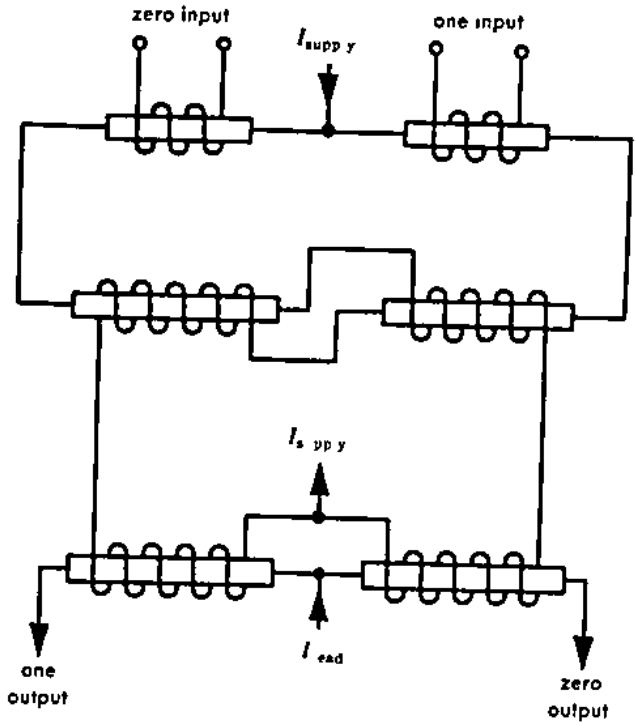


Fig 5 Cryotron flip flop with read in and read-out cryotrons

Cryotron circuitry does not involve other linear components usually present in vacuum tube and transistor circuits Their absence stems from an inherent advantage of magnetically controlled gating elements—that of direct current isolation between stages One can interconnect cryotrons without regard to dc levels running the output of one cryotron to the input of a second and so on through the circuit Loops are then permissible This advantage allows one to conceive of large systems of simple cryotrons manufactured in large sheets with all the interconnections made automatically [DAB]

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Cryptobranchoidea

A suborder of the Caudata These Amphibia are the Asiatic salamanders family Hynobiidae and the giant salamanders family Cryptobranchidae Six genera are recognized in the Hynobiidae the most important of which is *Hynobius* with 17 species found over much of Asia from Japan to the Ural Mountains One species even crosses the Arctic Circle the farthest north reached by any salamander There are only two living genera each with a single species in the Cryptobranchidae the hellbenders *Cryptobranchus* of the eastern United States and the giant salamanders *Megalobatrachus* of Japan and China *Andrias* a fossil genus of Europe is apparently identical with *Megalobatrachus* and if this is the case the Asiatic giant salamander should be called *Andrias*

The members of this primitive suborder differ from other salamanders in having external fertilization Aquatic larvae are present in all forms and some hynobiid larvae are peculiar in having sharp recurved claws Hynobiids undergo normal metamorphosis but cryptobranchids retain many larval characteristics and are partially neotenic *See* NEOTENY

The hellbender which reaches a length of over 2 ft and its giant Asiatic relative which is the world's largest salamander with a length to 5 ft are aquatic species that live in rivers and streams In the Hynobiidae there are both terrestrial and aquatic species *See* CAUDATA [RGZ]

Cryptococcales

An order in the class Fungi Imperfecti created to accommodate the yeasts which do not form sexual spores This group is also known as Torulopsidales Some species like *Torula utilis* are used in industrial fermentation to make food and fodder yeast other species such as *Pityrosporum ovale Candida albicans* and *Cryptococcus neoformans* are pathogenic for man and animals *P ovale* is usually found associated with dandruff *C albicans* causes thrush in infants *C neoformans* causes cryptococcosis *See* MYCOLOGY MEDICAL YEAST INDUSTRIAL

Vegetative reproduction may be by budding fission formation of pseudomycelium true mycelium or combinations thereof The Cryptococcales are separated from the related order Moniliales by their lack of aerial mycelium and aerial asexual reproductive structures *See* MONILIALES

This order comprises the genera *Cryptococcus Rhodotorula Torulopsis Pityrosporum Candida Brettanomyces Kloeckera Trigonopsis* and *Trichosporon*

Members of the genus *Cryptococcus* have budding cells often surrounded by a slimy capsule Under certain conditions of growth they form starchlike polysaccharides All species of *Cryptococcus* lack fermentative ability *See* FERMENTATION

Species of *Rhodotorula* are very similar except that they produce noticeable amounts of either yellow or red carotenoid pigments and in some species both types of pigments are produced Starchlike compounds are usually not synthesized

The genus *Torulopsis* is characterized by budding cells absence of mycelium arthrospores and pseudomycelium Species of this genus have an oxidative or fermentative metabolism

Pityrosporum has only budding cells which are bottle shaped or oval It requires fats or oil for growth and its metabolism is strictly oxidative

Candida is a genus of yeast which produces more or less extensive pseudomycelium and sometimes true mycelium but no arthrospores Its metabolism is fermentative or oxidative

Brettanomyces has budding cells often pointed (ogive) at the end Its metabolism is principally fermentative producing aromatic esters and acid

Kloeckera has apiculate cells and is the imperfect form of the genus *Hanseniaspora* (Ascomycete)

Trigonopsis has cells in the shape of a tetrahedron, budding at the corners Its metabolism is strictly oxidative

Members of the genus *Trichosporon* possess budding cells, true mycelium arthrospores, and pseudomycelium The metabolism of the species is oxidative and in some cases also fermentative *See* FUNGI IMPERFECTI, YEAST [H J P]

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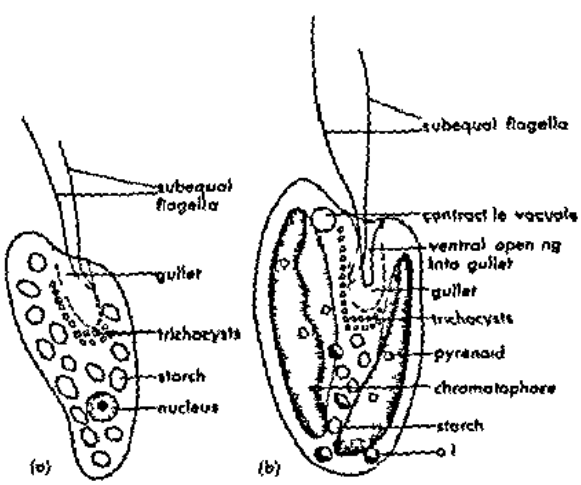
Cryptococcosis

An infection of man, primarily of the central nervous system, having as its etiological agent an encapsulated yeast, *Cryptococcus neoformans* The disease is also known as torulosis The skin lungs bones and viscera may also be invaded by this organism *See* YEAST

C neoformans is widespread in nature and world wide in distribution Diagnosis of the disease is made by cultural and histological methods No antigens are available for serological studies Although no satisfactory treatment is available, amphotericin B (an antibiotic) is the drug of choice for it reduces the number of organisms present in lesions *See* AMPHOTERICIN B, ANTIBIOTIC, ANTIGEN, MONILIALES, MYCOLOGY, MEDICAL, SEROLOGY [L D H]

Cryptomonadida

An order of the class Phytomastigophorea also known as the Cryptomonadina Cryptomonads are considered to be protozoans by zoologists and algae by botanists Most species occur in fresh water They are olive green blue red brown or colorless All flagellated members have two subequal flagella inserted in a gullet opening through an obliquely truncate anterior end In *Nephroselmis* and *Protochrysis* the gullet is laterally displaced and a contractile vacuole opens into it The nucleus is posterior Oil and starch or a related compound are formed and pyrenoidlike bodies are present *Cyathomonas* and *Chilomonas* are colorless, the latter has been widely used in nutritional studies, and Hollande has made extensive studies of its cytology demonstrating the trichocysts around the gullet and muciferous bodies under the pellicle



(a) *Chilomonas paramecium* (b) *Cryptomonas*

Phaeoplax is a palmelloid type with nonmotile cells embedded in a gelatinous matrix The reproductive cells are flagellated Radiolarians have symbiotic yellow cells, *Zooxanthella*, which are cryptomonads Although few in genera and species, Cryptomonadida form extensive marine and freshwater blooms *See* PHYTOMASTIGOPHOREA [J B L]

Cryptostomata

An order of fossil Gymnolaemata of the phylum Bryozoa which extended from the Ordovician to the Permian It includes about 13 families and 127 genera (R Bassler) Cryptostomata, with the Trepostomata, are perhaps the most abundant American Postcambrian Paleozoic fossils and could be of stratigraphic value if thoroughly studied

Cryptostomata resemble Cheilostomata in having boxlike to tubular zooids with anterior orifices but differ from them in lacking avicularia and ovicells and in having a thicker calcareous front

Cryptostomatous colonies are unilaminate or bilaminate and vary from delicate lacelike fronds to branched cylindrical or ribbonlike stems *See* BRYOZOA, BRYOZOA FOSSILS, GYMNOLAEMATA [M D RO]

Cryptozoon

A form genus of fossil algae The colonies are shaped like a cabbage or flattened cabbage and commonly range in size from 6 in to more than 2 ft across Structurally, they are composed of thin laminae, but they show little or no microstructure (Fig 1)

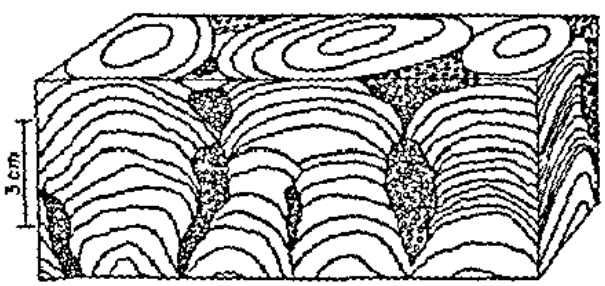


Fig 1 Cryptozoan structure in the Lower Magnesian dolostone (Ordovician) of western Wisconsin Oolites are common in the depressions between adjacent masses Successive layers are characteristically convex upward Two-thirds natural size (*From R R Shrock, Sequence in Layered Rocks, McGraw-Hill, 1948*)

Locally, *Cryptozoon* colonies developed in such numbers as to be important builders of limestone (Fig 2) Probably the best known occurrence is at Saratoga Springs, New York However, they are found in all continents in rocks ranging in age from



Fig 2 Weathered slab of Lower Ordovician lime stone containing concentrically banded *Cryptozoon*, Saratoga Springs N Y (*N Y State Museum and Sci ence Service*)

abundant during the late Proterozoic Cambrian and Early Ordovician *See* ALGAE FOSSILS [J H J]

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Crystal

This term, as used in science and technology, usu ally denotes a single crystal A single crystal is a solid throughout which the atoms or molecules are arranged in a regularly repeating pattern In elec tronics the term crystal is usually restricted to mean a single crystal which is piezoelectric Exam ples of single crystals are most gems piezoelectric quartz crystals used in controlling the frequencies of radio transmitters and single crystals of galena (lead sulfide) used in crystal radios *See* PIEZO ELECTRIC CRYSTAL, SINGLE CRYSTAL

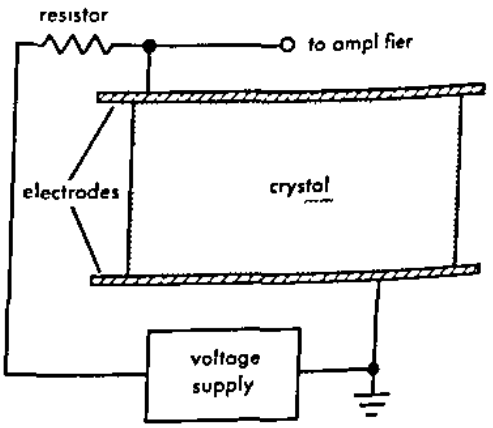
Most crystalline solids are made up of millions of tiny single crystals called grains and are said to be polycrystalline These grains are oriented ran domly with respect to each other Any single crys tal however, no matter how large, is a single grain Single crystals of metals many cubic centi meters in volume are relatively easy to prepare in the laboratory

Single crystals differ from polycrystalline and amorphous substances in that their properties are anisotropic Young's modulus, for example is dif ferent for different directions in the crystal Ani sotropy is responsible for the fact that crystals will cleave (split) along very flat planes which are char acteristic of the atomic stacking pattern *See* CRYS TAL DEFECTS, CRYSTAL GROWTH, CRYSTAL OPTICS CRYSTAL STRUCTURE, CRYSTALLOGRAPHY

[R H HO]

Crystal counter

A particle detector in which the sensitive material is a dielectric (nonconducting) crystal mounted between two metallic electrodes (*see* PARTICLE DETECTOR) Crystal counters are used in the detec tion of γ rays emanating from radioactive nuclei since their efficiency for the detection of γ rays is very high When a charged particle enters the crys tal or a γ ray creates high energy electrons in the crystal the charged particles interact with the atoms liberating low energy electrons which move freely within the crystal An electric field is estab lished in the crystal by a potential difference ap plied to the metallic electrodes (see illustration) The freed low energy electrons move under the in fluence of the field and are collected at an electrode unless they are caught on the way in the imperfec tions and impurities of the crystal known as trap ping centers An electrical pulse is created in either case by the motion of the charge These pulses can be as short as 2×10^{-8} sec



Crystal counter circuit

The applied field is usually about 5000 volts/cm Crystals which have been used in crystal counters include silver chloride diamond zinc sulfide cad mium sulfide, thallium chloride, and thallium io dide In the case of ionic crystals such as silver chloride which have appreciable ionic conducti n at room temperature the counters must be operated at the temperature of liquid nitrogen *Counters* using diamond zinc sulfide and cadmium sulfide may be operated at room temperature *See* GAMMA RAYS [W B F]

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Crystal defects

The perfect crystalline solid is a mathematical abstraction often useful in discussions of crystals A perfect crystal consists of a certain number of prescribed atoms molecules or ions distributed over a regular lattice or network of points which are rigidly fixed in space (*see* CRYSTAL STRUCTURE CRYSTALLOGRAPHY) Each point of the space lattice is equivalent to every other point so that the neighbors of a given atom are arranged about it in a way which is exactly congruent to the neighbors about every other atom of the crystal Quite generally then anything which destroys the essential symmetry of the lattice and the complete equivalence of all the lattice points and atoms of the solid is a defect Actually any real crystal is an imperfect or defective crystal if it is of macroscopic size

Some of the more obvious violations of the symmetry of a perfect lattice are free surfaces disorder impurities vacancies and interstitials dislocations lattice vibrations and grain boundaries In this list imperfections or excitations which are specifically electronic have been omitted only imperfections in the placement of atoms on the lattice have been listed Also such defects as *F* centers are not listed since the *F* center a type of color center is merely an electron trapped at a vacancy in an ionic crystal Certain types of imperfections are discussed in detail in other articles See COLOR CENTERS DIFFUSION IN SOLIDS GRAIN BOUNDARIES (METALLURGY) LATTICE VIBRATIONS LUMINESCENCE TWINNING (CRYSTALLOGRAPHY)

Importance of defects Many properties of a crystalline solid are not sensitive to small amounts of defects present in the crystal For instance if the effect of the imperfection is roughly proportional to the percentage of imperfection in the crystal then the effect of the imperfections on the measurement of the property can be made negligibly small by ordinary means of purification Examples of structure insensitive properties are the elastic constants of the crystal the average lattice constant or the density of the crystal the total energy of sublimation or the cohesive energy the specific heat (except when measured near absolute zero) and the electrical conductivity of metals at high temperatures

There are other properties which are extremely sensitive to the presence of very minute percentages of defect concentrations These properties are called the structure sensitive properties For instance samples prepared in similar ways may fluctuate widely when structure sensitive properties are measured even when reasonable care is used in the preparation of the samples Often extreme care is necessary to obtain reproducible results An example is the manufacture of semiconducting crystals for transistor use where the impurity must be controlled to parts in 10^5 to 10^6 in order to obtain the proper conductivity properties In this case the conductivity characteristics are governed by the impurities present which contribute either positive or negative electronic charge carriers, depending on the type of impurity *See* SEMICONDUCTOR ZONE REFINING

Free surfaces So-called surface effects are always important when the size of the crystal is small as in colloids However even in the case of macroscopic crystals the properties of the surfaces themselves may be important One of the most interesting effects is the possible existence of so-called surface levels which are special traps or sources for electrons on the surface and whose presence is simply due to the difference between the quantum states of atoms on the surface and atoms in the interior These levels have apparently been observed in semiconducting crystals

Disorder If the solid under study is a mixture of more than one element there will be many different ways of arranging the different kinds of atoms on a given lattice Usually however one particular arrangement corresponds to a lower crystal energy than all the others because of the interactions between the atoms This arrangement is called the ordered state and a common example is the case where all the nearest neighbors of a particular atom are of a different kind to it Such an ordered arrangement obviously is again a perfectly regular array of atoms and has the properties of the perfect crystal described earlier Putting the wrong kind of atom on a lattice site is a defect and is called disorder For further discussion *see* ALLOY STRUCTURES

Impurities The impurity is perhaps the most ubiquitous and at the same time one of the most intensively studied defects Because control of the impurity content is basic to any study of impurity effects the evolution of purification techniques has been one of the most important developments in the field of defect study This control is often difficult to achieve because as has been mentioned the critical range of impurity content may be very low indeed

Not only are impurities ever present but they have very widespread effects They contribute to the low temperature resistance found in metals they are important in determining the mechanical properties of crystals they alter diffusion rates in ionic crystals and so forth

Resistance of metals and insulators As the temperature of a metal is lowered toward absolute zero and the thermal vibrations of the lattice decrease a point is reached where the electrons become scattered more by the impurities present than by the lattice vibrations The impurity content is not altered by changing the temperature in contrast to the lattice vibrations which are strongly temperature dependent Thus the resistance of any metal levels off at some low value as the temperature is lowered the value being proportional to the amount of impurity present The law stating the proportionality is called Matthiessen's rule but it is not always strictly obeyed If the impurities have a tendency to clump together or in

other way are attracted to preferred sites of the crystal the scattering from one impurity center may not be independent of the scattering from another center and the resistance will not show the proportionality law In short interference effects are possible but in the great majority of cases are not important

In insulating crystals a precise charge balance exists so that the electron bands are either all full or all empty Therefore when an external voltage is applied the electrons are not free to respond and the resistance is consequently very high However when impurities are added complications are possible because the impurities may be very easy to ionize compared to the regular atoms of the crystal In the case of semiconductors even the thermal energy at ordinary room temperatures is sufficient to ionize an appreciable number of impurities Free conduction electrons are thus created and the crystal becomes conducting The opposite situation also is possible Suppose a number of electrons are injected into the conduction or free electron band of an insulator Then at low temperatures as in the case of metals the impurities determine the mobility and mean free path of the electrons in an external electric field

Optical properties of impure insulators Optical properties of crystals containing impurities have been widely studied Many insulating crystals are transparent to visible light This means that the light photons have insufficient energy to excite the electrons from the highest filled band to the next band which is empty and therefore the light traverses the crystal without interacting with it It is possible to put into the crystal an impurity atom with an electronic structure so different from the regular atoms of the crystal that one of the electrons of the impurity atom can be excited by a photon of visible light This process leads to the general phenomenon of luminescence or light reemission When the impurity atom absorbs a photon of light it is in an excited state but eventually returns to its normal ground state The energy of excitation has two general ways of being dissipated One is by reemission of the light and the other is by conversion of the excitation into heat motion If the excitation energy is reemitted it normally has a lower frequency than the incident light meaning that part of the energy has been dissipated as heat The type of transition which actually takes place is determined by considering the Franck Condon principle as applied to the atoms surrounding the impurity *See* FRANCK CONDON PRINCIPLE

Vacancies and interstitials In the case of a solid where all atoms are composed of a single element a vacancy is created if an atom is extracted from a normal lattice site and placed in another normal lattice site on the surface If an atom is taken from a normal surface position and squeezed into a part of the lattice which is already perfect an interstitial atom is created The interstitial atom does not sit in a normal lattice site because all these are already taken, it sits in one of the interstices between the atoms of the normal lattice If the lattice is tightly packed it is necessary to squeeze the atoms of the surroundings considerably to fit in the interstitial

In many ways interstitials and vacancies can be considered as especially simple types of impurities The vacancy is an impurity of vacuum sitting on a normal lattice site while the interstitial is an impurity of the same element sitting in an interstitial site Impurities can either take up ordinary lattice sites in which case they are called substitutional impurities or they can fit into an interstitial site in which case they are called interstitial impurities The analogy to impurities suggests some of the properties of vacancies and interstitials They are scattering centers for free electrons as well as trapping centers They also alter the optical properties of transparent crystals in a similar way to impurities For example an F center (color center) in sodium chloride (NaCl) is an electron trapped at a positive ion vacancy the electron alters the absorption spectrum of the pure crystal

Thermal behavior One of the striking properties of vacancies and interstitials and one which is in contrast to the case for impurities is the thermal behavior of these defects At any temperature above absolute zero a certain definite number of interstitials and vacancies is always in thermal equilibrium in the lattice The reason is that the crystal can always manufacture or annihilate its vacancies and interstitials in just the way indicated at the beginning of this subsection The impurity content of a crystal is athermal and is specified by the method of preparation It might be expected that since energy is required to form an interstitial or vacancy in an otherwise perfect crystal the crystal would exhibit a tendency to exist in its lowest energy state of perfection This statement is true at absolute zero temperature However, according to thermodynamics the quantity which is to be minimized by a system in equilibrium at a given pressure and temperature is the Gibbs free energy $G = U - TS + PV$ (*see* THERMODYNAMIC PRINCIPLES) Here U is the total internal energy which includes the energy of formation of the vacancies T and S are the temperature and entropy of the system and P and V are the pressure and volume At temperatures above absolute zero G can be lowered by increasing the entropy even if in so doing the internal energy is increased somewhat It turns out that S is increased and G decreased when a few vacancies and interstitials are present in a perfect crystal

[illegible] a vacancy atom is approximately proportional to the so-called Boltzmann factor $e^{(-E/kT)}$ Here E is the energy of formation of the defect while k is the Boltzmann constant The concentration of vacancies or inter

stitials is extremely small for all temperatures up to the melting point of the solid Characteristically a solid may possess an atom fraction of the order of 10^{-4} to 10^{-6} of vacancies or interstitials at the melting point and of the order of 10^{-17} or lower at room temperature

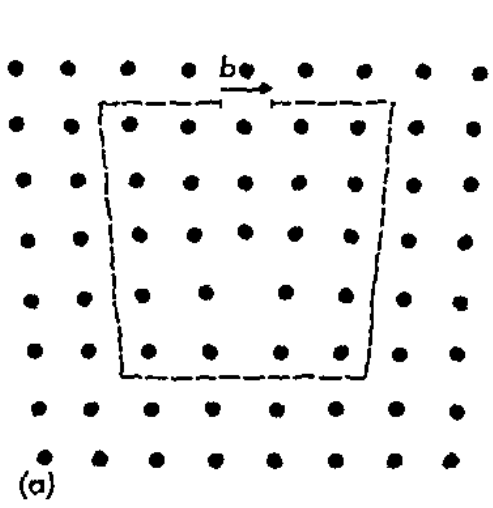
Frenkel defects In addition to the natural methods available for creating and annihilating vacancies and interstitials it is possible to create imperfections in the crystal artificially For example vacancies and interstitials are created by irradiation with nuclear particles In this case an atom at a local lattice site is knocked off its original site and into a nearby interstitial position Thus an interstitial vacancy pair is created This pair is called a Frenkel defect after J Frenkel who first proposed it

Ionic crystals and Schottky defects Vacancies and interstitials in ionic crystals have special features because of the fact that the ions of the crystal are charged and in producing defects, the electrical neutrality of the crystal must be preserved A perfect ionic crystal is electrically neutral on the whole If one of the ions is extracted from a neutral ionic crystal the net effect is the same so far as the charge of the configuration is concerned as if a charge of the opposite sign were added Hence the vacancy in an ionic crystal has associated with it an effective charge of the amount of the ion removed but of opposite sign In a neutral NaCl crystal (equal numbers of positive Na and Cl ions) vacancies would be created if a certain number of Cl ions were plucked out of the interior and placed on the surface In this case however the surface would become highly charged (*see* IONIC CRYSTALS) Frenkel and Schottky defects are the simplest types of defects which leave an ionic crystal electrically neutral The Schottky defect after W Schottky is the name given to a pair of vacancies in a crystal like NaCl and is one positive ion vacancy and one negative ion vacancy For calcium chloride ($CaCl_2$) in order to preserve the neutrality two negative ion vacancies must be created for each positive ion vacancy For purposes of definition it is assumed in the Schottky defect that the vacancies of the pair are completely separated Actually however there is a tendency for the positive ion vacancy to attract a negative ion vacancy to form a neutral defect consisting of two neighboring vacancies The Frenkel defect is a neutral defect since the vacancy of the Frenkel pair has a sign opposite to that of the interstitial ion

Relative abundance of defects The relative abundance of Frenkel defects versus Schottky defects in ionic crystals or of vacancies versus interstitials in other types of crystals, can be predicted According to the thermodynamic argument given earlier concerning the numbers of vacancies and interstitials, the density of defects is a sensitive function of the energy of creation Since the energy occurs in an exponential a small difference in the energy of creation will be reflected in a large difference in the relative abundances of the different types of defects With regard to the interstitials versus the vacancies if the lattice is closely packed (face centered cubic or hexagonal close packed) the large distortion necessary to accommodate the interstitial makes the interstitial creation energy larger than the vacancy creation energy On the other hand in a crystal with an open type lattice like the diamond lattice the distortion energy is lower and there is a possibility that the energy of formation of the interstitial may be smaller than that of the vacancy Thus while it has been found that the predominant defect in metals like copper is the vacancy scientists are still uncertain in regard to crystals like silicon and germanium

Dislocations A dislocation is a one dimensional imperfection as contrasted to vacancies and interstitials which are point imperfections The dislocation is always a closed line in the crystal There are two types of dislocation line the edge and the screw which are depicted in Fig 1*a* and *b* In addition to the direction of the line the dislocation is also characterized by a vector called the Burgers vector (after J W Burgers) whose magnitude is a measure of the strength of the singularity represented by the dislocation and whose direction relative to the line itself gives the type of dislocation When the vector is perpendicular to the line the dislocation is of the edge type and when parallel to it of the screw type The plane defined by the line of the edge dislocation and the Burgers vector is called the slip plane and defines the plane upon which a dislocation with edge component must move when subjected to a force The Burgers vector can point in other directions besides the precise parallel and perpendicular ones but the positions of the atoms in these cases are more difficult to visualize The Burgers vector is defined by the closure error found in a crystal containing a dislocation The closure errors for the edge and screw are shown in Fig 1

Plastic slip in crystals Dislocations were originally proposed as an attempt to solve the problem of plastic slip in crystals When the external mechanical stress on a crystal exceeds a certain value called the critical shear stress for slip the deformation becomes permanent and the crystal does not return to its original position when the stress is removed The critical shear stress is much lower for a pure single crystal than can be explained by assuming that the permanent set is caused by sliding atoms of a perfect crystal over one another On the other hand a dislocation is a defect which can sometimes be moved through the crystal with quite low stresses The reason is that the disturbed region in the core or center of a dislocation can be viewed as if the atoms were already slightly displaced from their positions of perfect order so that the position occupied by the dislocation can move from one place to another without the large increase or activation of energy [illegible] only a relatively low [illegible]



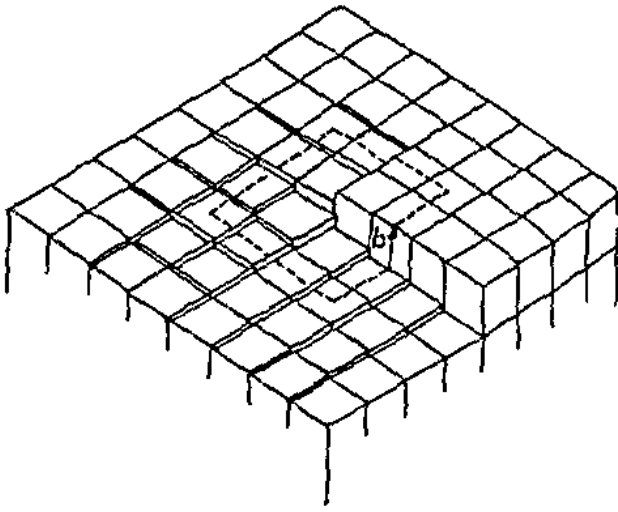


Fig 1 Two types of *dislocation* (*a*) Arrangement of atoms around an edge dislocation *line* The dislocation line is perpendicular to the plane of the diagram just below *the end* of the extra row of atoms which stops in the middle of *the crystal* The closure error which defines *the Burgers vector* is shown by the dotted line which makes a circuit about *the dislocation* line and would be closed in the normal crystal However because of the dislocation the circuit does not close and the amount by which it fails is the Burgers vector (*b*) Arrangement of atoms around a screw dislocation showing how the crystal is transformed into a spiral ramp by the dislocation line The blocks represent the atoms of the crystal, and the dotted line shows the closure error

shows how the *motion* of an edge dislocation through a crystal *actually* corresponds to a shear or slip in the crystal A similar figure can be drawn *for a screw* dislocation

Frank Read generator One of the original difficulties with dislocation theory was how to explain the possibility of large amounts of slip in a crystal when the crystal originally contained only a very small number of dislocations Well annealed crystals may have only a fraction 10^{-8} to 10^{-12} of their atoms lying near a dislocation line The number of dislocations originally present if moved completely out of the crystal would correspond to a microscopic *amount of slip* However under the action of a stress the dislocations multiply Figure 3 represents the operation of a so called Frank Read generator Such a generator first proposed by C Frank and W Read is capable of producing *any number* of dislocations on a given slip plane thus causing an *indefinite* amount of slip The phenomenon of work hardening is connected with the multiplication process (Work hardening refers to the hardening of metals or alloys by cold plastic deformation for details *see* PLASTIC DEFORMATION OF METAL) As the crystal is stretched above the critical shear stress limit the stress necessary to add a given increment of strain increases at first slowly and then very rapidly until just before the breaking point the stress necessary to move the dislocations becomes very large This work hardening is presumably due to impeding interactions between groups of dislocation lines when their density is high

Dislocations as internal surfaces One of the most important properties of dislocations is their ability to act as sources and sinks for vacancies and interstitials Figure 1*a* shows that the edge dislocation line is at the end of a line of atoms which extends only part way into the crystal The line of atoms in the figure is in reality a plane of

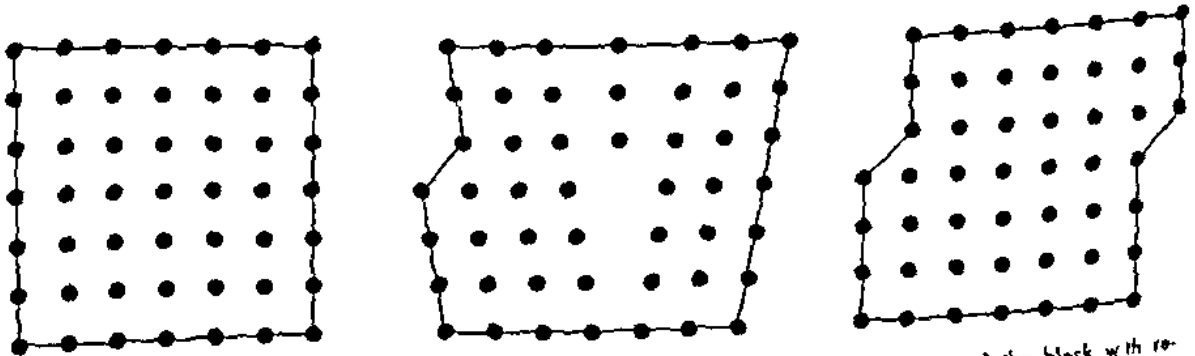


Fig 2 Demonstration of the motion of an edge dislocation from left to right through a block of crystal shearing the atoms of the top of the block with respect to the atoms of the bottom

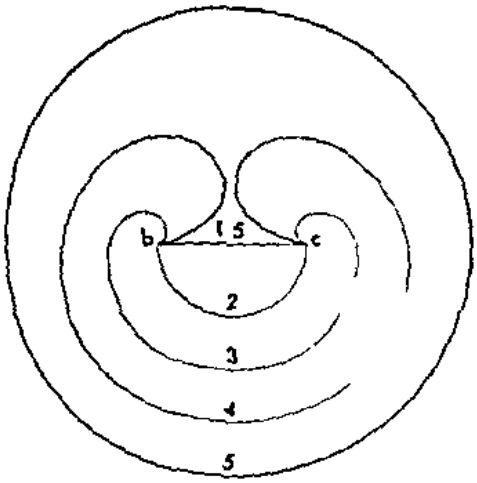


Fig 3 A Frank Read generator for multiplication of dislocations The numbers show the progress of a dislocation line represented by the two points B and C when a stress is put on the dislocation The process not only multiplies the original segment BC into a large partial loop but also allows the partial loop to complete itself while regenerating a new segment that can repeat the whole process



Fig 4 Crystal growth spirals on the surface of a silicon carbide crystal magnified 250 diameters Each spiral step originates in a screw dislocation defect From the side the surface looks like an ascending ramp wound around a flat cone (General Electric)

atoms since the figure is only a cross sectional view of the dislocation Vacancies in the crystal can be created by taking atoms from the interior and placing them on the extra half plane thus making the dislocation move perpendicular to the slip plane It is necessary for diffusion to take place in order for the dislocation to have a component of motion perpendicular to the slip plane Interstitials are created in the crystal by removing atoms from the end of the extra half plane Thus the dislocation is in effect a kind of internal surface and the vacancies and interstitials do not have to diffuse clear to the surface of the crystal in order to be removed from the lattice

Applications in crystal growth Screw dislocations have been shown to be important in providing a continuous nucleation site for the growth of crystals For a small growing crystal with smooth sides in equilibrium with its own vapor it is difficult to make new atoms stick on the sides long enough for the crystal to continue to grow In order to grow at reasonable rates from the vapor phase the crystal must have sides with corners and crevices where new atoms can stick On the other hand a crystal with a screw dislocation in it is essentially a continuous spiral ramp and the edge of the ramp on the growing surface affords a good place for new atoms to stick (Fig 4) Also as the crystal grows the dislocation never disappears and always provides sticking sites for new atoms A crystal can grow by precipitation from the vapor phase where the supersaturation is small only if it possesses screw dislocations See CRYSTAL GROWTH [R S T]

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Crystal growth

The growth of crystals of which all metals and all other crystalline solids are composed generally occurs either in nature or in the laboratory by the following sequence of processes (1) diffusion of the molecules through the medium to the surface of the crystal (2) diffusion of the molecules of the crystallizing substance through the surrounding environment (or solution) to the surface of the crystal (3) incorporation of molecules into the crystal at these sites and (4) diffusion of the heat of crystallization away from the crystal surface The rate of crystal growth may be limited by any of these four steps

Consider the transformation of a system from a state *A* to a state *B* This may occur if the entire system goes through a continuous set of states between *A* and *B* Alternatively small domains of *B* may form at various points and grow at the expense of *A*, all transformation taking place at the boundaries between *A* and *B* The growth of crystals apparently always occurs in this way that is by the transformation of matter at the interface between the crystal and the medium The formation of

TION

Increasing the supersaturation of the crystallizing component or increasing the temperature independently increases the rate of crystal growth However in many physical situations, the supersaturation is increased by decreasing the temperature In these circumstances the rate of crystal growth increases with decreasing temperature at first, goes through a maximum and then decreases Often the growth is greatly retarded by traces of certain impurities

After nucleation crystals in the medium grow

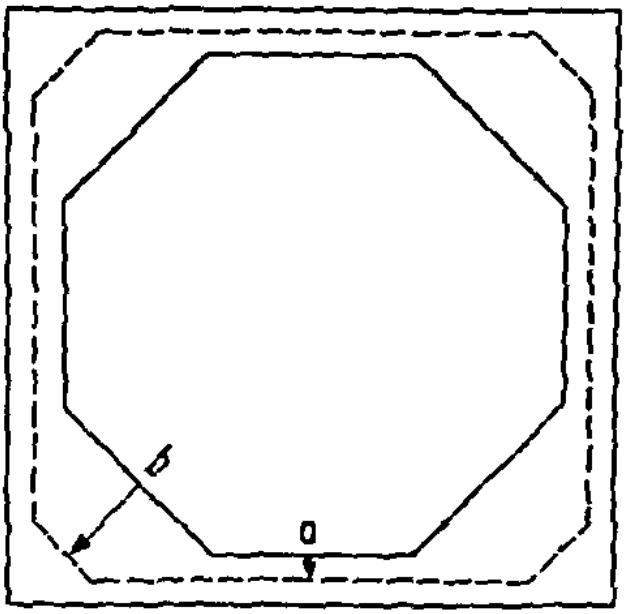


Fig 1 Schematic representation of cross section of growing crystal at three stages of growth, showing how crystal becomes bounded by slowest growing faces a while faster growing faces b disappear

several differently oriented crystals are growing they may finally impinge on one another with the formation of intercrystalline (grain) boundaries and may continue to grow as polycrystalline aggregates In some cases polycrystalline aggregates form as a result of secondary nucleation of differently oriented crystals on the surface of a parent crystal

Growth forms. During its growth, a crystal often develops and maintains a definite form This form may reflect the characteristic symmetry of the unit cell, and is determined by the relative rates of growth in the different crystallographic directions (For explanation of the term unit cell see CRYSTAL STRUCTURE) It has been shown (see Fig 1) that the form is such that the bounding planes of the crystal are perpendicular to the direction of slowest growth Well defined forms, such as that illustrated in the figure are most likely to develop in growth from dilute solutions at low supersaturation

According to a generalization due to A Bravais, the bounding planes which develop in growth are likely to be those which are parallel to the crystallographic planes of densest molecular packing However, there are many exceptions to this, and it is well established that the form of a growing crystal can be altered completely by the addition of certain impurities to the medium in trace amounts Generally, these impurities greatly decrease the crystal growth rate, but evidently much more in certain crystallographic directions than others

Crystals growing at relatively high supersaturation or undercooling often develop a dendritic (treelike) form the trunk and arms of which are usually parallel to definite crystallographic directions This form permits rapid crystal growth because the tips of the dendrite arms are always near parts of the medium which are relatively undepleted in the crystallizing component and unwarmed by the heat of crystallization

Molecular binding. W Gibbs pointed out that the molecular binding sites on the surface of a crystal can be of several kinds Thus a molecule must be more weakly bound on a perfectly developed plane of molecules at the crystal surface than at a ledge formed by an incomplete plane one molecule thick (see Fig 2) Therefore the binding of molecules in an island monolayer on the crystal surface will be less per molecule than within a completed surface layer There will be a critical size monolayer for each supersaturation such that all monolayers smaller than the critical size will shrink out of existence, and those which are larger will grow to a complete layer The critical size must decrease with increasing supersaturation

It has been shown that densely packed crystal planes in equilibrium with dilute solutions at temperatures well below the melting point of the crystal should be molecularly flat and virtually perfect

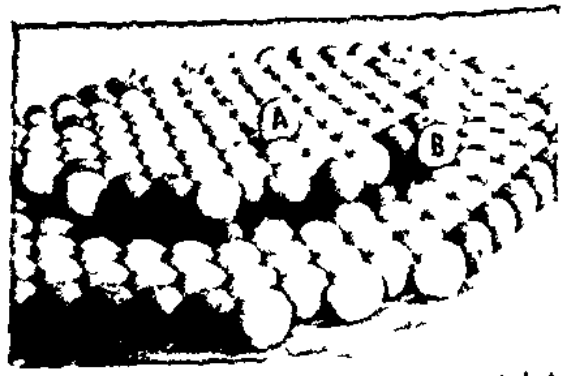


Fig 2 Model of crystal surface showing inequivalent binding sites at which atoms *A* and *B* are located (*General Electric*)

Growth rates and requirements From these ideas and the kinetic considerations due to M Vol

pendicular to planes of densest molecular

Actually, in ordinary experience, crystals found by densely packed planes grow in dilute media at a

F C Frank ar

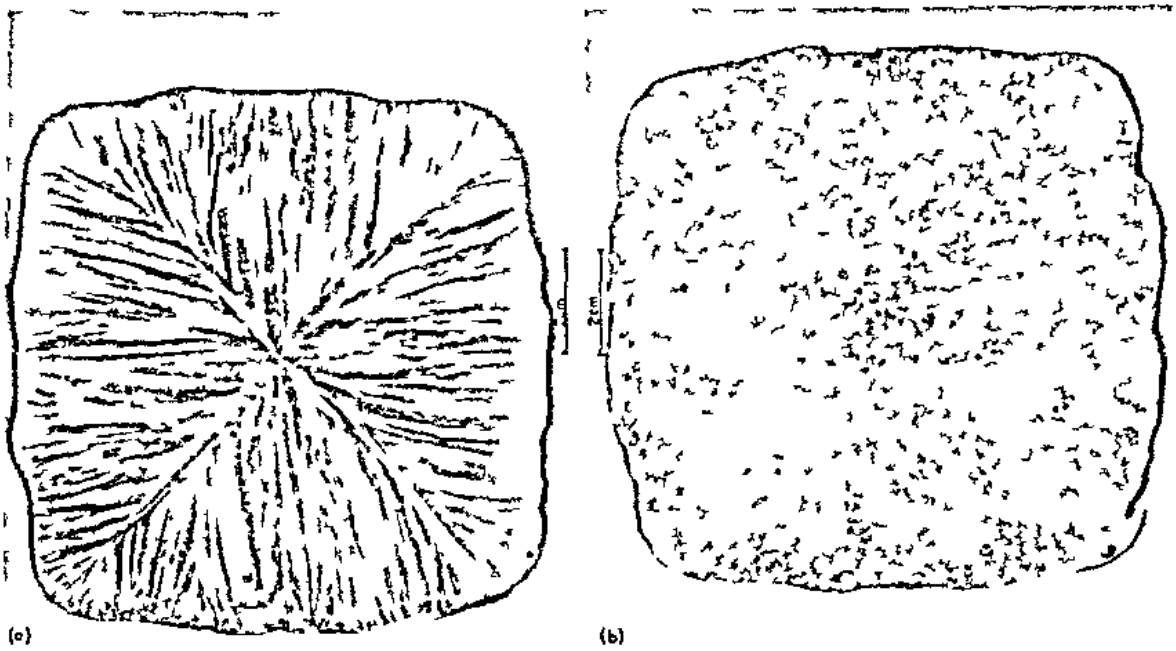
in theory of

to be borne

out fully by experience See CRYSTAL DEFECTS

Neither the structure of the interface between a crystal and a concentrated solution nor the mechanism of growth of crystals in concentrated solutions is as yet clearly known

In the crystallization of a concentrated solution or pure liquid, the temperature at the crystal liquid interface often is much higher than in the body of the crystal or liquid and the crystal growth rate



(a) (b)

Fig 3 Photographs showing grain structure of metal casting (a) Columnar structure (b) Equiaxed structure (*Furnished by J L Walker General Electric Research Laboratory*)

is controlled by the rate of flow of heat away from the interface When such a liquid is cooled by extraction of heat from the container walls as in the formation of metal castings many crystals nucleate and grow inward If no further nucleation occurs a columnar grain structure develops as shown in Fig 3*a* However in the presence of certain impurities further nucleation occurs immediately in advance of the crystal liquid interface and an equiaxed grain structure as shown in Fig 3*b* is formed *See* SINGLE CRYSTAL WHISKERS CRYSTAL ZONE REFINING [D T]

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Crystal optics

The study of the propagation of light and phenomena associated therewith in crystalline solids The propagation of light in crystals can actually be so complicated that not all the different phenomena are yet completely understood and not all theoretically predicted phenomena have been demonstrated experimentally

For a simple cubic crystal the atomic arrangement is such that in each direction through the crystal the crystal presents the same optical appearance The atoms in anisotropic crystals are closer together in some planes through the material than in others In anisotropic crystals the characteristics are different in different directions In classical physics the progress of an electromagnetic wave through a material involves the periodic displacement of electrons In anisotropic substances the forces resisting these displacements depend on the displacement direction Thus the velocity of a light wave is different in different directions and for different states of polarization The absorption of the wave may also be different in different directions For a discussion of these differences *see* DICHROISM TRICHROISM

In an isotropic medium the light from a point source spreads out in a spherical shell The light from a point source embedded in an anisotropic crystal spreads out in two wave surfaces one of which travels at a faster rate than the other The polarization of the light varies from point to point over each wave surface and in any particular direction from the source the polarization of the two surfaces is opposite The characteristics of these surfaces can be determined experimentally by making measurements on a given crystal

For a transparent crystal the theoretical optical behavior is well enough understood so that only a few measurements need to be made in order to predict the behavior of a light beam passing through the crystal in any direction It is important to remember that the velocity through a crystal is not a function of position in the crystal but only of the direction through the lattice For information closely related to the ensuing discussion *see* POLARIZED LIGHT *See also* CRYSTAL STRUCTURE REFRACTION OF WAVES

Index ellipsoid In the most general case of a transparent anisotropic medium the dielectric c n

oriented along each direction the velocity of light is different One method for calculating the behavior of a transparent anisotropic material is through the use of the index ellipsoid, also called the reciprocal ellipsoid, optical indicatrix, or ellipsoid of wave normals This is the surface obtained by plotting the value of the refractive index in each principal direction for a linearly polarized light vector lying in that direction (see Fig 1) The different indices of refraction, or wave velocities associated with a given propagation direction are then given by sections through the origin of the coordinates in which the index ellipsoid is drawn These sections are ellipses and the major and minor axes of the ellipse represent the fast and slow axes for light proceeding along the normal to the plane of the ellipse The length of the axes represents the refractive indices for the fast and slow wave respectively The most asymmetric type of ellipsoid has three unequal axes It is a general rule in crystallography that no property of a crystal will have less symmetry than the class in which the crystal belongs (*see* CRYSTALLOGRAPHY) In other words if a property of the crystal had lower symmetry, the crystal would belong in a different class Accordingly there are many crystals which, for example have four or sixfold rotation symmetry about an axis and for these the index ellipsoid cannot have three unequal axes but is an ellipsoid of revolution In such a crystal light will be propagated along this axis as though the crystal were isotropic and the velocity of propagation will be independent of the state of polarization The section of the index ellipsoid at right angles to this *direction is a circle Such crystals are called uni* axial and the mathematics of their optical behavior is relatively straightforward

Ray ellipsoid The normal to a plane wavefront moves with the phase velocity (*see* PHASE VELOCITY) The Huygens wavelet which is the light moving out from a point disturbance, will propagate with a ray velocity Just as the index ellipsoid can be used to compute the phase or wave velocity, so can a ray ellipsoid be used to calculate the ray velocity The length of the axes of this ellipsoid is given by the velocity of the linearly polarized ray whose electric vector lies in the axis direction

The ray ellipsoid in the general case for an anisotropic crystal is given by the equation

$$\alpha^2x^2 + \beta^2y^2 + \gamma^2z^2 = 1 \qquad (1)$$

where α β, and γ are the three principal indices of refraction and where the velocity of light in a vacuum is taken to be unity *From this ellipsoid the* ray velocity surfaces or Huygens wavelets can be calculated as just described These surfaces are of the fourth degree and are given by the equation

$$(x^2+y^2+z^2)\left(\frac{x^2}{\alpha^2}+\frac{y^2}{\beta^2}+\frac{z^2}{\gamma^2}\right) - \frac{1}{\alpha^2}\left(\frac{1}{\beta^2}+\frac{1}{\gamma^2}\right)x^2 - \frac{1}{\beta^2}\left(\frac{1}{\gamma^2}+\frac{1}{\alpha^2}\right)y^2 - \frac{1}{\gamma^2}\left(\frac{1}{\alpha^2}+\frac{1}{\beta^2}\right)z^2 + \frac{1}{\alpha^2\beta^2\gamma^2} = 0 \qquad (2)$$

In the uniaxial case $\alpha = \beta$ and equation (2) factors into

$$x^2+y^2+z^2 = \frac{1}{\alpha^2} \qquad (3)$$
$$\gamma^2(x^2+y^2) + \alpha^2z^2 = 1$$

These are the equations of a sphere and an ellipsoid The z axis of the ellipsoid is the optic axis of the crystal

The refraction of a light ray on passing through the surface of an anisotropic uniaxial crystal can be calculated with Huygens wavelets in the same manner as in an isotropic material For the ellipsoidal wavelet this results in an optical behavior which is completely different from that normally associated with refraction The ray associated with this behavior is termed the extraordinary ray At a crystal surface where the optic axis is inclined at an angle a ray of unpolarized light incident normally on the surface is split into two beams—the ordinary ray, which proceeds through the surface without deviation, and the extraordinary ray, which is deviated by an angle determined by a line drawn from the center of one of the Huygens ellipsoidal wavelets to the point at which the ellipsoid is tangent to a line parallel to the surface The construction is shown in Fig 2 The two beams are oppositely linearly polarized When the incident beam is inclined at an angle ϕ to the normal the ordinary ray is deviated by an amount determined by Snell's law of refraction the extraordinary ray

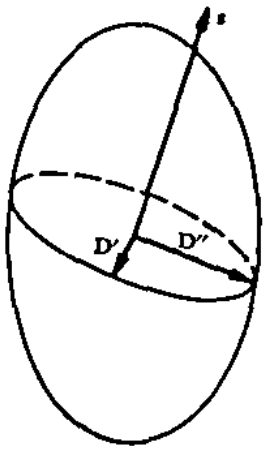


Fig 1 Index ellipsoid showing construction of the directions of vibrations of the D vectors belonging to a wave normal s (From *M Born and E Wolf, Principles of Optics*, Pergamon, 1959)

shown in Fig 2 ... wavelet to the point of tangency gives the ray direction and velocity

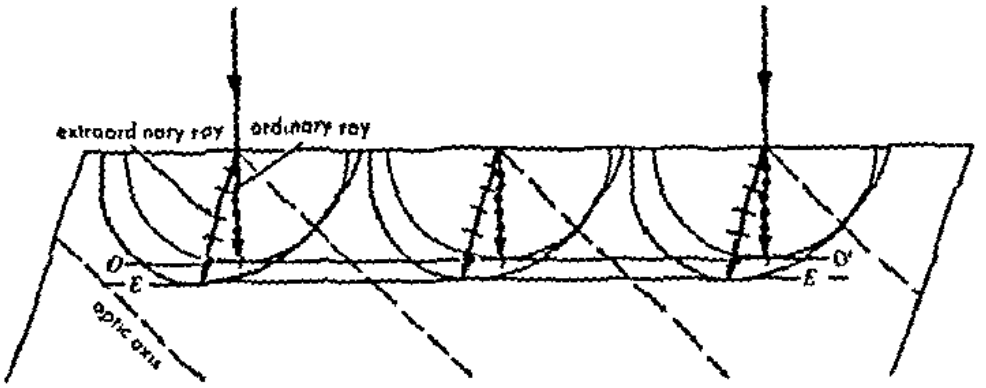


Fig 2 Huygens construction for a plane wave incident normally on transparent calcite If one proceeds to find the common tangents to the secondary wavelets shown the two plane waves labeled OO' and EE' are obtained (From F A Jenkins and H E White Fundamentals of Optics 3d ed McGraw-Hill 1957)

The relationship between the normal to the wave front and the ray direction can be calculated algebraically in a relatively straightforward fashion The extraordinary wave surface or Huygens wavelet is given by equation (3) which can be rewritten

$$\epsilon^2(x^2 + y^2) + \omega^2 z^2 = 1 \tag{4}$$

where ϵ is the extraordinary index of refraction and ω the ordinary index A line from the center of this ellipsoid to a point $(x_1\ y_1\ z_1)$ on the surface gives the velocity of a ray in this direction The wave normal corresponding to this ray is found by dropping a perpendicular from the center of the ellipsoid to the plane tangent at the point $(x_1\ y_1 z_1)$ For simplicity consider the point in the plane $y = 0$ The equation of the tangent at the point $x_1 z_1$ is

$$\epsilon^2 x x_1 + \omega^2 z z_1 = 1 \tag{5}$$

The slope of the normal to this line is

$$\frac{z}{x} = \frac{\omega^2 z_1}{\epsilon^2 x_1} \tag{6}$$

The tangent of the angle between the optic axis and the wave normal is the reciprocal of this number

$$\tan \varphi = \frac{\epsilon^2 x_1}{\omega^2 z_1} = \frac{\epsilon^2}{\omega^2} \tan \psi \tag{7}$$

where ψ is the angle between the ray and the optic axis The difference between these two angles, τ can be calculated from the expression

$$\tan \tau = \frac{\tan \varphi - \tan \psi}{1 + \tan \varphi \tan \psi} \tag{8}$$

This quantity is a maximum when

$$\tan \varphi = \pm \frac{\epsilon}{\omega} \tag{9}$$

One of the first doubly refracting crystals to be discovered was a transparent variety of calcite called Iceland spar This uniaxial crystal cleaves into slabs in which the optic axis makes an angle of 45° with one pair of surfaces An object in contact with or a few inches from such a slab will thus appear to be doubled If the slab is rotated about a normal to the surface one image rotates about the other For the sodium D lines at 589 mμ the indices for calcite are

$$\epsilon = 1.486 \qquad \omega = 1.659 \tag{10}$$

From these the maximum angle τ_{max} between the wave normal and the ray direction is computed to be 6° 16′ The wave normal at this value makes an angle of 41° 32′ with the optic axis This is about equal to the angle which the axis makes with the surface in a cleaved slab Accordingly the natural rhomb gives nearly the extreme departure of the ray direction from the wave normal

Interference in polarized light One of the most interesting properties of plates of crystals is their appearance in convergent light between pairs of linear circular or elliptical polarizers An examination of crystals in this fashion offers a means of rapid identification It can be done with extremely small crystals by the use of a microscope in which the illuminating and viewing optical systems are equipped with polarizers Such a polarizing microscope is a common tool for the mineralogist and the organic chemist

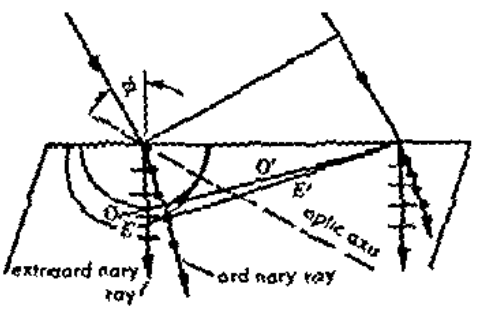


Fig 3 Huygens construction when the optic axis lies in the plane of incidence (From F A Jenkins and H E White Fundamentals of Optics 3d ed, McGraw Hill

In convergent light the retardation through a birefringent plate is different for each direction The slow and fast axes are also inclined at a different angle for each direction Between crossed linear polarizers the plate will appear opaque at those angles for which the retardation is an integral number of waves The locus of such points will be a series of curves which represent the characteristic interference pattern of the material and the angle at which the plate is cut (*see* INTERFERENCE OF WAVES) In order to calculate the interference pattern it is necessary to know the two indices associated with different angles of plane wave propagation through the plate This can be computed from the index ellipsoid

Ordinary and extraordinary indices For the uniaxial crystal there is one linear polarization direction for which the wave velocity is always the same The wave propagated in this direction is called the ordinary wave This can be seen directly by inspection of the index ellipsoid Since it is an ellipsoid of revolution each plane passing through the center will produce an ellipse which has one axis equal to the axis of the ellipsoid The direction of polarization will always be at right angles to the plane of incidence and the refractive index will be constant This constant index is called the ordinary index The extraordinary index will be given by the other axis of the ellipse and will depend on the propagation direction When the direction is along the axis of the ellipsoid the extraordinary index will equal the ordinary index

From the equation of the ellipsoid

$$\frac{x^2}{\omega^2}+\frac{y^2}{\omega^2}+\frac{z^2}{\epsilon^2}=1 \tag{11}$$

one can derive the expression for the ellipse and in turn the formula for the extraordinary index n_e as a function of propagation direction Since the ellipsoid is symmetrical it is necessary to define this direction only with respect to the ellipsoid axis

$$n_e=\frac{\omega\epsilon}{(\epsilon^2\cos^2 r+\omega^2\sin^2 r)^{1/2}} \tag{12}$$

where r is the angle in the material between the normal to the wavefront and the axis of the ellipsoid n_e is the extraordinary index associated with this direction ω is the ordinary index and ϵ is the maximum value of the extraordinary index (usually referred to simply as the extraordinary index)

A slab cut normal to the optic axis is termed a Z cut or C cut plate (Fig 4) When such a plate is placed between crossed linear polarizers such as Nicol prisms it gives a pattern in monochromatic light shown in Fig 5 The explanation of this pattern is obtained from the equations given for the indices of refraction To a first approximation the retardation for light of wavelength λ passing through the plate at an angle r can be written

$$\Gamma=\frac{(n_e-\omega)d}{\lambda\cos r} \tag{13}$$

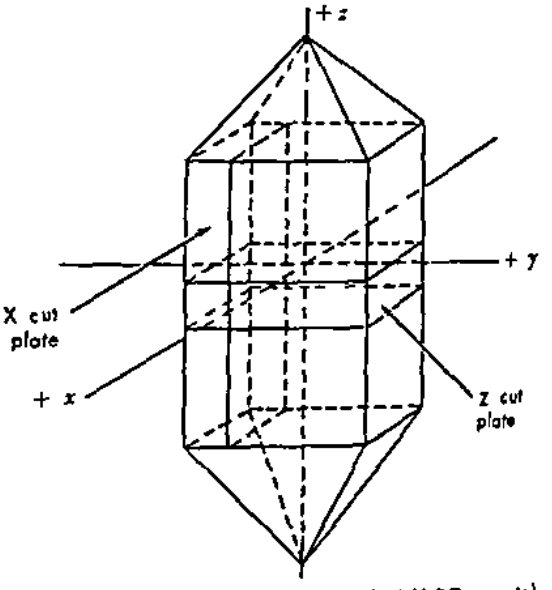


Fig 4 X cut and Z-cut plates in $NH_4H\,PO_4$ crystal

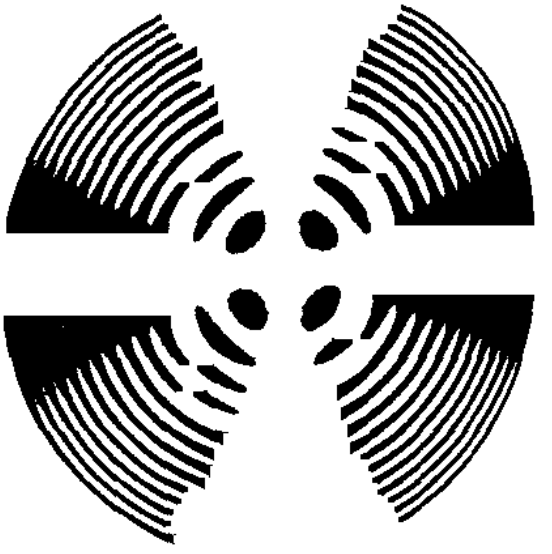


Fig 5 Interference figure from fluorspar that has been cut perpendicular to the optic axis and placed between crossed Nicol prisms (*From M Born and E Wolf Principles of Optics Pergamon* 1959)

where d is the thickness of the plate The axis of the equivalent retardation plate at an angle r will be in a plane containing the optic axis of the plate and the direction of light propagation Wherever Γ is a whole number of waves the light leaving the plate will have the same polarization as the incident light The ordinary index is constant The extraordinary index is a function of r alone as seen from Eq (12) Accordingly the locus of direction of constant whole wave retardation will be a series of cones If a uniform white light background is observed through such a plate a series of rings of constant whole wave retardation will be seen Since the retardation is a function of wavelength the rings are colored The innermost ring is red for The outer rings appear as the

blue end of the spectrum for one ring covers the red end of its neighbor The crystal plate has no effect along the axes of the polarizers since here the light is polarized along the axis of the equivalent retardation plate The family of circles is thus bisected by a dark cross When the crystal is mounted between like circular polarizers the dark cross is not present and the center of the system of rings is clear During World War II crystal plates were used in this fashion as gun sights The rings appear at infinity even when the plate is close to the eye Lateral movement of the plate causes no angular motion of the ring system The crystal plate could be rigidly fastened to a gun mount and adjusted so as to show at all times the direction in space in which the gun was pointing

Uniaxial crystal plates in which the axis lies in the plane of the plate are termed X cut or Y cut When such plates are observed between crossed polarizers a pattern of hyperbolas is observed

When crystal plates are combined in series the patterns become much more complex In addition to the fringes resulting from the individual plates a system of so-called moire fringes appears

Negative and positive crystals In calcite the extraordinary wave travels faster than the ordinary wave Calcite and other materials in which this occurs are termed negative crystals In positive crystals the extraordinary wave travels slower than the ordinary wave In the identification of uniaxial minerals one of the steps is the determination of sign This is most easily demonstrated in a section cut perpendicular to the optic axis Between crossed linear polarizers the pattern in convergent light as already mentioned is a series of concentric circles which are bisected by a dark cross When a quarter wave plate is inserted between one polarizer and the crystal with its axis at 45° to the polarizing axis the dark rings are displaced outward or inward in alternate quadrants If the rings are displaced outward along the slow axis of the quarter wave plate the crystal is positive If they are displaced inward it is negative

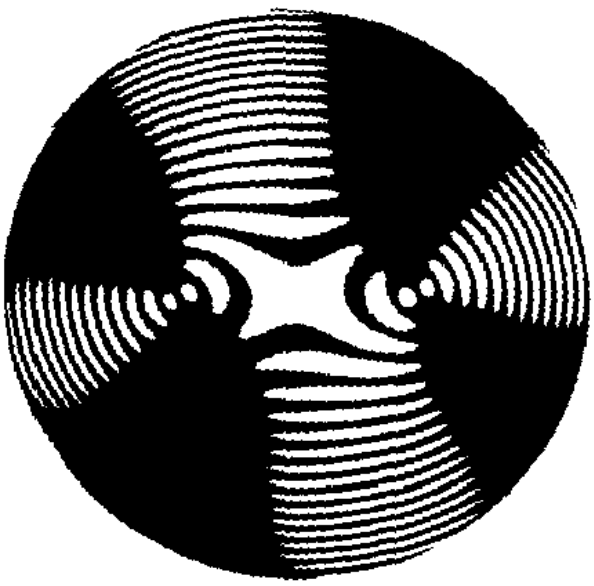


Fig 6 Interference figure from Brazil topaz (From M Born and E Wolf *Principles of Optics* Pergamon 1959)

If a Z-cut plate of a positive uniaxial crystal is put *in series* with a similar plate of a negative crystal it is possible to cancel the birefringence so that the combination appears isotropic

Biaxial crystals In crystals of low symmetry the index ellipsoid has three unequal axes These crystals are termed biaxial and have two directions along which the wave velocity is independent of the polarization direction These correspond to the two sections of the ellipsoid which are circular These sections are inclined at equal angles to the major axes of the ellipsoid and their normals lie in a plane containing the major and intermediate axes In convergent light between polarizers these crystals show a pattern which is quite different from that which appears with uniaxial crystals A plate cut normal to the major axis of the index ellipsoid has a pattern consisting of a series of lemniscates and ovals The directions corresponding to the optic axes appear as black spots between crossed circular polarizers The pattern between crossed linear polarizers is shown in Fig 6

Angle between optic axes One of the quantities used to describe a biaxial crystal or to identify a biaxial mineral is the angle between the optic axes This can be calculated directly from the equation for the index ellipsoid

$$\frac{x^2}{\alpha^2}+\frac{y^2}{\beta^2}+\frac{z^2}{\gamma^2}=1 \tag{14}$$

where α β and γ are the three indices of refraction of the material The circular sections of the ellipsoid must have the intermediate index as a radius If the relative sizes of the indices are so related that

$$\alpha > \beta > \gamma \tag{15}$$

the circular sections will have β as a radius and the normal to these sections will lie in the xz plane The section of the ellipsoid cut by this plane will be the ellipse

$$\frac{x^2}{\alpha^2}+\frac{z^2}{\gamma^2}=1 \tag{16}$$

The radius of length β will intersect this ellipse at a point x_1z_1 where

$$x_1^2+z_1^2=\beta \tag{17}$$

The solution of these two equations gives for the points x_1z_1

$$x_1=\pm\sqrt{\frac{\alpha^2(\gamma^2-\beta^2)}{\gamma^2-\alpha^2}}$$
$$z_1=\pm\sqrt{\frac{\gamma^2(\alpha^2-\beta^2)}{\alpha^2-\gamma^2}} \tag{18}$$

These points and the origin define the lines in the xz plane which are also in the planes of the circular sections of the ellipsoid Perpendiculars to these lines will define the optic axes The angle Ω between the axes and the z direction will be given by the expression

$$\tan^2 \Omega = \frac{z_1^2}{x_1^2} = \frac{(1/\alpha^2) - (1/\beta^2)}{(1/\beta^2) - (1/\gamma^2)} \qquad (19)$$

The polarization direction for light passing through a biaxial crystal is computed in the same way as for a uniaxial crystal The section of the index normal to the propagation direction is ordinarily an ellipse The directions of the axes of the ellipse represent the vibration direction and the lengths of the half axes represent the indices of refraction One polarization direction will lie in a plane which bisects the angle made by the plane containing the propagation direction and one optic axis and the plane containing the propagation direction and the other optic axis The other polarization direction will be at right angles to the first When the two optic axes coincide this situation reduces to that which was demonstrated earlier for the case of uniaxial crystals

Conical refraction In biaxial crystals there occurs a set of phenomena which have long been a classical example of the theoretical prediction of a physical characteristic before its experimental discovery These are the phenomena of internal and external conical refraction They were predicted theoretically in 1832 by Sir William Hamilton and experimentally demonstrated in 1833 by H Lloyd

As shown earlier the Huygens wavelets in a biaxial crystal consist of two surfaces One of these has its major axis at right angles to the major axis of the other The two thus intersect In making the geometrical construction to determine the ray direction two directions are found where the two wavefronts coincide and the points of tangency on the two ellipsoids are multiple In fact the plane which represents the wavefront is found to be tangent to a circle which lies partly on one surface and partly on the other The directions in which the wavefronts coincide are the optic axes A ray incident on the surface of a biaxial crystal in such a direction that the wavefront propagates along an axis will split into a family of rays which lie on a cone If the crystal is a plane parallel slab these rays will be refracted at the second surface and transmitted as a hollow cylinder parallel to the original ray direction Similarly if a ray is incident on the surface of a biaxial crystal plate at such an angle that it passes along the axes of equal ray velocity it will leave the plate as a family of rays lying on the surface of a cone The first of these phenomena is internal conical refraction the second is external conical refraction The following equation

$$\tan \psi = \frac{\beta}{\sqrt{\alpha\gamma}} \sqrt{(\beta - \alpha)(\gamma - \beta)} \qquad (20)$$

gives the half angle ψ of the external cone [R H B]

Bibliography M Born *Optik* 1933 M Born and E Wolf *Principles of Optics* 1959 F Jenkins and H White *Fundamentals of Optics* 3d ed 1957 F Pockels *Lehrbuch der Kristalloptik* 1904 E E Wahlstrom *Optical Crystallography* 2d ed 1951

Crystal structure

The arrangement of atoms or ions in a crystalline solid Knowledge of the precise ways in which atoms and ions are distributed in crystals is of prime importance in solid state physics chemistry metallurgy mineralogy geochemistry and other fields In 1912 M von Laue W Friedrich and P Knipping first discovered that x rays could be diffracted by crystals Prior to this discovery little was known about the arrangement of atoms and ions in solid materials Knowledge of crystal structure is and has been obtained mainly from x ray diffraction data although electron diffraction and more recently neutron diffraction have become important tools in crystal analysis

This article discusses the important concepts and terminology involved in the structure of crystalline solids and describes the structure of various metals and some relatively simple crystalline compounds For related information *see* ALLOY STRUCTURES CHEMICAL BINDING CRYSTAL DEFECTS CRYSTALLOGRAPHY ELECTRON DIFFRACTION FER

DIFFRACTION

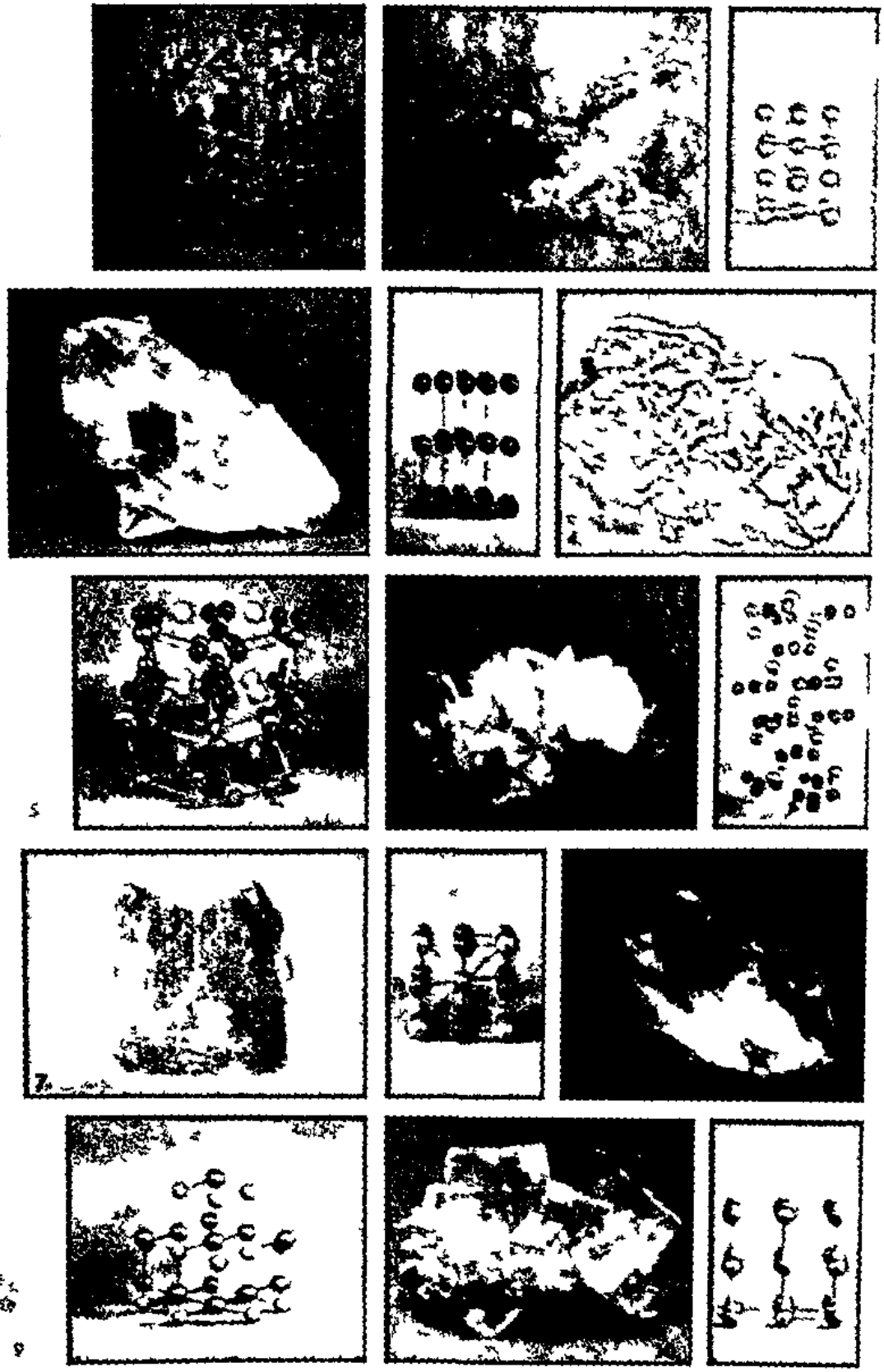
CONCEPTS AND TERMINOLOGY

In order to understand and describe crystal structures several terms and concepts have been developed *Brief explanations of* the most important are given *in the following* paragraphs

Space lattices A three-dimensional indefinitely extended array *of points each* of which is surrounded in an identical way by its neighbors is known as a *lattice or space lattice* The space lattice *of a crystal is the* representation of the periodicity with which matter is distributed in it It is *essential to distinguish* a lattice from a crystal

identical in

tion The space lattice concept was introduced by R J Hauy as an *explanation for* the special geometric properties *of crystal* polyhedrons It was postulated that an elementary unit having all the *properties of the crystal* should exist or conversely *that a* crystal was built up by the juxtaposition of such elementary units If mathematical points forming the vertices of a parallelepiped $OABC$ (defined by three vectors $\overrightarrow{OA}$ $\overrightarrow{OB}$ $\overrightarrow{OC}$) *are* considered (Fig 1) a space lattice is *obtained by* translations parallel to and equal to $\overrightarrow{OA}$ $\overrightarrow{OB}$ $\overrightarrow{OC}$



Some m ne als and models of the r crystal structures (Bell Telephone Labo ator es

1 Pyr te
2 Copper
3 Alpha quartz
4 Graph te
5 Potassium d hyd_ogen phosphate
6 Calc te
7 Sp nel
8 Perovsk te
9 Z nc
10 Hal te (sod um chloride)

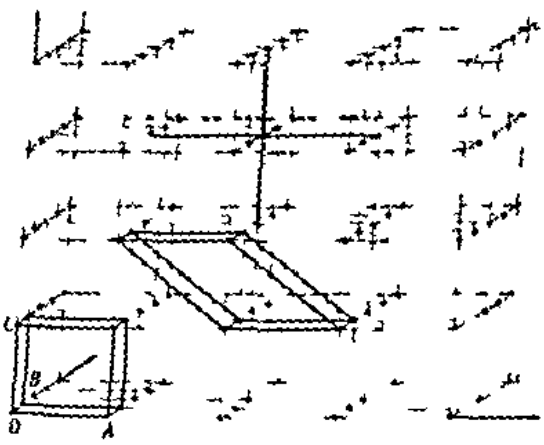


Fig 1 A space lattice two possible unit cells and the environment of a point are shown

The parallelepiped is called the *unit cell* The vector r joining O to any lattice point can be written as $\mathbf{r} = m\overrightarrow{OA} + n\overrightarrow{OB} + r\overrightarrow{OC}$ where m n and r are integers

In a space lattice two points define a row and three define a lattice plane Taking the directions of OA OB OC as axes and ABC as the unit plane all planes and rows can be expressed by Miller indices For a discussion of Miller indices *see* CRYSTALLOGRAPHY

In a row $[uvw]$ two neighboring points are separated by a distance p_{uvw} which is characteristic for that row and all parallel ones Two adjacent parallel rows of the family represented by $[uvw]$ are a distance r_{uvw} apart The plane (hkl) defines a family of lattice planes in which the points are identically distributed and form a two dimensional lattice Figure 2 is an example

This two dimensional lattice can be deduced from two vectors such as $\overrightarrow{OA}$ $\overrightarrow{OB}$ The parallelogram OAB is the smallest unit from which the whole assembly can be obtained by parallel translation This statement applies equally well to the other two parallelograms OAB and OAB' in Fig 2 and in fact to an infinite number of such parallelograms all of which have the same surface area $S_{hkl} = p_{uvw}r_{uvw}$ Thus the density of points in a given row $1/p_{uvw}$ is proportional to the distance between rows

In the same way an infinity of unit cells can be considered in the space lattice These cells all have the same volume $V = S_{hkl}\,d_{hkl}$ if d_{hkl} is the distance between two adjacent planes (hkl) The distance d_{hkl} is proportional to $1/S_{hkl}$ the latter providing a measure for the density of points or the packing in (hkl) This remark as well as the similar one made for the rows is important when the properties of the crystals are considered on an atomic scale The faces and the edges of crystals are respectively densely packed lattice planes and rows It is clear from a mathematical standpoint that from all pos-

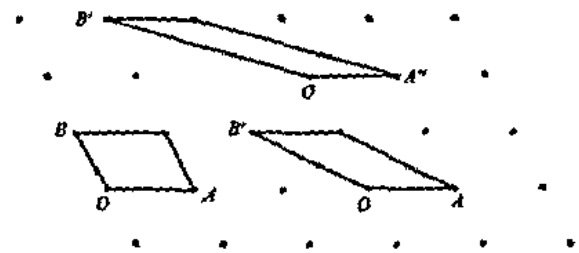


Fig 2 Two-dimensional lattice formed by the points in a lattice plane (hkl) All possible primitive parallelograms have the same surface area

sible cells the *most convenient one should* be chosen and that whenever possible preference should be given to a parallelepiped with mutually perpendicular edges

The volume V of the unit cell is given by the expression

$$V = abc\sqrt{1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma + 2\cos\alpha\cos\beta\cos\gamma}$$

where α β and γ are the angles defined by the crystal axes as shown in Fig 3*a* The general expression for d_{hkl} (called d for convenience) is given by the relation

$$\frac{1}{d^2} = \frac{h\begin{vmatrix} h/a & \cos\gamma & \cos\beta \\ k/b & 1 & \cos\alpha \\ l/c & \cos\alpha & 1 \end{vmatrix} + k\begin{vmatrix} 1 & h/a & \cos\beta \\ \cos\gamma & k/b & \cos\alpha \\ \cos\beta & l/c & 1 \end{vmatrix} + l\begin{vmatrix} 1 & \cos\gamma & h/a \\ \cos\gamma & 1 & k/b \\ \cos\beta & \cos\alpha & l/c \end{vmatrix}}{\begin{vmatrix} 1 & \cos\gamma & \cos\beta \\ \cos\gamma & 1 & \cos\alpha \\ \cos\beta & \cos\alpha & 1 \end{vmatrix}}$$

If $\alpha = \beta = \gamma = 90°$ $\cos\alpha = \cos\beta = \cos\gamma = 0$ and the expression reduces to

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

and if furthermore $a = b = c$ as in cubic lattices this becomes $1/d^2 = (h^2 + k^2 + l^2)/a$ When $a = b \neq c$ $\alpha = \beta = 90°$ and $\gamma = 120°$ as in the hexagonal case

$$1/d = (4/3a)(h + k + l) + l/c$$

Symmetry can also be considered in a lattice The lattice being indefinitely extended there is no longer a point group but an array of regularly repeating symmetry elements Each lattice point

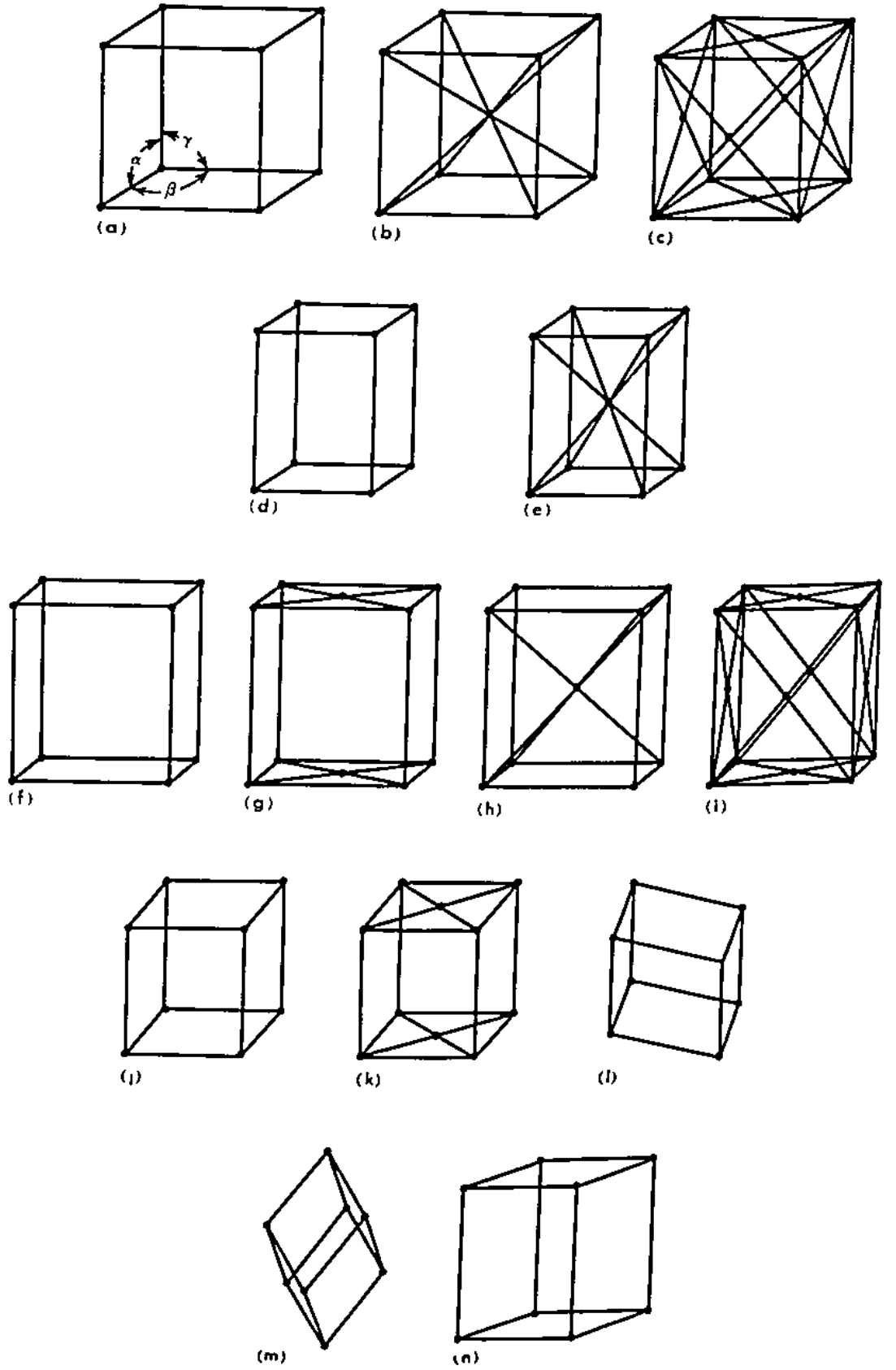


Fig 3 The fourteen Bravais space lattices (*a*) Simple cubic (*b*) Body centered cubic (*c*) Face-centered cubic (*d*) Tetragonal (*e*) Body-centered tetragonal (*f*) Orthorhombic (*g*) Base-centered orthorhombic (*h*) Body centered orthorhombic (*i*) Face-centered orthorhombic (*j*) Monoclinic (*k*) Base-centered monoclinic (*l*) Triclinic (*m*) Trigonal (*n*) Hexagonal

s a center of symn etry Symmetry planes are parallel to lattice planes Symmetry axes m st be perpend cular to a lattice plane and coinc de with or be parallel to a row

Bravais lattices Tl e e are the 14 d fferent pos ble space latt ces ol ta ned on tl e l asis that two l tt ces are d fferent wl en the environment of tl eir po nts is d fferent Tl e 14 unit cells are represented n F g 3 If cons dered as sol ds tl e coml nat on of symmetry elements tl ey exhil t can l e deter m ned Seven point groups whicl are respect vely the mo t symmetrical of each system are found Accord ngly the t n t cells an l l v extension the latt ces can be d vided into se en groups corre- pond ng to the seven crystall graph c systems Among the cells shown in Fig 3 some l ave po nts at places other than corners The e cells are not primitive but are mult ple cells cl osen f r con en ence As an example the three prim t e cells of the cubic lattices are re pectively a cul e a rhombohedron with a plane angle of 109°28 and a rhombohedron w th an angle of 60° The two rhombohedra are extremely inconven ent to han dle consequently the body-centered and face cen tered cubes are adopted in their stead Figure 4 shows the three cub c systems and the relationsh p of the last two to their prim t ve rhombohedra The letters P I and F stand for primitive body cen tered and face centered respectively A P cell conta ns one po nt s nce each corner is used eight t mes n the format on of the complete assembly An I cell conta ns two points an F cell four (one at the corners and six halves as each po nt in the center of the faces belongs to two cells)

The external symmetry of a crystal is due to the per odically repeated arrangement of its atoms or ons The Brava s lattices give the poss ble perio- dicities A further step must cons st in finding the number of possible period c arrangements two such arrangements being cons dered as d fferent when they g ve r e to a different symmetry

Two-d mens onal structures are very well suited to illu trate this In Figs 5 and 6 a numeral 9 is

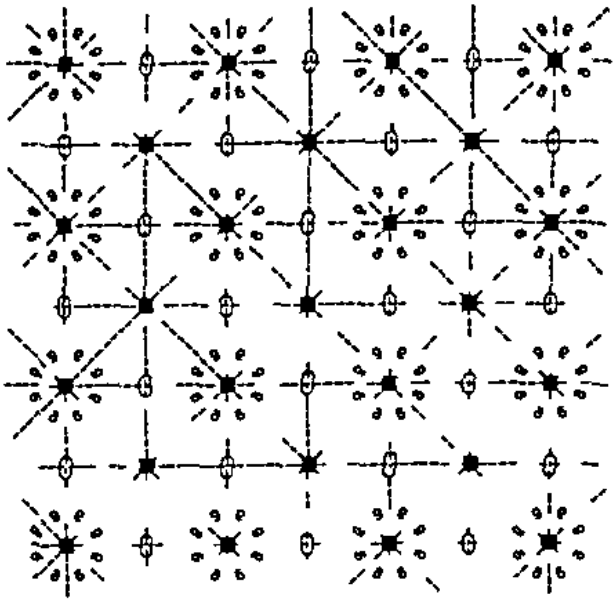


Fig 5 Per od c pattern obta ned by the mult pl cat on of an asymmetr c ob ect by the nd cated o ay of sym met y elements Both pattern and latt ce have the same *symmetry elements* M or planes nd cated by dotted l nes

chosen as the object it is fully asymmetr c and no fal e symmetry can therefore be introduced It is multiplied by a periodic array of mirror planes and four fold axes Several interpenetrating identi cal latt ces are formed The two arrangements have the same Brava s lattice but not the same sym metry In three d mensional space the problem is s milar but add t onal symmetry elements are con s dered

Screw axes These comb ne the rotat on of an ordinary symmetry axis w th a translation parallel to it and equal to a fract on of the unit d stance in th s d rection Figure 7 illustrates such an operation which is symbol cally denoted 3 and 3 The trans lat on is respectively 1/3 and 2/3 The helices are added to help the v sualization and it is seen that they are respectively right and left handed Tl e

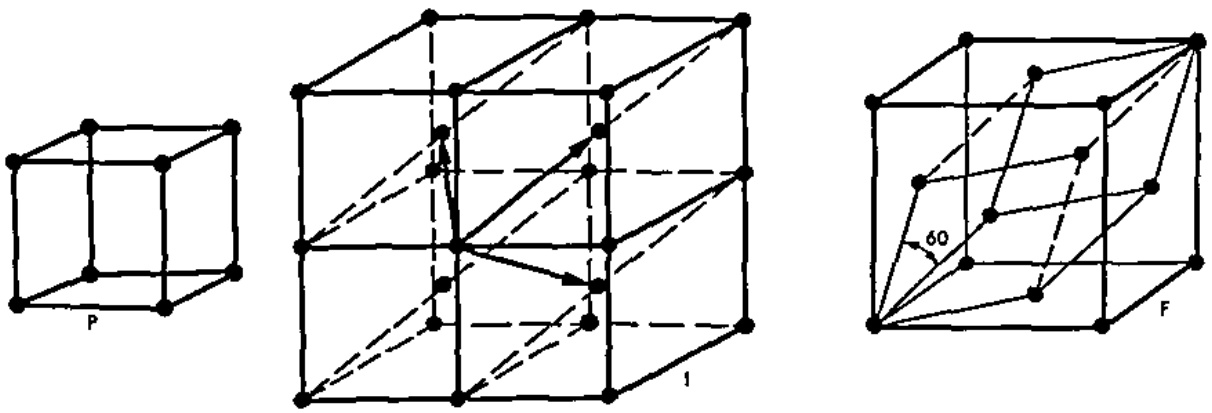


Fig 4 The three cub c pr m t ve cells and the rela t on to the F and I cells (*Af er C K ttel Int oduct on to Sol d State Phys cs 2d ed W ley 1956*)

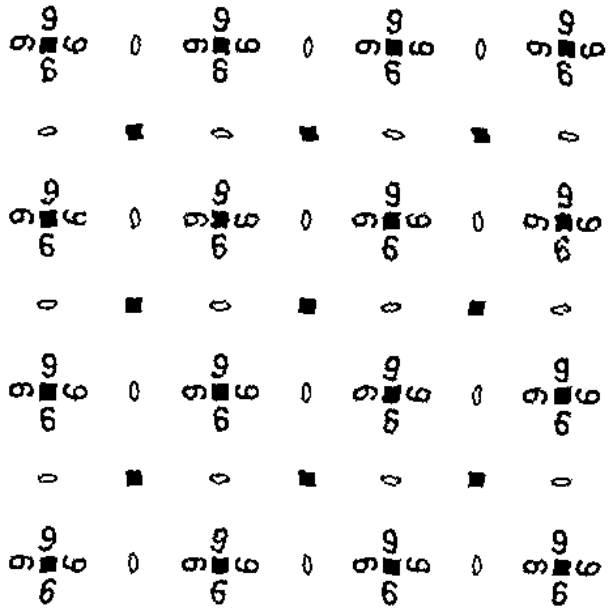


Fig 6 Arrangement in which the periodic pattern has fewer symmetry elements than the lattice This shows that the symmetry of the Bravais lattices can be lowered by the structure of the lattice points

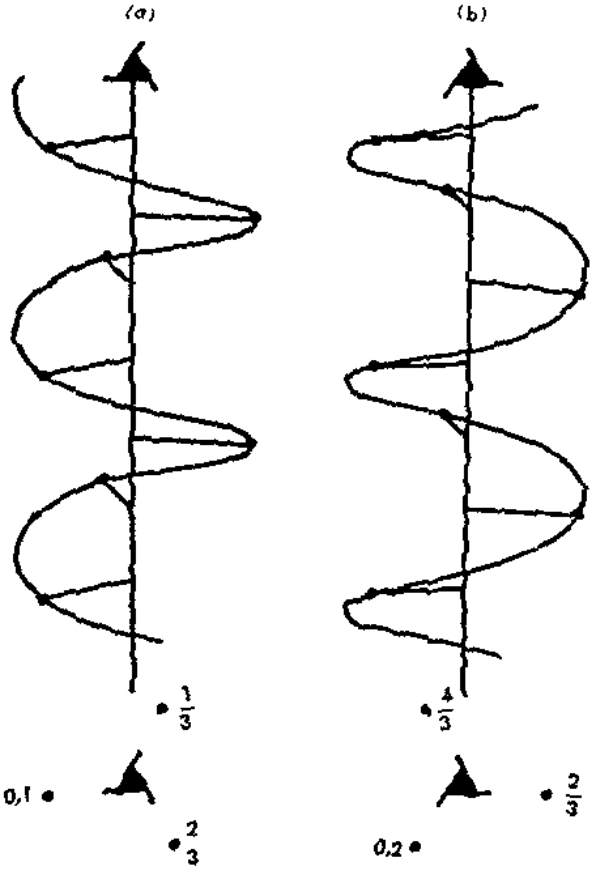


Fig 7 Screw axes 3_1 (a) and 3_2 (b) The lower parts of the figure are projections on a plane perpendicular to the axis The numbers indicate the heights of the points above that plane

projection on a plane perpendicular to the axis shows that the relationship about the axis remains in spite of the displacement A similar type of arrangement can be considered around the other symmetry axes, and the following possibilities arise $\bar{2}_1$, 3_1, 3_2, 4_1, 4_2, 4_3, 6_1, 6_2, 6_3, 6_4, and 6_5

If screw axes are present in crystals, it is clear that the displacements involved are of the order of a few angstroms and that they cannot be distinguished macroscopically from ordinary symmetry axes The same is true for glide mirror planes

Glide mirror planes. These combine the mirror image with a translation parallel to the mirror plane over a distance which is half the unit distance in the glide direction This is illustrated in Fig 8 Axial glide planes, denoted by *a*, *b*, *c*, have

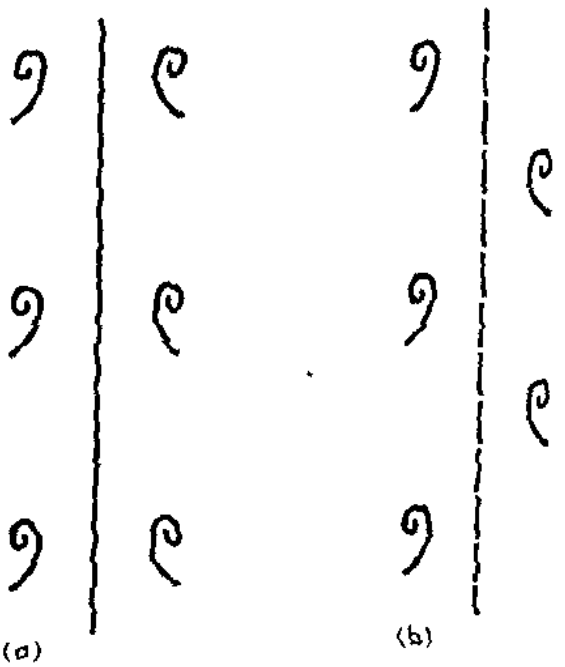


Fig 8 (a) Mirror and (b) glide plane

translations which are equal to $a/2$, $b/2$, $c/2$ respectively, where a, b, c are the lattice vectors Diagonal glide planes denoted by *n* have translations of $(a+b)/2$, $(b+c)/2$, or $(c+a)/2$

These new symmetry elements must be taken into account when the number of possible periodic arrangements is considered This problem was solved independently by R S Federow (1885), A M Schoenflies (1891), and W Barlow (1894) A total [illegible] is possible [illegible] scopically [illegible] extended arrays of symmetry elements disposed on a space lattice A space group acts as a three-dimensional kaleidoscope an object submitted to its symmetry operations is multiplied and periodically repeated in such a way that it generates a number of interpenetrating identical space lattices The fact that 230 space groups are possible means of course 230 kinds of periodic arrangement of objects in

space When only two dimensions are considered 17 space groups are possible

Space groups are denoted by the Hermann Maugum notation preceded by a letter indicating the Bravais lattice on which it is based For example P $2_12_12_1$ is an orthorhombic space group the cell is primitive and three mutually perpendicular screw axes are the symmetry elements All space groups are listed in advanced textbooks

J D H Donnay and D Harker have shown that it is possible to deduce the space group from a detailed study of the external morphology of crystals

COMMON STRUCTURES

Metals In general metallic structures are relatively simple characterized by a dense packing and a high degree of symmetry Manganese gallium mercury and one form of tungsten are exceptions Metallic elements situated in the subgroups of the periodic table gradually lose their metallic character and simple structure as the number of the subgroup increases A characteristic of metallic structures is the frequent occurrence of allotropic forms that is the same metal can have two or more different structures which are most frequently stable in a different temperature range

The forces which link the atoms together in metallic crystals are nondirectional This means that each atom tends to surround itself by as many others as possible This results in a dense packing similar to that of spheres of equal radius and yields three distinct systems close packed (face centered) cubic hexagonal close packed and body centered cubic

Close packing For spheres of equal radius close packing is interesting to consider in detail with respect to metal structures Close packing is a way of arranging spheres of equal radius in such a manner that the volume of the interstices between the spheres is minimal The problem has an infinity of solutions The manner in which the spheres can be most closely packed in a plane A is shown in Fig 9 Each sphere is in contact with six others the centers form a regular pattern of equilateral triangles The cavities between the spheres are numbered A second similar plane can be positioned in such a way that its spheres rest in the cavities 1 3, 5 between those of the layer A The new layer B has an arrangement similar to that of A but is shifted with respect to A Two possibilities exist for adding a third layer Its spheres can be put exactly above those of layer A (an assembly ABA is then formed) or they may come above the interstices 2 4 6 In the latter case the new layer is shifted with respect to A and B and is called C For each further layer two possibilities exist and any sequence such as $ABCBABCACBA$ in which two successive layers have not the same denomination is a solution of the problem They are all characterized by the fact that each sphere touches 12 others and all are equally densely packed Such assemblies are rare in crystals Complicated periodic sequences have however been observed especially in carborundum One structure is known where 89 layers form a sequence which is regularly repeated In the vast majority of cases *periodic assemblies with a very short repeat distance* occur The cavities between the spheres occupying 27% of the total volume are of two types tetrahedral cavities between four spheres and octahedral ones between six spheres For an assembly of N spheres $3N$ cavities exist $2N$ are tetrahedral and N are octahedral

Face centered cubic structure This utilizes close packing characterized by the regular repetition of the sequence ABC The centers of the spheres form

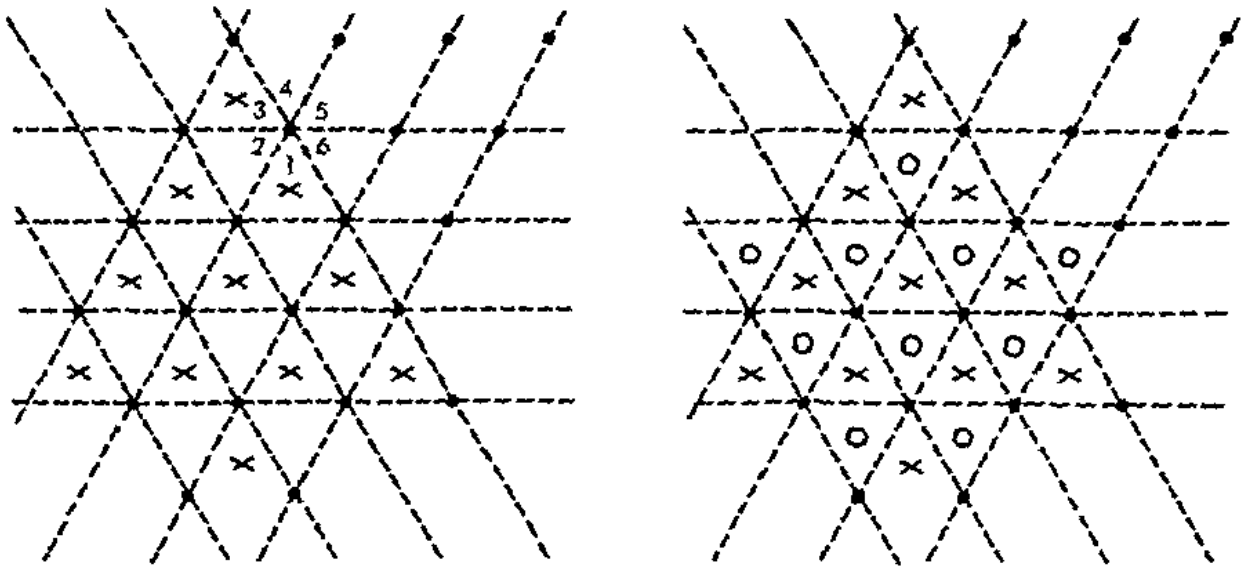


Fig 9 Close packing of spheres The centers for the A B and C layers are indicated by a dot a cross and an open circle respectively

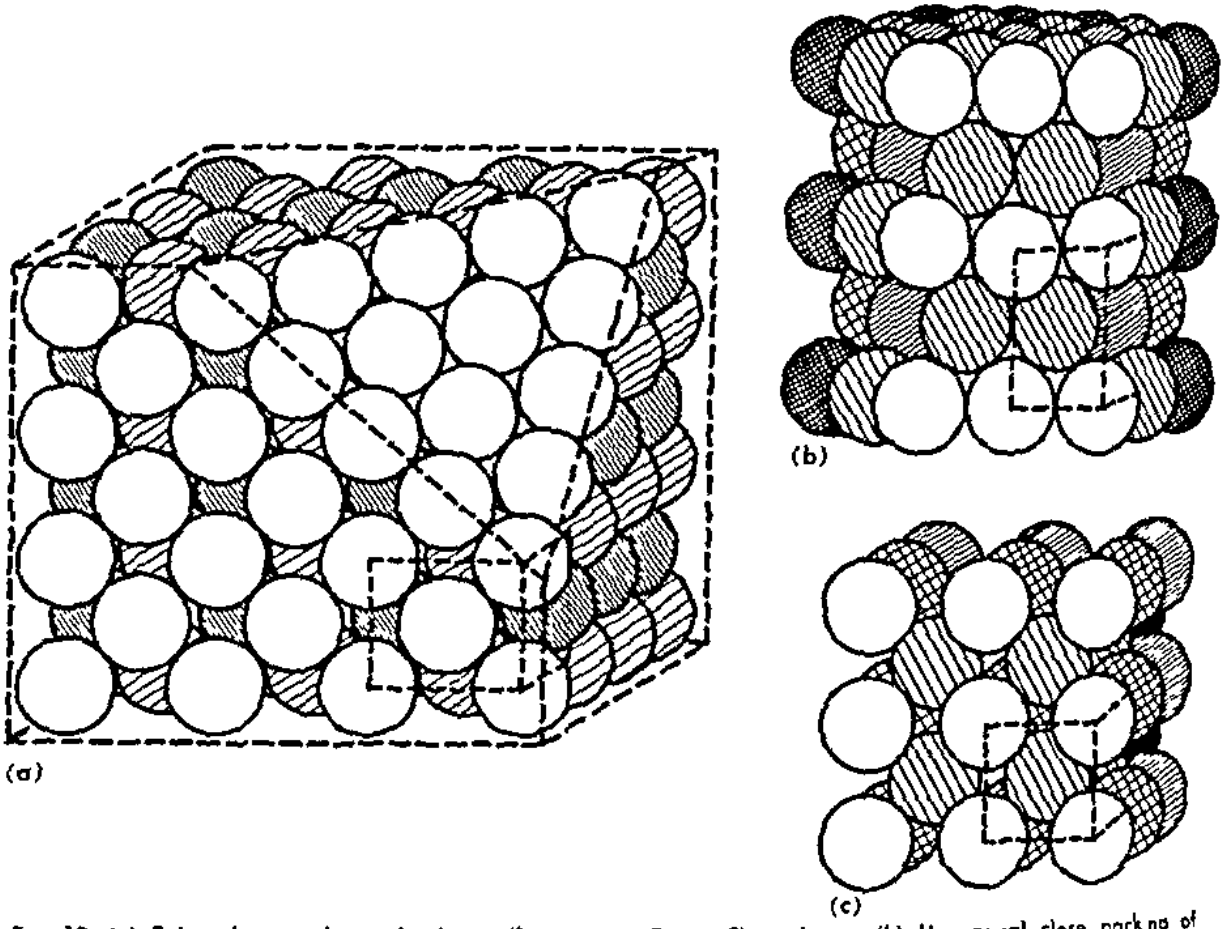


Fig 10 (a) Cubic close packing of spheres (face centered cubic) One set of close packed (111) planes (A, B, or C) is shown (b) Hexagonal close packing of spheres (c) Body centered cubic arrangement

a cubic lattice F as shown in Fig 10a The densely packed planes of the type A B C are perpendicular to the three fold axis and can therefore be written as {111} This form contains four sets of planes These being the closest packed planes of the structure d_{111} is greater than any other d_{hkl} of the lattice The densest rows in these planes are $\langle 110 \rangle$

It is relatively easy to calculate the percentage of the volume occupied by the spheres The unit cell has a volume a^3 and contains four spheres of radius R, their volume being $16\pi R^3/3$ The spheres touch each other along the face diagonal (Fig 10a), $a\sqrt{2}$ is therefore equal to $4R$, or $R = a\sqrt{2}/4$ Substitution gives for the volume of the spheres $\pi\sqrt{2}a^3/6$ which is 73% of the volume of the cube It is clear that the same percentage of the unit volume is filled in all other close packed assemblies that is, assemblies corresponding to other alternations of the planes A, B C

Hexagonal close packed structure This is a close packing characterized by the regular alter

(1/3, 1/3 1/2) The ratio c/a is easily calculated The length $BD = a$ the edge of the unit cell The height of the cell is $AE = 2AG = c$

$$AG = \sqrt{a^2 - \left(\frac{2}{3}\frac{a\sqrt{3}}{2}\right)^2} = a\sqrt{3/8}$$

$$c = 2AG = a\sqrt{8/3} \qquad c/a = \sqrt{8/3} = 1.633$$

This latter value is important, for it permits determination of how closely an actual hexagonal structure approaches ideal close packing

Body centered cubic structure This is an assembly of spheres in which each one is in contact with eight others as shown in Fig 10c

The spheres of radius R touch each other along the diagonal of the cube, so that measuring from the centers of the two corner cubes the length of the cube diagonal is $4R$ The length of the diagonal is also equal to $a\sqrt{3}$ if a is the length of the cube edge, and thus $R = a\sqrt{3}/4$ The unit cell contains two spheres (one in the center and $\frac{1}{8}$ in each corner) so that the total volume of the spheres in each cube is $8\pi R^3/3$ Substituting $R = a\sqrt{3}/4$ and dividing by a^3, the total volume of the cube gives the percentage of filled space as 67% Thus the structure is less dense than the two preceding cases

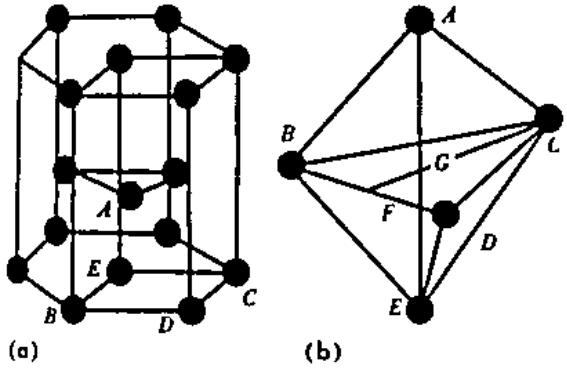


Fig 11 (a) Three unit cells of the hexagonal close-packed structure, showing how the hexagonal axis results One of the cells is fully outlined (b) Calculation of the ratio c/a The distance AE is equal to the height of the cell

The closest packed planes are {110}, this form contains six planes They are however not as dense as the A, B, C planes considered in the preceding structures The densest rows have the four <111> directions

Tabulation of structures The structures of various metals are listed in the accompanying table in which the abbreviations fcc, hcp and bcc respectively, stand for face centered cubic, hexagonal close packed, and body centered cubic In this table, the hexagonal structures, classified as ?, are still in doubt The structures listed hcp are only roughly so, only magnesium has a c/a ratio (equal to 1 62) which is very nearly equal to the ratio (1 63) calculated earlier for the ideal hcp structure For cadmium and zinc, the ratios are respectively 1 89 and 1 86, which are significantly larger than 1 63 Strictly speaking, each zinc or cadmium atom has therefore not twelve nearest neighbors but only six This departure from the ideal case for subgroup metals follows a general empirical rule, formulated by W Hume Rothery and known as the $8\,N$ rule It states that a subgroup metal has a structure in which each atom has $8\,N$ nearest neighbors, N being the number of the subgroup *See* COORDINATION NUMBER

Metal structures

Metal	Modification	Stability range	Structure
Beryllium	α	To melting point	hcp
	?β	630°C to melting point	Hexagonal
Cadmium	α	To melting point	hcp
Calcium	α	To 450°C	fcc
	?β	300–450°C	Hexagonal
	γ	450°C to melting point	bcc
Cerium	α	To melting point	fcc
	?β	50°C	Hexagonal
Chromium	α	To melting point	bcc
	?β	Electrolytic form	Hexagonal
Cobalt	α	To 420°C	hcp mixed with fcc
	β	420°C to melting point	fcc
Gold	α	To melting point	fcc
Iron	α	To 909°C	bcc
	γ	909–1403°C	fcc
	δ	1403°C to melting point	bcc
Lead	α	To melting point	fcc
Magnesium	α	To melting point	Nearly hcp
Nickel	α	To melting point	fcc
	β	Electrolytic form	Hexagonal
Silver	α	To melting point	fcc
Tungsten	α	To melting point	bcc
Zirconium	α	To 862°C	hcp
	β	862°C to melting point	bcc
Zinc	α	To melting point	hcp

Crystalline compounds. Simple crystal structures are usually named after the compounds in which they were first discovered (diamond or zinc sulfide, cesium chloride, sodium chloride, calcium fluoride) Many compounds of the type A^+X^-, $A^{++}X_2^-$ have such structures They are highly symmetrical, the unit cell is cubic, and the atoms or ions are disposed at the corners of the unit cell and at points having coordinates which are combinations of 0 1, 1/2, or 1/4

Sodium chloride structure This is an arrangement in which each positive ion is surrounded by six negative ions and vice versa The arrangement is expressed by stating that the coordination is 6/6 The centers of the positive and the negative ions each form a face centered cubic lattice They are shifted one with respect to the other over a distance $a/2$, where a is the repeat distance (Fig 12*a*) Systematic study of the dimensions of the unit cells of compounds having this structure has revealed that

1 Each ion can be assigned a definite radius A positive ion is smaller than the corresponding atom and a negative ion is larger

2 Each ion tends to surround itself by as many others as possible of the opposite sign because the binding forces are nondirectional

On this basis the structure is determined by two factors, a geometrical factor involving the size of the two ions which behave in first approximation as hard spheres and an energetical one involving electrical neutrality in the smallest possible volume In the ideal case all ions will touch each other, therefore, if r_A and r_X are the radii of the ions, $4r_X = a\sqrt{2}$ and $r_A + r_X = a$ Expressing a as a function of r_X gives $r_A/r_X = \sqrt{2} - 1 = 0\,41$ When r_A/r_X becomes smaller than 0 41 the positive and negative ions are no longer in con

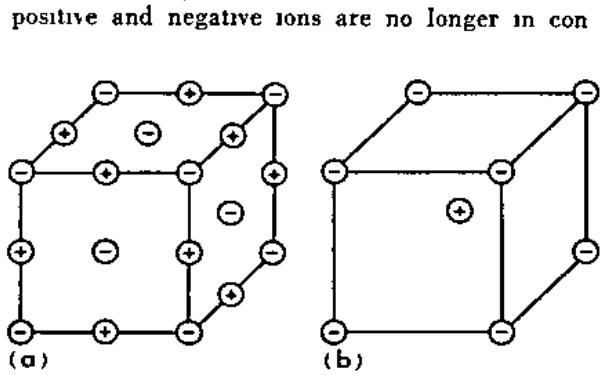
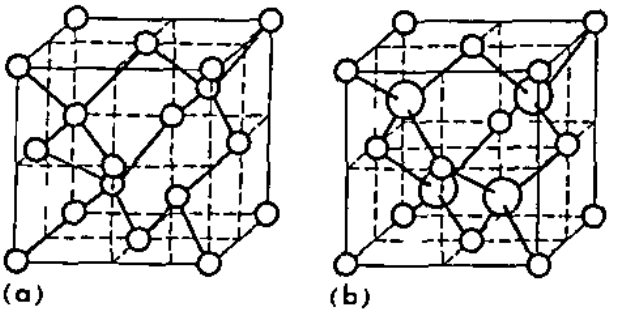


Fig 12 (a) Sodium chloride structure (b) Cesium chloride structure



(a) (b)

Fig 13 (a) Diamond structure (b) Zinc blende structure

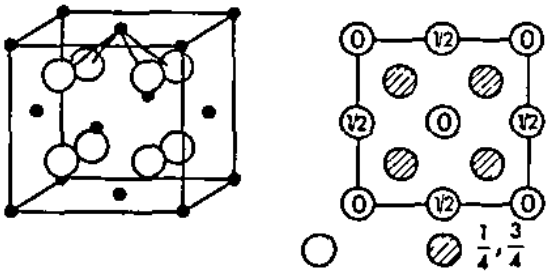


Fig 14 Calcium fluoride structure

tact and the structure becomes unstable When r_A/r_X is greater than 0 41 the positive ions are no longer in contact but ions of different sign still touch each other The structure is stable up to a value of $r_A/r_X = 0\ 73$ which occurs in the cesium chloride structure

Cesium chloride structure This is characterized by a coordination 8/8 (Fig 12*b*) Each of the centers of the positive and negative ions forms a primitive cubic lattice the centers are mutually shifted over a distance $a\sqrt{3}/2$ The stability condition for this structure can be calculated as in the preceding case Contact of the ions of opposite sign here is along the cube diagonal

Diamond structure In this arrangement each atom is in the center of a tetrahedron formed by its nearest neighbors The 4-coordination follows from the well known bonds of the carbon atoms This structure is illustrated in Fig 13*a* The atoms are at the corners of the unit cell the centers of the faces and at four points having as coordinates (1/4 1/4 1/4) (3/4 3/4 1/4) (3/4 1/4 3/4) (1/4 3/4 3/4) The atoms can be divided into two groups each forming a face centered cubic lattice the mutual shift is $a\sqrt{3}/4$

Zinc blende structure This structure shown in Fig 13*b* has coordination 4/4 and is basically similar to the diamond structure Each zinc atom (small circles in Fig 13*b*) is in the center of a tetrahedron formed by sulfur atoms (large circles) and vice versa The zinc atoms form a face centered

14 shows the
nit cell is di
vided into eight equal cubelets calcium ions are situated at corners and centers of the faces of the cell The fluorine ions are at the centers of the eight cubelets There exist three interpenetrating fcc lattices one formed by the Ca ion and two by the F ions the mutual shifts being (0 0 0) (1/4 1/4 1/4), (3/4 3/4 3/4) [WD]

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Crystallization

The formation of crystalline substances from solutions or melts Crystallization is an important industrial operation because of the large number of materials marketed as crystals Before the introduction of ion exchange and solvent extraction processes fractional crystallization (the crystallization of a portion of one dissolved substance from a solution containing several substances) was one of the most widely used methods of separating substances in a state of high purity This article will discuss crystallization of substances from solution For discussions of methods for preparing relatively pure crystalline substances from other media *see* SINGLE CRYSTAL SUBLIMATION ZONE REFINING Theoretical aspects of the relationships between solid and liquid (or dissolved) phases are discussed in other articles *See* EQUILIBRIUM PHASE FUSED-SALT PHASE EQUILIBRIA

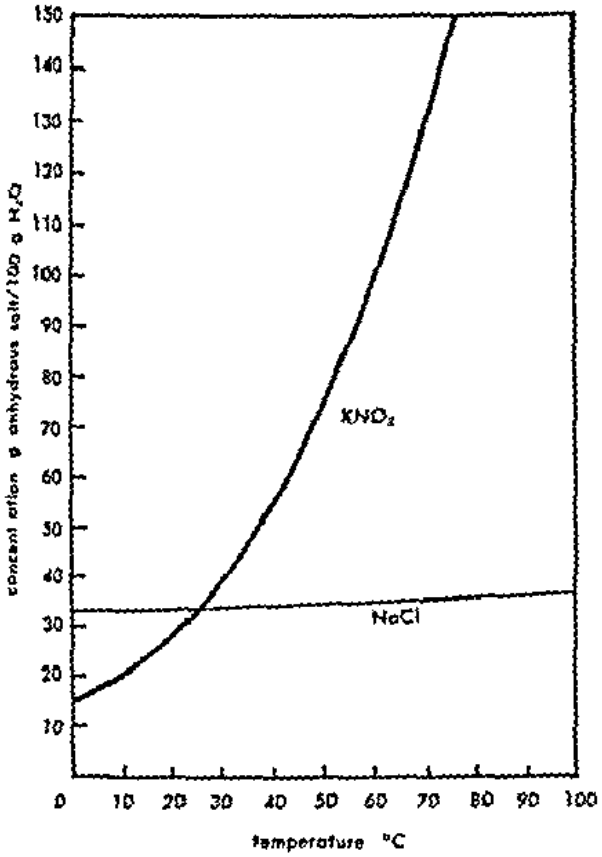
Crystal structure Each pure crystalline substance is made up of regularly spaced and oriented atoms ions or molecules Crystals forming from an impure solution or melt are themselves of definite composition

Crystals can be classified into five main types depending upon the type and strength of the bonds between the constituent atoms ions or molecules The nature of these bonds determines the electrical magnetic and mechanical properties of the crystal

The five types of crystals are metals ionic crystals (salts) valence crystals (diamond silicon carbide) semiconductors and molecular crystals Many crystals have characteristics and properties that are intermediate between these main types *See* CHEMICAL BINDING CRYSTAL STRUCTURE

The crystals of a single substance all show the same geometrical structures that is corresponding crystal faces have the same angles between them The crystal structure has been used as the basis for classification of crystals *See* CRYSTALLOGRAPHY ISOMORPHISM (CRYSTALLOGRAPHY)

Crystal formation In order for crystals to form a solution must be saturated with respect to the substance desired The amount of solute required to saturate a given amount of solvent is characteristic of the solute and solvent and it varies as a function of the temperature The effect of tempera



Temperature solubility curves for two salts

ture on the solubility of two solutes is shown in the illustration

Because the initial solutions in almost all crystallization processes are unsaturated they must be evaporated to remove solvent or cooled to reduce the solubility of the solute *See* SATURATION OF SOLUTIONS

The formation of the first crystals of solute in a solution is called *nucleation* These first particles called nuclei may be formed from solid particles already present in the system (dust glass or undissolved ionic substances) or spontaneously generated in the saturated solution itself Sometimes a small crystal of the desired substance is added to the solution as a seed to induce the formation of the first crystals *See* NUCLEATION

After the first particles have been formed the rate of growth of the crystals depends upon the extent of supersaturation the rate at which solvent may be evaporating from the solution or the rate of cooling For a discussion of the growth of crystalline substances *see* CRYSTAL GROWTH

Fractional crystallization All the dissolved substances in a solution can be recovered by complete evaporation of the solvent However this is seldom done especially when a single substance is desired in a state of high purity because the initial solutions usually contain more than one solute

By carefully regulating the conditions of temperature and concentration it is possible to bring about the crystallization of the individual solutes in fairly pure crystals This is accomplished more easily when the desired substance is the most abundant material in solution In fractional crystallization the crystals formed at a specified temperature from a solution are of fairly well defined composition and can be separated into fractions that are of different composition from the crystals formed at other temperatures Because the first formed and last formed crystals of a particular fraction are the least pure it is seldom possible to obtain all of any particular solute from a solution containing several solutes If the originally formed crystals of a particular fraction are not of the desired state of purity they can be redissolved in a small amount of the same or a different solvent and recrystallized

By repeated steps of fractional crystallization dissolving and recrystallization it is possible to obtain crystalline substances of very high purity However the process is tedious and time consuming and quite inefficient in terms of the percentage of material recovered from complex mixtures

Methods The starting material is dissolved in the smallest possible amount of solvent preferably at elevated temperature and the solution is filtered to remove foreign matter Next the solution may be heated to evaporate some of the solvent After heating or after filtration if the solution has not been heated the solution is cooled to induce the formation of crystals After crystallization has proceeded to the desired extent the crop of crystals is filtered from the mother liquor and washed with fresh solvent to remove the adhering mother liquor which contains impurities The process conditions of temperature rate of cooling and concentration of solution determine the type of crystal formed for example needles fine crystals or plates

The solvent can be evaporated under lowered pressure to prevent decomposition of heat sensitive substances such as sugar Commercially used crystallizers sometimes are combined with classifiers to permit the separation of crystals of predetermined size The heat balance of an operation must be regulated to allow for evaporation heat of crystallization and removal of heat by solvent or crystals *See* UNIT OPERATIONS

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Crystallography

The branch of science that deals with the geometric description of crystals their internal arrangement and their properties Long a part of mineralogy crystallography is now a vast no man's land between physics chemistry physical metallurgy mineralogy and even biology

This article deals with the geometric description of crystals for other facets of crystallography *see* CRYSTAL STRUCTURE and the articles that are listed therein

Formal description of crystals The anisotropic nature of crystals results in a freely growing crys-

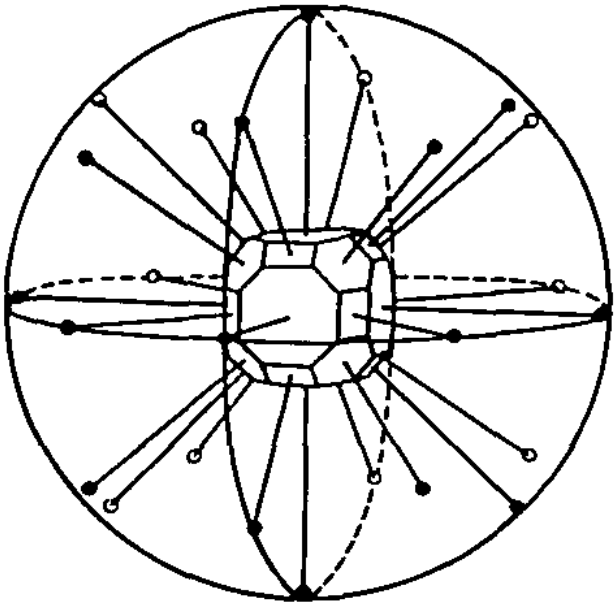


Fig 1 Replacement of the constellation of faces by a constellation of poles on a sphere Faces parallel to the same edge that is forming a zone have their poles on a great circle called the zone circle

tal bounded by flat faces The following discussion presents a formalism for describing crystals ex actly in terms of these faces

Faces which are parallel to the same edge are said to form a zone, the direction of the edge is the zone axis The number and relative importance of the faces bounding crystals of the same chemical compound can be very different The crystals are then said to have a different habit Faces and edges which are present as well as those which are geo metrically possible must therefore be taken into account, and in the following discussion the term face is extended to any plane determined by two edges An edge is, in the same sense, the intersec tion of two faces

N Steno found that the angle between similar faces is constant for different sized crystals of the same substance This means that a crystal grows by the parallel displacement of its faces Therefore, only the direction of a normal to a face is of importance As a consequence, the crystal is con sidered to be in the center of a sphere (Fig 1) The normals to its faces from the center cut the sphere in points or poles whose position can be fixed by two coordinates φ and ρ (Fig 2*a*) The constellation of faces is in this way replaced by a constellation of points on a sphere The zone axes are replaced by great circles or zone circles, they are the intersections of the sphere with planes pass ing through the center of the sphere, perpendicular to the zone axis In practice, φ and ρ values are obtained by "measuring" the crystal, two circle goniometers are used for the purpose All problems which can arise are connected with angles between faces and between zone axes, they can in principle be solved by spherical trigonometry once the φ and ρ values are known Graphical constructions are, however, most helpful and gnomonic and stereographic projections are used in such con structions These projections are shown in Fig 2 In stereographic projection circles are projected as circles, and the angles between them are not altered In gnomonic projection great circles are projected as straight lines

Crystal symmetry Symmetry is a basic property of crystals A crystal polyhedron (or better the constellation of the normals) can be brought into successive indistinguishable positions by nontrivial operations These are inversion rotation around an axis over a specific angle, reflection into a plane or combinations of these (Fig 3) It is however convenient to consider all operations as rotations and two types of axis can be considered (1) a rotation or symmetry axis involving a rotation over

spect to a point of the axis It is found that only multiplicities of 1 2, 3 4 and 6 occur This has a deeper meaning and is connected with the homo geneous filling of space It can be understood in tuitively by considering the two dimensional ex ample in Fig 4 An assembly of identical polygons can completely cover a surface only when the polygons possess one of the following symmetry elements 2 3 4 6 The symmetry axes are represented by their multiplicity, inversion axes are written $\bar{1}$ $\bar{2}$, $\bar{3}$, $\bar{4}$ $\bar{6}$ Axis $\bar{1}$ is in fact an inver sion center, $\bar{2}$ is equivalent to a mirror plane and is therefore written m Not all of the other inversion axes are specific symmetry elements that is, $\bar{3}$ is a combination of the operations 3 and $\bar{1}$ and $\bar{6}$ a combination of a threefold axis and a mirror plane perpendicular to it Finally the distinct sym metry elements are 1 2 3 4 6 $\bar{1}$ m $\bar{4}$

It can be proved that a symmetry axis, the per pendicular to a symmetry plane the plane perpen dicular to a symmetry axis and a symmetry plane are all possible edges or faces of the crystal

A crystal can exhibit a number of these sym metry elements all going through a common point A collection of symmetry elements applied about such a point is called a point group

Combinations of symmetry elements are ruled by the following theorems

1 When two out of the three elements $\bar{1}$ m 2 are present the third follows automatically

2 The intersection of two mirror planes forming an angle φ is a symmetry axis with multiplicity $n = 360/2\varphi$

3 When a mirror plane contains a symmetry axis of multiplicity n this axis is the intersection of n mirror planes forming angles of $360°/n$

4 When two twofold axes forming an angle φ intersect the perpendicular at the intersection point on the plane they determine is a symmetry axis with multiplicity $n = 360/2\varphi$

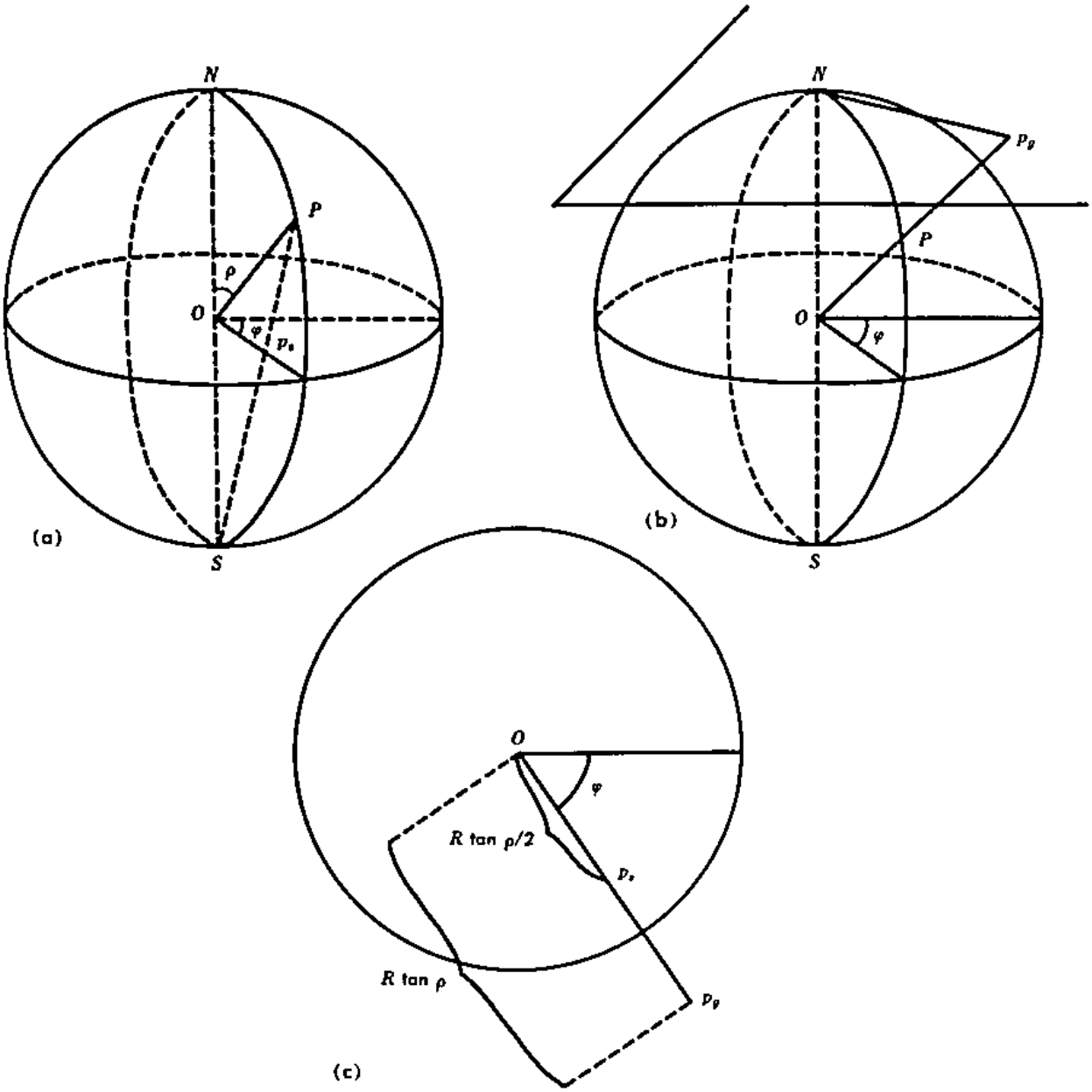


Fig 2 (a) Stereographic projection of P The line joining a pole P defined by φ and ρ to the south pole S cuts the equator at p_s (b) Gnomonic projection of P The line OP cuts the plane tangent to the sphere at N at a point p_g (c) Stereognomogram Both projection planes are superposed p_s and p_g are on a radius making an angle φ with the origin and at distances respectively equal to R tan $\rho/2$ and R tan ρ

5 Any crystal polyhedron containing more than two axes with a multiplicity higher than two must necessarily present the combination of symmetry axes present in a cube or in a tetrahedron

Taking these five theorems into account it can be shown that 32 combinations or point groups are possible These are conveniently represented by the Hermann Mauguin notation which provides the minimum information from which with the aid of the five theorems all the symmetry elements of a point group can be deduced The code is as follows if the axis of highest multiplicity is written first the succeeding directions are perpendicular to it and the succeeding planes are either perpendicular to it or pass through it A mirror plane perpendicular to an axis is written $3/m$ The diagonal is not present when the plane passes through the axis that is one writes $3m$ The notation $m3$ means that the threefold axis is neither in the plane m nor perpendicular to it A combination such as $3/mm$ represents a threefold axis three planes passing through it and one perpendicular to it The intersections of these mirror planes are twofold axes which are not written because they can be deduced

All crystals can accordingly be divided into 32 classes if the point group is used as a cri Examples belonging to each class are known

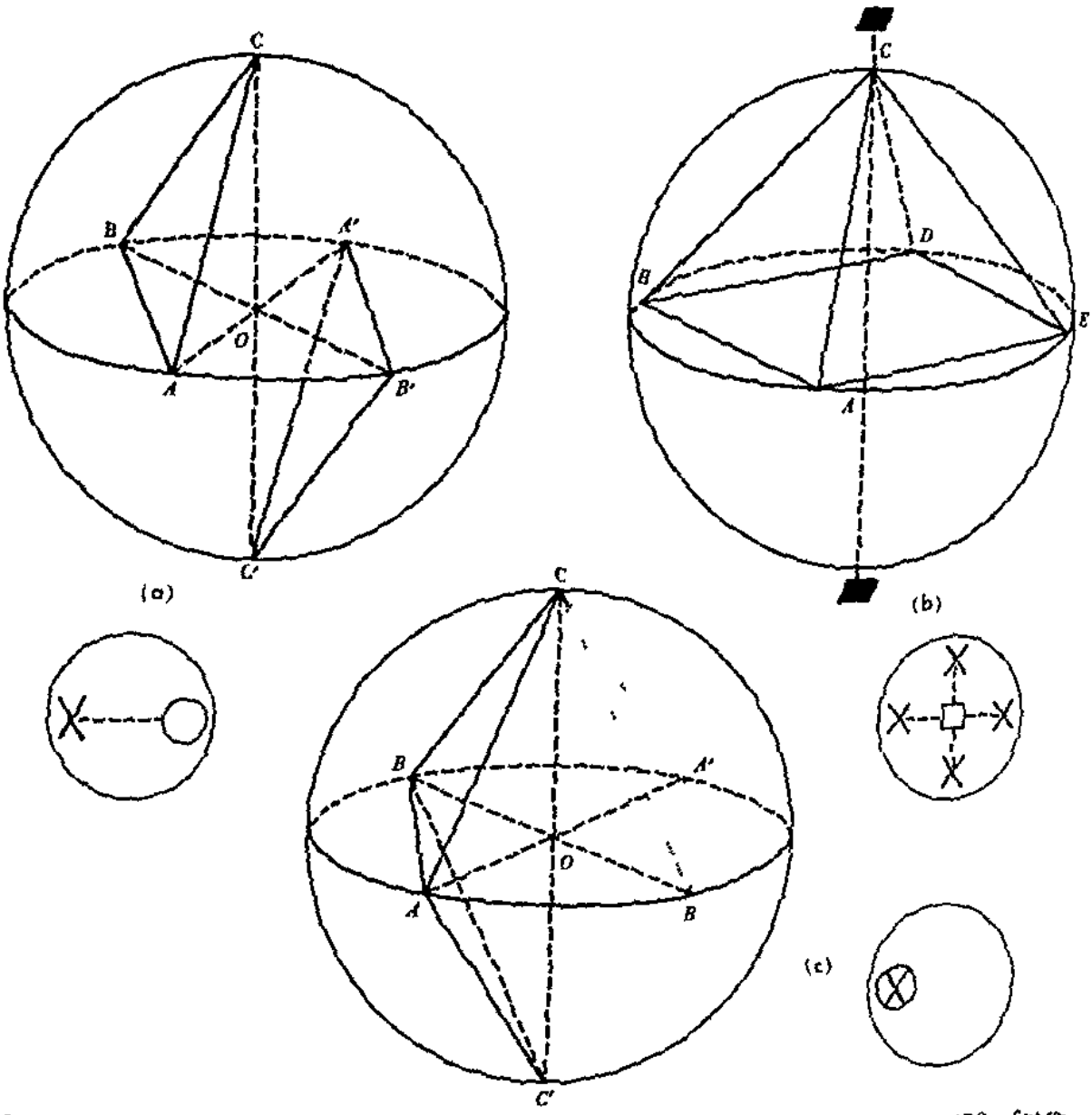


Fig 3 Elementary symmetry operations in space and in projection (a) O is in an inversion center The pole of ABC (X in the small diagram) is projected stereographically from C' that of $A'B'C'$ from C (O in the diagram) (b) Fourfold axis and stereographic projection of the four planes related by its symmetry operation (c) CC' is a twofold inversion axis ABC is first rotated over 180° into the intermediate position $CA'B'$ and by inversion to ABC' This operation $\bar{2}$ gives the same result as a reflection of ABC into the equatorial plane thus showing that $\bar{2} = m$

Crystal systems The seven groups obtained when only the dominant symmetry elements of the classes are taken into account are called crystal systems In order of decreasing symmetry they are called cubic, hexagonal tetragonal trigonal orthorhombic, monoclinic, and triclinic Sometimes the hexagonal and trigonal systems are considered as a single system The systems and classes are summarized in Table I in which the Hermann Mauguin notation is used The expression "a cubic crystal" means that the crystal belongs to the cubic system

Miller indices These are used for the analytical description of crystal faces, and are shown in

Fig 5 A specially well suited reference system used for that purpose consists of three nonparallel possible edges of the crystal which are chosen as axes and a possible plane of the crystal which intersects all three axes respectively at A B C It is defined by the three angles α β γ and the ratio OA OB OC Another plane HKL, of the same crystal is defined by the ratio OH OK OL The lengths OH, OK, OL are respectively measured with $OA = a$, $OB = b$, $OC = c$ as units that is by the ratios a/OH b/OK, c/OL A measurement is a comparison (ratio) between what must be measured and a unit The unit is generally written

Table 1 Crystal systems and classes

Cubic	Hexagonal	Tetragonal	Trigonal	Ortho-rhombic	Mono-clinic	Triclinic
23	6	4	3	2mm	2	1
(2/m)3̄	6̄	4̄	3̄	222		1̄
3̄3m	6/m	4/m	3m	(2/m)(2/m)(2/m)	m	
432	6mm	4mm	3(2/m)		2/m	
(4/m)3̄(2/m)	6m2	4̄2m	32			
	622	422				
	(6/m)(2/m)(2/m)	(4/m)(2/m)(2/m)				

as the denominator in such ratios, the reverse is done here for a special reason which will be explained later It is found that

$$(a/OH)/(b/OK)/(c/OL) = h/k/l$$

in which h, k, l are rational numbers which are small when the axes are well chosen (the law of rational indices) A different unit is used along each axis to take the anisotropy of the crystal into account When, for instance, the temperature is raised, a, b, and c expand differently, but the ratios a/OH, b/OK, c/OL remain constant The

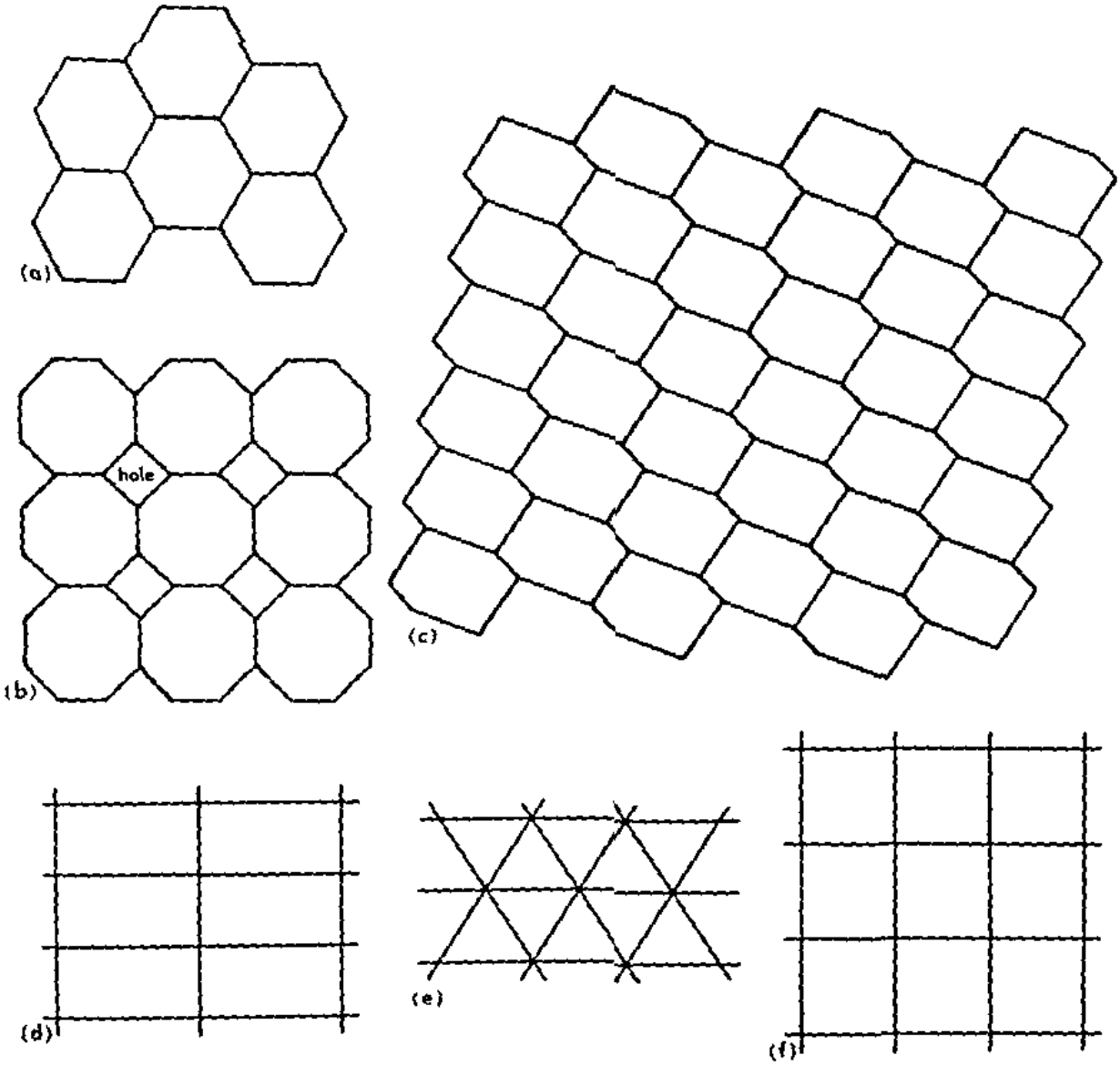


Fig 4 Examples of different mosaics The homogeneous filling of a surface with polygons is only possible when they have definite symmetry holes formed (b) when octagons are used Mosaics (a), (c), (d), (e), (f) fill space completely

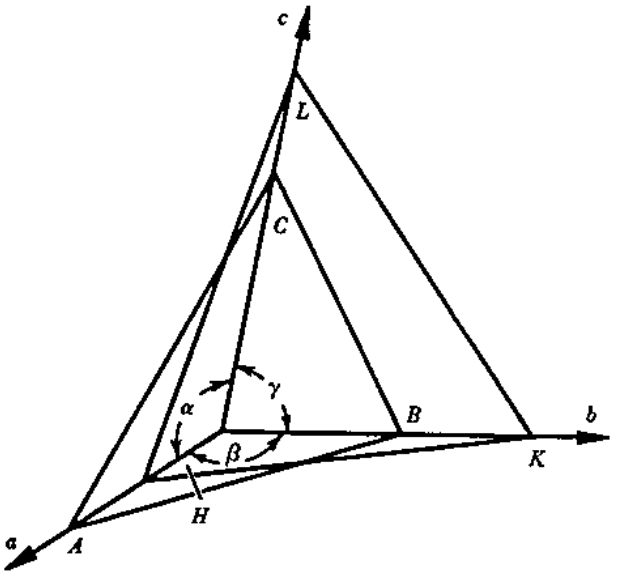


Fig 5 The reference system used to define Miller indices ABC is the unit plane

ratios $h\ k\ l$ define the plane HKL, h, k, l are called its Miller indices, and by convention this is written (hkl), or $(\bar{h}\bar{k}\bar{l})$ when the indices are negative numbers In geometrical crystallography, it is customary to precede the indices with a letter The letters a, b c are generally used for the axial planes, and the letter o is used for the plane ABC The indices of these planes are respectively $a(100)$, $b(010)$, $c(001)$, $o(111)$ The latter is therefore called unit plane A plane (hkl) cuts from the axis segments OH, OK, OL whose ratios are, following the definition, equal to $(a/h)/(b/k)/(c/l)$ The equation of the plane in cartesian coordinates therefore is

$$h\frac{x}{a}+k\frac{y}{b}+l\frac{z}{c}=d$$

The quantity d is a parameter, since the plane can be shifted parallel to itself The indices are respectively the coefficients in x/a y/b, z/c in the equation of the plane This is the special reason mentioned earlier

Zone indices Two planes $(h_1k_1l_1)$ and $(h_2k_2l_2)$ define an edge, the direction coefficients of which are determined by simultaneous solution of the two equations

$$h_1\,x/a+k_1\,y/b+l_1\,z/c=0$$
$$h_2\,x/a+k_2\,y/b+l_2\,z/c=0$$

The direction coefficients are given by

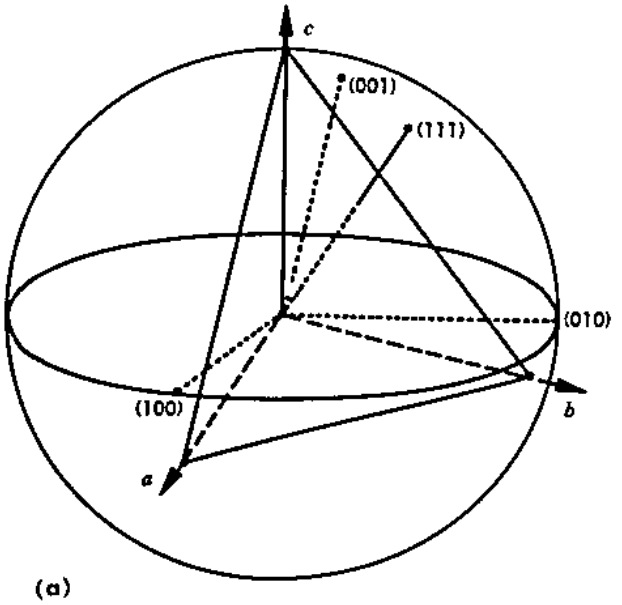
$$a\begin{vmatrix}k_1 & l_1\\ k_2 & l_2\end{vmatrix}\qquad b\begin{vmatrix}l_1 & h_1\\ l_2 & h_2\end{vmatrix}\qquad c\begin{vmatrix}h_1 & k_1\\ h_2 & k_2\end{vmatrix}$$

or ua, vb, wc, when the determinants are respectively denoted by u, v, w If a, b, c are taken as units along each of the axes, u v, w are the coordinates of a point The edge, or zone axis determined by the two planes has the direction of the line joining the origin to the point with crystallographic coordinates u, v, w, it is represented by $[uvw]$

pl
pr

longs to a zone $[uvw]$ is found by requiring that this plane be parallel to $[uvu]$, that is, that the plane passing through the origin must contain the point ua, vb, wc This gives $hu+kv+lw=0$

Choice of reference system It is useful to consider the stereographic and gnomonic projection of the reference system (Fig 6) The c axis is vertical that is, perpendicular to the projection plane The poles $a(100)$, $b(010)$, $c(001)$, $o(111)$



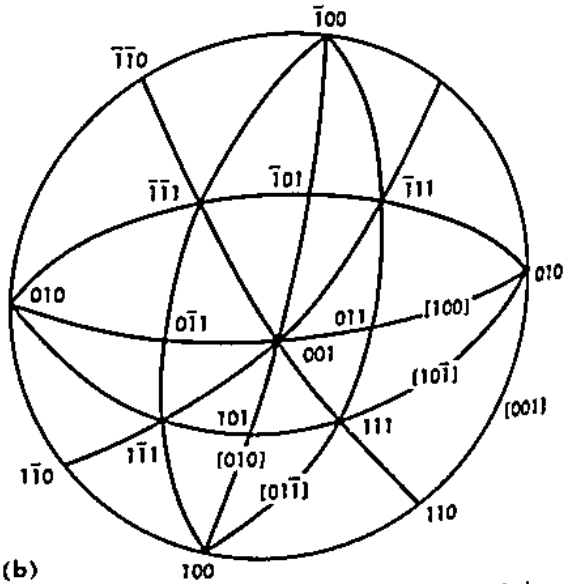


Fig 6 (*a*) Orientation of the reference system and poles of the axial and unit plane (*b*) Projection By the construction of great circles four quadrants of the type 001–010–100 are obtained

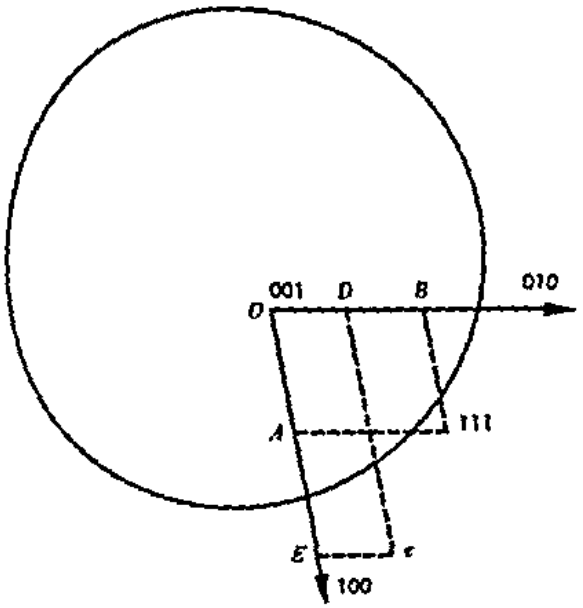


Fig 7 Gnomonic projection of reference system illustrating how indices can be graphically assigned to a plane *e*

define a number of zones and the representative circles are easily constructed Their indices, as well as those of the planes defined by their intersection are found by the rules quoted earlier In this way 26 planes having indices which are combinations of 0 1 and $\bar{1}$ are obtained The zone circles [100] [010] [001] divide the projection into four quadrants Each intersection of one of these with the reference circle as well as an interior point having indices formed by 1 or $\bar{1}$ is the intersection of three zone circles Such a pattern is referred to as the basic pattern in the discussion that follows The angles α β γ and the ratios a b c can be determined graphically

With the method of gnomonic projection (as in Fig 7) indices can be assigned to a plane such as *e* by the following construction Zones [100] and [010] are considered as axes of a coordinate system The coordinates of the gnomonic projection of the plane *e* are measured with the coordinates of (111) as units that is by the ratio OE/OA OD/OB It can be shown that provided the c axis is vertical the indices of this plane are (OE/OA OD/OB 1) or in the case under consideration (2 ¼ 1) or (4 1 2) This graphical construction only works for simple indices ⅓ can be easily distinguished from ¼ but not ⅓ and ⅛ In such cases the indices must be calculated but such small fractions are highly improbable provided the axes are well chosen This choosing of the axes is a major problem Symmetry elements and the related elements which are possible faces or edges are usually chosen as axis and unit plane as explained in the earlier discussion of crystal symmetry The axis of highest symmetry is chosen as the *c* axis and is oriented vertically except in the monoclinic system where *b* is usually the vertical axis Inspection of the symmetry elements of the different classes indicates plainly that it is only in the cubic system that enough symmetry elements are present to permit an unambiguous determination of the reference system that is three mutually perpendicular twofold axes and a plane perpendicular to a threefold axis as unit plane further inspection shows that mutually perpendicular axes can be chosen except in the monoclinic ($\beta \neq 90°$) and triclinic systems ($\alpha \neq \beta \neq \gamma \neq 90°$)

This means that two different observers describing the same noncubic crystal will probably choose a different reference system that is orient or set the crystal differently The same face of the crystal will consequently have different indices in the two settings Different procedures have been worked out to obtain uniformity The Barker method is the simplest and best known It consists of a number of convenient rules which allow two observers to come independently to an identical choice This is based on the consideration that the basic pattern considered earlier is the generalization of what exists in the cubic system The main idea is therefore to find in a stereographic projection a quadrant as in a basic pattern and to choose the corners and an inside intersection of three zones as elements of the reference system Rules are provided to distinguish between them that is to find out which pole will be denoted as *a* *b* *c* or *o* and what sense will be assigned to the axis At the same time one has also a maximum chance that a maximum number of planes will have simple indices It is clear that the number of rules grows as the indeterminacy becomes greater It is also clear that the rules have no physical meaning

Bravais indices These are frequently used in the hexagonal and trigonal systems because they reveal the symmetry more clearly than do other indices In this case the hexagonal (trigonal) axis is the *c* axis the other axes a_1 a_2 a_3 are perpendicular to it (Fig 8) and make angles of 120° with each other The four indices are denoted ($hkil$) but it is easy to prove that $h + k = \bar{i}$, therefore one may write ($hk.l$) Thus *i* is a redundant index but is used because of the additional clarity which it yields in this system The unit plane is ($1\bar{1}01$)

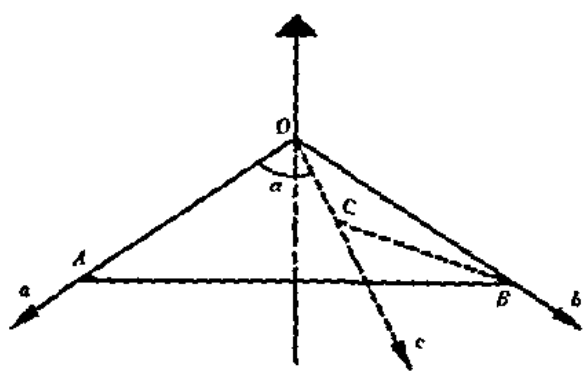


Fig 8 Bravais indices in hexagonal system

The zone axes are found by considering the first two and the last indices as usual and inserting the sum of the first two with an opposite sign for the third one As an example the planes (0001) and $(1\bar{1}01)$ define the zone $[11\bar{2}0]$ When Miller indices are used in the trigonal system the three axes are chosen equally inclined around the three fold axis and making an equal angle α between them (Fig 9) A plane normal to the symmetry axis is chosen as the (111) face The system is therefore defined by α a a a Bravais indices $(hkil)$ are easily transformed into Miller indices here denoted (pqr) by the following relations

$$p = 2h + i - l$$
$$q = -h + i + l$$
$$r = -h - 2i + l$$

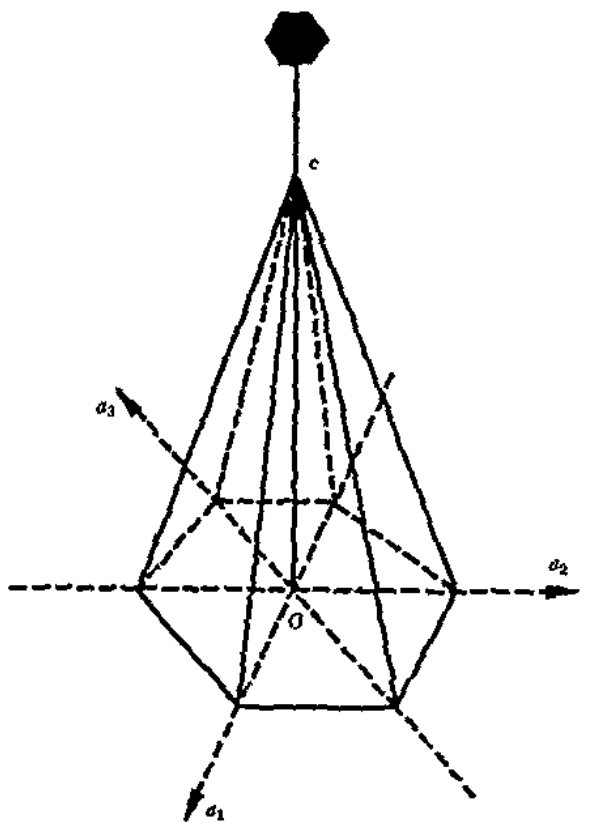


Fig 9 Miller indices in the trigonal system

The reference system used in the seven crystal systems is shown in Table 2

Table 2 Crystallographic reference systems

Crystal system	Angles formed by crystal axes	Defining ratio
Cubic	$\alpha = \beta = \gamma = 90°$	a a a
Hexagonal	$\alpha = \beta = 90°$ $\gamma = 120°$	a a c
Tetragonal	$\alpha = \beta = \gamma = 90°$	a a c
Trigonal	$\alpha = \beta = 90°$ $\gamma = 120°$	a a c
	$\alpha = \beta = \gamma \neq 90°$	a a a
Orthorhombic	$\alpha = \beta = \gamma = 90°$	a b c
Monoclinic	$\alpha = \gamma = 90°$ $\beta \neq 90°$	a b c
Triclinic	$\alpha \neq \beta \neq \gamma \neq 90°$	a b c

Crystal form The set of planes obtained by submitting a plane (hkl) to the symmetry operations of a point group is called a crystal form All these planes together are written as $\{hkl\}$ they all have indices which are cyclic permutations of h k l $\bar{h}$ $\bar{k}$ $\bar{l}$ The plane (hkl) can occupy a general or special position with respect to the symmetry elements accordingly one obtains a general or special form

A crystal polyhedron can be described by using zone axes $[uvw]$ the group obtained is written $\langle uvw \rangle$

Practical crystal description In practice a crystal description is made as follows The crystal is measured that is the φ and ρ values of the faces are determined and are plotted in a stereognomogram Zone circles are drawn and the intersections give possible faces The Barker rules are applied to find the reference systems The indices are found graphically as are all other needed elements Some of them are calculated afterward if more accuracy is wanted A crystal drawing deduced from the projection is also made A complete description of the crystals measured so far is to be found in the book by P Groth listed in the bibliography These have been revised and completed in the Barker index [W O]

1919 F M Jaeger *Le principe de la symétrie* 1925 F C Phillips *Introduction to Crystallography* 2d ed 1956 M W Porter and R C Spiller *The Barker Index of Crystals* vol 1 1951 vol 2 1957 R W G Wyckoff *Crystal Structures* 1948

Ctenophora

A phylum of exclusively marine organisms This group of jellyfish commonly referred to as the comb jellies are characterized by having eight rows of comblike plates as the main locomotory structure Most of these animals are pelagic and exceptionally sedentary The body is gelatinous and extremely fragile The body form may be globular pyriform bell or helmet shaped Some species resemble a ribbon All are biradially symmetrical Many are transparent and colorless others are faintly to brightly colored These organisms are hermaphroditic and the gonads are of endodermal origin There is no vestige of a polypoid stage Two classes and five orders constitute this phylum as follows

Phylum Ctenophora
- Class Tentaculata
  - Order Cydippida
  - Order Lobata
  - Order Cestida
  - Order Platyctenea
- Class Nuda
  - Order Beroida

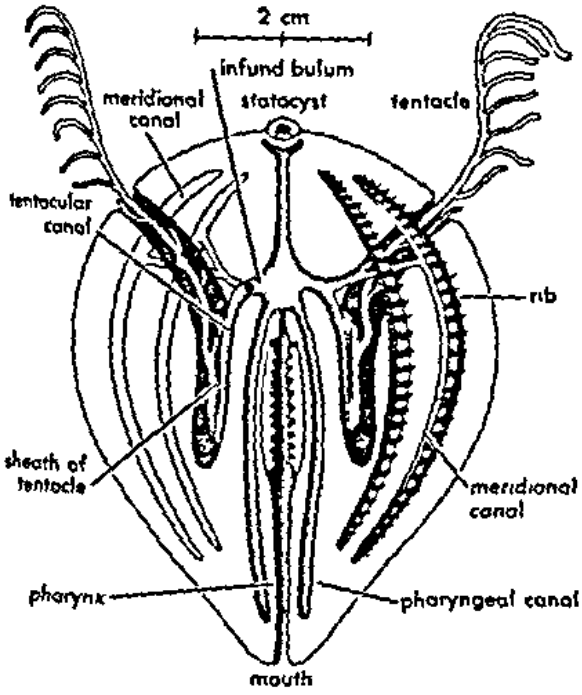


Fig 1 Plan of structure of a cydippid ctenophore

Morphology The mouth opening is at one pole of the main axis of the body while the statocyst an organ of equilibrium is located at the other pole The mouth leads into the flattened elongate pharynx The sagittal plane is thus referred to as the pharyngeal plane of symmetry The other plane of symmetry is perpendicular to the pharyngeal plane and is marked by tentacles This is known as the tentacular or transverse plane Eight comb-plate rows or ribs are arranged meridionally on the surface of the body

Gastrovascular system The pharynx is connected aborally with a small chamber the stomach (infundibulum) which is the source of the entire canal system The system follows a plan common to all the ctenophores (Fig 1) The most important of the peripheral canals are the meridional canals which underlie the ribs the tentacular canals which go to the base of the tentacles and the pharyngeal canals which run along the pharynx The canal system is lined with endodermal cells except for the pharynx which has an ectodermal lining

Tentacles With the exception of members of the order Beroida all ctenophores have two tentacles situated at the opposite ends of the tentacular axis The tentacle is a highly extensile organ composed mainly of a bundle of longitudinal muscle fibers It has a typical plume like structure with many lateral branches These branches are thickly covered with adhesive cells (colloblasts) which are very characteristic of the phylum Each colloblast (Fig 2) consists of a bell shaped main structure and two cords attached to its concave surface The convex side of the bell is covered with sticky granules One of the cords is thick and spirally twisted, the other is thin and forms the core of the spiral of the other cord Colloblasts are probably the counterpart of the nematocysts which occur in all classes of coelenterates The base of the tentacle is anchored on the bottom of a sheath formed by a deep depression of the body surface into which the tentacle may be completely retracted The formative tissue of the tentacle is located at the bottom of the sheath Tentacles are used as balancing organs when the ctenophores are floating in water In the adult stages of the orders Lobata and Cestidea the primary tentacles as described above are reduced and replaced by 'secondary tentacles These latter are a series of short tentacles arranged on the margin of the mouth

Comb plates These are the most characteristic structures of the ctenophores possessed by all members of the phylum Each plate consists of a transverse row of stiff cilia The plates are arranged meridionally and extend from the vicinity of the statocyst to points close to the mouth The consecutive plates in the ribs are united and extend to the statocyst as a thin ciliary tract Of the eight ribs four are subpharyngeal and occur on both sides of the pharynx The remaining four are the subtentacular ribs and occur on both sides of the tentacles These ribs are secondarily modified in some specialized ctenophores and may be entirely absent in the adult stages of some Platyctenea

Statocyst The statocyst (Fig 3) in the ctenophores represents the best differentiated example of this type of structure in the Radiata It is a cyst containing a centrally located statolith of a composite nature The wall is formed by ciliated columnar cells interspersed with some secretory cells which are involved in the formation of the component granules of the statolith The statolith is supported on four stiff S-shaped bristles the balancers located on the interradial planes Two ciliary tracts lead from the base of each balancer to the pair of ribs in the same quadrant Fused cilia form a dome-shaped cover for the statocyst Another organ of unknown function but presumably sensory lies close to the statocyst It is a paired structure called the polar fields and consists of linear or crescentric ciliated areas situated in the pharyngeal plane

Gonads All ctenophores are hermaphroditic The gonads develop in the endodermal wall on the outer side of either the meridional canals or their branches Both the ovaries and spermaries generally develop as continuous tracts of germ cells The ovaries develop on the perradial and the spermaries on the interradial side of the wall

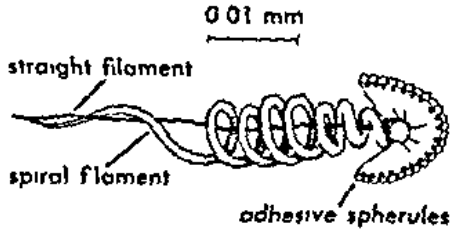


Fig 2 Colloblast

Embryology. The mature germ cells drop into the canal and are moved to the exterior by the action of the cilia lining the wall Fertilization usually occurs in sea water The development of ctenophores proceeds according to a biradially symmetrical scheme Ctenophores furnish the only examples of biradial cleavage (Fig 4) The blastomeres are arranged biradially with respect to the two main planes of symmetry, which correspond to those in the adult animal Gastrulation is epibolic, since the macromeres are gradually covered by the multiplication of the micromeres The youngest larva formed in the development of all types of ctenophores is the cydippid This larva is characterized by having a globular body, a pair of primary tentacles, and eight ribs In members of the orders Lobata, Cestidea and Platyctenea, the larva undergoes secondary changes in its development

Physiology and ecology. As the Ctenophora are marine organisms, their physiology is influenced by that habitat

Locomotion The comb plates are the principal organs of locomotion The beating of the combs in all the ribs is controlled by nerve impulses traveling from the statocyst through the ciliary tracts to the ribs Muscular contractions are also involved in locomotion and in catching prey

Digestion The food of ctenophores is exclusively plankton The tentacles entangle the planktonic organisms which are then swallowed Digestive activity occurs first in the pharyngeal cavity where the gland cells secrete a digestive fluid These cells are abundant in the folds of the pharyngeal wall The partially digested material is then carried by water currents throughout the canal system Here the particles are ingested by phagocytic cells which lie among the endodermal cells lining the canal walls

Sensory and nervous functions The statocyst is probably the center of sensory and nervous functions It is primarily an organ of equilibrium The polar fields have been assumed to have an olfactory function and appear to be chemoreceptors, susceptible to changes in the chemical composition of the surrounding water Ctenophores possess a diffuse system of nerve cells and fibers similar to those of the coelenterates and are extremely sensitive to movements of the water When the sea is calm and the weather is good, they are found near the surface A slight breeze, stirring the surface water, causes them to disappear Almost all ctenophores

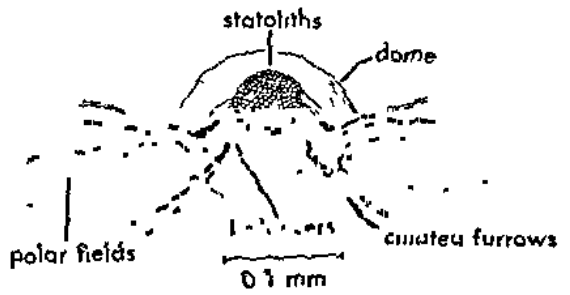


Fig 3 Statocyst

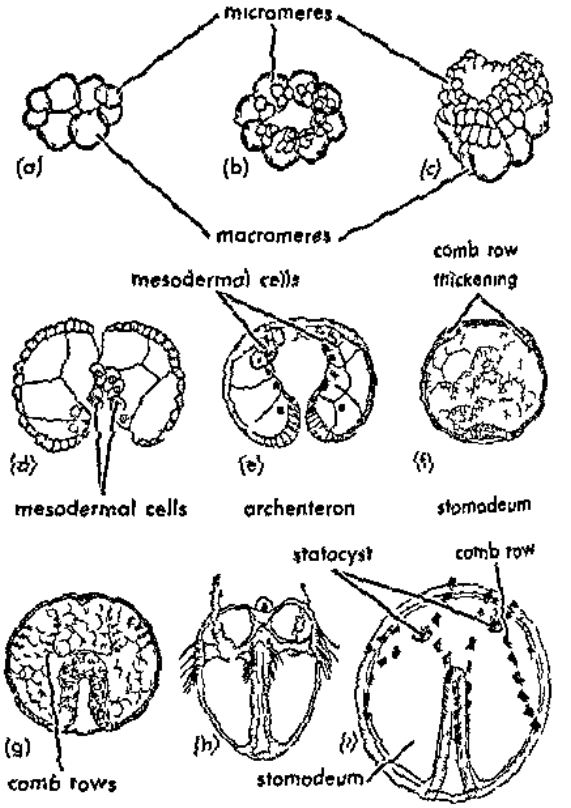


Fig 4 Embryology of ctenophores (a) Eight cell stage (b) Micromeres, viewed from above (c) Later stage in division of micromeres (d) Gastrula section (e) Invagination (f) Stomodeum and thickenings for comb rows (g) Stomodeum invaginated comb rows differentiated (h) Cydippid larva (i) Embryo with statocysts and comb rows

this phenomenon

Ecology These animals are important plankton organisms They are quite common and have a world wide distribution in all seas Ctenophores often appear in such enormous numbers that a large area of water may be completely covered by them

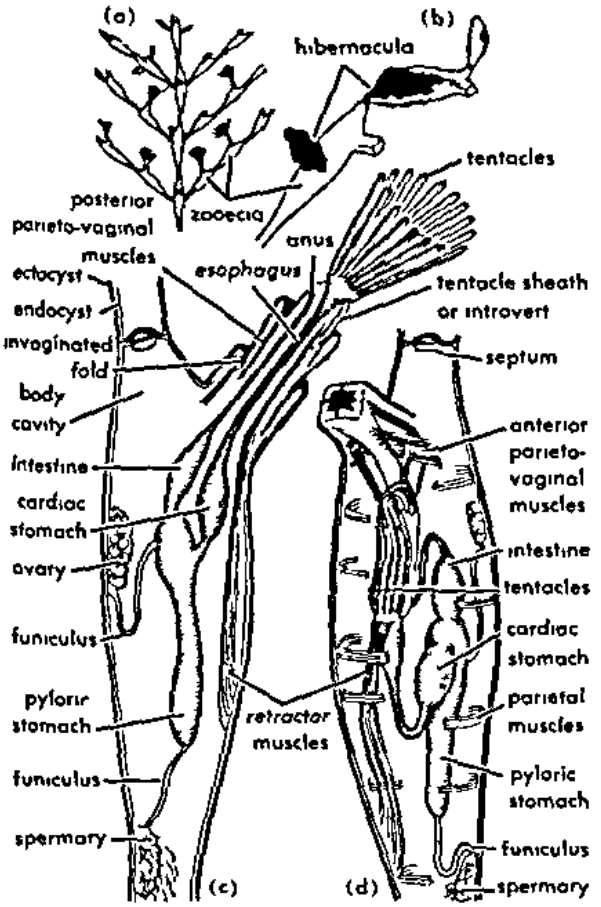
Phylogeny. The Ctenophora constitute a specialized and well defined group of organisms
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have evolved in [illegible]
The ancestor of this group is possibly to be found among the Trachylina in the Hydrozoa On the other hand ctenophores have often been suspected of having an affinity with the Bilateria, especially the polyclad Turbellaria The presence of such forms as *Coeloplana* among the Platyctenea strengthens this view Many zoologists consider the Ctenophora to be a class of the Coelenterata *See* ANIMAL KINGDOM, BILATERIA, POLYCLADIDA, [TK] TRACHYLINA

Bibliography: C Chun, *Die Ctenophoren des Golfes von Neapel*, Fauna und Flora des Golfes von Neapel I, 1880, L H Hyman *The Interte*

brates, vol 1, 1940; A G Mayer, *Ctenophores of the Atlantic Coast of North America*, Carnegie Institution of Washington Publication 162, 1912

Ctenostomata

An order of gymnolaematous Bryozoa, having 16 families and 43 genera (R Bassler) Fossil records are rare but some date to Ordovician strata Recent species are mostly marine, soft textured, and not calcified Colonies may be erect, incrusting, stolon



Paludicella articulata, a ctenostomatous bryozoan (a) Growth habit of colony Several zooids with tentacles extended (b) Two hibernacula on an old zooid A new zooid has sprouted from the upper right hibernaculum (c) Detail of zooid whose tentacles are evaginated (d) Detail of zooid whose tentacles are retracted into the body cavity

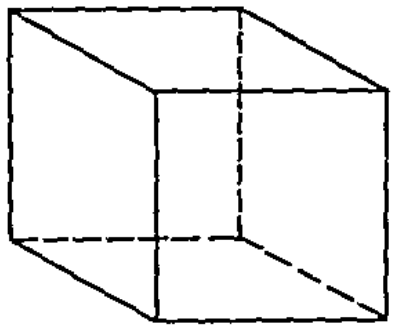
ate, or burrowing The slender, tubular, chitinized, or membranous zooids are mostly isolated Their walls are not commonly shared with neighboring zooids, except in genera like *Alcyonidium* Zooids generally sprout from slender tubular stolons The aperture is terminal and closed by a flexible, reinforced fold of the body wall or tentacular sheath Ovicells and avicularia are absent

The cosmopolitan fresh water *Paludicella* produces special germinative bodies, the hibernacula *See* BRYOZOA, BRYOZOA FOSSILS, GYMNOLAEMATA

[M D RO]

Cube

A parallelepiped whose 6 faces are all squares (*see* PARALLELEPIPED) The cube is one of the 5 regular solids known to the ancient Greeks, who proposed the famous problem (now proved to be unsolvable) of constructing, with the use of the compass and unmarked straightedge alone, a cube



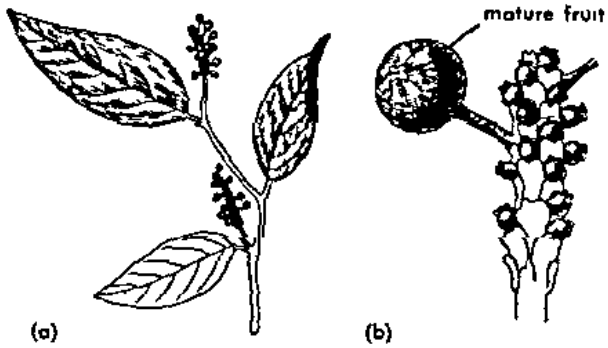
Cube

whose volume is twice that of a given cube The edge of the desired cube may be found by use of conic sections (*see* PARABOLA) Besides its 6 faces, a cube has 8 vertices and 12 edges Each vertex is on 3 edges and 3 faces each edge is on 2 vertices and 2 faces and each plane is on 4 vertices and 4 edges *See* POLYHEDRON, POLYTOPES, REGULAR

[L M BL]

Cubeb

The dried, nearly ripe fruit (berries) of a climbing vine *Piper cubeba*, of the pepper family (Piperaceae) This species is native to Eastern India and



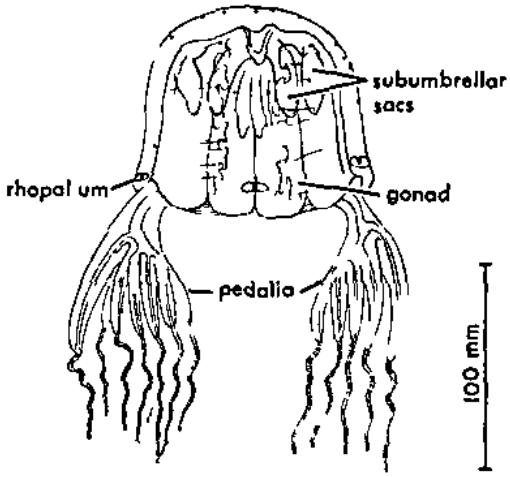
(a) Cubeb (*Piper cubeba*) (*from T L Brunton, A Text book of Pharmacology, Therapeutics and Materia Medica Lea Bros, 1885*) (b) Spike showing a mature fruit with long pedicel (*after Meyer from E P Claus, ed, Gathercoal and Wirth Pharmacognosy, 3d ed, Lea and Febiger, 1956*)

Indomalaysia The crushed berries are smoked, and the inhaled smoke produces a soothing effect in certain respiratory ailments Cubebs are used in medicine as a stimulant, expectorant, and diuretic Medicinal properties of cubeb are due to the presence of a volatile oil which formerly was thought to stimulate healing of mucous membranes *See* PIPERALES

[P

Cubomedusae

An order of the class Scyphozoa The genus *Charybdea* is typical Cubomedusae are good swimmers and their distribution is mostly tropical The umbrella is cubic and a pedalium a gelatinous leaf shaped body is present at the base of each ridge of the exumbrella A well developed tentacle or a cluster of tentacles arises from each pedalium The sensory organs are on the perradii They are the most highly developed in the Coelenterata



Cubomedusae *Chiropsalmus quadrumanus* (L Hyman *The Invertebrates vol 1 McGraw Hill 1940*)

each one having six ocelli and a statocyst The manubrium a peduncle connecting the mouth with the stomach has four lips The cubic stomach connects with four radial pockets and between these pockets are the interradial septa The leaf shaped gonads develop from the septa and extend into the pockets No connecting stage between polyp and medusa is known *See* SCYPHOZOA

[T U]

Cuckoo

Any of several species of birds belonging to the cosmopolitan family Cuculidae This family also includes the road runners and anis

Many Old World cuckoos are parasitic and lay their eggs in the nests of other birds however the three species found in the United States rear their own young American cowbirds (Icteridae) also lay their eggs in the nests of other birds The mangrove cuckoo *Coccyzus minor* is a tropical species which occurs in southern Florida The yellow billed cuckoo *C americanus* and the black billed cuckoo *C erythrophthalmus* are slender long tailed brown birds that nest in the United States and Canada The black billed cuckoo is found mainly in the eastern deciduous forest whereas the yellow billed species occurs throughout most of the United States and southern Canada They are often called rain crows Cuckoos are useful insectivorous birds their favorite food is the tent caterpillar *See* CUCULIFORMES ROAD RUNNER [J D B]

Cuculiformes

The order of birds containing the cuckoos family Cuculidae The turacos (Musophagidae) are conventionally placed here also but this African family is of uncertain affinities and is possibly related to the Galliformes Turacos share several anatomical features with cuckoos notably the zygodactyl arrangement of the toes two in front and two behind Cuckoos are virtually cosmopolitan but are concentrated in warmer regions Most are arboreal but terrestrial forms typified by the road runner (*Geococcyx*) have evolved independently in several areas The European cuckoo (*Cuculus canorus*) inspiration for the cuckoo clock is typical of a large group of parasitic species whose young are raised by foster parents usually of smaller species Several groups of cuckoos are nonparasitic including the coucals (*Centropus*) of the Old World tropics *See* AVES [K C P]

Cucumber

A warm season annual cucurbit (*Cucumis sativus*) native to India and belonging to the plant order Campanulales The cucumber is grown for its immature fleshy fruit which is used primarily for pickling and for slicing as a salad Cultural practices for cucumbers are similar to those used for squash Important varieties are Marketer for slicing and Wisconsin SMR 12 and Model for pickling Greenhouse production generally with parthenocarpic varieties is common in northern Europe The plant is monoecious and is pollinated by insects Harvesting generally begins 60–70 days after planting Important cucumber producing states are Florida and North Carolina for fresh market and Michigan and Wisconsin for pickling The total annual farm value in the United States is approximately $35 000 000 *See* CAMPANULALES SQUASH VEGETABLE GROWING [H J C]

Cucumber diseases Diseases of cucumbers reduce plant growth fruit yield and product quality



Fig 1 Angular leaf spot disease of cucumber caused by the bacterium *Pseudomonas lachrymans* (a) leaf symptoms (b) fruit symptoms (*Photographs courtesy of J C Walker*)



Fig 2 Downy mildew of cucumber leaf showing yellow angular blotches induced by *Pseudoperonospora cubensis* (Photograph courtesy of D E Ellis)

in both field and greenhouse plantings Because cucumbers are grown all months of the year, it is necessary to guard against seeding in unfavorable environments and to control seed decay and seedling blight

Bacterial diseases Bacterial wilt is a serious disease in the midwestern, north central, and northeastern regions of the United States, but it is not important in the South or West Plants infected with the causal bacterium *Erwinia tracheiphila* first show a wilting of a single leaf which remains green but later all the leaves wilt and the plant dies A white, stringy, viscid bacterial ooze shows in freshly cut wilting stems Bacteria infested spotted and striped cucumber beetles infect the plant while feeding upon it The bacteria multiply in the plant and become distributed throughout the vascular system The bacteria overwinter in the body of the insect Because the only way in which the plants can become infected is through the feeding of the cucumber beetles, control depends upon early and prompt destruction of these pests by insecticides

Angular leaf spot, incited by the bacterium *Pseudomonas lachrymans*, causes water soaked spots on leaves and bordered circular lesions on fruits The lesions later develop into a brown firm rot extending into the flesh (Fig 1) The causal bacterium overwinters on infected vine refuse, is seed borne and is spread by rain and surface water Control consists of using California produced seed which is low in infection, soaking it for 5 min in a mercuric chloride solution (1 part in 1000 parts of water) rinsing the seed in water, and planting it promptly

Fungus diseases Downy mildew is a destructive disease in the eastern and southern states where the weather is warm and moist is less damaging in the north central states, and rarely occurs in the Southwest It is incited by the leaf inhabiting fungus *Pseudoperonospora cubensis*, which causes angular yellowish spots, the spots later turn brown when the leaves shrivel (Fig 2) The loss of foliage interferes with normal flower set and fruit development Maturing fruits fail to color properly, are tasteless, and are usually sunburned Planting of resistant varieties such as Ashley, Palmetto, Palomar, Santee and Stono, and treating plants with copper fungicides will provide maximum protection from downy mildew

Scab is a serious disease in the northern and northeastern states especially during cool moist weather The causal fungus, *Cladosporium cucumerinum* produces small, circular, halo bordered, water soaked lesions on leaves and stems The greatest damage is to the fruit and appears as sunken dark brown spots on immature fruit and as rough corky lesions on fruit that is mature Control is achieved by planting resistant varieties, such as the slicing variety Highmoor or the pickling varieties Wisconsin SR 6 and SMR 12

Virus diseases The cucumber mosaic virus causes mottling of terminal leaves and dwarfing of vines as well as mottling and varying malformations of the fruits The virus is harbored in a number of perennial hosts and is spread by aphids The best means of control is provided by planting of resistant varieties, such as the slicing varieties Burpee Hybrid Niagara, Ohio MR 200, Sensation Hybrid, Shamrock, and Surecrop Hybrid, and pickling varieties Ohio MR 17, Ohio MR 25, Wisconsin SMR 12, and Yorkstate *See* APHID, HEMIPTERA, PLANT DISEASE PLANT VIRUS

[J T M]

Culture

A growth of cultivated cells or microorganisms under controlled conditions is referred to as a culture and is either a bacterial or a tissue culture Cultures are prepared to isolate or to study a single species of microorganisms, observing biologic characteristics either for basic or for applied purposes Cultures of mammalian cells, such as kidney, epithelial, and others, are prepared most frequently to serve as a culture medium for viruses which otherwise will not survive and multiply Cultures of only one species of microorganisms are called pure cultures, otherwise cultures are called mixed or contaminated Cultures are usually prepared in test tubes or small flasks containing the culture medium, which is a broth or gelatinous mixture usually composed of water, salts, and proteins or amino acids *See* CULTURE TECHNIQUE, MICROBIOLOGICAL METHODS

[M S M]

Culture, elective

No single culture medium or environment will support growth of more than a small proportion of the known types of microorganisms Each organism has characteristic nutritional and environmental requirements Thus in a culture composed of more than one type of organism the medium and conditions are selective for only one type of organism present and the other types are suppressed These selective, or elective culture principles and techniques are invaluable for the detection and isolation of specified organisms from natural sources Elective culture techniques are more effective for obtaining bacteria from natural sources than for obtaining fungi actinomycetes and other groups the faster growth rates larger numbers and greater variety of bacteria usually confer a competitive advantage upon them In general elective culture procedures are applicable to organisms capable of utilizing particular sources of energy carbon nitrogen and other nutrients in a given physicochemical environment There is no principle whereby elective cultures may be employed to obtain selectively organisms capable of producing particular compounds Basically two procedures are available direct isolation and liquid enrichment

Direct isolation This requires a solid medium usually agar in petri plates The surface is lightly sprinkled with finely divided particles of soil or other inoculum material Only organisms favored by that medium and those conditions will produce colonies of appreciable size these may then be purified Laterally thousands of other kinds of bacteria fail to develop although they might develop in other selective media Thus the direct isolation technique is a means of selecting certain minority members from natural mixed microbial populations Since most of the colonies on a solid medium develop independently and are physically separate competition rarely is a factor determining the emergence of the various colonies Although certain fast growing and characteristically spreading colonies may tend to overgrow neighboring colonies the chief advantage of the procedure is that slow growing bacteria have a chance to reveal themselves This technique is therefore the best for obtaining the largest variety of bacteria capable of developing on a given medium Colonies from a natural inoculum appearing under any one environmental condition are a small representation of a wider spectrum of bacteria capable of developing. For example two sets of plates incubated respectively in the presence and absence of oxygen will yield different organisms as will plates adjusted to different hydrogen ion concentrations (pH) and plates incubated at various temperatures

Elective media containing common organic compounds such as carbohydrates or amino acids will yield large numbers of different organisms Similarly most such organisms are capable of utilizing a number of different but related compounds However certain substrates and conditions are highly specific for a few organisms or even for a single kind of organism Occasionally growth of a colony occurs at the expense of degradation or biosynthetic products or accessory growth factors which are liberated from one or more adjacent colonies and diffuse into the medium

Although the direct isolation method does not permit preferential development of colonies capable of forming specific products such colonies as may be desired may be detected among those on an agar plate Thus acid producers may be detected by the flushing with a zone of color change of an indicator in the medium or dissolution of powdered calcium carbonate suspended in the medium Clear zones result from the destruction of other insoluble substrates, such as starch proteins and lipids by colonies producing the corresponding enzymes Other metabolic products may be detected by flooding or spraying colony containing plates with chemical or biological reagents giving a distinctive reaction with the desired product

The specificity can be enhanced by incorporation of substances that selectively inhibit growth of certain kinds of organisms especially of those in the majority For example in a medium adjusted to pH 4.0–4.5 most bacteria and actinomycetes are inhibited and thus filamentous fungi and yeasts may be selectively obtained Other chemicals are used to inhibit undesirable organisms in specimens of body fluids thereby facilitating isolation of the pathogenic bacteria in the minority

Liquid enrichment cultures A small amount of soil or other natural material is added to a prescribed fluid medium which then is incubated After appreciable growth of bacteria occurs a drop of the culture is used to inoculate a second flask of the same medium Organisms originally represented by small minorities are thus preferentially selected by the medium and the conditions and by the time turbidity develops in the secondary culture they represent practically the majority populations The chief disadvantage of this procedure is that only a small proportion of all the bacterial types potentially capable of developing in a given medium will be found Potentially competent organisms are in direct competition and the specific conditions usually select a relatively few of the fastest growers Liquid enrichment cultures also contain organisms unable to attack the original substrate these scavenge products of degradation and biosynthesis as well as living and dead cells of the primary organisms

Culture, embryonated egg

Embryonated eggs are among the most useful and available forms of living animal tissue for the isolation and identification of animal viruses, for titrating viruses and for quantity cultivation in the production of viral vaccines The embryo proper the chorioallantoic membrane yolk sac allantoic sac or amniotic sac may be inoculated in hen's eggs of various ages so that a wide choice of types of tissue

is available to fit the characteristics of the virus under study or for special studies The chorioallantoic membrane is frequently used in some infections such as smallpox vaccinia and herpes simplex characteristic lesions are produced which in some cases may resemble those in the natural host For example *smallpox virus when cultured* on the chorioallantoic membrane produces pocks *and typical inclusions within the infected cells* When the embryo is inoculated characteristic skin eruptions appear Influenza virus however when inoculated into the amniotic cavity does not give rise to pathology like that of the natural infection *See* HERPES SIMPLEX INFLUENZA SMALLPOX

The growth of influenza virus in the allantoic cavity of embryonated egg is probably the best known use of eggs for animal virus culture After *inoculation into the allantoic cavity the number of* virus particles decreases exponentially with almost 50% *adsorbed to cells within an hour* After adsorption the virus particles disappear (presumably by penetration of the cells) and an eclipse period of about 4 hours follows Evidence of viral multiplication first appears in the middle of the eclipse period when soluble complement fixing antigen (noninfective and nonhemagglutinating) is detectable Hemagglutinating antigens can be found 3–4 hours following inoculation but in no greater amount than *in the original* inoculum increases in hemagglutinating activity are seen only after 4 *hours or more Infective virus is detectable* 5–6 hours after the allantoic cavity was inoculated it is *released almost at once into the allantoic fluid* Infective virus particles thus released then infect other cells of the allantoic sac and virus continues to accumulate in the allantoic fluid for about 48 hours after which the system is exhausted *See* ANIMAL VIRUS ANTIGEN, COMPLEMENT FIXATION TEST [J L M]

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Culture, media components of

Combinations of nutrients used for the growth of microorganisms and plant and animal tissues Water is the chief constituent of most media A medium may consist of natural materials such as enzymatic digests or extracts of yeast or beef Milk potato slices and chick embryos are other common *examples Artificial media are prepared by mixing* various ingredients according to particular formulas A complex *medium contains at least one crude* ingredient derived from a natural material hence of unknown *chemical composition A chemically* defined or synthetic medium is one in which the chemical structure and amount of *each component* is known All media furnish minerals sources of nitrogen carbon and energy and sometimes vitamins or other growth factors An ingredient furnishing carbon—usually the chief *source*—is called the substrate for the utilizing organism

Selective medium Usually this medium contains an individual organic compound as the sole source of carbon nitrogen or sulfur for growth of an organism *The organism* oxidizes the carbon compound thereby obtaining energy for vital processes Strictly inorganic media are utilized by some bacteria the chemoautotrophs They obtain carbon exclusively from carbon dioxide and energy from the oxidation of ammonia, nitrate hydrogen gas, or reduced inorganic sulfur compounds Algae and *a few bacterial types are photoautotrophs securing* their energy from light

An agar medium of a given composition permits selection through development of colonies of organisms capable of utilizing the specific sources of carbon energy nitrogen or sulfur available A colony on such a medium is prima facie evidence that such organisms have been selected but this must be confirmed by restreaking (subculturing on agar medium) on a medium of the same composition

Enrichment media These are *liquid media of a* given composition which permit preferential emergence of *certain organisms that initially may have* comprised a relatively minute proportion of a mixed inoculum This enrichment of the population in the desired type expedites isolation by direct plating on the corresponding selective solid medium Owing to numerous subtle competitive forces enrichment cultures yield only a relatively small proportion that is, the fastest growers of all the organisms potentially capable of developing in *a given enrichment medium*

Indicator media These media usually solid *contain substances capable of undergoing a color* change in the vicinity of the colony which has effected a *particular chemical change such as fer*menting a certain sugar Thus organisms with distinctive types of metabolism may *be readily de*tected by the color change in the medium even when the surface of the medium contains many other colonies Indicators may be used in liquid media to characterize a pure culture of organisms. *See* CULTURE ELECTIVE MICROBIOLOGICAL METHODS [J W F]

Culture, pure

A culture that contains cells of one kind all progeny of a single cell The concept of a pure culture is an important one in microbiology because most considerations of microorganisms require dealing *with only one kind of a cell at a time Many tech*niques have been evolved for the isolation and *maintenance of pure cultures*

Pure culture isolation Isolation of pure cultures *may be achieved by a variety of methods*, the main differences being in isolation of aerobic versus anaerobic *bacteria*

Pour plate procedures These involve a thorough *distribution of a microbial mixture in cooled* melted agar medium After solidification of the medium individual cells are embedded and proliferate to form a colony Purity of the colony cannot be taken for granted since it may have arisen from two adjacent cells (mixed colony) so the colony

per ed in sterile water and the *pour plate* proce dure repeated Well isolated colonies in the second plating ordinarily can be shown to be pure This method is based on the use of a homogenous sus pension of individual cells The great majority of the colonies on secondary plates should be similar and seen microscopically the cells of such colonies should be of one kind However certain organisms mutate characteristically producing different col ony types (dissociation)

Streak plates The surface of the solid medium in a petri dish is streaked with an inoculating wire or glass rod in a continuous movement so that most of the surface is covered The later parts of the streak should not intersect with the earlier parts In later portions of the streak the separate colonies are the outgrowth of individual cells The chief advan tage of this method is isolation of majority mem bers of a mixed population

Roll tube technique This technique employed chiefly in tissue culture achieves a homogeneous gaseous and nutrient environment by the elimina tion of diffusion gradients. During incubation the tubes are held in a wheellike instrument at an an gle of about 15° from the horizontal The wheel ro-tates vertically about once every 2 minutes Con stant liquid film formation over the inner surface of the tube facilitates oxygen transfer to the medium

Submerged culture In this method the microor ganisms are grown in a liquid medium subjected to continuous vigorous agitation A homogeneous cellular suspension results and all cells in the me dium are simultaneously provided with nearly opti mal rates of diffusion of oxygen and nutrients The mechanical agitation may be achieved by continu ous bubbling of sterile air through the medium by a propellor system by combination of both or by continuous rotary or reciprocating shaking ma chines

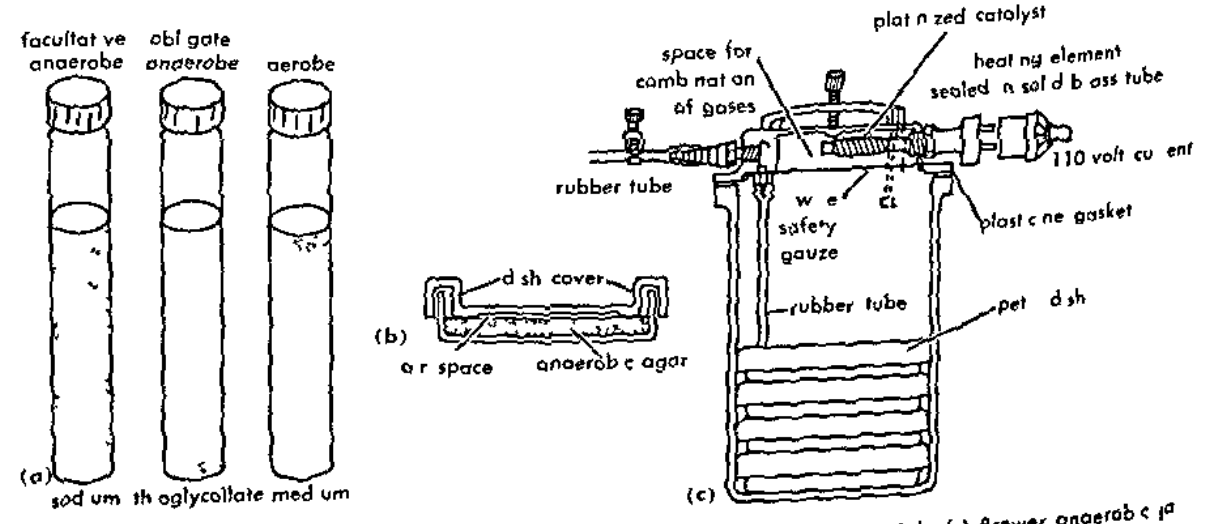
Isolation of anaerobic bacteria Special cul tural conditions may be provided for anaerobes or ganisms that do not require oxygen or that grow only in the complete absence of oxygen Fluid thi oglycollate medium the Brewer anaerobic petri dish and the Brewer anaerobic jar are some of the methods used Fluid thioglycollate medium con tains sodium thioglycollate a reducing compound which lowers the oxygen content of the med um In the anaerobic petri dish the thioglycollate agar me dium and the petri dish over with its restricted air space and close fit to the media surface gi e anaerobic conditions The anaerobic jar is operated by replacing the air in the jar with hydrogen or il luminating gas A platinized catalyst heated by electricity causes the oxygen remaining in the jar to combine with hydrogen to form water or in the case of illuminating gas water and carbon d ox de In this way free oxygen is removed from the jar

Shake culture This is a method for isolating ana erobic bacteria Various dilutions of an inoculum are thoroughly mixed with cooled melted agar me dium occupying about two thirds the volume of test tubes Following solidification there is added a 1 in layer of melted vaspar a 50 50 mixture of paraffin wax and petrolatum When the mixture has hardened the culture is sealed against d iffu

[illegible] hat on In tubes contain ted discrete in the agar

With soft glass tubes the glass is cut and the agar column broken in the region of a desired colony which is then isolated Sometimes the seal is first removed by warming that area of the tube the column of agar is then slowly ejected into a sterile container by compressed air carried to the bottom of the tube through a fine capillary tube introduced between the agar and the glass Colonies are reached by slicing the agar with a sterile scalpel

Anaerobic plates Pour or streak plates are in cubated in a closed vessel in which the a r is re-placed by an inert oxygen free gas such as hel um or nitrogen Alternatively the oxygen n a closed



Same techn ques for the cult vation of anaerobic bac teria (a) Flu d th oglycollate med um show ng aerob c anaerob c and faculiative anaerob c growth (b) Brewer anaerob c petr d sh (c) Brewer anaerob c ja (Balt more B olog cal Laboratory Inc)

vessel is absorbed chemically by mixing pyrogallol and alkali Specially designed petri dishes permit oxygen absorption in individual dishes

Single cell isolation Single-cell isolation employs microscopic techniques to verify the presence of a single cell which is then used to initiate a culture

Little drop technique Minute drops of dilutions of a cellular suspension are examined microscopically on a glass slide A drop containing a single cell is transferred with a capillary pipet to an appropriate culture medium This procedure is best suited for isolation of large cells such as yeasts and mold spores which can be located quickly with the high dry lens of the compound microscope Evaporation problems and the difficulty of obtaining drops small enough to examine with oil immersion lens limit this procedure for bacteria A variation of this procedure was originated by J Lederberg Little drops of a diluted cellular suspension are deposited on a slide covered with a thin film of oil The Lederberg technique by permitting rapid isolation of single bacterial cells obviates to some extent the problems enumerated previously

Micromanipulation The disadvantages of the little drop technique for the isolation of single bacterial cells are eliminated with this technique A micromanipulator permits study of drops in a moist chamber on the microscope stage reducing evaporation difficulties and enabling the use of the oil immersion lens The manipulations are performed by remotely controlled capillary micropipettes activated by air pressure *See* MICROMANIPULATION

Pure culture maintenance This is concerned with the preservation of culture viability and is accomplished by practices that reduce the basal metabolism of the cells thereby enhancing longevity and eliminating the need for frequent transfers

Lyophilization This procedure also called freeze drying is the best method for preserving culture viability Freshly grown cells are suspended in a glass tube in a small volume of a sterile fluid such as blood serum or skim milk A small amount of a reducing agent such as ascorbic acid may help prolong the viability of the culture The suspension is quickly frozen at approximately −70°C by immersion in a dry ice-acetone mixture The frozen material is then dehydrated without melting under high vacuum The container is sealed under vacuum or the gas space may be filled with nitrogen or helium prior to sealing Storage in the absence of oxygen may preserve the viability of a culture for years even without refrigeration The mortality during the lyophilization process and during storage varies with the culture and the suspending fluid Lyophilized cells are rejuvenated by inoculation into fresh nutrient medium

Slants Slants are the most convenient method of maintenance for periods of 1–2 months Cotton plugged tubes containing an agar medium are slanted after sterilization until the agar solidifies The inoculum is streaked on the agar surface After maximal growth at the appropriate temperature the slant culture is stored in a refrigerator and used repeatedly as inoculum With long storage periods the tube should be sealed to retard desiccation Viability of slant cultures not used frequently may be prolonged by filling the tube with sterile mineral oil to about 1 in above the agar This retards water loss from and oxygen access to the culture

Stabs Stabs are used to maintain anaerobic bacteria A tube about two-thirds filled with agar medium is pierced vertically for about 2 in with an inoculating wire Growth develops in the anaerobic depths of the agar along the stab

Strict anaerobe maintenance Strict anaerobes in liquid or solid media may be maintained in an atmosphere from which the oxygen has been absorbed by alkaline pyrogallol Also the air may be replaced by an inert gas such as helium or nitrogen The most convenient procedure employs liquid media containing approximately 0 1% of a reducing agent such as sodium thioglycollate to keep the oxidation reduction potential low enough for growth of anaerobes and to protect it from oxygen diffusing from the air Special vessels or atmospheres are not required but fully developed cultures are sealed against oxygen and refrigerated

Use of sterile soil Sterile soil may be used to carry stock cultures of sporeforming organisms Autoclaved soil supports limited growth of the organism which then sporulates The spores remain viable indefinitely when kept refrigerated [J W F]

Culture, tissue

The branch of biology in which tissues or cells of higher animals and plants are grown artifically in a controlled environment Such studies were undertaken in the hope that the behavior of various body components could be studied and their potentialities more readily analyzed under the simpler and more readily manipulated conditions which are possible in the test tube

Study of the growth and interaction of animal cells with physical and chemical environments outside the body began about 1900 During the first decade it was demonstrated that cell multiplication from chick tissue transplanted into glass vessels could be maintained indefinitely if suitable physical conditions for cell attachment to a solid substrate were provided and if the necessary complex nutrient medium was replenished as fast as it was depleted by the cells activities From early primitive beginnings tissue culture has developed in many directions (Fig 1)

Early methods of tissue culture were successful in promoting cell multiplication only when large numbers of cells were seeded together in a community Growth of such large populations permitted many kinds of important experimentation on the multiplication process but it also left many questions unsolved For example it was impossible to determine which fraction of the cells of any population had retained the ability to multiply It also was difficult to determine the specific con

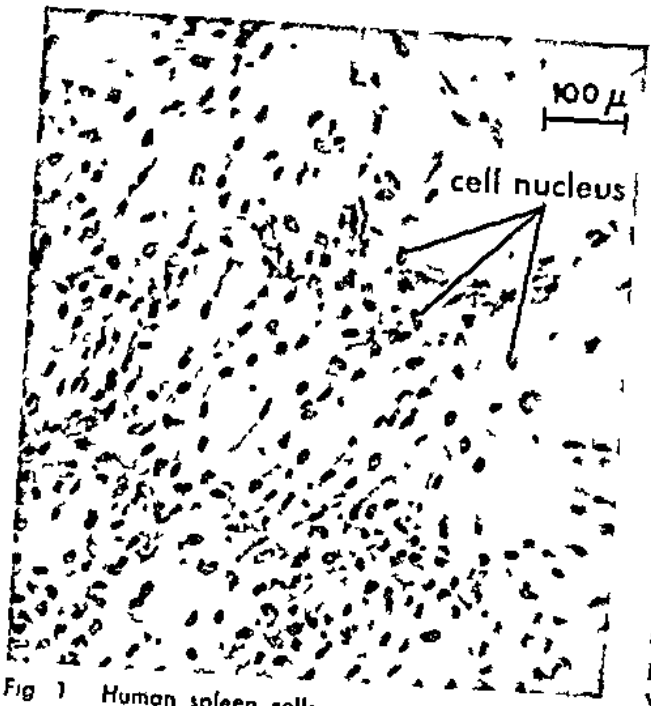


Fig 1 Human spleen cells, grown in a glass vessel containing a nutrient medium

tions which the individual cell requires in order to be able to initiate its reproductive process A major advance along these lines was made by a group of scientists at the U S National Institutes of Health, who succeeded in providing conditions permitting growth of single cells when individually sealed in capillary tubes These cells were later grown into huge populations so that it was demonstrated that at least some cells which had originated in the mammalian body maintain their ability to multiply indefinitely in isolation just like independent bacteria

Early tissue culture succeeded in growing cells only when they were attached to a solid substrate like glass or cellophane Recently (1954) it has become possible to grow cells in liquid suspension as well a technique which permits many new operations such as continuous farming of cells in the same vessel for indefinite periods In addition it has been possible to simplify greatly the medium required for cell multiplication so as to eliminate at least in some cases the need for animal whole serum Definition of the chemical requirements for mammalian cell growth in vitro has proceeded in a variety of laboratories and has reached the stage wherein massive populations can be grown for long periods in a completely synthetic medium Single cells can be reliably grown into discrete colonies in a medium containing completely defined small molecular constituents and two purified proteins obtained from blood The completely defined small molecular constituents are salts, amino acids glucose, and the vitamins biotin pantothenic acid choline folic acid inositol niacinamide pyridoxine riboflavin thiamine, and vitamin B_{12} The two purified proteins obtained from blood are albumin and α_1 globulin which has identical properties as the glycoprotein fetuin Such advances are tremendously important in establishing the specific nutrient requirements for different types of mammalian cells and for elucidation of the metabolic pathways taken by the different molecules in health and disease

Quantitation Research was undertaken to quantitate the requirements for cell growth Means were found by which animal cells grown in tissue culture could be dispersed singly, then added to a glass dish under conditions wherein every single cell would reproduce in isolation to form a discrete colony This aim was at first successfully achieved for cancer cells and then was also achieved for cells from normal human and animal tissues (Fig 2) This method of "plating' single mammalian cells made possible many more precise kinds of experiments The effects of different physical and chemical agents on growth of cells could now be measured with much greater accuracy, since the number of cells able to reproduce under the required conditions could be precisely determined by a simple colony count It also became possible accurately



Fig 2 Colonies developed from single human cancer (HeLa) cells (a) Colonies grown on a glass dish (b) Photomicrograph of a typical colony

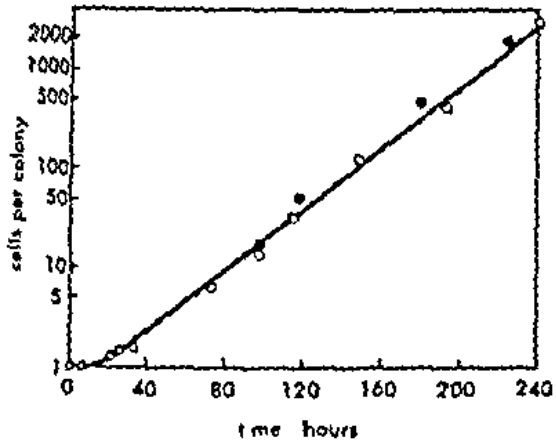


Fig 3 Typical growth curves of single cells plated in a complete nutrient medium After an initial delay of about 18 hours the cells begin to reproduce and continue to double every 20 hours as long as the medium is not exhausted

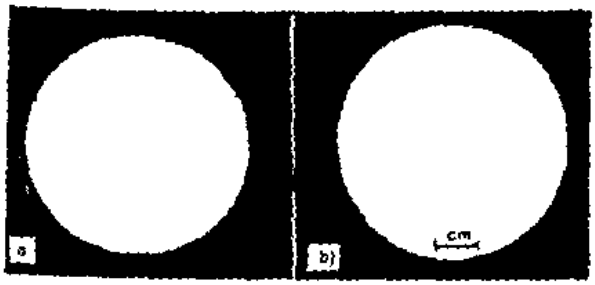


Fig 4 Behavior of different mutant cells from the same cell population Both cell types are identical in appearance and general behavior 100 cells of each type plated in identical dishes containing the same nutrient medium (a) The S3 strain reproduced and developed approximately 100 colonies (b) With the S1 strain no colonies whatever were formed

and conveniently to measure the growth rate of such single cells in different media A sample of such a growth curve is shown in Fig 3 These and other techniques are now being used in many laboratories to study quantitatively the action on living cells of a wide variety of drugs hormones antibodies and other agents Such investigations may soon help to define the cellular basis of the reaction of many potent biological substances and the various patterns by which cells succumb or adapt to different kinds of stress

Study of hereditary mechanisms Development of single cell techniques has afforded tissue culture means for study of hereditary mechanisms in animal cells Such techniques have permitted much easier recognition and isolation of colonies with different genetic characteristics that have arisen from mutated cells Mutant cells have been found occurring spontaneously in animal cell populations and have been produced by the action of high energy radiation and other mutagenic agents (*see* MUTATION) A large variety of mutants has by this time been isolated which differ from each other in their gross morphology nutritional requirements, and sensitivity to destruction by viruses and other agents (Fig 4) Studies are now in progress to attempt to define genetic mechanisms and their biochemical concomitants that govern behavior of human and other animal cells just as was done previously for more primitive kinds of organisms

Cells grown in tissue culture by older techniques have demonstrated changes in their chromosome numbers and structures occurring with the passage of time Since these bodies contain the genes which determine the hereditary potentialities of the cells the genetic constitution of such cells was uncertain Inferences drawn from the behavior of such cultures and then applied to interpretation of functions and potentialities of cells in the body where chromosomal integrity is rarely altered were often of doubtful significance Various investigators turning attention to these problems developed new methods for study of the chromosomal constitution of mammalian cells in tissue culture One result of such advances in technique was the production of methods for regulating cell growth in culture so that the chromosomal integrity was maintained as reliably throughout extended periods of cultivation as is the case in the body It now becomes possible to make many kinds of biochemical and genetic studies on such cells with considerably more confidence in the applicability of results to an understanding of cell functions in the intact animal New advances in methods of taking cell specimens for culture have now reached the point where it is possible to obtain with ease a cell sample from a minute amount of skin taken from any individual and to cultivate these stably in vitro It is not inconceivable that such cell culturing techniques may one day be important in medical diagnostic procedures and in the development of cell banks useful in certain types of therapeutic operations

Another fundamental result arising from chromosomal studies in tissue culture was the demonstration that the chromosome constitution of man which had been accepted for approximately 30 years was in error In 1956 tissue culture studies demonstrated that the normal cells of man contain 46 instead of 48 chromosomes These results have been verified in many laboratories by study of cells

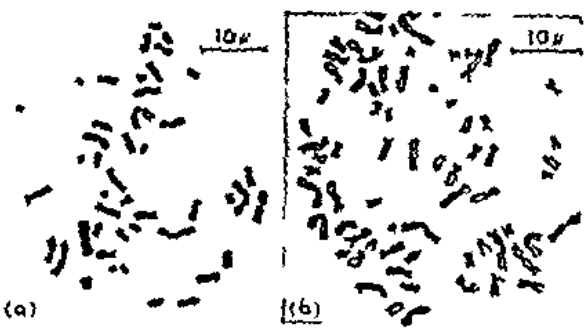


Fig 5 Chromosome constitution (a) Cells taken from normal human male and grown in tissue culture There are 46 chromosomes. (b) Human cancer cell with stem line chromosome number 73

drawn from a variety of tissues of many human subjects While the occasional occurrence of a chromosome number other than 46 has been demonstrated in human subjects with genetic disease there is no question that 46 is the major human chromosome number Further characterization of these chromosomes has been accomplished and each one of the human chromosomes has now been identified and its structure delineated In contrast to the normal human cell with its normal complement of chromosomes the karyotype of human cancer cells has been studied and many of these have been found to possess abnormally high chromosome numbers (Fig 5) A karyotype is the chromosome complement characteristic of any individual or group of related organisms The normal karyotype of human somatic body cells is shown in Fig 6 The Y chromosome possessed only by males is less than one third the size of the X chromosome which occurs singly in male cells but is doubled in female cells All other chromosomes have been characterized by their sizes the position of their centromeres and by special structures which are present in certain of the chromosomes Diseases like ovarian dysgenesis (Turner s syndrome) have been found to be accompanied with a chromosome number of 45 instead of the normal 46 The missing chromosome is a sex chromosome so that such individuals have the X O sex chromosomal constitution

Radiation studies Investigations of the effect of high energy irradiation on single human and other animal cells have for the first time accurately defined the dose required to prevent colony formation by reproduction of single cells (Fig 7) This dose has been found to be approximately 100 roentgens for certain cancer cells but only 50 roentgens for human cells with normal chromosomal constitution These figures were surprising because it had been generally considered that the human cell is many times more resistant to radiation than this figure implies These measurements have made possible interpretation of the effect of high energy radiation on a whole body in a manner that satisfactorily explains many hitherto obscure aspects of radiation pathology Study of the mechanisms by which radiation interferes with reproductive processes in mammalian cells has shown that most of the damage is confined to the cellular genetic apparatus and particularly to the chromosomes Figure 8 presents a series of pictures showing normal human chromosomes and those from human cells irradiated with various doses of x rays *See* RADIATION INJURY (BIOLOGY)

Use in virus studies Tissue culture studies have initiated a new era in investigations of mammalian viruses By means of these techniques it has become possible to prepare large quantities of viruses so that for the first time the virologist and immunologist have had ample material with which to agents Many new and fundamental results have emerged which are opening whole new vistas of understanding of the virus cell interaction It has also been possible to adapt to tissue culture the plaque technique method in which single virus particles are recognized by the round area of cell

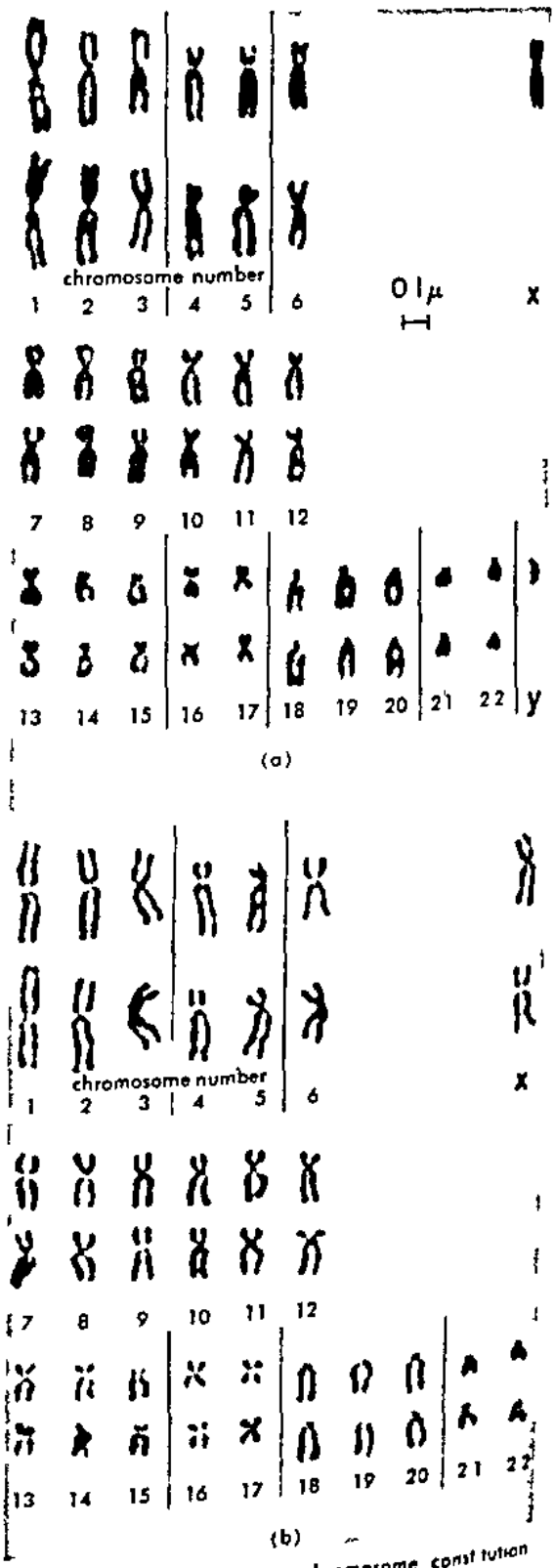


Fig 6 The normal human chromosome constitution (a) Male cells (b) Female cells

destruction they produce (Fig 9) Thus an accu rate determination can be made of the number of virus particles in the original suspension This tech n que allows a much more prec se measurement of the effects of viruses under different kinds of con trolled physical and chemical situations Since all the virus progeny of a single plaque area have de scended from the same single individual it becomes more readily possible to carry out controlled ge netic investigations on viruses

Other techniques Many new advances have been carried out by means of cinema photomicrog raphy which has portrayed the surprising variety of movements of different kinds of cells growing in tissue culture The ability of cells taken from a whole animal and dispersed individually to reag gregate in tissue culture to form tissues very much like those of their original site in the animal has also been demonstrated These developments afford extraordinary promise in unlocking mysteries of mammalian cell differentiation—the process by which a single cell develops into the vastly complex and highly organized structures of the body

While this discussion has been confined to ani mal tissue culture mention should be made that many parallel developments have taken place in the field of plant tissue culture

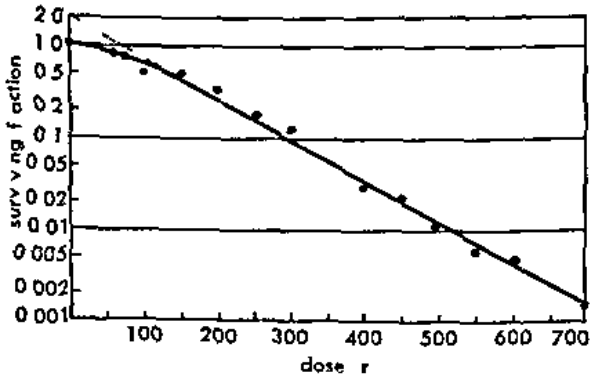


Fig 7 Surv val of reproduct ve capac ty of cells from a culture of a human cancer The average lethal dose obtained from th s curve is 96 roentgens (r)

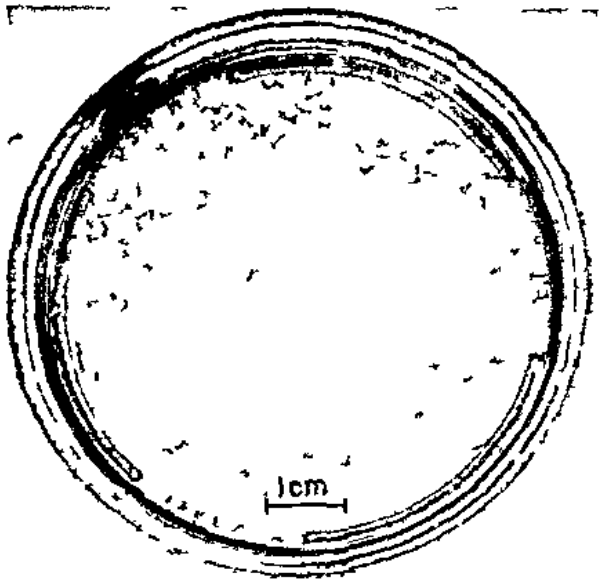


Fig 9 Plaques or areas of cell destruction produced by the act on of the v rus of Newcastle d sease on chick f broblasts cult vated n a glass dish

The list of new possibilities in this field now l e ing actively pursued or appearing on the horizon could be greatly extended There can be no doubt that tissue culture promises profound increase in fundamental understanding concerning the func tions and potentialities of the constituent cells of complex organisms Further it will probably greatly clarify physiologic biochemical and ge netic mechanisms involved in the body economy of multicellular plants and animals *See* MICROBIOLOGICAL METHODS VIRUS [T T P]

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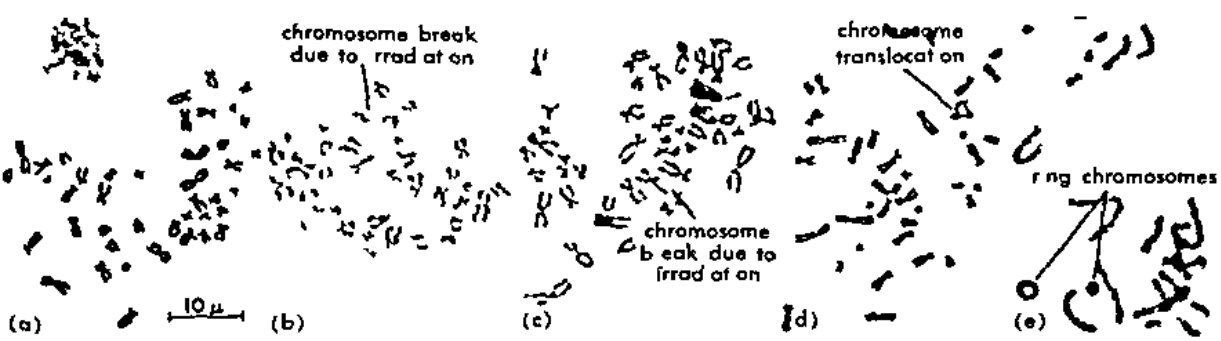


Fig 8 Typ cal chromosomal les ons produced in hu man cells grown in t ssue culture and rrad ated w th var ous doses of x rays (a) Normal human chromosome complement un rrad ated cell (b) Chromosomes of cell after rrad at on w th 50r (c) Chromosomes of cell rrad ated w th 75r (d) Chromosomes of cell rrad ated w th 75r Translocat ons have appeared as a result of abnormal rest tution of the mult ple breaks (e) Devel opment of r ng chromosomes as a result of rrad of a normal human cell w th 150r

Cieciura *J Exptl Med* 103 273–284 1956 J H Tjio and T T Puck *Proc Natl Acad Sci U S* 44 1229 1958 J H Tjio T T Puck and A Robinson *Proc Natl Acad Sci U S* July 1959

Culture technique

Procedures for isolation cultivation and manipulation of microorganisms including viruses and rickettsia and for propagation of plant and animal cells and tissues A relatively minute number of cells the inoculum is introduced into a sterilized nutrient environment the medium The culture medium in a suitable vessel is protected by cotton plugs or loose fitting covers with overlapping edges so as to allow diffusion of air yet prevent access of contaminating organisms from the air or from unsterilized surfaces The transfer or inoculation is usually done with the end of a flamed then cooled platinum wire Sterile swabs may also be used and in the case of liquid inoculum sterile pipets

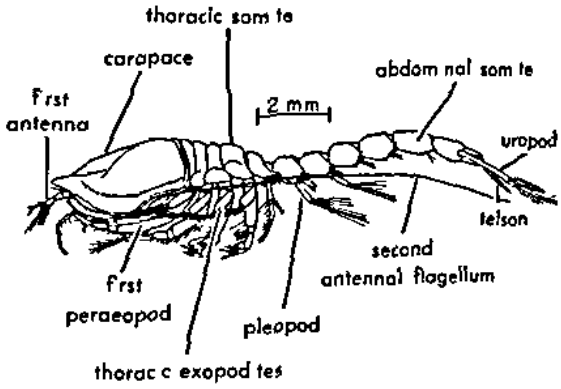
The aqueous solution of nutrients may be left as a liquid medium or may be solidified by incorporation of a nutritionally inert substance most commonly agar or silica gel Special gas requirements may be provided in culture vessels closed to the atmosphere as for anaerobic organisms Inoculated vessels are held at a desired constant temperature in an incubator or water bath Liquid culture media may be mechanically agitated during incubation Maximal growth visible as a turbidity or as masses of cells is usually attained within a few days although some organisms may require weeks to reach this stage *See* CHEMOSTAT CULTURE ELECTIVE CULTURE EMBRYONATED EGG CULTURE PURE CULTURE TISSUE CULTURE MEDIA COMPONENTS OF INOCULATION MICROBIOLOGICAL METHODS

[J W F]

Cumacea

An order of the class Crustacea and subclass Malacostraca All have a well developed carapace which is fused dorsally with at least the first 3 thoracic somites and which overhangs the sides to enclose a branchial cavity The telson may be free or may appear lacking because fused with the last abdominal somite Eyes are sessile and except for a few genera are coalesced in a single median organ or wholly wanting There are 8 pairs of thoracic appendages the first 3 modified as maxillipeds and the last 5 as pereiopods The first maxillipeds bear an epipodite forming a respiratory organ with a forward directed siphon and a posterior part carrying branchial lobes Natatory exopodites may be present on the third maxillipeds and the first 4 pairs of peraeopods or some of them The uropods are styliform There is no free larval stage In the few species whose life history has been investigated there are 5 7 molts after release from the brood pouch

There is always some sexual dimorphism in adults but immature males resemble females until the later stages The second antennae are always



Adult male of a typical cumacean

vestigial in females and nearly always well developed with a long flagellum in males Females often have a reduced number of thoracic exopodites Pleopods are never present in the female but there may be 1 5 pairs in the male The form and sculpturing of the body and the number of spines and setae on the appendages often differ between the sexes Oostegites are present on the third to sixth thoracic limbs of the female

All known species have a characteristic shape owing to the inflated carapace and slender abdomen Most are small 1 12 mm in length the largest reach 35 mm The order is rather uniform and classification is based on trivial characters Seven families are recognized Affinities are probably closer to the Mysidacea than to the Tanaidacea No fossils are known

Cumacea are found in all seas and in some estuaries and areas of brackish water including the Caspian Sea Most inhabit water shallower than 200 m but many occur in great depths They normally burrow in sand or mud with the front protruding Coastal species and especially the more active adult males may often be captured above the bottom They feed on organic detritus or very small organisms and may themselves form part of the diet of various fishes In 1959 about 645 species had been described and placed in 78 genera Many more remain to be found as they have been poorly investigated in most areas *See* MALACOSTRACA SEXUAL DIMORPHISM

[N S J]

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Cumin

Aromatic fruits which were highly prized by the ancients The plant *Cuminum cyminum* is an attractive little annual herb now cultivated extensively in southern Europe and India The fruits are used in soups curries bread cake cheese and pickles The oil is used in perfumery and for flavoring beverages *See* SPICE AND FLAVORING UMBELLALES

[P D S]

Cummingtonite

The name given to the calcium poor monoclinic amphiboles that form a limited solid solution series between the iron end member grunerite $Fe_7Si_8O_{22}(OH)_2$ and a magnesian end member of approximately $Mg_5Fe_2Si_8O_{22}(OH)_2$ More magnesium rich minerals apparently form the closely related orthorhombic form anthophyllite The exact composition for the change of form and the equilibrium relations are unknown The observed ranges of composition of cummingtonite and anthophyllite overlap considerably the two minerals can occur in the same specimen Cummingtonite is optically positive and thus distinct from the other monoclinic amphiboles its inclined extinction distinguishes it from the very similar appearing anthophyllite It is usually yellow brown to brown in color and is slightly colored in thin sections It forms elongate prismatic to fibrous crystals that exhibit the 54°30′ amphibole 110 cleavages an angle approximately 1° smaller than the other monoclinic amphiboles Grunerite commonly occurs as brown fibrous crystals with a silky luster and is usually found associated with iron formation

Cummingtonite is a metamorphic mineral that occurs in various schists contact metamorphic rocks and in some ore deposits It is found associated with such minerals as hornblende biotite garnet plagioclase quartz and anthophyllite *See* AMPHIBOLE ANTHOPYLLITE [C W D]

Cuprite

A mineral having composition Cu_2O and crystallizing in the isometric system Cuprite is commonly in crystals showing the cube octahedron and dodecahedron More rarely it is found in long capillary crystals known as chalcotrichite It is also in fine-grained aggregates or massive The color is various shades of red and a fine ruby red in transparent crystals which have a metallic to adamantine luster The hardness is 3 5–4 (Mohs scale) and the specific gravity is 6 1

Cuprite is a widespread supergene copper ore found in the upper oxidized portions of copper deposits in which it is associated with limonite malachite azurite native copper and chrysocolla Fine crystals have been found at Cornwall England and Chessy France In the early mining operations of many copper deposits cuprite has been an important ore mineral but gives way to the primary ores in depth It has served as an ore in the French and Belgian Congo Chile Bolivia and Australia In the United States it has been found at Clifton Morenci and Bisbee Arizona *See* COPPER [C S HU]

Curie

A unit for measurement of amount of radioactivity One curie is defined as the amount of a radioactive substance which is undergoing 3.7×10^{10} disintegrations/sec The number of radioactive atoms in a 1 curie source is given by R/λ where R is 3.7×10^{10} disintegrations/sec and λ is the disintegration constant for the particular radioactive species in the source *See* RADIOACTIVITY RADIOACTIVITY STANDARDS [L F CS]

Curie temperature, magnetic

The temperature marking the transition between ferromagnetism and paramagnetism Below this temperature all ferromagnetic materials show spontaneous magnetization that is magnetization in the absence of an external applied field This magnetization decreases as the temperature increases at first gradually then very rapidly until it completely disappears at the Curie temperature Above this temperature the magnetic susceptibility follows the Curie Weiss law *See* CURIE WEISS LAW FERROMAGNETISM MAGNETIZATION SUSCEPTIBILITY MAGNETIC

The ferromagnetic Curie temperature T_c is the temperature just defined The constant θ in the Curie Weiss law is frequently called the paramagnetic Curie temperature since it is the temperature at which the susceptibility should go to infinity Near the transition however the Curie Weiss law breaks down and in general θ is slightly greater than the actual transition temperature T_c

The transition between ferrimagnetism and paramagnetism is also marked by a Curie temperature *See* FERROMAGNETISM PARAMAGNETISM

The transition between antiferromagnetism and paramagnetism is marked by the Neel temperature T_N Below T_N antiferromagnets show spontaneous sublattice magnetization although the total magnetization is zero *See* ANTIFERROMAGNETISM

Probably all paramagnets align into ferro- ferri or antiferromagnets at some transition temperature although this may be very low for dilute salts

The Curie temperature marks an order disorder transition in the alignment of the elementary magnetic moments and this phenomenon is very similar to other order disorder transitions There is a specific heat anomaly and the Curie temperature can be altered by changes in composition pressure and other thermodynamic parameters [E A F K]

Curie Weiss law

A relation between magnetic or electric susceptibilities and the absolute temperature which is followed by ferromagnets antiferromagnets nonpolar ferroelectrics and antiferroelectrics and some paramagnets The Curie Weiss law is usually written

$$\chi = C/(T - \theta)$$

where χ is the susceptibility C is a constant for each material T is the absolute temperature and θ is called the Curie temperature Antiferromagnets and antiferroelectrics have a negative Curie temperature The Curie Weiss law refers to magnetic and electric behavior above the transition temperature of the material in question It is not always precisely followed particularly in the

gion close to the transition temperature Often the susceptibility will behave according to a Curie Weiss law in different temperature ranges with different values of C and θ *See* CURIE TEMPERATURE MAGNETIC, SUSCEPTIBILITY, ELECTRIC, SUSCEPTIBILITY MAGNETIC

The Curie Weiss behavior is usually a result of an interaction between neighboring atoms which tends to make the permanent atomic magnetic (or induced electric) dipoles point in the same direction The strength of this interaction determines the Curie temperature θ In the magnetic case the interaction is caused by Heisenberg exchange coupling

In many paramagnetic salts especially those of the iron group the Curie Weiss behavior is due to crystalline distortions and their effect upon the atomic orbital angular momenta which contribute to the magnetization

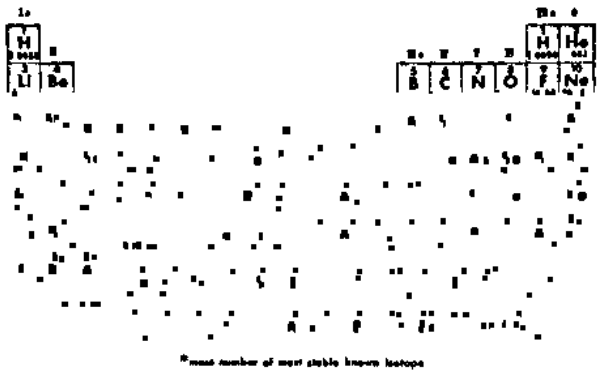
For further discussion and derivation of the Curie-Weiss law *see* FERROMAGNETISM *see also* ANTIFERROMAGNETISM FERROELECTRICS

[E A , F K]

Curium

Element number 96 curium Cm is a member of the actinide series of elements The electronic configuration of the neutral atom (beyond the radon core) is $5f^7 6d 7s^2$

Curium does not occur naturally in the terrestrial environment but may be produced artificially as



was first done in 1944 by G T Seaborg R A James and A Ghiorso who synthesized and then identified the isotope Cm^{242} The synthesis was effected by the bombardment of Pu [239] (plutonium 239) with helium ions of about 32 million electron volt (Mev) energy $Pu^{239}(\alpha\, n)Cm^{242}$ Curium 242 has long remained the most abundant source of the element It was this isotope which provided material for the first isolation of curium in the macroscopic state by L. B Werner and I Perlman in 1947 Macroscopic amounts may be made by intense neutron irradiation of Am^{241}

$$Am^{241}(n\,\gamma)Am^{242m} \xrightarrow{\beta} Cm^{242}$$

Most of the work with macroscopic amounts of
ecause of
(6 Mev)
- chemical

Isotopes of curium

Mass no	Half life	Mode of disintegration
238	2 5h	Orbital electron capture, <90% α particle emission >10%
239	2 9h	Orbital electron capture >99 9%
240	26 8d	α Particle emission
	$7\,9 \times 10^6$y	Spontaneous fission
241	35d	Orbital electron capture 99+% α particle emission 0 96%
242	162 5d	α Particle emission
	$7\,2 \times 10^6$y	Spontaneous fission
243	35y	α Particle emission >99% orbital electron capture 0 26%
244	19y	α Particle emission
	$1\,4 \times 10^7$y	Spontaneous fission
245	about 10^4y	α Particle emission
246	about 5000y	α Particle emission
	$2\,0 \times 10^7$y	Spontaneous fission
247	$>4 \times 10^7$y	α Particle emission
248	$4\,7 \times 10^5$y	α Particle emission
	$4\,6 \times 10^6$y	Spontaneous fission
249	64m	β Particle (electron) emission
250	2×10^4y	Spontaneous fission

investigation In solid compounds there is rapid damage to crystal lattices and in aqueous solutions, steady state concentrations of hydrogen per oxide of the order of 0 1 M are achieved as a result of the α radiation

The known isotopes of curium along with their half lives and modes of decay are listed in the table Where for a given mass separate half lives and modes of disintegration are indicated the decay processes occur simultaneously However each half life is for decay by only the indicated mode of disintegration The isotopes of higher mass number and longer life may become increasingly available in the future thereby permitting extension of the present limited knowledge of the properties of curium

Metallic curium has a silvery luster tarnishes rapidly in air and has a low specific gravity of about 13

Four solid compounds of curium have been well characterized by their x ray diffraction patterns These are CmF_3 CmF_4 Cm_2O_3 and CmO_2 isostructural with CeF_3 CeF_4 Gd_2O_3 (cubic) and CeO_2 respectively Curium trifluoride is readily prepared by precipitation of aqueous Cm(III) with hydrofluoric acid and drying of the precipitate This reacts at about 300°C with elemental fluorine to yield the tetrafluoride The dioxide is obtained by treating Cm(III) oxalate with ozone and oxygen at about 300°C The product oxide has the fluorite structure with crystal lattice parameter $a = 5\,37$ A The dioxide is relatively unstable as it may be decomposed in vacuum at 600°C to yield the cubic sesquioxide with $a_0 = 5\,50$ A

Only the tripositive state of curium is known in aqueous solution and repeated efforts to achieve oxidation to higher states have been unsuccessful Hydrated Cm(III) shows negligible absorption in the visible region of the spectrum [compare with gadolinium(III)] but weak lines are found in the region from 3700 to 4000 A the strongest being at

4000 A Strong absorption occurs further into the ultraviolet particularly near 2800 A The ionic radius of unhydrated Cm^{3+} is 0 99 ± 0 02 A

The magnetic susceptibility of CmF_3 measured near room temperature gives a calculated effective magnetic moment of 7 9 Bohr magnetons in excellent agreement with a theoretical value of 7 94 calculated for an ion of the expected $^8S_{7/2}$ ground state

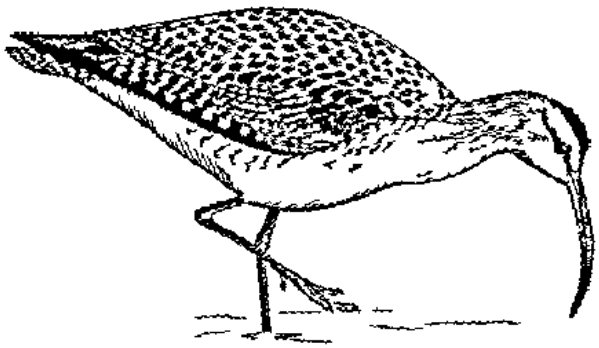
The ground state configuration has been confirmed by a study of the paramagnetic resonance of $CmCl_3$ in dilute solution in solid $LaCl_3$

Curium is the seventh member of the actinide series of elements The electronic configuration $(5f^6 6d 7s^2$ that is a half completed f subshell) is analogous to that of gadolinium in the lanthanide series The chemical properties of curium are so similar to those of members of the lanthanide series that if it were not for its radioactivity it might easily be mistaken for one of these rare earth elements *See* ACTINIDE ELEMENTS ATOMIC STRUCTURE AND SPECTRA NUCLEAR REACTION RADIOACTIVITY TRANSURANIUM ELEMENTS [B B CU]

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Curlew

Any of eight species of the genus *Numenius* family Scolopacidae distinguished by the long bill which is distinctly curved downward The genus is Holarctic Three species were formerly present in the United States The Eskimo curlew *N borealis* once extremely common is now believed to be extinct It was once slaughtered by the thousands during migrations Both the long billed curlew *N americanus* which breeds in the Great Basin of the United States and the Hudsonian curlew *N phaeopus* which breeds in the Arctic are still present in fairly large numbers *See* CHARADRIIFORMES [J D B]



The Hudsonian curlew Numenius phaeopus length to 18¾ in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

Currant

A shrubby deciduous plant of the genus *Ribes* plant order Rosales related to the gooseberry The fruits are berries borne in clusters (Fig 1) The black currant *R nigrum* popular in Europe is not cultivated in the United States

Red currants are derived from five species mostly European There are also white currants which are variants of the red type Only the red varieties are produced commercially Currants are grown in home gardens throughout most of the central and northern part of the United States The greatest commercial production occurs in New York Washington and Michigan In 1954 the value of the currant crop in the United States was $518 000 *See* GOOSEBERRY ROSALES [J H CE]

Currant and gooseberry diseases The diseases of currants and gooseberries are similar and are rather generally distributed throughout the areas in which these crops are grown

Anthracnose (*Pseudopeziza ribis*) first produces numerous small brownish spots thickly scattered over the upper surfaces of the leaves (Fig 2) As the disease progresses, the leaves turn yellow and drop and in severe cases the entire plant may become defoliated Anthracnose is controlled by applying a commercial lime-sulfur spray while the plants are dormant followed by sprays with copper or dithiocarbamate fungicides during the growing season

American powdery mildew (*Sphaerotheca morsuae*) first appears as a white powdery growth on the young leaves shoots and fruits and eventually forms a thin felty reddish brown coating over the affected tissues This mildew is favored by cool



Fig 1 Black currant Ribes nigrum (a) Branch with leaves and flowers (b) Branch with cluster of fruits (From L H Bailey ed The Standard Cyclopedia Horticulture vol 1 Macmillan 1937)

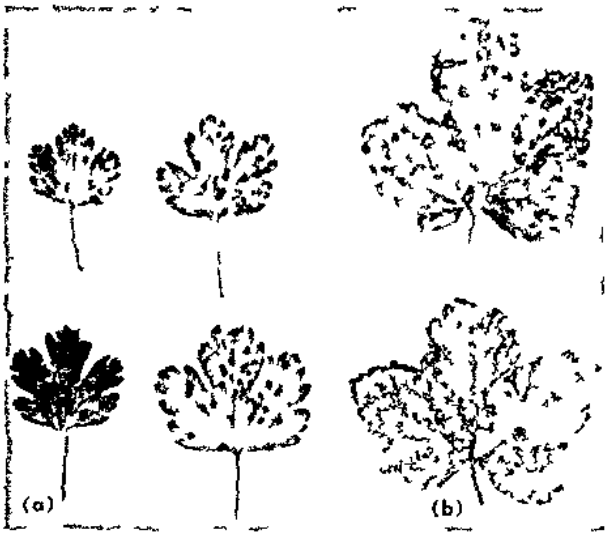


Fig 2 Anthracnose disease (a) On gooseberry (small leaves) (b) On currant (large leaves)

humid weather It is most damaging on gooseberries especially those of European origin The disease is difficult to control but clean culture and spraying or dusting with sulfur usually are effective to some degree

Other important diseases of currants and gooseberries are leaf spot (*Mycosphaerella ribis*) and cane blight (*Botryosphaerea ribis*)

Both currants and gooseberries are alternate hosts for the white pine blister rust (*Cronartium ribicola*) a destructive disease of 5 needle (white) pines in Europe and America The common black currant is the favored host of the fungus Because the white pines are among the most valuable timber trees in the United States the black currant has been declared a menace and eradicated in most areas *See* FRUIT GROWING (SMALL), PLANT DISEASE, TREE [E K V]

Current, electric

The net transfer of electric charge per unit time It is usually measured in amperes The passage of electric current involves a transfer of energy Except in the case of superconductivity a current always heats the medium through which it passes (For a discussion of the heating effect of a current, *see* JOULE'S LAW) On the other hand a stream of electrons or ions in a vacuum which also may be regarded as an electric current produces no local heating Measurable currents range in magnitude from the nearly instantaneous 10^5 or so amperes in lightning strokes to values of the order of 10^{-16}

with which electric current is transmitted through it Most metals electrolytic solutions and highly ionized gases are conductors Transition elements such as silicon and germanium are semiconductors while most other substances are insulators

Electric current may be direct or alternating Direct current is necessarily unidirectional but may be either steady or varying in magnitude By convention it is assumed to flow in the direction of motion of positive charges opposite to the actual flow of electrons Alternating current periodically reverses in direction Direct current is abbreviated dc and alternating current ac

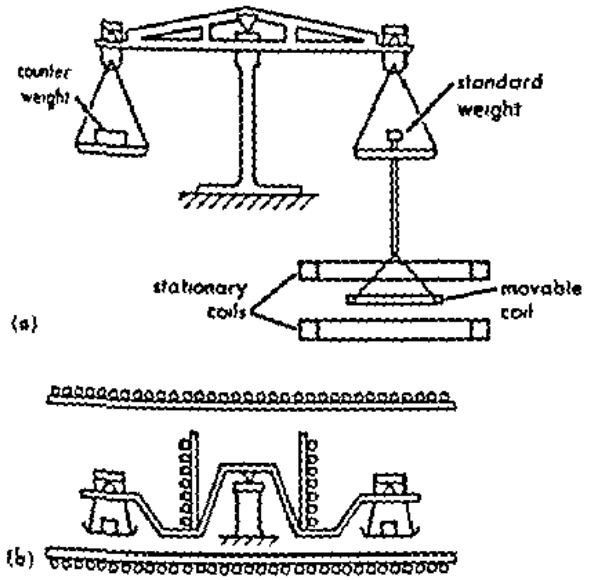
Conduction current This is defined as the transfer of charge by the actual motion of charged particles in a medium In metals the current is carried by free electrons which migrate through the spaces between the atoms under the influence of an applied electric field Although the propagation of energy is a very rapid process the drift rate of the individual electrons in metals is only of the order of a few centimeters per second In a superconducting metal or alloy the free electrons continue to flow in the absence of an electric field after once having been started In electrolytic solutions and ionized gases the current is carried by both positive and negative ions In semiconductors the carriers are the limited number of electrons which are free to move and the 'holes' which act as positive charges

Displacement current When alternating current traverses a condenser there is no physical flow of charge through the dielectric (insulating material), but the effect on the rest of the circuit is as if there were a continuous flow Energy can pass through the condenser by means of the so called displacement current James Clerk Maxwell introduced the concept of displacement current in order to make complete his theory of electromagnetic waves *See* DISPLACEMENT CURRENT, *see also* ALTERNATING CURRENT, CONDUCTION (ELECTRICITY) DIELECTRICS, DIRECT CURRENT FREE ELECTRON THEORY OF METALS, INSULATOR ELECTRIC, RESISTANCE ELECTRICAL, SEMICONDUCTOR, SUPERCONDUCTIVITY [J W ST]

Current balance

An apparatus with which force is measured between current carrying conductors The purpose of the measurement is to assign the value of the ampere therefore the relative locations of the conductors are prescribed so that the force between them can be computed from their geometry and the current they carry Experimentally this force is measured in terms of the gravitational force on a known mass, thus the ampere may be said to be weighed

The determination of the ampere is one of the basic measurements used to assign values to electrical units in terms of mechanical units of length mass and time By this assignment the electrical units of power and energy are made to have values identical with the corresponding mechanical units The current balance is employed at the U S National Bureau of Standards and at the national laboratories of other countries as one of the steps in establishing the values of the absolute electrical



Current balances (a) Rayleigh (b) Pellat

units used in science and technology throughout the world

Operation. In a current balance force is measured between fixed and movable coils (see illustration) This force can be expressed as the product of the currents in the coils by the rate of change of their mutual inductance with displacement If the coils carry the same current

$$F = I^2 \frac{\partial M}{\partial x}$$

for a linear displacement or

$$F = I^2 \frac{\partial M}{\partial \theta}$$

for an angular displacement where F is the mechanical force M is the coefficient of mutual inductance and I is the current being measured The coil construction must be such that $\partial M/\partial x$ or $\partial M/\partial \theta$ can be computed from dimensional measurements The movable coil is attached to an equal arm weighing balance and the force between the coils is made equal to a weight which is the gravitational force on a known mass

Three types of current balance have been used in ampere determinations In two of these the Rayleigh and the Ayrton Jones balances the fixed and movable coils are coaxial and the motion is linear along the coil axis In the third type the Pellat balance the axes of the fixed and movable coils are at right angles and the movable coil turns about its center the pivot point of the weighing balance

In the Rayleigh balance the coils are circular and have a square winding section The fixed coils are located above and below but coaxial with the smaller movable coil The coil spacing is such that the force on the movable coil is maximum Because of the small winding section the ratio of radii of fixed and movable coils is the most important geometrical constant needed and this ratio can be measured by electrical means The radius of the movable coil is about half that of the fixed coils because for this ratio the exact dimensions of the winding cross section are of reduced importance The value of current is determined from two weighings With the standard weight removed from the right hand balance pan the current is given such direction that the force is downward The counter weight is of such value that the beam is balanced The current is then reversed in the fixed coils so that the force is upward and the standard weight is simultaneously placed on the pan to restore balance If the two rest points of the balance are the same the standard weight is just double the force between fixed and movable coils

In the Ayrton Jones balance and in a modification of this balance used at the National Bureau of Standards the fixed and movable coils are single-layer solenoids Here the diameter and winding pitch of the coils are of critical importance in computing force and the coil construction is such that these dimensions can be measured accurately The balance arrangement and the weighing procedure are the same as in the Rayleigh balance

Single layer solenoids constructed so that diameter and pitch can be accurately determined are also used in the Pellat balance The coil forms are of fused silica or low expansion glass for dimensional stability and the winding is laid in a spiral groove cut in the outer face of the cylinder so that the pitch is uniform The balance beam is of fused quartz The weighing procedure is similar to that described above and the torque required for balance is the product of the weight by its lever arm

The emf of a standard cell is also assigned in an absolute ampere determination The current being measured is passed through a standard resistor and the resulting voltage drop is compared to the emf of the cell The resistor and cell are stable reference standards and are used to preserve the values of the electrical units in the intervals between absolute ampere and ohm determinations

See CURRENT MEASUREMENT [F K H]

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Current density

A vector quantity equal in magnitude to the instantaneous rate of flow of electric charge, perpendicular to a chosen surface per unit area per unit time If a wire of cross sectional area A carries a current I, the current density J is I/A The units of J in the rationalized meter kilogram second system are amperes per square meter

The concept of current density is useful in treating the flow of electricity through a conductor of nonuniform cross section and in electromagnetic theory In terms of current density Ohm's law can be written $J = E/\rho$ where E is electric field strength and ρ is resistivity Current density is related to the number per unit volume n the charge e and the average velocity v of the effective charge carriers in a conductor by the formula $J = nev$ [J W ST]

Current measurement

The measurement of the flow of electric current The unit of measurement the ampere (amp) is defined in the system of electromagnetic units through its electromagnetic reaction One abampere (10 amp) of unvarying unidirectional current (direct current) flowing through a wire and returning through an adjacent parallel wire will when the two parallel wires are 1 cm apart on centers produce a force between the wires of 2 dynes for each cm length so positioned This electromagnetic reaction was first studied by Andre Marie Ampere in 1820 The reaction or force is proportional to the current in each wire or to the square of the current where it returns on itself as in the definition The force is also inversely proportional to the square of the distance between the wires

In the practical determination of current value the current carrying wires are formed into circular coils The moving coil may move up and down as in the Rayleigh balance where the reaction is balanced by the force of gravity on known weights or it may rotate as in the Pellat balance being supported on a knife edge here the force is balanced by an appropriate mass acting a known distance from the support *See* CURRENT BALANCE

Direct and low frequency currents The current balance is tedious to operate and is ordinarily used only by the national laboratories of the various countries for the determination of the absolute ampere whereby simpler (but less accurate) current measuring devices may be calibrated

The moving coil may rotate in jeweled bearings against the counter torque of a spiral spring If a pointer is attached to the moving system rotating over an appropriately marked scale calibrated in terms of the absolute current determinations of an ampere balance the result is an indicating electrodynamometer ammeter Such instruments are widely used as laboratory standards for both direct and alternating current measurements and for the calibration of secondary instruments

Direct current (dc) may also be measured by placing the movable coil in the magnetic field of a permanent magnet This is the construction of the conventional type of dc ammeter *See* AMMETER

Structures incorporating a permanent magnet give a reversed deflection with reversed direction of current and therefore are usable only on direct current For the measurement of alternating current (ac) the instrument must take no account of current direction and further must give a reading of that function of the current oscillation which is to be measured For example, only the peak value of current may be desired An example is in the measurement of the maximum value of a lightning discharge to a transmission tower where a small magnetic link is magnetized by the peak value of the current, a test of the degree of its magnetization can be correlated to the peak current value

In most cases it is desired to measure that value of the alternating current which is a measure of the power in a motor, or heat in a stove or lamp filament namely, its root mean square or rms value The electrodynamometer ammeter indicates in these terms If calibrated on direct current it becomes a transfer instrument and may be used to calibrate other types of ac instruments in terms of true rms current value

For ordinary switchboard or test indications of alternating current the fixed coil moving iron type of instrument with its high torque and quite adequate accuracy is widely used A fixed iron vane and a similar vane on a staff are magnetized by the current in the coil the force between the vanes acting to rotate the staff against a spring as a function of the rms value of the current

The hot wire ammeter indicating the mechanically amplified stretch of a fine wire heated by the current has been wholly replaced by the thermoammeter In this instrument a short metal strip or wire is heated by the current in question its temperature rise is measured by a contacting thermocouple connected in turn to a sensitive dc meter which deflects in proportion to the temperature rise The scale is marked in terms of the heating current This type of instrument is insensitive to variations in frequency and ambient temperature

When direct currents of over a fraction of 1 amp are to be measured the bulk of the current is diverted around the instrument through a shunt or bypass circuit or simply a shunt *Large alternating* currents on the other hand are connected to meters rated at 5 amp through current *step*-down transformers or current transformers Both are available in wide range variety and are of *good* accuracy

Very low direct currents below 10 ^{9} amp *can* be measured by charging a capacitor with the current in question and calculating its value *from the* rate of voltage rise Vacuum tube methods are like *are more useful in the*

e 10^{4} amp

can be measured with a transductor *essentially* an ac transformer with the iron core surrounding the dc bus By properly proportioning *the windings* the ac input as indicated on an ac ammeter is a measure of the direct current and *the scale* can be so calibrated [J H M]

Very small currents *Small direct currents* in low resistance circuits can be measured with a standard resistance shunt and a *potentiometer* In high resistance circuits vacuum tube devices are

now usually preferred to electrometers Currents as low as 10^{-15} amp can be measured with shunts of 10^{1} or 10^{12} ohms and lower values can be measured by observing the rate at which the input capacitance is charged by the flow of current Negative feedback can be employed to reduce the voltage drop in the input loop when a shunt is used or to reduce the effective input capacitance and so increase the current sensitivity when the rate of charge method is used Small alternating currents can be measured with a shunt and an amplifier type vacuum tube voltmeter *See* ELECTROMETER

Current at high frequencies High frequency current is usually measured by its heating effect Thermocouple meters are most common and available single range commercial instruments are accurate to 1% up to 10 Mc Special purpose designs have been used to about 100 Mc Bridges incorporating thermistor elements in which resistance varies greatly with the heating are also widely used One of the best methods is to measure the voltage drop across a shunt with a diode rectifier type vacuum tube voltmeter At frequencies over a few hundred megacycles current is seldom measured directly but is usually computed from impedance and power measurements *See* VACUUM TUBE VOLTMETER VOLTAGE MEASUREMENT [W N T]

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Curry

A mixture of plant spices used with meats fish and sea foods. each *requiring its own specific curry* One favorite recipe calls for turmeric coriander cinnamon cumin ginger cardamon cayenne pepper pimiento black pepper long pepper cloves and nutmeg See separate articles on each of these spices *See also* SPICE AND FLAVORING [P D S]

Curve fitting

A procedure in which the basic problem is to pass a curve through a set of points representing experimental data in such a way that the curve shows as well as possible the relationship between the two quantities plotted It is always possible to pass some smooth curve through all the points plotted but since there is assumed to be some experimental error present such a procedure would ordinarily *not be desirable (see* INTERPOLATION)

The first task in curve fitting is to decide (1) how many degrees of freedom (number of unspecified parameters or independent variables) should be allowed in fitting the points and (2) what the general nature of the curve should be Since there is no known way of answering these questions in a completely objective way curve fitting remains something of an art It is clear however that one must make good use of any background knowledge of the quantities plotted if he is to answer the above two questions Thus if one knew that a discontinuity might occur at some value of the abscissa one would try to fit the points above and below that value by separate curves

Against this background knowledge of what the curve should be expected to look like one may observe the way the points fall on the paper One may even find it advantageous to make a few rough attempts to draw a reasonable curve through the points

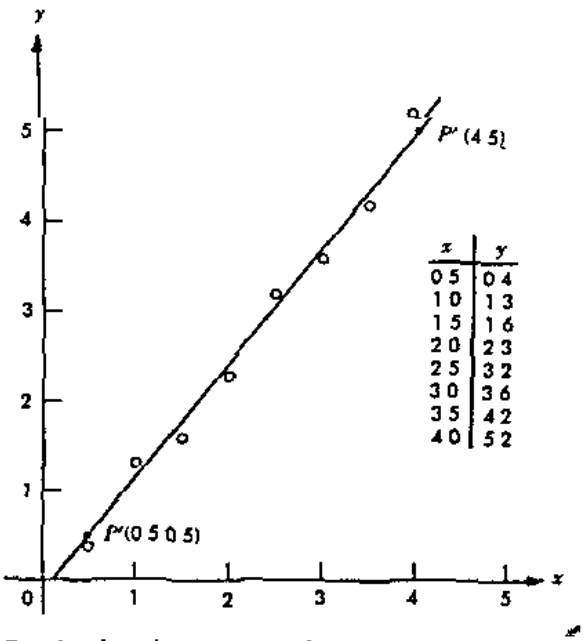
A knowledge of the accuracy of the data is needed to help answer the question of the number of degrees of freedom to be permitted in fitting the data If the data is very accurate one may use as many degrees of freedom as there are points The curve can then be made to pass through all the points and it serves only the function of interpolation At the opposite extreme when the data are very rough one may attempt to fit the data by a straight line representing a linear relation

$$y = ax + b \qquad (1)$$

between y and x Using the above information and one's knowledge of the functions that have been found useful in fitting various types of experimental curves one selects a suitable function and tries to determine the parameters left unspecified At this point certain techniques have been worked out to choose the optimum value of the parameters *One of the most general methods* used for this purpose is the method of least squares In this method one chooses the parameters in such a way as to minimize the sum

$$S = \sum_{i=1}^{n} [y - f(x)]^2 \qquad (2)$$

where y is the ordinate of ith point and $f(x)$ the



Graphical method of curve fitting

ordinate of the point on the curve having the same abscissa x as this point

Method of least squares If one attempts to fit the data with a straight line one lets

$$y = f(x) = ax + b \tag{3}$$

and Eq (2) becomes

$$S = \sum_{i=1}^{n} [y_i - ax_i - b]^2 \tag{4}$$

Since S is to be a minimum

$$\frac{\partial S}{\partial a} = \frac{\partial S}{\partial b} = 0$$

and therefore

$$\begin{aligned} a \sum x_i^2 + b \sum x &= \sum x_i y_i \\ a \sum x_i + bn &= \sum y_i \end{aligned} \tag{5}$$

The solution of these equations is

$$\begin{aligned} a &= \frac{1}{\Delta}\left[\sum_i x_i \sum_i y_i - n \sum_i x y_i\right] \\ b &= \frac{1}{\Delta}\left[\sum_i x_i \sum_i x y_i - \sum_i x_i^2 \sum_i y_i\right] \end{aligned} \tag{6}$$

where $$\Delta = (\sum_i x)^2 - n \sum_i x_i^2 \tag{7}$$

These values of a and b are those that minimize S and therefore represent the proper choice of the parameters of a straight line according to the criterion of least squares *See* LEAST SQUARES METHOD OF

Method of averages This method has less theoretical justification but it is easier to apply than the method of least squares

If all the points $(x\ y)$ for $i = 1\ 2 \quad n$ representing the data were to lie on a straight line one could require that a and b satisfy all n of the equations

$$y_i = ax + b \qquad i = 1\ 2 \qquad n \tag{8}$$

Any two of these equations could then be used to determine a and b One could also add these equations together in two groups to obtain the two equations

$$\begin{aligned} \sum_{i=1}^{k} y_i &= a \sum_{i=1}^{k} x_i + bk \\ \sum_{i=k+1}^{n} y_i &= a \sum_{i=k+1}^{n} x_i + b(n-k) \end{aligned} \tag{9}$$

Suppose now that the points do not lie on a straight line then Eqs (8) are no longer valid One may however assume that a best line through the points is given by Eq (3) with a and b determined by requiring that Eqs (9) be satisfied There is some arbitrariness in the choice of k but it is usually taken to be a whole number near $n/2$

Consider the data below

x	y
0 5	0 4
1 0	1 3
1 5	1 6
2 0	2 3
2 5	3 2
3 0	3 6
3 5	4 2
4 0	5 2

Letting $k = 4$ one obtains for the equations in (9)

$$\begin{aligned} 5a + 4b &= 5\ 6 \\ 13a + 4b &= 16\ 2 \end{aligned}$$

Subtracting one has $8a = 10\ 6$ or $a = 1\ 325$ and therefore $b = -0\ 256$, thus the best straight line is given by the equation

$$y = 1\ 325x - 0\ 256$$

Graphical method In this method one first plots the points $(x\ y)$ on coordinate paper using suitable scales along the X and Y axes (see illustration) One then takes a transparent straightedge and adjusts it so the points lie as near the edge as possible with about the same numbers above as there are below The straight line corresponding to the position of the edge is drawn in and the coordinates of two points $(x'\ y')$ and $(x''\ y'')$ near each end of the line are read off The straight line drawn is then given by Eq (3) with a and b determined by the simultaneous equations

$$\begin{aligned} y' &= ax' + b \\ y'' &= ax'' + b \end{aligned} \tag{10}$$

The coordinates of points P' and P'' in the illustration are respectively $(0\ 5\ 0\ 5)$ and $(4\ 5)$ therefore $a = 1\ 286$ and $b = -0\ 144$

Use of nonlinear scales Suppose one tries to fit the data points $(x\ y_i)$ with any general functional relation $y = f(x\ \alpha\ \beta)$ having two undetermined parameters α and β It often happens that it is possible to introduce two new variables

$$X = F(x) \quad \text{and} \quad Y = G(y) \tag{11}$$

that will satisfy the linear equation

$$Y = aX + b \tag{12}$$

From the given data points $(x_i\ y_i)$ one can obtain a new set of data points $(X_i\ Y_i)$ by the use of Eqs (11) One may then fit these points by a straight line in the XY plane given by Eq (12) using any of the techniques described above The required equation in x and y is then

$$G(y) = aF(x) + b$$

which will determine the original constants α and β

For example, suppose one assumes that

$$y = \beta e^{\alpha x} \tag{13}$$

Then, by taking the natural logarithm of both sides one has

$$\log y = \alpha x + \log \beta \tag{14}$$

Thus a linear equation as given in Eq (12) exists between

$$X = x \quad \text{and} \quad Y = \log y \tag{15}$$

with

$$a = \alpha \quad \text{and} \quad b = \log \beta \tag{16}$$

A graphical solution involves use of semilog paper in which the vertical displacement of points is proportional to $\log y$ On such paper, therefore Eq (14), or its equivalent, Eq (13), plots as a straight line

Consider next fitting data by the relation

$$y = \beta x^{\alpha} \tag{17}$$

which may also be written

$$\log y = \alpha \log x + \log \beta$$

Thus again the linear equation (12) connects

$$X = \log x \quad \text{and} \quad Y = \log y \tag{18}$$

and Eqs (16) again hold for the constants Logarithmic paper makes it simple to give the data points the rectangular coordinate values X and Y The best line through these points then determines a and b and, therefore, also α and β

If the plotting on logarithmic paper seems to lie about a curved line, one may try an equation of the form

$$y = \beta x^{\alpha} + \gamma \tag{19}$$

which may be written

$$\log (y - \gamma) = \alpha \log x + \log \beta \tag{20}$$

One therefore works with a linear relation between $\log x$ and $\log (y - \gamma)$

To obtain γ one draws a smooth curve through the points (x_i,y_i) and picks out two points (x',y') and (x'',y'') near the ends of this curve Next one chooses $x''' = \frac{1}{2}(x'x'')$ and finds the point on the curve (x''',y''') with this value of x It can be shown quite simply that

$$\gamma = \frac{y'y - (y'')^2}{y' + y'' - 2y}, \tag{21}$$

The values of a and b and therefore of α and β are found as before

If one decides to fit the data by a parabolic curve

$$y = \alpha + \beta x + \gamma x^2 \tag{22}$$

one may first draw a smooth curve through the points and select some point (x',y') on this curve The parabola will pass through this point if

$$y' = \alpha + \beta x' + \gamma x'^2 \tag{23}$$

From Eqs (22) and (23) one has

$$\frac{y - y'}{x - x'} = \beta + \gamma(x + x') \tag{24}$$

which shows that $(y - y')/(x - x')$ is a linear function of x Therefore for each data point (x_i,y_i) one may plot a new point (X_i,Y_i) with

$$X_i = x_i \quad \text{and} \quad Y_i = \frac{y_i - y'}{x_i - x'} \tag{25}$$

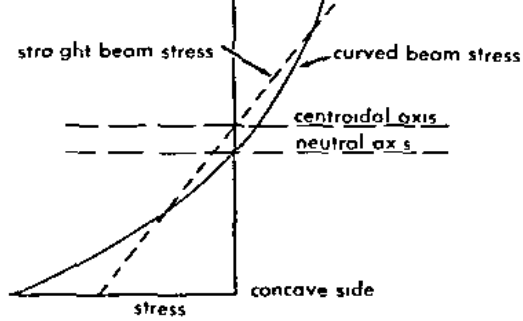
The best straight line through these points given by Eq (12) can be determined as before and this determines β and γ in Eq (24) The value of α is then determined from Eq (23) *See* COORDINATE SYSTEMS GRAPHICAL, EXTRAPOLATION, GRAPHIC METHODS [K S K]

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Curved bars

Structural members with relatively large initial curvature used as hooks chain links rings clamps and machine frames A curved bar is understood to mean a solid section as distinguished from an I T or hollow section also used in structural and machine frames

Stresses in curved bars accompanying change of curvature due to applied moment vary hyperbolically across the section rather than linearly as in an initially straight beam Also the neutral surface is not centroidal but is displaced toward the concave side Maximum stress occurs on the concave side of the curved bar For bars with large initial curvature, the stress predicted by direct application of the straight beam formula may be greatly in error This error decreases rapidly as the curvature decreases and may be only a few per cent for bars normally considered curved The simple flexure formula is applied to curved bars having commonly used cross sections with a correction factor determined by comparison of stresses predicted by the simple and more exact theory Thus stress S equals KMc/I, where M is bending moment, K



Comparison of stress distributions

Values of K for selected R/c ratios

R/c \ K	Rectangular section		Circular section*		Trapezoidal section†	
	Inside	Outside	Inside	Outside	Inside	Outside
1 2	2 89	0 57	3 41	0 54	3 09	0 56
1 6	1 79	0 67	1 96	0 65	1 91	0 66
2 0	1 52	0 73	1 62	0 71	1 61	0 73
3 0	1 30	0 81	1 33	0 79	1 37	0 81
6 0	1 12	0 90	1 14	0 89	1 17	0 91
10 0	1 07	0 94	1 08	0 93	1 11	0 95

* Same values for elliptical sections

† For ratio of bases of 1 2 and a depth 3 times the narrow base Factor does not vary greatly for other common dimensions Values of K for intermediate R/c ratios can be found by interpolation

varies with the R/c ratio and has different values for stresses on the concave and convex sides R is initial radius of curvature of the centroidal axis and c is distance from centroid to extreme element Correction of computed stresses is important when the R/c ratio is less than about 10 Values of K are presented in the table

Curved bars in pure bending When terminal couples are applied curved bars undergo changes in curvature accompanied by normal stresses on radial sections which are evaluated by the Winkler Bach formula derived with the same assumptions as for straight bars but accounting for the initial curvature The elastic flexural stress at distance y from the centroidal axis due to bending moment M in a bar with initial radius of curvature R is

$$S = \frac{M}{AR}\left(1 + Z\frac{\gamma}{R+\gamma}\right)$$

where A is sectional area and

$$Z = -\frac{1}{A}\int \frac{\gamma}{R+\gamma}\,dA$$

a property of the section Distance γ' to the neutral axis ($S = 0$) for pure bending is $\gamma' = -ZR/(Z+1)$ The hypobolic stress distribution according to the Winkler Bach formula for solid sections is compared with straight beam stresses in the graph For I or T sections warping of the flanges with nonuniform stress across the width requires a modified solution

Combined axial and bending stresses When the bending moment is accompanied by a normal force acting through the centroid of the section usually components of the external load both axial and bending stresses result Assuming uniform normal stress P/A, the resultant stress is found by superposition adding the normal stress to the stress at any point due to bending according to the curved bar theory or corrected straight bar formula

Deflection of curved bars The deformation of a curved bar, functioning as a part of a machine or structure may need to be limited by clearance tolerances, or performance characteristics The straight beam deflection formulas may be used without appreciable error when the radius of curvature is large compared with the depth of the section The deflection of beams with large initial curvature is usually found by energy methods applying Castigliano's theorem or the method of virtual work According to Castigliano's theorem when several forces operate on an elastic body the displacement Δ_p corresponding to any one force is proportional to the partial derivative of the strain energy with respect to that force, or $\Delta_p = \partial U/\partial P$ where Δ_p is the deflection at the point of application of a load P in the direction of P, and U is strain energy In the general case where the loading produces moment, shear and normal force on the sections strain energy U is given by

$$U = \int_0^s \left(\frac{M^2}{2ER^2A}\quad\frac{Z+1}{Z} + \frac{N^2}{2EA} + \frac{MN}{ERA} + \frac{\alpha V^2}{2AG}\right) ds$$

where α is a coefficient depending on the shape of the cross section s is the distance measured along the centroidal axis E is Young's modulus G is modulus of rigidity V is shear and N is axial force, the other terms are as before *See* BEAM COLUMN, COLUMN, CRANE HOOK, RING [W J KR]

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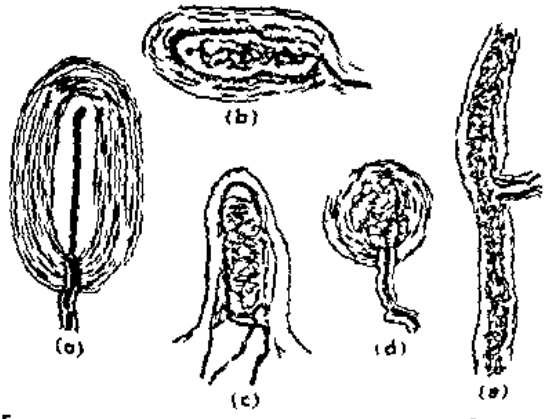
Cutaneous sensation

Any of several kinds of feeling originating in sensory nerve endings of the skin Current classifications of the senses usually specify four main types pressure or touch warmth cold and pain Other distinguishable cutaneous feelings such as contact prick heat and wet may be shown to consist either in variants of the basic four (for example contact is a bright lively pressure) or a blend of two or more of them (for example wet may be synthesized from cold and pressure)

Cutaneous nerve endings The skin has three main layers (1) epidermis the outermost protective tissue (2) corium or dermis and (3) subcutaneous tissue Sensory nerves proliferate into all three though most of them have their endings in the corium Free nerve endings naked fibrils that arborize somewhat promiscuously through the dermal tissues are the commonest sensory endings in the body They are found at all skin levels even penetrating the lower reaches of the epidermis All other types of endings may be regarded as elabora



Diagram of the skin in cross section (*E Gardner, Fundamentals of Neurology*, Saunders 1947)



Encapsulated nerve endings of the skin (*a*) Corpuscle of Vater Pacini, (b) Golgi Mazzoni's corpuscle (c) Meissner's corpuscle, (*d*) Krause's end bulb (e) Ruffini cylinder (*F A Geldard, Human Senses*, Wiley, 1953)

tions of this fundamental form Merkel disks representing a first step, consist of minute flattened platelets at the nerve tips Another variation of free nerve endings is the hederiform (ivylike) ending seen close to the epidermal boundary Aggregates of fibers are frequently found near the bases of hair follicles Those wrapped around the follicle or matted into a cup-shaped form near its base are known as basket endings In this position they are obviously optimally situated to be stimulated by hair movement

All other sensory endings of the skin represent greater anatomical elaboration The chief forms are the Meissner's corpuscle, sometimes called the tactile corpuscle for its presumed function in being responsible for the touch sensation in hairless portions of the skin, Krause's end bulb, for which strong claims have been made as a cold receptor, Ruffini cylinder suspected as a mediator of warmth, corpuscle of Vater Pacini and Golgi Mazzoni's corpuscle both of them lamellated and complexly organized The corpuscle of Vater Pacini is the largest encapsulated ending in the body measuring up to 4 5 mm long and being visible to the unaided eye

Punctate sensibility of the skin. Exploration of the skin surface with a rounded metal point (or a dull pencil) will promptly show that it is not uniformly sensitive Moving such a stimulator gently across the back of the hand will bring out contact in some places, cold at other and perhaps tickle or itch at still others Systematic mapping of skin sensitivity with pointed blunted cooled and heated contactors will reveal somewhat stable patterns of spots or local areas having their own kind of sensitivity Thus there may be plotted maps of pressure points warm and cold spots and pain points The number and size of the spots in any exploration will be a function of the intensity of the stimulus (mechanical deformation for pressure and pain deviation from skin temperature for warm and cold)

Because skin sensitivity varies from locus to locus, and there are several different kinds of nerve terminations supplying the skin there has naturally been much effort directed at finding correlations between types of sensitivity and types of end organs Indeed this is the dominant theme in current cutaneous theory Thus far no invariable correspondences have been demonstrated with certainty

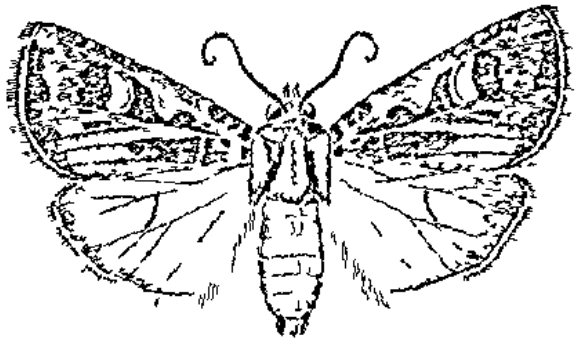
See Pain cutaneous, Temperature senses, Touch

[F A G]

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Cutworm

Any of several species of moths of the family Phalaenidae having nocturnal caterpillars They feed on succulent plant stems at the level of the ground thus cutting them down Cutworms frequently destroy young tomato cabbage, and other plants when they are first set out in the spring They can overwinter either as pupae or caterpil



The dingy cutworm, Cirphis unipuncta, wingspread 1½ in (*From E L Palmer, Fieldbook of Natural History, McGraw-Hill*, 1949)

lars There may be one or two generations a year Cutworms are usually mottled gray or brown in color, and most have the habit of coiling up like a snail shell when disturbed The adults usually called millers, are gray, brown or black, and mottled or banded on the forewings The hind pair of wings is usually white with darker outer margins Adults have a spread of 1–2 in *See* CATERPILLAR, LEPIDOPTERA, MOTH [J D B]

Cyanamide

A term used to refer to the free acid $CNNH_2$, or commonly to the calcium salt of this acid $CaCN_2$, which is properly called calcium cyanamide

Calcium cyanamide is manufactured by the cyanamide process in which nitrogen gas is passed through finely divided calcium carbide at a temperature of 1000°C

Most plants are equipped to produce the calcium cyanamide from the basic raw materials of air, limestone and carbon according to the following series of equations

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2 \quad (1)$$
$$CaO + 3C \rightarrow CaC_2 + CO \quad (2)$$
$$CaC_2 + N_2 \rightleftharpoons CaCN_2 + C \quad (3)$$

Most calcium cyanamide is used in agriculture as a fertilizer, some is used as a weed killer, as a pesticide and as a cotton defoliant.

Cyanamide ($CNNH_2$) is prepared from calcium cyanamide by treating the salt with acid It is used in the manufacture of dicyandiamide and thiourea *See* CARBON, NITROGEN [E E WR]

Cyanate

A compound containing the —OCN group and derived from cyanic acid HOCN Cyanates are isomeric with fulminates which have the same atoms arranged thus —ONC

Like hydrogen cyanide and thiocyanic acid cyanic acid may exist in two forms, HO—C≡N and H—N=C=O the latter of which is called isocyanic acid The alkali and alkaline earth metal cyanates contain an anion which may also be written in two forms [N≡C—O] and [O=C=N] These salts are water soluble

The heavy metal cyanates are more covalent in nature and are water insoluble The main use of cyanates is in the synthesis of organic compounds

Ammonium cyanate rearranges easily to urea as indicated in the equation

$$NH_4OCN \rightleftharpoons NH_2CONH_2$$

The alkali metal cyanates may be prepared by the direct oxidation of the cyanide with oxygen or another suitable oxidizing agent under controlled conditions *See* CARBON, CYANIDE, NITROGEN, THIOCYANATE [E E WR]

Cyanide

HCN Hydrogen cyanide may exist in two forms, HCN and HNC The latter or iso form gives rise to a class of organic compounds called isocyanides or isonitriles Organic derivatives of the first form are called nitriles as well as cyanides

The inorganic cyanides resemble the halides in many ways—in their chemical reactions and their tendency to form complexes as well as simple ionic salts In fact, a group of univalent inorganic radicals has been called halogenoids or pseudohalogens because of this similarity The group includes among others, cyanide, —CN, thiocyanate —SCN, cyanate, —OCN, and azide $—N_3$ Cyanogen $(CN)_2$, is the halogenoid corresponding to the free halogen, that is chlorine Cl_2

Of the simple ionic cyanides the potassium sodium, and calcium salts are most important commercially Three typical processes are given here The Castner process results in the formation of sodamide,

$$2NH_3 + 2Na \rightleftharpoons 2NaNH_2 + H_2$$

and the reaction with carbon at 400–700°C,

$$NaNH_2 + C \rightleftharpoons NaCN + H_2$$

In the Beilby process the following reaction occurs

$$K_2CO_3 + 4C + 2NH_3 \rightleftharpoons 2KCN + 3CO + 3H_2$$

A third process involves the conversion of calcium cyanamide in the presence of sodium chloride

$$CaCN_2 + C \xrightarrow{NaCl} Ca(CN)_2$$

The formation of coordination complexes is an important phase of the chemistry of cyanides in both the laboratory and the plant *This ability to* form complexes finds industrial use in plating baths and concentration of gold and silver ores

Representative types of cyano complexes are $[Au(CN)_2]^-$, $[Ag(CN)_2]^-$, $[Fe(CN)_6]^{-4}$, and $[Fe(CN)_6]^{-3}$ These last two are known as ferrocyanide and ferricyanide respectively Cyanides are also used for casehardening of steel as pesticides and in the manufacture of ferrocyanides *See* COORDINATION CHEMISTRY, CYANATE, FERRICYANIDE FERROCYANIDE, NITRILE, NITROGEN, THIOCYANATE [E E WR]

Cyanoethylation

A chemical reaction involving the addition of compounds carrying a reactive hydrogen to acrylonitrile (CH_2=CH—CN) to introduce the *β cyanoethyl* grouping ($—CH_2CH_2CN$)

$$ZH + CH_2{=}CH—CN \rightleftharpoons ZCH_2CH_2CN$$

Cyanoethylation can be effected with *HBr HCl* HCN, and with compounds containing the following functional groups —AsH, —BH —CH (*when activated by adjacent electron withdrawing groups*) —NH, —OH —PH, —SH, —SiH and —SnH The

products can be subjected further to the usual nitrile reactions, such as hydration, hydrolysis and reduction

$$ZCH_2CH_2CN \rightarrow ZCH_2CH_2CONH_2$$
$$ZCH_2CH_2CN \rightarrow ZCH_2CH_2COOH$$
$$ZCH_2CH_2CN \rightarrow ZCH_2CH_2CH_2NH_2$$

Because of its versatility, cyanoethylation has assumed great importance in synthesis, as shown by the fact that over 1200 compounds have been used as reactants Introduction of the cyanoethyl group tends to increase hydrophobic character and resistance to biological attack Natural products, notably cellulose, have been cyanoethylated to take advantage of these properties

Substrates for cyanoethylation. The nature of the catalyst is used to classify substrates into three groups

No catalyst —AsH, —BH, —NH (aliphatic), —PH, —SnH, HBr, and HCl,

Basic catalyst (for example, NaOH, $NaOCH_3$, benzyltrimethylammonium hydroxide) —CH —NH (amide and certain heterocycles), —OH, —PH, —P(O)H, —SH, and HCN,

Acid catalyst (for example acetic acid with or without a copper salt) —NH (aromatic), $—NH_2$ (t carbinamines)

Yields in cyanoethylation are generally high The reaction is strongly exothermic and is usually carried out at moderate temperatures in a solvent such as dioxane or t butanol Acrylonitrile itself has been used as a diluent but this method is not widely applicable in base catalyzed cyanoethylation because of competing anionic polymerization of acrylonitrile High temperatures and high concentrations of base tend to reverse the process

Cyanoethylation of natural polymers Since the extent of cyanoethylation can be varied by choice of conditions a variety of products can be obtained from a given material These may be further modified by reactions of the cyanoethyl group, for example to give polyelectrolytes

Partially cyanoethylated cellulose, in which one sixth of the hydroxyl groups have reacted is rot and termiteproof it has improved resistance to degradation by heat and by acids as well as altered dyeing characteristics and greater hydrophobicity Crystallinity and morphology of the cellulose are retained Utility is in marine nets and ropes, electrical insulation industrial fabrics structural wood and dimensionally stable paper

In the cyanoethylation of cotton, the fabric is first padded with 6% sodium hydroxide solution and with acrylonitrile and then passed continuously into a chamber heated to about 75°C by acrylonitrile vapor After a residence time of about 3 5 min, the caustic impregnated cotton is neutralized, washed and dried Unreacted acrylonitrile is recovered and recycled

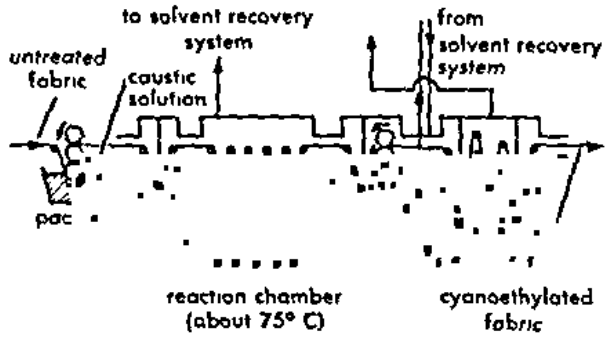


Fig 1 Flow diagram for cyanoethylation (From Cyanoethylation of Cotton, joint publication of American Cyanamid Co , Monsanto Chemical Co , and the Institute of Textile Technology, September, 1956)

Highly cyanoethylated cellulose (two-thirds or more of hydroxyl groups reacted) is an amorphous, thermoplastic material which is soluble in acrylonitrile, dimethylformamide, and pyridine Unhindered rotation of the polar cyanoethyl segments imparts an unusually high dielectric constant (13 3 at 60 cycles and 25°C) a property useful in capacitors and in matrices for electroluminescent phosphors

Starch cyanoethylated to retain water solubility, has the ability to prevent soil from redepositing on washed fabrics More highly cyanoethylated starch is soluble in organic solvents

In the cyanoethylation of proteins the free amino and possibly the amide groups are attacked Complete resistance to putrefaction results when casein is cyanoethylated with as little as a 5–10% by weight of acrylonitrile Cyanoethylated wool has increased affinity for cationic and direct dyes



Fig 2 Appearance of cotton after burial in s two weeks (a) Untreated (b) Partially cyanoet

See ACRYLONITRILE, ADDITION REACTION TEXTILE CHEMISTRY [N B]

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Cyanogen

A colorless highly toxic gas having the molecular formula C_2N_2 Cyanogen belongs to a class of compounds known as pseudohalogens because of the similarity of their chemical behavior to that of the halogens

Cyanogen may be prepared by heating mercuric cyanide

$$Hg(CN)_2 \rightarrow Hg + C_2N_2$$

or by allowing a solution of copper sulfate to flow slowly into a solution of potassium cyanide

$$2KCN + CuSO_4 \rightarrow Cu(CN)_2 + K_2SO_4$$

The copper(II) cyanide is unstable decomposing to give cyanogen and copper(I) cyanide

$$Cu(CN)_2 \rightarrow CuCN + \tfrac{1}{2}C_2N_2$$

When heated to 400°C cyanogen gas polymerizes to a white solid paracyanogen $(CN)_x$

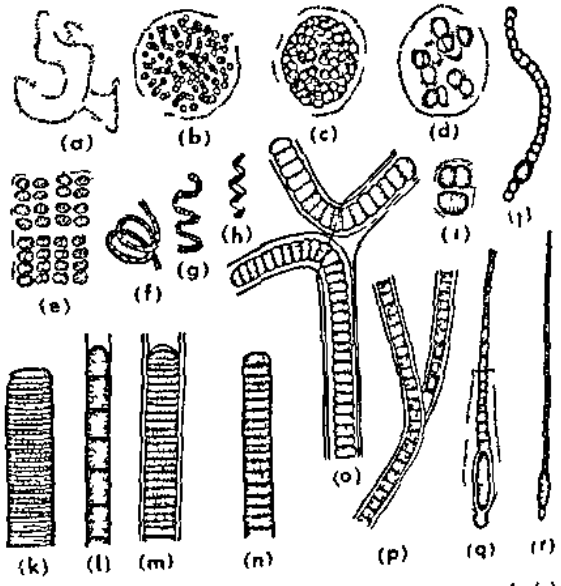
Structurally cyanogen is written $C{\equiv}N{-}N{\equiv}C$

See CYANIDE [F J J]

Cyanophyta

Blue green algae also known as Myxophyta a phylum of primitive microscopic unicellular plants which sometimes become organized into loose aggregations called colonies The nuclear or hereditary material probably chromatin is scattered throughout the center of the cell rather than being organized into a definite nucleus as in higher plants The chlorophyll similarly diffused throughout the peripheral portion of the cell is not localized in plastids as in more advanced forms In addition to the green chlorophyll there is also present a blue pigment called phycocyanin sometimes mixed with a red pigment (The Red Sea derives its name from the fact that one species of the Cyanophyta gives it a reddish color)

Distribution Most of the species of Cyanophyta occur in fresh water although a few are marine Certain types may become so abundant in lakes and ponds as to give the water a green or yellow green color Many blue green algae occur in the soil and in such damp places as flower pots and the sides of stones Some species are common pests in greenhouses where they foul the soil in beds and pots Dripping rock ledges and cliffs are often richly covered with these plants Several species grow in hot springs such as those in Yellowstone National Park where the temperature of the water may be 170°F These thermal algae as they are called cause the precipitation of calcium and magnesium salts forming travertine which is brilliantly colored by the algae present Blue green algae may also cause the precipitation of calcium carbonate from lake water leading to the formation of marl deposits at the bottom of the lake Other species grow as epiphytes (upon other plants) or are found in their cavities such as in the intercellular spaces of leaves Occasionally a blue green alga becomes associated symbiotically with a fungus in the formation of a lichen (*see* LICHENS) A few species are rather mild parasites in the digestive tracts of man and other animals



Forms of blue green algae Genera represented (a) *Microcystis* (b) *Aphanocapsa* (c) *Coelosphaerium* (d) *Chroococcus* (e) *Merismopedia* (f) and (m) *Lyngbya* (g) and (j) *Anabaena* (h) *Spirulina* (i) Chroococcus (k) and (n) *Oscillatoria* (l) *Phormidium* (o) *Scytonema* (p) *Tolypothrix* (q) *Gloeotrichia* (r) *Cylindrospermum* (*E N Transeau H C Sampson and L H Tiffany Textbook of Botany* rev ed Harper 1953)

Reproduction The only method of reproduction is asexual usually by simple cell division or by fission (constriction) None of the cells vegetative or reproductive has flagella (whiplike structures of locomotion) Often the cells are enclosed in a slime or gelatinous sheath The storage food is either glycogen (a carbohydrate similar to starch) or a glycoprotein

Origin and relations to other organisms The phylogenetic origin of the Cyanophyta is unknown but it is thought that they probably arose from non flagellated forms This ancestral stock may or may not be related to the flagellated unicells which apparently gave rise to the other phyla of algae In some respects the Cyanophyta resemble the Rhodophyta or red algae They both lack flagellated motile cells and they both possess a red pigment which is chemically similar The cell structure of the Cyanophyta is more primitive than that of any other organisms known to science except the bacteria The two are alike in their lack of a highly organized nucleus and in their method of reproduction The blue-greens occur as the oldest known fossil plant remains They have been described from the Proterozoic rocks which are judged to be 2,300 000 000 years old

Economic importance Economically Cyanophyta are important as food for fish and other aquatic organisms which in turn may be eaten by man They are a nuisance in that they may render water in reservoirs unfit to drink because they impart a foul odor (pigpen odor) and a fishy taste to the water Dilute concentrations of copper sulphate may be used to poison or control them Sometimes they form a dense growth on the surface of pools discoloring the water and producing the phenomenon known as water bloom It has been reported that cattle have been poisoned by drinking this water Blue-green algae often grow in large colonies on soils and as they die contribute to the organic fertility *See* ALGAE [P D S]

Bibliography See THALLOPHYTA

Cybernetics

The science of control and communication in all of its various manifestations in machines animals, and organizations It is thus an interdisciplinary science which incorporates and unifies the work of the servomechanisms and systems engineer the communications engineer and certain aspects of the work of the physiologist neurologist psychologist sociologist and economist

There are several unifying threads which link all these activities into the science of cybernetics One is the notion of feedback which seems common to all problems of regulation and control—or to use the psychologists's term goal directed activity—whether that activity be the training of a gun toward a target or the reaching to grasp a pencil or the setting of the price on a commodity Another is the fact that, contrary to most other sciences the transfer of energy is usually of little consequence it is the transfer of information which is vital Still another is the language of statistics which seems most useful in describing the performance of these closed loop systems

History The name cybernetics was first applied to this science by Norbert Wiener in 1947 It is taken from a Greek word which is variously translated steersman or governor For some years a number of people notably Norbert Wiener and Arturo Rosenblueth had recognized an important degree of unity in the problems of communication and control wherever they arose and had been hampered by the lack of unity in terminology applied to the same phenomena when discussed in the contexts of different fields Their choice of a new name for the unified field was due largely to their desire to employ a term that would not indicate a bias toward any of the disciplines which they visualized as comprising the unified field The beginnings of this field may be traced to a Macy Foundation Conference on cerebral inhibition in May 1942 at which some of the problems presented focused attention on the fact that the control engineer may have something to offer the neurologist The early development of the field was greatly stimulated by a series of conferences sponsored by the Macy Foundation during the years 1946–1953 The transactions of the last five of these conferences are published

Scope Although the originators of the word cybernetics as used in this context had a broad definition in mind the common connotation of the term applies to those activities in which the work of the communication and control engineer specifically interacts with the work of the physiologist and neurologist This interaction may be in either of two senses (1) the notions familiar to the systems engineer may be used to describe certain processes in muscle and nerve systems and (2) the organization of systems in the animal as well as they are understood may lead to improved organization or design of control and communication systems

The appropriation of systems engineering concepts by the physiologist and neurologist has resulted in a substantial furthering of the understanding of processes in living organisms Probably the earliest example of this kind of activity was the work of Wiener and Rosenblueth in 1946 at the Instituto Nacional de Cardiologia in Mexico They studied the phenomenon of clonus the periodic contraction and relaxation of a muscle loaded to near capacity which occurs even without loading as a result of certain nervous disorders Working chiefly with cats they measured the transmission of impulses through the various nervous and muscular elements that comprised the closed loop system under test—the loaded muscle Knowing the open loop transfer characteristics of this system and employing the standard feedback relations they were able to predict with encouraging accuracy the frequency of the oscillations of the closed loop system

Since that time a great many of the processes in living tissues have been described in terms familiar to the systems engineer In regard to certain of its processes the central nervous system may be treated as a switching network in which the switching components are the neurons or nerve cells and the logical organization of these components is defined by the synapse the properties of the junction areas between neurons The output of each neuron is binary in nature—either it is at rest or it fires—and its output condition at any instant depends in a logical sense upon its own prior condition and upon the conditions of the afferent neurons those whose output is brought to bear upon the given neuron Usually the closed feedback loops which are considered such as that involved in clonus, include effector neurons muscle tissue outside environment sensor neurons and synapse However it may be possible for the synapse to form closed loops strictly within the central nervous system It is then possible to have neuron loops with a steady state condition of oscillation as in a multivibrator circuit Experimental evidence has been obtained for the existence of such loops and these self sustained oscillations, perhaps with variable frequency have been postulated as mechanisms for a wide variety of phenomena including short

memory *See* BIOPOTENTIALS AND ELECTROPHYSIOLOGY, ENDOCRINE MECHANISMS, HOMEOSTASIS, MUSCLE (BIOPHYSICS), NERVOUS SYSTEM

Application to equipment design. The application of insight gained in the study of living systems to the design of electromechanical control and communication systems is in its infancy Undoubtedly there is much to be learned from such study It is clear that the bat realizes a remarkable resolution for the wavelength used in its radarlike sensor, animals have a highly developed capability for adapting to changing environments—a capability which is desired in every control system, the reliability with which complex living organisms function should be the envy of every systems engineer

A great deal has been said about the relation of redundancy to reliability Among the first to explore this matter in an organized fashion was John von Neumann who lectured in 1952 on the subject of the synthesis of reliable organisms from unreliable components In these lectures he presented an organized approach to the use of redundant components—"multiplexing," as he termed it—as a means of improving the reliability of a system using components of given reliability The achievement of significant improvements in reliability depends on the use of many times the number of components that the original system called for In the human nervous system there are approximately 10^{10} neurons so that an adequate number of basic components is available to achieve systems of high reliability by multiplexing It seems clear that in no living organism yet explored has there been a dependence on the proper functioning of a particular neuron in every case the result depends on the cumulative effect of the operation of a large number of neurons so that the importance of any individual neuron is greatly diminished The application of these notions to other systems awaits the further microminiaturization of components that will permit their use in large numbers within practical constraints on size weight, and power

There is also great interest in systems with the adaptability to compensate automatically for changes in their operating environments or perhaps even for errors in their own construction Such systems are in a sense capable of learning how to behave properly and as such exhibit in an elementary way the homeostatic behavior of living organisms that is, the behavior which holds certain important properties relatively constant in spite of varying environment The adaptive mechanisms of such systems may be of widely differing degrees of

tem remain within

rameters of the system, such as loop gains are then chosen at random and so long as the system displays good behavior, these parameter values are used If the system displays poor behavior, as it would, for example, if it were unstable for the particular choice of parameter values then a new set of parameter values is chosen at random By continuing these random choices upon evidence of poor behavior, unsuitable sets of parameter values are rejected until a suitable set is obtained *See* COMMUNICATIONS, ELECTRICAL, CONTROL SYSTEMS, SYSTEMS ENGINEERING [WEVV]

A Bibliography of Information Theory, Communications Theory—Cybernetics, 1953, H S Tsien *Engineering Cybernetics*, 1954, N Wiener, *Cybernetics*, 1948

Cycadales

An ancient order of the plant class Gymnospermae having a few living representatives (living fossils) These plants, popularly called palms range in height from 2 ft (*Zamia*) to 60 ft (*Macrozamia*) The tuberous or columnar stems bear a crown of large, usually pinnate leaves (*Cycas revoluta* the best known cycad, is called sago palm)



Sago palm, *Cycas revoluta* Two to the right show megasporophylls grouped into the ovulate cones (*New York Botanical Garden*)

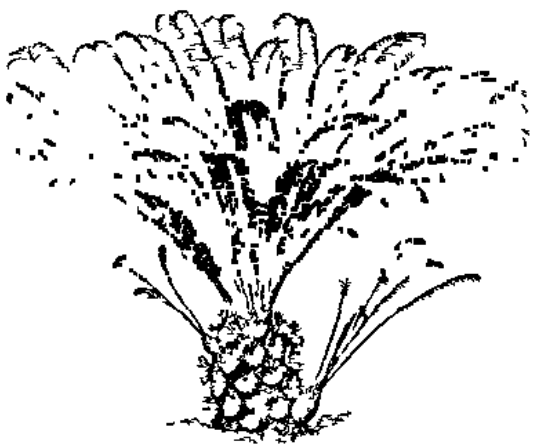
The cycads appeared along with the Bennettitales, in the Upper Carboniferous and made their greatest display in the Cretaceous (*see* GEOLOGY) In the Mesozoic, the distribution was world wide but the living members of the order are confined to the tropical and subtropical regions where they occur in scanty patches Both microsporophylls and megasporophylls are borne in cones male and female cones appearing on separate plants (dioecious) This group evolved from the Cycadofilicales Today, there is but one family with 9 genera and approximately 100 species *See* EMBRYOPHYTA, PLANT KINGDOM [PDS]

Cycadeoidales

An extinct order of plants that formed a conspicuous part of the landscape during the Triassic, Jurassic, and Cretaceous periods The Cycadeoidales (or Bennettitales) had unbranched, or sparsely branched trunks with a terminal crown of leaves (family Cycadeoidaceae), or they were branched, at times profusely (family Williamsoniaceae)

The squat barrel shaped trunks of members of the Cycadeoidaceae were covered with a dense armor of persistent leaf bases and were terminated by a crown of pinnately divided leaves On the trunk surface, among the leaf bases, were borne complex, flowerlike fruiting structures, each with a central seed bearing receptacle, surrounded by a whorl of frondlike pollen bearing appendages Two rows of pollen sacs were borne on each of the lateral members of the frond Dicotyledonous embryos have been observed in the seeds

In members of the Williamsoniaceae the flower like fruiting structures were not borne among leaf bases, and were often stalked They had both pollen



Reconstruction of a *Cycadeoidea* showing a terminal crown of leaves on each of the stems persistent leaf bases and the flowerlike fruiting structures (*From W H Brown The Plant Kingdom*, Ginn 1935)

bearing and seed bearing structures in the same "flower" or these organs may have been borne in separate "flowers" Seeds were borne on the surface of a domelike receptacle while the pollen bearing organs were fused at the base to form a whorl of simple or pinnate structures Foliage was either pinnately divided or entire No known relatives of the Cycadeoidales exist at the present time, although members of the order Cycadales show some resemblances to the extinct group *See* EMBRYOPHYTA, PALEOBOTANY PLANT KINGDOM [TD]

Cycadofilicales

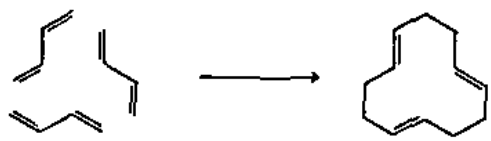
An ancient order of the plant class Gymnospermae now known only as fossils These plants, either trees or vines bore large 2 or 3 pinnate fernlike leaves The fossil imprints resemble fern leaves so closely that botanists first thought the plants were ferns However, in 1903 the naked seeds were discovered, revealing that they were gymnosperms, hence they were called pteridosperms or seed ferns These plants appeared in the Devonian reached their zenith in the Upper Carboniferous, and became extinct in the Jurassic The sporophylls, bearing either microsporangia or megasporangia, did not form cones The Cycadofilicales probably evolved from a fern ancestry During their zenith these plants were associated with the giant lycopods and calamites and formed an important part of the coal forming vegetation *See* EMBRYOPHYTA, PALEOBOTANY, PLANT KINGDOM, PTERIDOSPERMAE [PDS]

Cycadophytae

A subclass of the plant class Gymnospermae The cycadophytes are comparatively small plants having mostly unbranched stems pinnate leaves large pith scanty wood and a thick cortex The group includes three orders Cycadofilicales Bennettitales, and Cycadales of which only the latter has living representatives See separate articles describing each of these orders, *see also* EMBRYOPHYTA, PALEOBOTANY, PLANT KINGDOM [PDS]

Cyclododecatriene

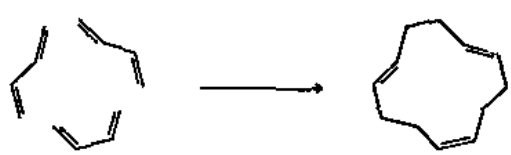
The discovery by G Wilke in 1957 that Ziegler type catalysts could selectively trimerize butadiene to 1 5,9 cyclododecatriene $C_{12}H_{18}$, has made available a new chemical having a large industrial potential Depending on the heavy metal employed in the preparation, either the *trans,trans,trans*



(I)

cyclododecatriene (I), boiling point (11 mm Hg) 100–101°C melting point −18°C is obtained in 80% yield, or a mixture of the above with its stereoisomer, *trans,trans,cis* cyclododecatriene (II) melting point 34°C is obtained, with a yield of over 90%

Treatment of (II) with acetaldehydeperacetate gives a 95% yield of liquid monoepoxides consisting of a mixture of two stereoisomers Under the same conditions (I) gives a similar yield of a crystalline monoepoxide The epoxides may be hydrogenated to an alcohol which on oxidation gives dodecandioic acid The hydrogenated epoxide can be rearranged to the ketone, the oxime of which un

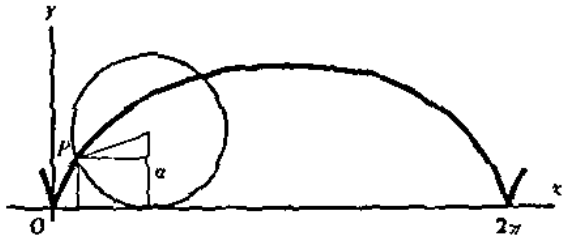


(II)

dergoes a Beckmann rearrangement to give ω amino dodecanoic acid lactam The acid may be used for the production of polyester fibers and the lactam for the production of *superpolyamides* *See* ALKENE CYCLOOCTATETRAENE, EPOXIDATION [C A C]

Cycloid

A curve traced in the plane by a point on a circle that rolls without slipping on a line If the line is the x axis of a rectangular coordinate system at whose origin O the moving point P touches the



Cycloid

axis parametric equations of the cycloid are $x = a(\theta - \sin\theta)$ $y = a(1 - \cos\theta)$ when a is the *radius of the rolling* circle and the parameter θ is the variable angle through which the circle rolls (*see* illustration) One arch is obtained where θ assumes all values from 0 to 2π The length of an arch is $8a$ and the area bounded by an arch and the x axis is $3\pi a$ (that is three times the area of the rolling circle)

Two important properties of the cycloid are the following (1) it is isochronous that is if the line is horizontal then the time of *descent of a* particle starting from rest at a point of a cycloidal runway and falling to its lowest point is independent of the starting point (2) it is a brachistochrone that is if P_1 P_2 are two points in a vertical plane but not in a vertical line the curve down which a particle will fall from P_1 to P_2 in the shortest time is an arc of a cycloid *See* ANALYTIC GEOMETRY [L M BL]

Cyclone

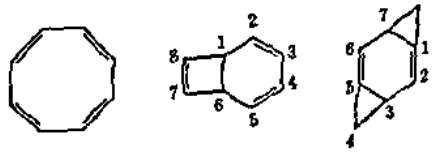
A low pressure region of the earth's atmosphere with roundish to elongated oval ground plan in moving ground air currents centrally upward (commonly spiraling) air movement and generally outward movement at various higher elevations in the lower layer (troposphere) of the terrestrial atmosphere This type of air circulation is called cyclonic and develops in many variations but it is distinctly different and approximately the reverse of anticyclonic which is developed in similarly shaped air portions of high atmospheric pressure (*see* ATMOSPHERIC HIGH) The unqualified term cyclone is used by meteorologists to designate atmospheric disturbances of considerable size in tropical middle or high latitudes *See* AIR PRESSURE, ATMOSPHERIC LOW FRONT, PRECIPITATION (METEOROLOGY), STORM, WIND Certain small and usually violent cyclonic disturbances of the tropical and middle latitudes are designated by special names *See* HURRICANE, TORNADO, WATERSPOUT [C V C]

Cyclooctatetraene

A cyclic olefin (formula C_8H_8) first synthesized by R Willstatter in 1911 who obtained 4 g of it from

yield was obtained with nickel cyanide as catalyst in tetrahydrofuran at 60–70°C and 15 20 atm pressure Physical constants are boiling point (760 mm Hg) 142–143°C boiling point (17 mm Hg) 42–42 5°C melting point −7°C density 0 9206 refractive index 1 5290 In its reactions it behaves as a typical olefin and can be hydrogenated epoxidized oxonated with carbon monoxide and hydrogenated It undergoes a Diels Alder condensation reaction with maleic anhydride

Based on the products formed it may react (I) as an eight membered ring 1 3 5 7 cyclooctatetraene (II) as a bicyclo(4 2 0)2,4 7 octatriene and (III) as tricyclo[5 1 0 0 3,5] 1 5 octadiene The eight membered ring remains intact during hydrogenation, epoxidation oxonation and metallation with lithium and sodium Structure (II)

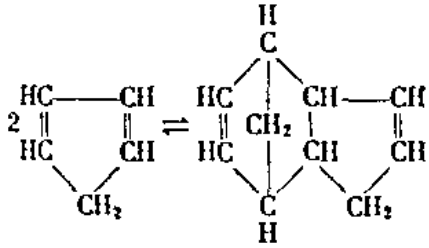


(I) (II) (III)

best explains the formation of benzoic acid on oxidation Also treatment of the olefin with aqueous mercuric sulfate produces phenyl acetaldehyde and addition of hydrogen bromide gives α bromoethylbenzene On the other hand structure (III) best explains the formation of terephthalic acid when the tetraene is oxidized with chromic acid and the production of terephthaldehyde upon treatment with sodium hypochlorite The wide variety of products that may be formed from cyclooctatetraene should make this material an important industrial chemical in the future *See* ALKENE POLYALKENE [C A C]

Cyclopentadiene

A colorless liquid with a sweet terpenelike odor boiling point (760 mm) 41.5°C melting point −85°C density 0 8026 refractive index 1 4120 formula C_5H_6 It rapidly dimerizes at ordinary temperatures to dicyclopentadiene from which the monomer may be readily regenerated by simple distillation Cyclopentadiene forms higher polymers such as the trimer and tetramer by heating under pressure It reacts readily with dienophiles to give bicycloheptene derivatives (*see* DIELS



Cyclopentadiene Dicyclopentadiene

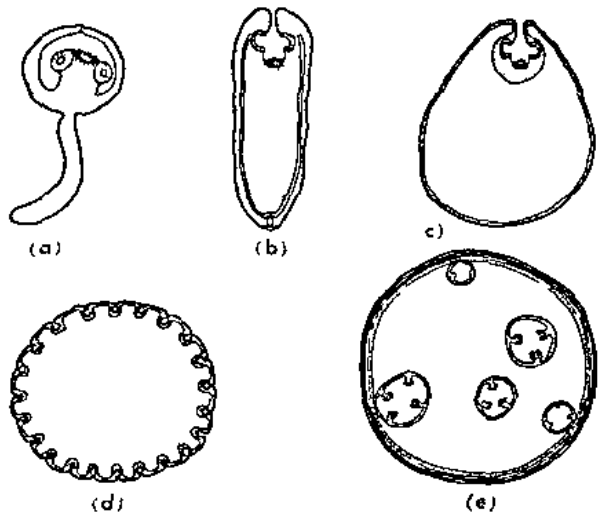
ALDER REACTION) One hydrogen of the methylene may be replaced with sodium and the sodium cyclopentadienyl converted to biscyclopentadienyl iron (Ferrocene) or carbonated to the dimer dicarboxylic acid Cyclopentadiene undergoes aldol condensation with aldehydes and ketones to give highly colored fulvenes Commercially important products derived from cyclopentadiene or its methyl homolog are norbornylene carbic anhydride insecticides such as aldrin and dieldrin and modified resins and drying oils *See* DIENE [C A C]

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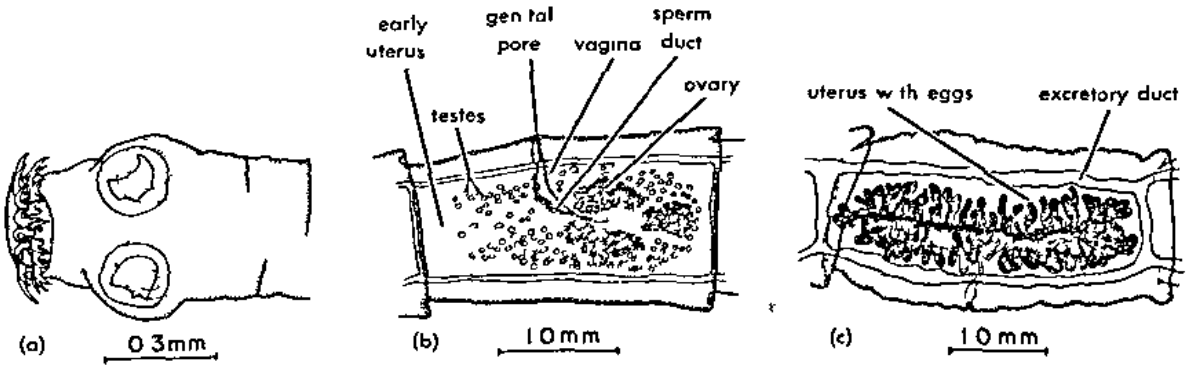
Cyclophyllidea

worm has a head or scolex and a segmented body called the strobila The scolex typically has an apical rostellum or muscular pad and hooks and two pairs of lateral suckers New segments are produced immediately posterior to the scolex so that the oldest segment is at the hind end As a segment is pushed further from the scolex the male and female reproductive organs mature and open on the lateral margin Ova fertilized by sperm from the same or another segment gather in a uterus The ripe terminal segments containing infectious eggs are shed into gut contents of the host

If an intermediate host such as an invertebrate or less often a vertebrate eats the eggs an immature stage the metacestode develops Commonly it grows in the hemocoel or blood cavity of invertebrates or in the liver of vertebrates, but depending on the tapeworm it may occur on or in almost any organ Generally the metacestode has one or more scoleces characteristic of the adult worm but the remainder of the body may have one of several forms The cysticercoid, usually small and found in invertebrate hosts has the scolex retracted but not invaginated and frequently there is a tail like appendage The remaining types of metacestodes of this group lack the tail appendage and have the scolex invaginated that is pulled in on itself as when the finger of a glove is pushed inside out A plerocercoid which occurs in both invertebrates and vertebrates has a solid body whereas the other types of metacestodes all of which occur only in vertebrates have a body formed into a bladder If a single invaginated scolex is present the bladder is called a cysticercus When many scoleces up to a hundred or so protrude inward from the common bladder wall this is called a coenurus The hydatid cyst is a modified bladder containing large numbers of attached and free floating brood capsules each with one or more scoleces The metacestode usually remains quiescent until the intermediate host is eaten by a definitive host and then the tapeworm



Immature stages of tapeworms (a) Cysticercoid (b) Plerocercoid (c) Cysticercus (d) Coenurus (e) Hydatid



Tapeworm (a) Scolex (b) Mature proglottis (c) Ripe proglottis

Some cyclophyllidean tapeworms

Name	Definitive host	Intermediate host	Type of metacestode
Dipylidium caninum (Double-pored tape worm of dogs and cats)	Dogs and cats occasionally children	Fleas and biting lice	Cysticercoid
Echinococcus granulosus (Hydatid tapeworm)	Dogs other canines	Many vertebrates including man	Hydatid
Hymenolepis nana (Dwarf tapeworm)	Man mice rats	None or fleas and beetles	Cysticercoid
Moniezia expansa (Double pored ruminant tapeworm)	Sheep other ruminants	Oribatid mites	Cysticercoid
Taenia saginata (Beef tapeworm)	Man	Bovine	Cysticercus
Taenia solium (Pork tapeworm)	Man	Swine and man	Cysticercus
Multiceps multiceps (Gid tapeworm)	Dog other canines	Sheep other vertebrates including man	Coenurus

matures in the gut thus completing the cycle

A number of tapeworms occur in man and his domestic animals either as adults or metacestodes but rarely in both stages Symptoms caused by the adult worm vary from no visible effect to diarrhea severe abdominal pain convulsions and occasionally an increased appetite Diagnosis of tapeworms in the gut is based on finding eggs or segments in the feces whereas diagnosis of metacestodes usually requires x ray pictures and various skin tests Certain drugs remove tapeworms from the gut but removal of the metacestodes usually requires surgery *See* COENUROSIS CYSTICERCOSIS ECHINOCOCCOSIS PLATYHELMINTHES SARCOPTIFORMES

[R S FR]

Cyclopoida

A suborder of small copepod Crustacea The abundant fresh water and salt water species form an important link in the food chains of aquatic life consuming tiny plants animals and detritus and in turn furnishing food for small fish some large fish and other organisms Some species are important intermediate hosts for human parasites Females of the family Ergasilidae are parasitic on aquatic animals while the males are free swimming

The front part of the body is oval and sharply separated from the tubular hind end which bears 2 caudal rami with distinctly unequal setae Usually 10 body segments are present in the male and 9 in the female due to fusion of two to form a genital segment Appendages (Fig 2) are the first and second antennae mandibles first and second maxillae maxillipeds and 5 pairs of swimming legs the last of which are alike and rudimentary Males usually have rudimentary sixth legs Appendages are usually biramous with a 1 or 2 segmented basal portion One branch is missing from the first antennae and usually from the second antennae the mandibles and fifth legs The first antennae are never much longer than the anterior portion of the body and consist of 6–18 segments Usually there are either 12 or 17 Both first antennae of the males are modified for grasping females The digestive tract consists of a narrow dilatable esophagus an expanded stomach a long [illegible] opening on the dorsal [illegible] absent [illegible] uscles is circulated by general body movements and rhythmic movements of the digestive tract External respiration is through the body surface Striated muscles are highly developed The genital systems are shown in Fig 1 In mating the male grasps the female with the first antennae and by means of the swimming legs places two kidney shaped spermatophores at the opening of the seminal receptacle of the female Egg sacs are paired and lateral Rarely they are subdorsally located There are 6 nauplius and 6 copepodid stages the last being the adult

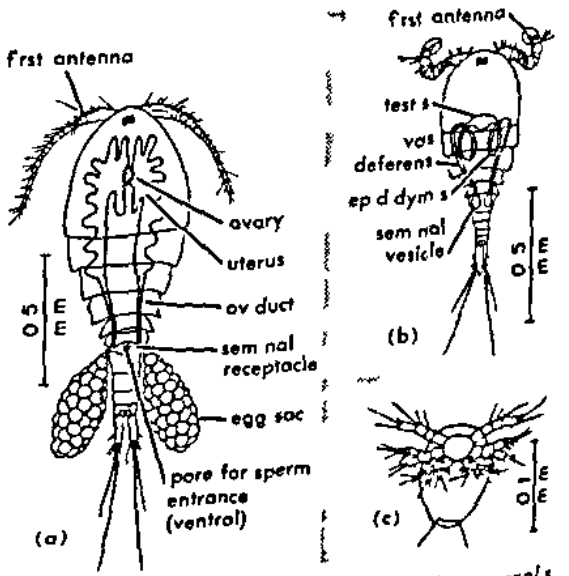


Fig 1 (a) Dorsal view of female *Cyclops vernal s* Fischer (b) Dorsal view of male *Cyclops vernal s* (c) Ventral view of first nauplius stage of *Cyclops verna l s*

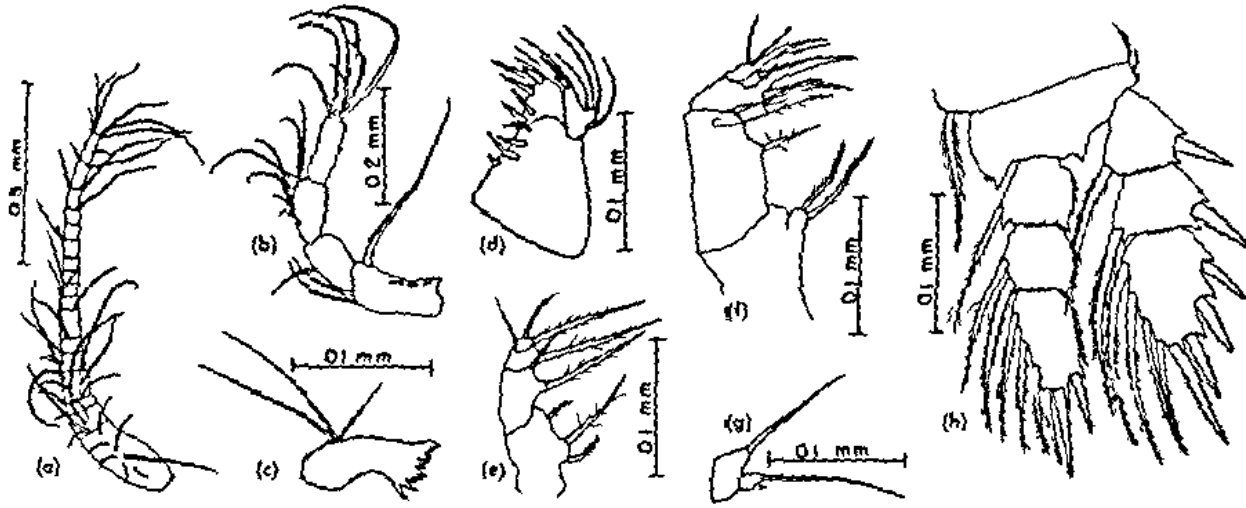


Fig 2 Representative appendages of Cyclops (a) First antenna of female (b) Second antenna (c) Mandible (d) First maxilla (e) Second maxilla (f) Maxilliped (g) Typical swimming leg (right third leg) (h) Fifth leg

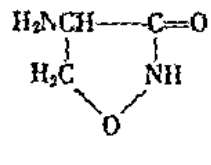
Some species encyst in the copepodid stages to survive adverse conditions A small brain in the head is connected around each side of the esophagus to a ventral chain of ganglia There is a median dorsal eye Cyclopoids are intermediate hosts of the parasitic guinea worm *Dracunculus medinensis* and sometimes the fish tapeworm *Dibothriocephalus latus* Most fresh water species live in shallow water swimming from plant to plant but salt water species are generally water treaders Food is not secured by filtration but is seized and eaten with the biting mouthparts Many species have a world wide distribution *See* COPEPODA [H C Y]

Cycloserine

A broad spectrum antibiotic produced during the growth of certain species of the genus *Streptomyces* R Harned E Kropp and P Hidy isolated it from *S orchidaceous* D Harris and coworkers from *S garyphalus* while G Shull and J Sardinas isolated it from *S lavendulae* It is known commercially as Seromycin (cycloserine Lilly) and Oxamycin (cycloserine Merck) It is effective in man in the treatment of tuberculosis including cases resistant to other drugs such as streptomycin isoniazid and p aminosalicylic acid It is also effective in urinary tract infections caused by gram negative bacteria which are often resistant to other antibiotics *See* PARA AMINOSALICYLIC ACID ANTIBIOTIC ISONICOTINIC ACID HYDRAZIDE STREPTOMYCIN TUBERCULOSIS

Industrial production Cycloserine is produced by fermentation A culture such as *S orchidaceus* is grown in large fermentors under submerged aerated conditions A suitable medium for growing the culture contains soybean meal sugar and calcium carbonate After several days growth appreciable amounts of the antibiotic have been synthesized and have accumulated in the broth The whole culture is then filtered to give a cell free filtrate from which the antibiotic can be recovered in pure form The first step in purification is an adsorption on a strong base anion exchange resin (*see* ION EXCHANGE) A concentrated and partially purified form of the antibiotic is obtained from the resin by elution with a dilute acid A water insoluble silver salt may then be prepared by adding silver nitrate to the eluate The free amphoteric crystalline form of the antibiotic is obtained from the silver salt by adding hydrochloric acid to a water slurry filtering off the insoluble silver chloride and precipitating with acetone

Chemistry *Cycloserine is a white crystalline* powder soluble in water but insoluble in most organic solvents It gives a red color with ferric chloride an orange color with ninhydrin and forms a water insoluble crystalline silver salt Cycloserine has a molecular weight of 102 It has been synthesized chemically and the structural formula is



The chemical name is D-4-amino-3-isoxazolidinone

Pharmacology Cycloserine is absorbed rapidly following oral administration Absorption takes place mainly in the upper digestive tract Distribution occurs rapidly in all body fluids including the spinal fluid A high proportion of a single dose can be accounted for by excretion in the urine over a period of two to three days The concentration in urine is higher than in other body fluids

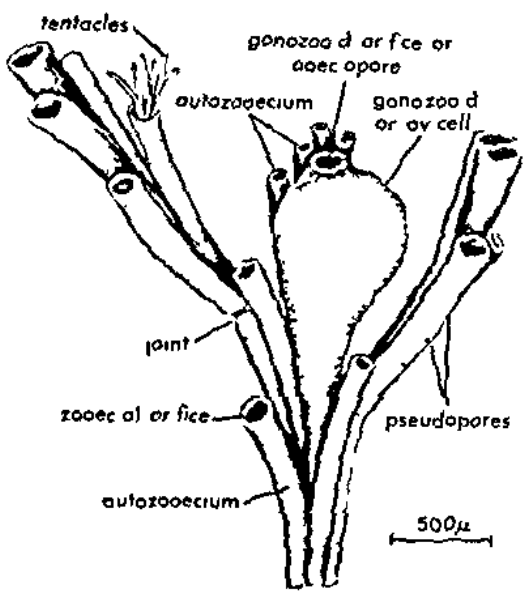
Laboratory animals are essentially free from toxic manifestations when given rather large doses over prolonged periods In albino mice the acute toxicity is in the same order as that of penicillin The clinically effective dose in man appears to be one half to one gram per day given orally at 250 mg per dose The only major toxic manifestation convulsive seizures has been observed in man from doses of one gram or more per day The incr-

dence of this type of reaction appears to be about 8% and seems to be related to high blood levels Patients with low urinary excretion rates tend to accumulate greater amounts in the blood The reason for greater toxicity in man than was expected from experiments in laboratory animals is also apparently due to slower urinary excretion in man Reducing the dose or temporarily withdrawing the drug results in prompt relief from toxic symptoms Concurrent administration of vitamin B_6 has been reported to alleviate the neurotoxic reactions experienced at higher dosage levels [R L H]

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Cyclostomata (Bryozoa)

An order of ectoproct Bryozoa which first appeared in the Ordovician and is widespread today It comprises 34 families and 332 genera and subgenera but its classification is in very imperfect condition



Crisia a cyclostomatous bryozoan fragment of a colony

Colonies consist of simple thinwalled calcareous tubes pitted with pseudopores generally without diaphragms The apertures are plain unconstricted and closed not by an operculum but by a terminal membrane Avicularia are absent Ovicells sometimes are extensive and provided with a special diagnostic ooeciopore house many embryos or larvae which originated by polyembryony from a single egg cell Colony form varies from fragile branched sprigs to encrusting solid masses 10 cm in diameter (R S Bassler 1953) *See* BRYOZOA BRYOZOA FOSSILS [M D R O]

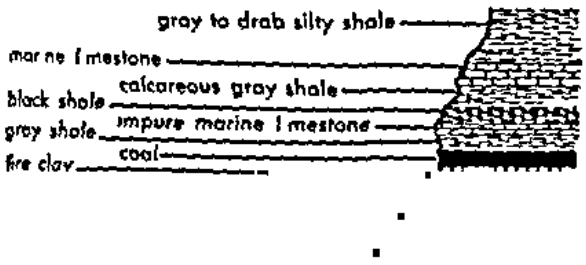
Cyclostomata (Chordata)

The simplest and most primitive of living vertebrates Cyclostomes also known as Cyclostomi and Marsipobranchii are the modern representatives of the class Agnatha the remainder of which are not known after the close of Devonian time Soft bodied animals with naked skin and a cartilaginous skeleton are not suitable objects for fossilization thus the apparent absence of agnaths for a vast interval in the geological record is understandable The Cyclostomata constitute a subclass that is descended at least in part from the subclass Cephalaspidormorphi Whether the Myxiniformes are similarly related or derived from the Pteraspidomorphi is debated by paleontologists

Cyclostomes differ notably from all other Recent fishes The absence of jaws and the presence of a single median nostril are distinctive In addition they have an uncalcified cartilaginous skeleton lack true teeth and have paired fins and girdles a complex branchial basket is present and consists of 5 15 pairs of spherical pouches that open internally and have 1–15 pairs of porelike external apertures Only one or two semicircular canals occur ribs spleen and sympathetic nervous system are lacking and the heart has no conus arteriosus There is no cloaca Cyclostomes are eel like in form and have tough more or less slimy skin They are oviparous and may be either bisexual or hermaphroditic Development may involve a protracted larval stage followed by profound structural change at metamorphosis as in lampreys or it may be direct as in hagfishes *See* AGNATHA MYXINIFORMES PETROMYZONTIFORMES [R M B]

Cyclothem

A complex succession of several lithologically distinctive sedimentary members commonly including coal The succession represents a depositional cycle involving successive fluctuations of the sea that are generally repeated many times in a recognizable sequence Typical cyclothems of late Paleozoic age consist of coarse grained sandy strata below coal in the middle and shale and limestone with marine fossils above The sandstone was generally deposited above sea level on gently sloping alluvial plains the coal strata consist of the remains of plants that grew in extensive coastal swamps and most upper strata are deposits of the shallow sea Cyclothems of this kind in the geologic record indicate 100 or more successive fluctuations of the sea that alternately submerged and withdrew from large areas in North America Europe and some other parts of the world in late Paleozoic time They constitute stratigraphic units averaging less than 50 and rarely exceeding 100 ft in thickness



Cyclothem showing the complete succession of members recognized in Illinois

that are continuous throughout thousands of square miles where all individual strata are too discontinuous to be traced for long distances They furnish means of establishing the identity and relative ages of coal beds and other strata in areas hundreds of miles apart

Cyclothems vary greatly in number of members and other details Lithologic members well developed in some cyclothems or in some areas are poorly represented or absent in others Characteristic changes are observed as cyclothems are traced from a position near an old upland region where erosion provided the sandy and clayey sediment toward the permanent sea as it existed in the past In the United States cyclothems in Pennsylvania include many sandstones thick coals and few marine limestones Those of Kansas contain fewer and finer grained sandstones fewer and much thinner coals and many more marine limestones These differences indicate the relations of land and sea and aid in reconstructing the geography of the past

The causes of cyclothem development are not known The principal speculative explanations are (1) marine depositional basins sank periodically and then were filled with sediment above sea level (2) the land alternately rose above and sank below the sea level which remained stable and (3) the sea level rose and fell as water was removed to form great continental glaciers and then returned as glaciers melted Somewhat similar cyclical deposits of other ages have been termed cyclothems Some like those of Cretaceous age in Utah and neighboring states also include coal These deposits are neither as extensive nor as complex as late Paleozoic cyclothems and probably they owe their existence to different causes *See* SEDIMENTATION (GEOLOGY) STRATIGRAPHY [J M W]

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Cyclotron

A device which accelerates particles and heavy ions (deuterons α particles molecular hydrogen ions) in a constant magnetic field The acceleration is produced by a pair of semicircular electrodes across which a high alternating voltage is produced At a given frequency of excitation depending on the value of the magnetic field and the type of particle to be accelerated the particles spiral out from the center of the magnet at such a rate that their period of revolution in the magnetic field equals the period of the applied alternating voltage thus maintaining synchronism with the accelerating field For an extended discussion *see* PARTICLE ACCELERATOR [W K H P]

Cyclotron resonance experiments

Experiments that lead to a determination of the effective mass of charge carriers in semiconductors by study of the spiral motion of the charge carriers in an applied magnetic field Such experiments are especially powerful in that the character of the effective mass can be studied in detail Because the effective mass depends upon the direction of motion of the charge carriers in the crystal variation of effective mass can be investigated by applying the magnetic field along different directions in the crystal For an explanation of the concept of effective mass *see* BAND THEORY OF SOLIDS

The angular frequency ω of a carrier of effective mass m in a circular orbit under an applied field H is given by

$$\omega = qH/mc$$

where c is the velocity of light and q the charge of the carrier This is also the equation used to describe the motion of a charged particle in a circular particle accelerator such as a cyclotron In a semiconductor q is $-e$ for conduction electrons and $+e$ for holes in the valence band

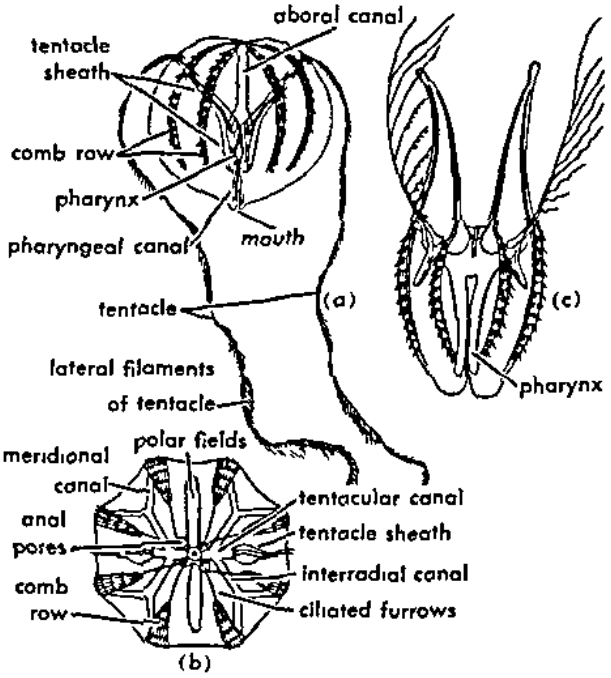
A circularly polarized electric field in the plane perpendicular to the magnetic field produces continuous acceleration of the carriers if the frequency ν of the applied electric field is equal to the cyclotron frequency $\nu_c = \omega/2\pi$ Thus resonance absorption of energy from the electric field occurs at $\nu = \nu$ Usually the strength of the magnetic field producing resonance absorption at a given frequency of the electric field is measured and the effective mass is then determined Actually it is not necessary to use circularly polarized fields plane polarized radiation may be considered as consisting of two circular components, one of which will rotate in the same direction as the carriers

It is usually arranged to have the cyclotron resonance frequency fall in the microwave region For example with an effective mass equal to the electron mass a magnetic field of about 3000 oersteds yields a cyclotron frequency of 10 000 Mc/sec Moving carriers in a solid are scattered by collisions with ions of the crystal lattice In order to observe the cyclotron resonance it is necessary to have the carriers cover an appreciable part of a circle in the time τ between successive collisions The condition for the cyclotron effect is therefore that $\omega\tau \gtrsim 1$ Usually the value of τ is quite small (10^{-12} to 10^{-13} sec) at ordinary temperatures and increases with decreasing temperature By cooling to liquid helium temperatures it is often possibl

to make $\tau \geqq 10^{-11}$ sec It is also possible to perform cyclotron resonance experiments with strong magnetic and electric fields in the infrared region of the electromagnetic spectrum *See* LARMOR PRECESSION, MAGNETIC RESONANCE, SEMICONDUCTOR [HYF]

Cydippidea

An order of the Ctenophora which retains the cydippid state (resembles the cydippid larva) until the adult stage is reached in development They are globular, pyriform or cylindrical They show a nearly round appearance in cross section across the main axis They are often oblong, being elongate



Structure of cydippid ctenophores (a) Pleurobrachia, from life Puget Sound (b) View of same from aboral pole (c) Callianira only bases of long tentacles shown (From L H Hyman, The Invertebrates, vol 1, 1940)

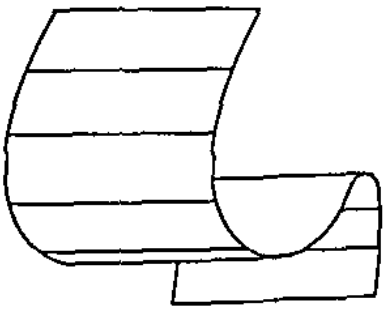
along the tentacular axis The ribs are nearly equal in length All meridional canals are simple and terminate blindly The primary tentacles are well developed and have lateral branches Representative genera are *Hormiphora, Pleurobrachia, Callianira, Lampetia,* and *Euchlora See* CTENOPHORA, TENTACULATA [TK]

Cygnus

The Swan in astronomy, is a conspicuous northern summer constellation The five major stars of the [illegible] cross Hence [illegible] Cross, to dis[illegible] the constel[illegible] ation is represented by a [illegible] wings flying southward The bright star Deneb, signifying tail is the tail of the swan, it lies at the head of the cross Albireo, a beautiful double star of contrasting orange and blue colors, is the head of the swan The whole constellation lies in and parallel to the path of the Milky Way It contains several splendid star fields *See* CONSTELLATION [CSY]

Cylinder

The solid of revolution obtained by revolving a rectangle about a side is called a cylinder, or more precisely a right circular cylinder More generally the word cylinder is used in solid geometry to describe any solid bounded by two parallel planes and a portion of a closed cylindrical surface In analytic geometry, however, the word cylinder refers not to a solid but to a cylindrical surface (see illustration) This is a surface generated by a straight line which moves so that it always intersects a given plane curve called the directrix and remains parallel to a fixed line that intersects the plane of the directrix (Part or all of the directrix [illegible] segments) The generated an ele[illegible] cylinder



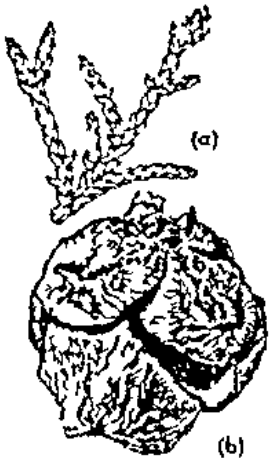
Cylinder (cylindrical surface)

made by a plane perpendicular to the elements is called a right section All right sections of a cylinder are congruent A circular cylinder (cylindrical surface) is one whose right sections are circles Its other sections made by planes cutting all the elements are ellipses Cylinders whose right sections are ellipses, parabolas, or hyperbolas are called [illegible] cylinders or hyperbolic cylin[illegible] special type of cylindrical surface whose directrix and right sections are polygons

The volume of a solid cylinder is $V = Bh$ where B denotes the area of the base and h its altitude (height), measured perpendicular to the base For a right circular cylinder whose base is a circle of radius r, the volume is $V = \pi r^2 h$, and the total surface area is $S = 2\pi r^2 + 2\pi rh$ *See* GEOMETRY EUCLIDEAN [JSF]

Cypress

The true cypress *Cupressus* which is very close botanically to the cedars *Chamaecyparis (see* CEDAR) The principal differences are that in *Cupressus* the cones are generally larger and the cone scales bear many seeds whereas in *Chamaecyparis*



Arizona cypress *Cupressus arizonica* (a) Branches showing small scalelike leaves (b) Cone (USDA)

each cone scale bears only two seeds Furthermore in *Cupressus* the branchlets are not flattened as in *Chamaecyparis*

All of the species of *Cupressus* in the United States are western and are found from Oregon to Mexico *C arizonica* the Arizona cypress of the southwestern United States and the Monterey cypress *C macrocarpa* of California are medium sized trees and are chiefly of ornamental value The Italian cypress *C sempervirens* and its varieties, are handsome ornamentals but usually do well only in the southern parts of the United States Other trees are also called cypress such as *Chamaecyparis lawsoniana* the Port Orford cedar known also as the Lawson cypress and the Alaska cedar *Chamaecyparis nootkatensis* known also as the Nootka cypress or cedar

The bald cypress *Taxodium distichum* is an entirely different tree that grows 120 ft tall and 3–5 ft in diameter It is found in the swamps of the South Atlantic and Gulf coastal plains and in the lower Mississippi Valley The soft needlelike leaves and short branches are deciduous hence they drop off in winter and give the tree its common name Also known as the southern or red cypress this tree yields a valuable decay resistant wood principally for building construction especially for exposed parts or where a high degree of resistance

000 000 board ft *See* FOREST AND FORESTRY TREE [A H G]

Cypriniformes

An order of actinopterygian fishes which ranks second in size only to the Perciformes This group is also known as the Ostariophysi Although the perciforms dominate modern seas the cypriniform fishes command preeminent faunal importance in fresh waters At least one half of the fresh water fishes of all the continents except Australia belong to this order

The characters of the Cypriniformes agree in the main with the Clupeiformes but with one notable difference the anterior four or five vertebrae are much modified as a protective encasement for a series of bony ossicles that form a chain connecting the swimbladder with the inner ear the so-called Weberian apparatus Other characters include an abdominal pelvic fin if present usually with many rays and a girdle which does not have contact with the cleithra and a more or less horizontal pectoral fin placed low on the side Usually there are no fin spines but one or two spines derived from consolidated soft rays may be found in dorsal anal or pectoral fins and a spinelike structure is present in the adipose fin of certain catfishes The upper jaw is often bordered by premaxillae and maxillae the latter commonly toothless and rudimentary An orbitosphenoid is present a mesocoracoid is usually present A swimbladder is present usually with a duct Cycloid scales are modified into bony plates or are absent and branchiostegal rays are variable in number and arrangement

Classification The order Cypriniformes consists of 2 well marked suborders about 33 families and approximately 5000 species The suborders are so different that they may be discussed separately The suborder Cyprinoidei (or Eventognathi) includes the characins minnows and their allies the suborder Siluroidei (ranked by some as an order Siluriformes or Nematognathi) consists of the catfishes

Cyprinoidei The Cyprinoidei is so similar to the Clupeiformes superficially that were it not for the distinctive Weberian apparatus they would doubtless be combined in a single order The Weberian apparatus of the Cyprinoidei involves only the first four vertebrae The body is typically invested in cycloid scales although these are sometimes lost The 8 families of the Cyprinoidei numbering about 2900 species may be arranged in 3 superfamilies Characoidea Gymnotoidea and Cyprinoidea

Characoidea This superfamily includes the single family Characidae or characins characterized by toothed jaws a maxilla which enters the gape the usual presence of an adipose fin and opposed upper and lower pharyngeal bones. The characins are primarily fresh water fishes that abound in South America where they have undergone an

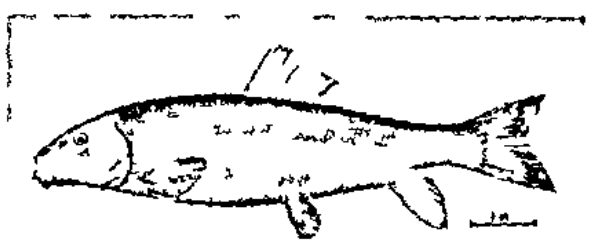


Fig 1 Northern redhorse *Moxostoma macrolepidotum* (After G B Goode Great International Fisheries Exhibition London 1883 U.S Natl Museum Bull 27 1884)



Fig 2 Gafftopsail catfish *Bagre marinus* (After G B Goode *Great International Fisheries Exhibition London 1883* U S Natl Museum Bull 27 1884)

extensive adaptive radiation resulting in more than 800 species A few have spread north into Central America and one enters the southern United States In African fresh waters there is less diversity of form but there are more than 100 species The group appears to date from the Cretaceous Tropical aquarium fishes include many characins some of which like the neon tetra are extremely colorful

Gymnotoidea The superfamily Gymnotoidea includes a single family Gymnotidae consisting of about 16 genera and 32 species that inhabit fresh waters of South and Central America They are not known as fossils These are eel shaped fishes with numerous vertebrae absence of pelvic and dorsal fins and an anus which is located far forward all species so far as is known can produce an electric shock The electric eel is the best known and largest species *See* ELECTRIC ORGAN (BIOLOGY)

Cyprinoidea The superfamily Cyprinoidea includes 6 families of primarily fresh water fishes They have toothless jaws no adipose fin and falciform lower pharyngeal bones usually with teeth which are opposed to a pair of padlike processes from the basioccipital bone The Cyprinidae including minnows and carps is the largest family of fishes with about 275 genera and more than 1500 species This group is known from the Paleocene of Europe and the Eocene of Asia but did not reach North America until the Miocene The center of abundance and diversity of form is in southeastern Asia The family is well represented in Africa Europe Asia and North America (about 230 species) but there are none in Central or South America Madagascar Australia or in that part of the East Indies lying east of Lombok Most species are small but many are large enough to be of major importance in the fisheries especially in eastern and southern Asia The carp *Cyprinus carpio* one of the hardiest of all fishes has been widely disseminated as a food fish It is the object of an active program of cultivation in many countries The suckers of the family Catostomidae comprise 13 genera and about 70 species living in North America and eastern Asia They probably origi-
- - - The loaches
- - ut 20 genera
- - Africa and

Europe Most are small and many are more or less eel shaped In the mountainous regions of southeastern Asia there are found 3 other small families of the Cyprinoidea the Homalopteridae with 12 genera and 51 species the Gastromyzontidae with 16 genera and 30 species and the Gyrinocheilidae with 1 genus and 3 species All are adapted to life in torrential streams

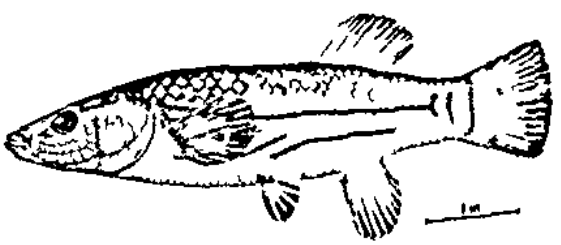
Siluroidei The suborder Siluroidei is structurally distinctive The Weberian apparatus is more complex than in the Cyprinoidei and involves the fifth vertebra the body is naked or the scales are enlarged and modified into large overlapping bony plates the premaxillae usually have teeth but except in one genus the maxillae have lost the teeth and are reduced to rodlike supports for maxillary barbels, there are no parietals suboperculum symplectic or opisthotic bones there are 2–4 pairs of barbels and both the pectoral and dorsal fins usually have a strong spine This is a large group including about 25 families and 2100 species of which nearly 1200 live in South America Catfishes are known from Eocene times

Two families of catfishes *live in salt water* the Ariidae in tropical waters of both hemispheres and the Plotosidae in the Indo Pacific Twelve families of fresh water catfishes are confined to South and Middle America three are restricted to Africa three are endemic to southeastern Asia three are shared by Africa and Asia one is found in Europe and Asia and one is peculiar to North America Some catfishes deliver a dangerous wound with the dorsal or pectoral spines which in certain species are associated with venom glands Many catfishes are highly prized as food fishes and support important local fisheries *See* ACTINOPTERYGII

[R M B]

Cyprinodontiformes

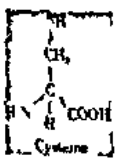
An order of actinopterygian fishes which seems to have affinities with the Gasterosteiformes They are also known as the Microcyprini Its characters include absence of fin spines single dorsal fin pelvic fin abdominal or absent pectoral fin base vertical well up on the side scales usually cycloid rarely ctenoid or absent orbitosphenoid and mesocoracoid bones absent swim bladder without a duct, branchiostegal rays arranged as in spiny rayed fishes, and usually small size



Striped killifish *Fundulus majalis* (After G B Goode *Great International Fisheries Exhibition London 1883* U S Natl Museum Bull 27 1884)

The killifishes and their allies are classified in 7 suborders 8 families about 100 genera and between 350 and 400 species They are chiefly inhabitants of fresh and brackish waters of the tropics and subtropics but some live in temperate zones or in marine shore waters three species are blind depigmented cave forms The best known family Poeciliidae includes the aquarium livebearers—guppies swordtails platyfishes and mollies The order dates from the Oligocene *See* ACTINOPTERYGII SWIM BLADDER [R M B]

Cysteine



Physical constants of the L isomer at 25° C
pK COOH 1.96 30°C pK₂ NH₃ 8.18 pK (SH) 10.28
Isoelectric point 5.0
Optical rotation $[\alpha]_D$ H₂O) 16.5 $[\alpha]_D$ 5 N HCl +6.5
Solubility g/100 ml H₂O) very sol

An amino acid The amino acids are characterized physically by the following (1) the pK_1 or the dissociation constant of the various titratable groups (2) the isoelectric point or pH at which a dipolar ion does not migrate in an electric field (3) the optical rotation or the rotation imparted to a beam of plane polarized light (frequently the D line of the sodium spectrum) passing through 1 decimeter of a solution of 100 grams in 100 ml (4) solubility *See* EQUILIBRIUM IONIC ISOELECTRIC POINT OPTICAL ACTIVITY SPECTROPHOTOMETRIC ANALYSIS

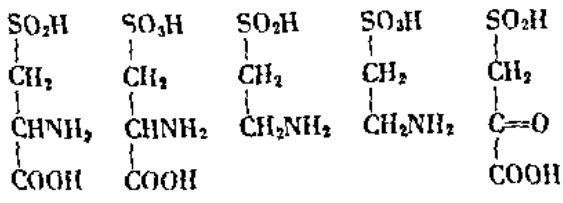
Cysteine forms a red brown color with 1 2 naphthoquinone 4-sodium sulfonate in a highly alkaline reducing medium (Sullivan reaction) A blue color is formed when cysteine is heated with *p* aminodimethylaniline in acid solution in the presence of ferric ammonium sulfate

In microorganisms cysteine probably is formed from serine and inorganic sulfate or sulfide In animals cysteine is formed by transsulfuration of serine with the homocysteine from dietary methionine A variety of metabolic degradation pathways are known of which the principal ones are

1 Degradation to pyruvate hydrogen sulfide (H_2S) and ammonia (NH_3)

2 Oxidation to cysteic acid and decarboxylation of this compound to taurine an intermediate is cysteinesulfinic acid which alternatively can be decarboxylated to hypotaurine

3 Transamination (as cysteinesulfinic acid) with α ketoglutarate to form β sulfinylpyruvate which breaks down spontaneously to pyruvate and sulfite



Cysteine furnishes the sulfhydryl group of coenzyme A and in microorganisms of homocysteine the precursor of methionine (*see* METHIONINE) It is a constituent of the tripeptide coenzyme glutathione and of the amino acid cystine *See* AMINO ACIDS CYSTINE TRANSAMINATION [F A AD]

Cysticercosis

The infestation by cysticerci of the genus *Taenia* The cysticerci are rarely larger than a pea and damage usually results from mechanical pressure on a variety of delicate tissues The intermediate host becomes infested with eggs from the feces of the definitive host which usually is a carnivore

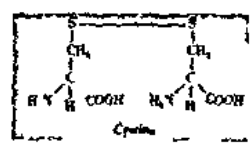
Cysticercus cellulosae is the old name for the metacestode of *Taenia solium* the pork tapeworm Man acquires the adult worm by eating inadequately cooked pork containing the cysticerci How the swine acquire cysticerci in certain areas such as North America where the incidence of infestation in humans is very low is a continuing mystery Not only does man harbor the adult worm but the much more dangerous cysticercus can develop in man as well The cysticercus has a predilection for nervous tissue frequently occurring in the brain or eye causing serious pathology Anthelmintics can eliminate the tapeworm from the gut but surgical removal is the only known cure for cysticercosis *See* CYCLOPHYLLIDEA [R S FR]

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Cystidea

A class of extinct Pelmatozoa which arose during the Ordovician and became conspicuous in Silurian faunas The ovoid body was either sessile or attached by a short aboral stem which comprised a series of columnar ossicles The thecal plates were variously arranged and rigidly sutured together The plates contained thecal canals whose function is uncertain but was perhaps respiratory The mouth at the center of the upper surface received the ambulacral grooves which in early forms were carried on the brachioles only but in later forms crossed the thecal plates also The anus opened in one interradius and near it lay the pore of the sex gland the gonopore and the presumed hydropore of the ambulacral water vascular system There were two orders the Rhombifera and Diploporita The Diploporita include forms transitional to blastoids Cystoids probably died out in the Devonian *See* BLASTOIDEA PELMATOZOA *see also* DIPLOPORITA RHOMBIFERA [H B F]

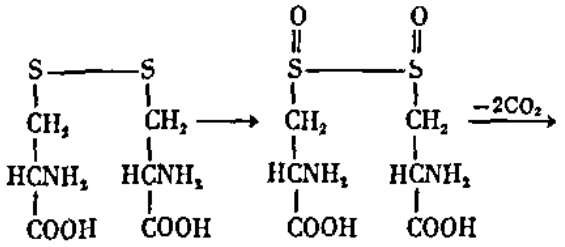
Cystine



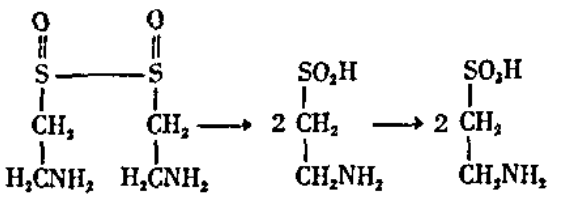
Physical constants of the L isomer at 25° C
pK₁ α COOH 1.00 (30°C) pK₁ (COOH) 1.7
pK₂ (NH₃⁺) 7.48, pK (NH₂) 9.02
Isoelectric point 4.60
Optical rotation $[\alpha]_D$ 5 N HCl) 232
Solubility g/100 ml H₂O 0.0 1

An amino acid The amino acids are characterized physically by the following (1) the pK_1 or the

dissociation constant of the various titratable groups, (2) the isoelectric point, or pH at which a dipolar ion does not migrate in an electric field, (3) the optical rotation or the rotation imparted to a beam of plane polarized light (frequently the D line of the sodium spectrum) passing through 1 decimeter of a solution of 100 grams in 100 ml, (4) solubility *See* EQUILIBRIUM IONIC, ISOELECTRIC POINT, OPTICAL ACTIVITY, SPECTROPHOTOMETRIC ANALYSIS



Cystine disulfoxide



Taurine

Cystine after reduction gives the specific reactions for cysteine Cystine can be reversibly reduced to cysteine It is formed biosynthetically from cysteine by oxidation In addition to the metabolic degradation pathway of cysteine, cystine may also be oxidized directly to cystine disulfoxide, which is decarboxylated and then further oxidized to taurine as illustrated in the formula shown above

[E A AD]

Cystitis

Inflammation of a fluid filled organ As employed in clinical medicine cystitis is assumed to refer to inflammation of the urinary bladder When other viscera are affected they are identified more accurately, for example cholecystitis being inflammation of a gallbladder Principal symptoms of urinary cystitis are pain and frequency of urination The usual cause is bacterial infection particularly by the coliform group of microorganisms (*see* ENTERIC BACILLI) Cystitis often occurs in association with infection of the kidneys *See* BACTERIOLOGY, MEDICAL

[P B BE]

Cytochemistry

The science dealing with the chemical constitution of cells and cell components The localization of chemical constituents within intracellular structures (cytochemistry) or within tissues and cell

alize morphological structures the procedures of these newer fields are designed to localize particular chemical substances within these structures

Most cytochemical procedures involve (1) microscopic examination of thin sections smears or cells in which the chemical substances or, in the case of enzymes the products of their activities are visualized, (2) the isolation of subcellular particles and their analysis by current biochemical methods, or (3) with large unicellular organisms such as *Amoeba*, a third procedure is practical By microdissection, the cell may be divided into halves only one of which contains the nucleus The behavior of each half may then be followed by radioautography or other means If the cell is centrifuged before it is dissected, two halves are available for biochemical comparison one of which for example contains most of the mitochondria *See* MITOCHONDRIA

Visualizing methods In the most widely used visualizing techniques stained tissues or cells are examined by the usual methods of visible light microscopy Staining methods for nonenzymatic components depend upon attachment of a colored molecule (chromophore) to the chemical constituent Those for enzymes depend upon the production of a generally insoluble reaction product which is either colored or otherwise detectable by microscopy or can be converted to colored form

In visualizing some cytochemical constituents use is made of other forms of microscopy such as interference polarizing electron ultraviolet fluorescence, and x ray It is also possible to gain cytochemical information from autoradiographic study of cells or tissues in which radioisotopes have been incorporated *See* MICROSCOPE RADIOGRAPHY

Nonenzymatic constituents Smaller molecules are usually soluble in the fixing or staining media and so cannot be demonstrated by staining methods However, development of the freeze substitution technique may alter this situation since such molecules may be immobilized when tissue is rapidly quenched at temperatures below −150°C and then chemically fixed near −70°C

Among the larger molecules proteins including [illegible] which [illegible] are [illegible] as long as the tissue is not treated with organic solvents, therefore paraffin embedding cannot be utilized and frozen sections must be used

By controlled variation of the medium pH acid and basic dye staining may be used to estimate the isoelectric point of proteins nucleic acids and mucopolysaccharides With some basic dyes there is a shift in color when the dye molecules attach to the cell constituent Such metachromatic staining can be used to characterize molecules such as sulfated mucopolysaccharides

There are several methods for staining proteins in which different portions of the molecule serve as the attachment points of the dyes In the Sakaguchi

test arginine serves as the attachment point In the Millon test tyrosine and tryptophan serve as the attachment points Recently stains have been developed which utilize most of the groupings in proteins such as basic groups phenolic hydroxyl groups amino groups sulfhydryl and disulfide groups and carboxyl groups

Several of the best established and most widely employed specific staining reactions depend upon the combination of aldehydes liberated by standardized procedures with Schiff's reagent which produces a purple-colored complex Such reactive aldehydes are liberated in deoxyribonucleoprotein by warm acid hydrolysis in polysaccharides and glycoproteins by periodic acid oxidation and in plasmalogens by mercuric chloride treatment

Fluorescein labeled antibody can be used to localize specific antigens (proteins or polysaccharides) in tissue The bound fluorescent antibodies emit visible light when examined under the ultraviolet microscope With highly specific antibody and parallel neutralization controls this procedure can be very selective *See* Microscope, Fluorescence

Lipids are generally revealed by oil soluble stains such as Sudan black B or oil red O which are dissolved in an organic solvent that does not dissolve the lipid Special stains may also be used to localize phosphatides and cholesterol

Specific enzymes sometimes help to establish the chemical nature of a cell constituent For example if a periodic acid Schiff positive material is removed from the cell by salivary amylase it is probably glycogen If a pyronine positive material is removed by ribonuclease it probably contains ribonucleic acid

Nucleic acids can be visualized in cells without staining if they are examined with ultraviolet light near 2600 A the wavelength at which they absorb strongly They can also be visualized in the fluorescence microscope if treated with the fluorochrome acridine orange

Radioautography has been used to follow changes in nucleic acids which have incorporated isotopes such as P^{32} C^{14} and tritium labeled precursors Similar work can be done with other cell constituents, for example with proteins which have incorporated S^{35}

Cytophotometric methods permit quantitation for example of nucleic acids by such means as ultraviolet absorption and the Feulgen nucleal reaction with Schiff's reagent and of proteins by acid staining and use of sulfhydryl reagent The interference microscope and x ray microscope can be used to estimate the mass of cell structures

A beginning has also been made in the use of electron microscopy for localizing nonenzymatic chemical constituents Microincineration has been used for metallic substances. Other inorganic substances such as pigments and vitamins A and C, can also be visualized within cells and tissues

Enzymes The possibility of false localizations due to diffusion of soluble substances and their adsorption by other cell structures is much greater in methods for enzymes than for nonenzymatic constituents Except for the use of the fluorescein labeled antibody technique to demonstrate digestive enzymes in the pancreas the methods employed for enzymes depend upon the ability of the molecule to catalyze a specific chemical reaction and not upon combination of a chromophore with a chemical grouping of the enzyme molecule The more soluble the product of the enzyme reaction the more likely are diffusion and adsorption artifacts If additional steps are required to convert the reaction product to colored form artifacts are more likely to result Such difficulties are more formidable in intracellular localization than in tissues

A wide variety of hydrolases and oxidative enzymes have been revealed by staining methods but reliable methods for syntheses have yet to be devised Some enzymes are more resistant than others and can be revealed only in fixed and embedded tissues others require unfixed frozen sections Electron microscopic localization of a few enzymes on the level of fine structure has already been achieved

Among the more valid methods for revealing the intracellular localization of enzymes are the newer tetrazolium techniques for oxidative enzymes like those involved in succinate and DPNH (diphosphopyridine nucleotide reduced) oxidation and the newer indoxyl naphthyl AS and lead salt methods for esterases and phosphatases

Biochemical methods The most widely employed biochemical method is differential centrifugation The tissue is dispersed (homogenized) in an aqueous medium generally containing the nonelectrolyte sucrose and is then subjected to progressively higher centrifugal forces in a refrigerated centrifuge In this fashion four fractions are generally obtained The first is the nuclear fraction which contains the nuclei and variable amounts of cytoplasmic particles blood cells and other contaminants The second is the mitochondrial fraction which contains most of the mitochondria but is usually contaminated by microsomes and perhaps by other structures such as lysosomes The third as observed in liver the most extensively studied organ is the microsomal fraction consisting largely but not exclusively of fragments of the endoplasmic reticulum and associated ribonucleoprotein particles The fourth fraction is the unsedimented soluble fraction The differential centrifugation technique has been modified for various purposes such as reduction of damage to cell organelles and separation of the mitochondrial and microsomal fractions into subfractions Gradient centrifugation is being used increasingly In this technique the subcellular particles of the homogenate are centrifuged through continuously or discontinuously increasing concentrations of solute generally sucrose *See* Cytoplasm

To minimize the possibility of elution of soluble components which may occur when tissue is

rupted in aqueous media nonaqueous media have been used This is valuable for the isolation of nuclei, which may be obtained in a high state of integrity and purity However this is achieved at the expense of quantitative recovery of the nuclei In addition, by this method it is not possible to separate the different cytoplasmic particles, the organic medium may extract lipide from the nuclei and some enzymes may be inactivated *See* CELL (BIOLOGICAL), CELL STRUCTURES, CYTOLOGY (MOLECULAR BASIS) [A B N]

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Cytochrome

A complex protein occurring within the cells of a wide variety of animals and plants An integral part (prosthetic group) of a cytochrome is a heme (iron tetrapyrrole) moiety The heme imparts a color generally red to the cytochrome as well as characteristic absorption bands which are used for the spectroscopic observation and identification of these intracellular hemoproteins The iron atom of the heme may be reduced and oxidized by appropriate substances in the cell thus constituting the function of the cytochromes as electron carriers and as essential components of biological oxidation systems

The cytochromes have been classified according to the position in the spectrum of their most characteristic alpha (α) bands observed when the compounds are in the reduced (Fe^{++}) state Thus a cytochrome a has an α(reduced) absorption band in the region of 600 mμ a cytochrome b at 555–565 mμ and a cytochrome c at approximately 550 mμ Variations in these positions in different cells have resulted in families of each major group for example cytochromes b_1 b_2 b_3 and so on Cytochrome a_3 also known as cytochrome oxidase, has special significance since its reduced form reacts directly with oxygen In a tissue such as heart muscle it appears that cytochrome b is reduced by flavoproteins, and electrons thus gained are passed sequentially through cytochrome c_1, cytochrome c, cytochrome a cytochrome oxidase and thence to oxygen

Cytochromes occur generally, but not exclusively, in the mitochondria of cells, and the cytochrome c of yeast and muscle tissue has been obtained in pure crystalline form *See* CELL (BIOLOGICAL), MUSCLE, PROTEIN, SPECIALIZED TISSUE, SPECTROPHOTOMETRIC ANALYSIS, YEAST [E H S]

Cytokinesis

The partitioning of cells following nuclear division or karyokinesis (*see* CELL DIVISION, MITOSIS) As a result each nucleus is contained in a portion of cytoplasm and is isolated from other nuclei by a cell membrane Where cytokinesis does not take place *following nuclear division a syncytium results*, that is, a cytoplasmic continuum containing more than one nucleus and correspondingly larger than the parent cell Syncytial organisms and tissues are fairly common but cytokinesis may be *considered a normal terminal step in cell reproduction* Syncytia may vary in form from shapeless plasmodial masses such as are seen in slime molds to highly elongated cells containing a chain of nuclei, such as are found sometimes among the bacteria

The partitioning of a biological mass into cells serves two functions First it subdivides the living material into small units with a large relative surface area obviating problems of diffusion Second it is most compatible with the common scheme of differentiation in which different cells adapt to specialized functions in the multicellular organism

The timing of cytokinesis with respect to the mitotic cycle is variable, the one rule that can be made is that it begins only after anaphase movement is completed It may coincide with telophase changes in the chromosomes or may come later The extreme case is that in which cytokinesis is delayed while many nuclear divisions proceed The syncytium so produced may later be partitioned off into cells usually providing a cell per nucleus This delayed cytokinesis is observed in the growth of plant endosperm and in spore formation and gamete formation in many lower organisms

Normally, and with remarkable precision the plane of cytokinesis corresponds to the equatorial plane of the mitotic spindle, that is the cell divides along a plane midway between the poles and at right angles to a *line connecting the poles* This relationship also holds in cases of multipolar mitosis, that is if there are three poles three planes of division appear midway between each pair of poles This suggests that mitosis is geared to cytokinesis in place as well as in time In plant cells it has been shown that when the nucleus is

other with none In animal cells the mitotic apparatus may be sucked out at anaphase yet cytokinesis will occur in the normal way It would follow that cytokinesis is determined at an early

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(a) Among animal cells two patterns are common One is simple cleavage the division of the cell body into two by the ingression of a furrow through the equatorial plane This is observed in eggs in the formation of gametes in the fission of many protozoa especially ciliates and flagellates, and in the division of bacteria In a second pattern observed in ameboid cells and in tissue cells of animals furrowing is accompanied by active bubbling of the cell surface In plants the essential feature of cytokinesis is the formation of a thin barrier across the equator of the spindle upon which other cell wall material is laid down This barrier called the phragmoplast is thought by some to be assembled from substances drawn from the spindle Among other methods of cytokinesis budding as seen in yeasts has been studied in some detail In yeasts the bud seems to form by the bulging out of a part of the cytoplasm at a weakened point in the surface which will be marked later by a scar How the bud finally pinches off is not known *See* YEAST

Of the various types of cytokinesis simple cleavage in animal cells has been studied in the greatest detail One view stresses the hypothesis that the furrow is formed by the contraction of a specialized ring around the equatorial surface Others stress an active role of an expanding cell membrane and still others implicate the mitotic apparatus as well as the cell surface [D M]

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Cytology

The name currently applied to that division of biology which deals with the structure behavior growth and reproduction of cells and the function and chemistry of cell components Cytology is therefore the branch of science that explores the properties of living matter or protoplasm

The serious study of cells and their parts stems from observations made about 1835 which indicated that animals and plants were made up for the most part of small separate units or cells These were too small to be seen with the unaided eye and so became objects for the best techniques of microscopy The initial studies were confined largely to a description of form and structure Gradually as this kind of information accumulated more attention was given to behavior and cytologists began to test the responses of cells to environmental conditions and to examine the requirements of cells for maintenance of life This kind of study is called cell physiology In time attention was also focused on the chemical composition of cells and the enzymatic reactions required for life processes and the performance of specialized functions Thus there developed a branch of knowledge called cytochemistry Since 1940 cytologists have become more aware of the importance of structural integrity of protoplasm for the maintenance of life processes and attention has thus come to focus on the submicroscopic organization of the cell's content The introduction of the electron microscope and the development of methods for applying it to the study of cells have helped greatly to define the numerous small compartments and surfaces and even the larger organic molecules which are involved in this organization (cell fine structure) Today as never before medical science is concerned with events taking place within cells and the expression of abnormalities of these events (cell pathology)

Thus modern cytology encompasses many areas of research These are attracting much attention among biologists not only because of the better devices and techniques available for the study of cells but also because of an increasing awareness that an understanding of life depends on an understanding of cells, the smallest units possessing all the properties of living systems *See* CELL (BIOLOGICAL) CELL MEMBRANES AND MONOLAYERS CELL ORGANIZATION CELL STRUCTURES CYTOLOGY (MOLECULAR BASIS) PROTOPLASM [K R P]

Cytology (molecular basis)

Cytology as the science of biological cells ultimately seeks the explanation of life processes at atomic and molecular levels of size The characteristic self regulatory properties of cells and their differentiation for specialized functions have long suggested a highly organized but dynamic internal structure extending to very small details To determine this biochemists and biophysicists

posed of cells ordinary light microscopes were used to disclose the more obvious bodies immersed in the colloidal cytoplasm During this period and subsequently other special microscopes have become useful Ultraviolet microscopes employ shorter wavelengths to locate cell components with strong ultraviolet absorption (nucleic acids and proteins) Infrared microscopes similarly detect

causes double refraction (birefringence) or where molecules or atom groups show oriented optical absorption (dichroism) Phase microscopes distinguish regions of slightly different refractive power useful because of the near optical homogeneity of most living cells Interference microscopes possess similar sensitivity to refraction differences and can also furnish quantitative measures of the masses of intracellular objects *See* BIREFRINGENCE DICHROISM MICROSCOPE OPTICAL, MICROSCOPE PHASE CONTRAST

These optical methods suffer from limited resolution which is approximately 2500 angstroms (A) in

visible light optics and from artifacts that may be introduced during specimen manipulation The electron microscope widely available since about 1940 overcomes much of the resolution difficulty (down to about 10 A) and allows the nature of artifact production to be more evident in promoting better preparative techniques *See* MICROSCOPE ELECTRON

Physicochemical methods employing ultracentrifugation diffusion viscosity electrophoresis and osmosis disclose the sizes shapes and ionic charges of the macromolecules isolated from cells *X ray diffraction procedures determine how whole* molecules pack into fibrillar or lamellar structures (observed at small angle diffraction) or investigate intramolecular (atomic) details (at wide angle diffraction) *See* X RAY DIFFRACTION

Biochemical methods determine compositions of isolated cellular constituents the interatomic connections within molecules and the transformations of these during life processes

Cellular elements Some of these are shown in Fig 1 The chromatin system of the nucleus contains the chromosomes and associated round bodies (nucleoli) which undergo extensive modifications of basic dye stainability form and number during cell division The colloidal sized features of chromosome structure are less well understood than are smaller details regarding the essential chemical components deoxyribonucleic acid (*DNA*) molecular chains which bear the genetic characteristics of the cell (*see* NUCLEIC ACID) Each DNA chain is a polymer of nucleotides each of which in turn contains a phosphate group a sugar (deoxyribose) and one of four main kinds of organic base Two chains are normally twisted in a double helix with bridges between the chains made by specific pairs of the bases (adenine with thymine and cytosine with guanine) The genetically characteristic base sequence along one chain must be complementary to the sequence along the other If the chains separate as in chromosome duplication each can entertain recombination only with complementary newly synthesized molecules The two resultant double helices are identical with the original one and are divided between the two daughter cells in cell division *See* CHROMOSOME DEOXYRIBONUCLEIC ACID

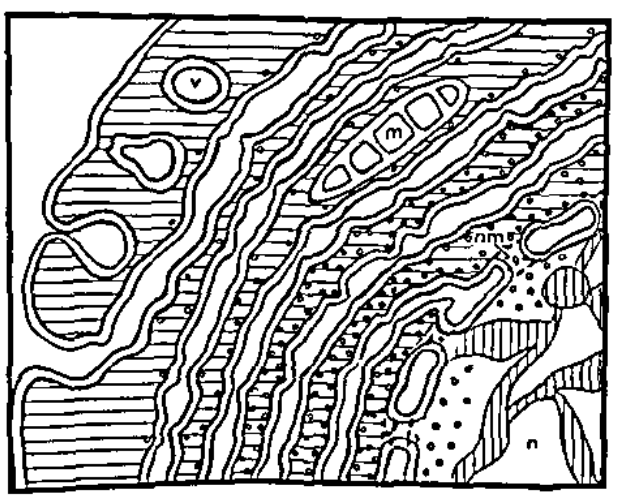


Fig 1 Some cellular elements

The nuclear membrane a distinct structure limiting the nucleus regulates the exchange of material *between the nucleus and surrounding cytoplasm* The nuclear membrane carries pores several hundred angstroms in diameter Ribosomes are small rounded particles of about 150 A diameter so named because of significant content of ribonucleic acid (like DNA but with ribose as sugar) They occur in the nucleus but principally in the cytoplasm sometimes free but generally in close association with membranous structures They are thought to be produced by the chromosomes and by diffusion through the pores of the nuclear membrane to provide control of synthetic processes of the cytoplasm *See* RIBONUCLEIC ACID

The endoplasmic reticulum or ergastoplasm is an extensive system of channels which pervades the cytoplasm The vaguely reticular nature of the cytoplasm as seen microscopically is accounted for when the ergastoplasm *is revealed electron* optically to consist predominantly of flattened membrane limited spaces (cisternae) which are believed to provide a continuous path from the fluids outside of the cell to the perinuclear space Thus the membranous borders may *divide cytoplasmic* space into a truly isolated cytoplasm and a peripherally and nuclearly connected volume The membranes together with the ribosomes attached to their cytoplasmic sides constitute the microsomal system which is active in biosynthetic processes notably the formation of protein The Golgi apparatus which appears electron optically as a constellation of closely packed cisternae without ribosomes is believed to be concerned with intracellular manipulation of lipids and water Sometimes the Golgi apparatus is located near round bodies called centrioles which have a function in cell division

Mitochondria are oval bodies closely associated with the ergastoplasm or other sites of pronounced activity The external limit of each mitochondrium is a typical *membrane from* which similar lamellar walls (cristae) extend across the internal plasm to form compartments Metabolic enzymes are thought to be properly arranged with respect to these walls and compartments to carry out the cyclic chemical *reactions which* provide energy rich molecules (adenosinetriphosphate) as fuel for other cellular processes *See* ADENOSINETRIPHOSPHATE (ATP) MITOCHONDRIA

Among other less distinctive cell inclusions are membrane limited vesicles possibly involved in packaging of food waste or secreted products for

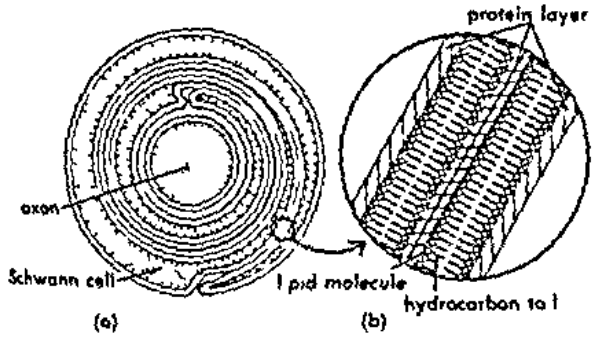


Fig 2 Membrane structure (a) Nerve cell axon enveloped by Schwann cell (b) Double membrane

transport into or out of the cell In the upper left corner of Fig 1 are shown three stages of vesicle formation (reading up) or of vesicle removal from the cell (reading down) Sometimes numerous vesicles become flattened and aligned then fuse their membranes to form multilaminar plastids such as the chloroplasts which carry on photosynthetic activity in plant cells Similar multilaminar structures characterize the light sensitive elements of rod and cone cells of the retina of the eye

Many of the structures described previously result from various ways of conforming membranes suggesting that they may have been developed by infolding and manipulation of the plasma membrane limiting the entire cell In Figs 1 and 2 membranes are indicated as double lines of exaggerated separation they are in reality less than 100 A thick

Cellular membrane structure in molecular detail is evident from studies of the nerve myelin sheath In Figure 2*a* the central cylindrical nerve process the axon shown in cross section with its limiting membrane is enveloped by a Schwann cell By proliferation of the Schwann cell membrane a spiral wrapping of double membranes is developed about the axon In Fig 2*b* the structure of a double membrane is shown with lipid molecules symbolized by circular (chemically polar) heads' and attached (hydrocarbon) tails Double layers of lipid molecules alternate with aqueous protein layers to form a layer which is about 180 A thick

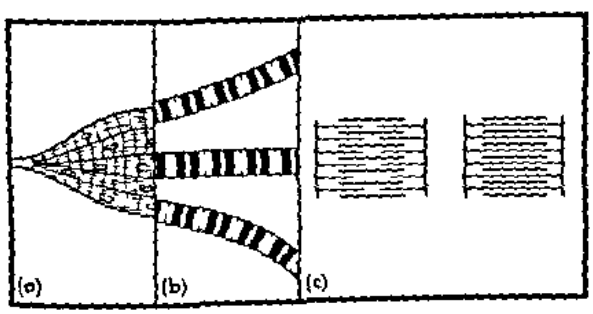


Fig 3 Voluntary muscle structure (a) Multinuclear muscle cells attached to tendon (b) Striated myofibrils (c) Relationship of optical striations in sarcomeres to locations of myofilaments

One half of the layer corresponds to the original limiting membrane of the Schwann cell

Cells often present well developed fibrous inclusions for special functions as in muscle cells in the elongated cells of hairs emerging from skin follicles and in the epidermal cells of the skin

In Fig 3*a* multinuclear muscle cells (fibers) are shown attached to a tendon Each fiber contains many striated myofibrils such as the few shown enlarged in Fig 3*b* where black areas represent above-average optical density and double refraction The diagrams in Fig 3*c* show how the optical striations are related in individual myofibrillar segments (sarcomeres) to locations of myofilaments composed of the proteins myosin and actin (thick and thin horizontal lines respectively) The relaxed sarcomere in Fig 3*a* shortens during muscle contraction by a process which slides actin filaments into the myosin system (Fig 3*c*) without marked length change in either filament type Vertical lines (Z membranes) at sarcomere boundaries are thus brought closer together Each sarcomere is about 25 000 A long each myofilament 50–150 A thick *See* MUSCLE MUSCLE (BIOPHYSICS)

Filaments of the proteins myosin keratin (of hair) epidermin (of epidermis) fibrin (of blood clots) and portions of many other proteins are believed to contain their strings of polymerized amino acids arranged in helical coils (the α helix diameter about 10 A) Filaments of these proteins are probably composed of a number of coils further twisted into cables The coils can be artificially stretched into more fully extended chains (β configuration) the natural condition found in feather keratin and silk fibroin *See* AMINO ACIDS

Extracellular fibrous polymers are often produced from cell exudates notably for tissue protection and support The fibrin and fibroin mentioned above are examples as are also the cellulosic structures of plants the chitinous exoskeletons of arthropods and the collagen of skin dermis connective tissue tendon and bone *See* BONE CONNECTIVE TISSUE INTEGUMENT TENDON

Beta proteins mentioned previously cellulose (a polymer of glucose) and chitin (polymerized acetylglucosamine) have molecular chains characterized by possession of a twofold screw axis that is the atoms are repeated as in a screwlike operation which places two monomeric units (amino acid or sugar) in each repeat of structure along the axis Screws and helices as in the chromosomal DNA and the α protein helices mentioned previously are the prevalent general types of structure for macromolecular chains in fibrous structures and are useful when general straightness and stiffness of colloidal elements are desirable

Figure 4 shows a disaccharide structure like those upon which the screws of cellulose and chitin are based The horizontal dotted lines mark off a length of 10 3 A which is repeated an indefinite number of times vertically to form the complete molecular chain

Figure 5 shows the triple chain helix of col lagen with amino acid units indicated diagrammati cally The three chains, which are twisted about each other in "right handed' fashion, are also in dividually 'left handed' coils of atoms The verti cally repeated length of structure is actually 28 6

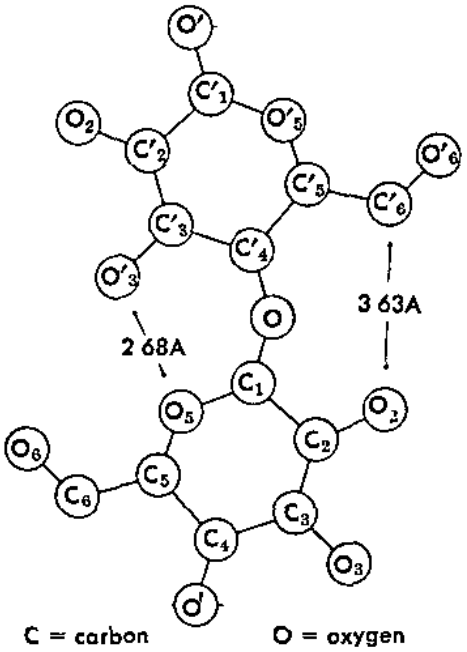


Fig 4 Molecular screw of cellulose and chitin Only the skeleton of carbon C and oxygen O are indicated (*After D Carlstrom J Biophys Biochem Cytol, 3(5) 669–683 1957*)

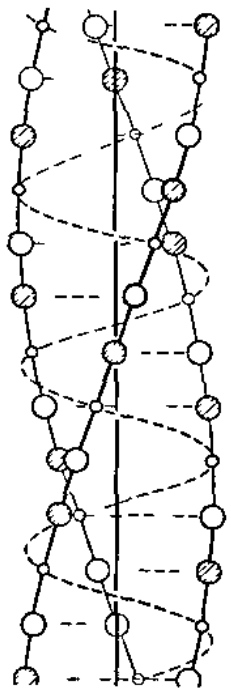


Fig 5 Diagrammatic presentation of the triple chain helix of collagen small circles represent glycine and large circles for imino acid residues (open circles = proline and hatched circles = hydroxy proline) (*A Rich*)

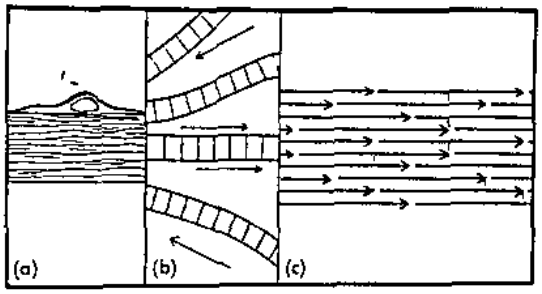


Fig 6 Collagen fibril structure (*a*) Collagen fiber and fibroblast cell (*b*) Diffusing collagen molecules arrows show directions (*c*) Molecular arrangement in fibril

A long In collagen the molecule has definite size 2800 A by 14 A, with molecular weight over 300 000

A collagen fiber in Fig 6*a* is shown with a fibro blast cell producing collagen molecules which diffuse to existing fibrils or "crystallize" to start new ones, as shown enlarged in Fig 6*b*

Details of molecular arrangement in a fibril are shown in Fig 6*c* where molecular ends occur at cross sections separated along the fibril by quarters of the molecular length When molecular detail cannot be resolved, as in the middle a pattern of cross striations is seen along each fibril repeating about every 700 A

When collagen fibrils are not too aged they can be redispersed into dilute acid solutions The actin molecules of muscles whose internal molecular structure is not known also can undergo reversible particle filament transformations Possibly many of the more transitory structures (for example the mitotic spindles of dividing cells) depend on dis placements of equilibria of this kind

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and the functions of intracellular structures are still largely unknown *See* CYTOCHEMISTRY, CY [R S B]
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Cytoplasm

The content of the animal and plant cell apart from the nucleus Cytoplasm surrounds the nucleus on all sides and extends from the surface of the nucleus to the plasma membrane which is the limiting layer of the protoplast

When observed under the most favorable optical conditions the cytoplasm of the living cell is seen to contain several types of particles or inclusions suspended in a clear structureless matrix called the ground substance, or hyaloplasm The inclu sions are classified on the basis of size shape refractility, and staining properties and they have derived names from these properties or from the man who first described them Thus, there are



Electron micrograph of cytoplasm of rat liver Magnification 40 000 m mitochondria er endoplasmic reticulum r ribonucleoprotein particles (ribosomes) cm cytoplasmic matrix

mitochondria so called because of their threadlike form chloroplasts a name indicating their green color the Golgi component named for the man who provided the best descriptions of it and centrioles which occupy central positions in the cell's organization Respectively these structures take part in such vital processes as respiration photosynthesis growth and reproduction and are described in more detail in separate articles In the living cell they occupy preferred sites or move from place to place in the cytoplasm thus apparently enhancing their ability to perform various functions Besides these vital elements it is common for the cytoplasm to show a number of other inclusions which represent for the most part various types of storage materials in the cell In this category are included the starch grains of plant cells and the lipid and protein granules of many cell types These are also of such significance as to deserve a more extended discussion in separate articles *See* CELL INCLUSIONS NONCYTOPLASMIC CELL PLASTIDS CENTRIOLE GOLGI COMPONENT MITOCHONDRIA

Ground substance The hyaloplasm or ground substance is the optically clear or structureless part of the cytoplasm which has excited much interest and speculation For some time cell biologists have recognized that here must reside the machinery for some of the most fundamental of life's processes That the ground substance is optically empty does not mean that it is structure free but simply that any structure present is made up of units too small to be resolved by the usual methods of visible light microscopy

As the name suggests the ground substance is the continuous phase of the cytoplasm in which formed bodies are suspended It is viscous to gelatinous in consistency resembling the white of an egg In many cells it is divisible into two zones a more rigidly gelled cortex or ectoplasm and a less viscous central part the endoplasm The cortex or ectoplasm is limited on the outside by the cell membrane or plasma membrane The colloidal nature of this part of the cytoplasm and its chemical composition are considered later in this article At this point the discussion will be limited to the major submicroscopic components which have been discovered in this part of the cytoplasm chiefly by electron microscopy *See* CELL ORGANIZATION

Although the ground substance or hyaloplasm appears quite structure free in the living cell it takes on a different appearance when the cell is fixed and stained by techniques commonly employed in light microscopy It frequently shows a diffuse affinity for acidic dyes (acidophilic) which means that it is rich in proteins with available basic groups Moreover in some cells there are clumps or strands of material which take up basic dyes and are therefore called basophilic Because these latter components are common in cells that work in the synthesis of complex materials for secretion this type of ground substance has long been referred to as ergastoplasm

Other structural elements just barely evident in the light microscope image of fixed and stained cells have been regarded as representing the fundamental or primitive framework of the cell and are called collectively the archiplasm These configurations and the theories based on them must be regarded with suspicion however because in many instances they represent coagulation patterns induced by the chemical reagents used in fixation

Electron microscopy has been instrumental in providing a wealth of new information on the ground substance and the plasma membrane However because this approach to the study of cells is in its infancy many of the concepts arising from it are still being formulated and are changing rapidly For this reason mention will be made of only a few features of the cytoplasmic fine structure which although newly discovered are now well established

Cell or plasma membrane The outermost limiting layer of the cytoplasm the plasma membrane is one of the most important parts of the cell because it exerts control over the passage of metabolites between the cell and its environment If not too severely damaged it is quickly repaired Th

is good indirect evidence that it is a bimolecular layer of lipoprotein and the latest high resolution images of it confirm this belief In electron micrographs it appears as two dense lines each about 3 mμ thick separated by a less dense space of 2 3 mμ Thus the entire structure is about 8 mμ or 80 angstroms thick

Endoplasmic reticulum The most prominent of the newly defined components gives the initial impression that the ground substance is rich in membranes However when these are examined carefully it is seen that they limit vesicles tubules and thin lamellar or sheetlike units with a contained space Further analysis shows that these are connected to form a continuous reticular structure essentially a finely divided vacuolar system Because this occupies the endoplasmic region of the cytoplasm it has been referred to as the endoplasmic reticulum This newly defined system of the cytoplasm is continuous with the envelope limiting the cell nucleus and repeats in its basic structure the general features of the envelope The impression is that it represents an outgrowth from the nuclear envelope

This reticular structure of the cytoplasm has now been identified in nearly all types of cell but in each cell type it adopts a slightly different pattern Some of these patterns are characteristic of cell types performing special functions Thus in cells producing protein secretions it is common for this system to appear in large lamellar units in parallel organization In other types especially involved in lipid metabolism the basic unit is tubular and these are connected to form a close three dimensional lattice In still others the system is represented in part by unconnected vesicles

The functions of the system are not completely understood but it appears that products of the cell s synthetic activity may be segregated within the cavities of the system and channeled along with metabolites to sites within the cell where both are used

Ribonucleoprotein (RNP) particles There is also a class of small dense particulates in the ground substance called ribosomes These particles are only about 0 0 1 5 μ (15 mμ) in diameter They have been shown to consist of ribonucleic acid and protein and the entire population in some cells may contain as much as 50% of the ribonucleic acid in the cell This type of particle occurs very generally in plant and animal cells They are especially abundant in growing cells in which new protoplasm is being rapidly synthesized In such cells they are randomly distributed in the cytoplasmic ground substance Similar particles are also abundant in mature cells engaged in producing protein for secretion but here they are attached to the membranes of the endoplasmic reticulum It is this association which constitutes the ergastoplasm previously discussed

The obvious association of these particles with protein synthesis and their content of ribonucleic acid (RNA) of which a part comes from the nucleus suggest that they carry genetic information to sites within the cell where such information finds expression

Microsomes The smallest particulates of the cytoplasm observed by light microscopy were initially called microsomes Beginning about 1940 the name came to be applied to a special category of small particulates rich in RNA which could be isolated from certain types of cells by fractional centrifugation Later still electron microscopy of this fraction has demonstrated that microsomes consist of small fragments of the endoplasmic reticulum with RNP particles attached The fraction in the presence of an energy source (adenosine triphosphate ATP) is able in vitro to bring about the incorporation of amino acids into polypeptides

Cytoplasmic matrix The ground substance of the cytoplasm exclusive of the endoplasmic reticulum and RNA particles may be called the cytoplasmic matrix It is a continuous phase of the cytoplasm rich in water inorganic ions nucleic acid carbohydrates and proteins Many of the latter seem to have the capacity to form fibrous arrays which are identified in the light microscope image as stress fibers fibroglial fibers or fibers of the achromatic spindle These are temporary condensations which depolymerize after performing their function to reappear again at another time in another location and association *See* CELL (BIOLOGICAL) [A B P]

Cytoplasmic inheritance

The transmission of hereditary characters through the cytoplasm The existence of cytoplasmic inheritance is established by the following criteria (1) differences in progeny from reciprocal crosses that is dependence of the phenotype of the progeny on the parent contributing most or all of the cytoplasm—this is the maternal parent in higher animals and plants the exconjugant giving rise to a clone in the conjugation of ciliates and the protoperithecial parent in fungi (2) establishment of the gene independence and permanence of a cytoplasmically transmitted condition by repeated back crosses to the paternal strain *this lead* to the gradual introduction of the complete set of paternal hereditary factors known as the paternal genome into the maternal cytoplasm (3) absence of Mendelian segregation the only criterion available for organisms with isogamous sexual processes (yeast *Chlamydomonas*) (4) exclusion of transmission through any one of the chromosomes in genetically well analyzed organisms (*Drosophila* corn) *See* FUNGI CYNETICS MENDELISM

Plasmon The totality of permanent cytoplasmically transmitted conditions in an organism is called the plasmon A plasmon could conceivably be based on plasmids which are self reproducing particles with genetic autonomy or on stable steady state equilibria *Self reproducing* cytoplasmic particles known as kappa particles have been

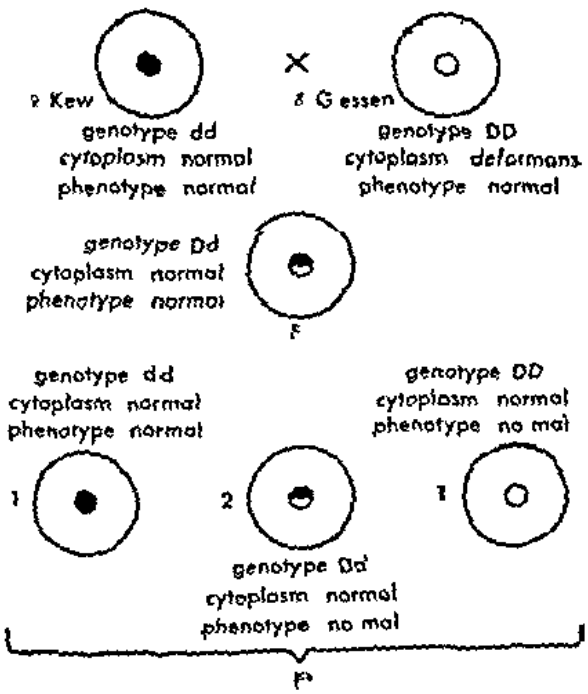
demonstrated in *Paramecium aurelia* to be responsible for the killer character which consists in the production of a poison that kills animals of the non killer or sensitive strains These *kappa* particles are granules 0 4 microns (μ) in diameter they contain deoxyribonucleic acid (*DNA*) and reproduce as the cell grows and divides although not necessarily at the same rate Kappa particles can be transmitted to sensitive animals by feeding broken-up killer cells. The particulate nature of cytoplasmic conditions has been suggested by similar observations for high carbon dioxide (CO_2) sensitivity in *Drosophila* by the sex ratio that is, death of male embryos in *Drosophila* and by certain developmental disturbances in the willow herb *Epilobium*

Among the characters transmitted through the cytoplasm are a number of cases in which recognizable cytoplasmic structures are affected In plants the pigmentation of the chloroplasts is frequently altered and in several cases in yeast and in a mold *Neurospora* enzymatic activities are changed which are known to be located in the mitochondria These observations do not in themselves prove that plastids and mitochondria are self reproducing genetically autonomous structures In a case of green white variegation in *Epilobium* known as status paralbomaculatus it has been concluded from the segregation pattern that the number of particles per cell responsible for the lack of pigment in the plastids is larger than that of visible plastids Nevertheless the genetic continuity of plastids seems to be demonstrated by species crosses in *Oenothera* in which the plastids of the two species may show different amounts of chlorophyll in the presence of the same hybrid genome Because in *Oenothera* plastids may be transmitted through the pollen the plastids of paternal origin may segregate out in development giving rise to variegation

Cytoplasmic hereditary factors are subject to changes or mutational events These may consist in loss by radiation or poisons of the particles responsible for the effect In yeast treatment with euflavine may induce newly formed buds to mutate to the cytoplasmic state petite colonie an inhibition of growth associated with inactivation of respiratory enzyme systems

Several different types of the cytoplasmic state occur in strains of the same species for example in the kappa particles in *Paramecium* the particles causing *CO* sensitivity in *Drosophila* the cytoplasmic conditions responsible for slow growth ("poky") in *Neurospora* and pollen sterility in corn Different local varieties of the same species frequently show differences in their plasmon constitutions An individual cell may contain two types of particles analogous to the two types of plastids present in species hybrids of *Oenothera* In *Epilobium* plants which are stunted through the action of the plasmon directed alterations have been observed to occur in individual development these alterations appear as characteristically changed growth patterns and are in turn transmitted through the cytoplasm

Interaction with genes Cytoplasmic interaction with chromosomal genes occurs frequently Genes and cytoplasm may collaborate in the production of



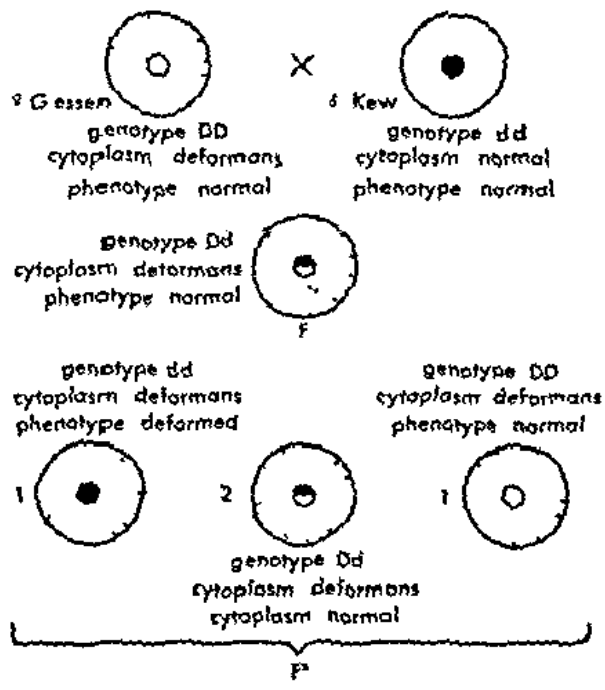


Fig 1 Interaction of genes and cytoplasmic factors in the determination of the phenotype deformed flowers in crosses of two strains of *Epilobium hirsutum* (After P Michaelis)

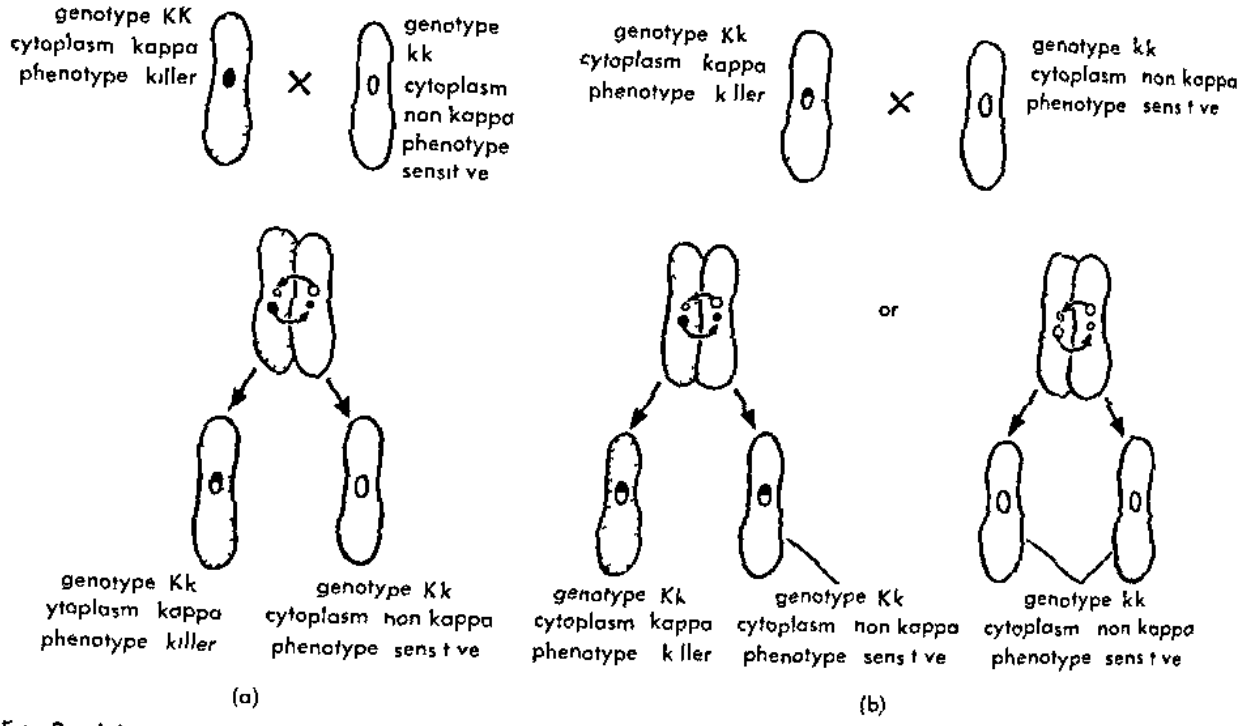


Fig 2 Inheritance of the killer character in *Paramecium* (a) Cross between killer and sensitive (b) Cross of F_1 killer to sensitive (*After T M Sonneborn*)

a phenotypic character If two strains are crossed one of which contains a gene and the other one a cytoplasmic condition which collaborate in the production of a character a new phenotype seems to appear as a result of the cross In many cases the character shows simple Mendelian segregation in one but not in the other of the cytoplasms indicating dependence on a plasmon and one Mendelian factor In crosses between local varieties of a species more complex segregations are frequently found indicating the activity of polygenic factors This type of gene plasmon interaction has been applied to plant breeding particularly the production of hybrid corn The inbred strains used contain cytoplasmic conditions causing pollen sterility so that the labor and expense involved in removing the male tassel becomes unnecessary In the final cross dominant genes (restorer genes) are introduced from the other parent which permit the production of pollen in the pollen sterile cytoplasm

The reproduction and maintenance of cytoplasmic particles may depend on the presence of particular genes The kappa particles of *Paramecium* are dependent on the presence of the gene *K*, in *kk* animals kappa is lost *Kk* heterozygotes contain a lower number of kappa particles than *KK* organisms Similar genes are necessary for the maintenance of the sex ratio and CO sensitivity conditions in *Drosophila*

Genes may induce cytoplasmic mutations In corn the gene iojap located on chromosome VII causes plastids to change from their normal green condition to white The resultant mutant condition is transmitted through the cytoplasm The same gene may also induce a mutation to cytoplasmic pollen sterility

If paramecia are injected into rabbits antibodies are formed which paralyze the paramecia (*see* ANTIBODY) The antigens inducing these antibodies are strain specific and are transmitted at conjugation through the cytoplasm (*see* ANTIGEN) They can be altered by such changes in the environment as temperature so that individuals of the same strain raised at different temperatures contain different antigens The types of antigens a particular strain is able to form depend on a number of chromosomal genes These genes then control the potentialities of reaction of the cytoplasm on the environment The cytoplasmic state is inherited as

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organisms Changes induced by the environment may be transmitted through the cytoplasm for several generations These modifications have a tendency to disappear gradually in the course of successive generations

An influence of cytoplasmic conditions on the nucleus has likewise been demonstrated particularly in the determination of mating types in ciliates Cells belonging to a particular mating type conjugate with organisms belonging to different mating types but not with organisms of their own type The mating type of a cell is determined by its macronucleus and is stable in vegetative reproducti n

through fission In sexual conjugation, it is transmitted cytoplasmically in many strains and species The cytoplasm has been determined by the macronucleus of the previous generation and in turn determines the developing macronucleus of the succeeding generation at a specific sensitive period

The evidence for different types of interaction between genes and cytoplasm which has been obtained in the study of cytoplasmic inheritance has been used to develop models of development in higher organisms *See* SEX DETERMINATION

[E W C]

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