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LETTERS

Sirs:

I have read with a great deal of interest the article on the earth's electricity by James E. McDonald in the April issue of *Scientific American*; however, it does not seem to me that the account is complete without some reference to the first man who made use of the potential gradient of the earth's atmosphere for communication by wireless telegraph.

Mahlon Loomis (1826-1886) was the son of Nathan Loomis, who in association with Benjamin Pierce of Harvard founded the *American Ephemeris and Nautical Almanac*. He was a dentist by profession, but devoted the best part of his life to research and invention.

He became interested in the electrical charges which could be obtained from the upper air by means of kites carrying metal wires. At first he planned to use this natural source of electricity to replace batteries, and it is stated in a biographical sketch of his life that he actually did so on a telegraph line 400 miles long. He next developed the idea of wireless telegraphy depending entirely upon the potential in the atmosphere as his source of energy. In 1868 in the presence of several congressmen and scientists he gave a successful demonstration of his system.

His method was as follows: From a mountain (A) near Lynchburg, Va., he sent up a kite secured by a wire. Connected to the wire was a sensitive galvanometer. On a mountain 18 miles away, which we will call B, a similar kite was flown with a galvanometer connected between the wire and the ground. When the wire of the kite at A was

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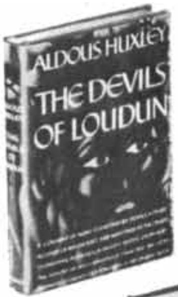

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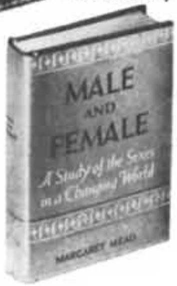

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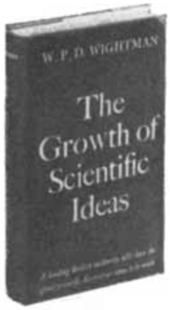

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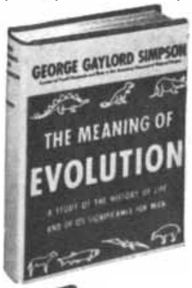

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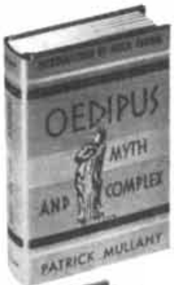

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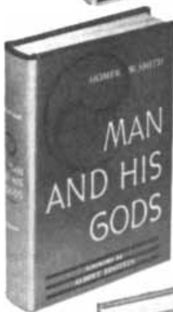

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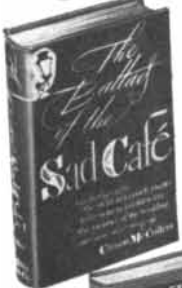

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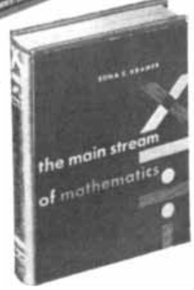

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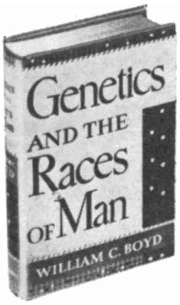

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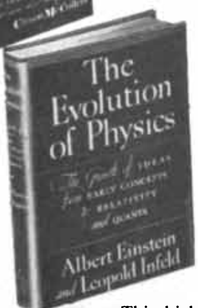

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touched to the ground the potential above mountain B was decreased sufficiently to cause a reduction in the deflection in the galvanometer at that station. When the ground connection at A was broken, the galvanometer at B returned to its former position. By this means Loomis was able to carry out two-way communication by Morse code over a distance of 18 miles without batteries or other sources of electrical energy, depending entirely upon the potential gradient of the air.

Loomis obtained the promise of financial aid from certain persons in Boston, but the stock market crash of 1869 caused them to withdraw. Later he obtained promises of support from bankers in Chicago, but this was dissipated by the fire of 1870. He then introduced a bill in Congress incorporating the Loomis Aerial Telegraph Company and including a grant of $50,000 to continue his experiments. The bill was passed by the House in 1872 and by the Senate in 1873, but the appropriation was cut out. It is said that Loomis died broken-hearted because of his inability to establish useful wireless communication.

THOMSON KING

Director
Maryland Academy of Sciences
Baltimore, Md.

Sirs:

The article by Alphonse Chapanis in your April issue entitled "Psychology and the Instrument Panel" was extremely interesting. I am absolutely in agreement with his aims; however, I must make a few remarks concerning his statement that "One wonders why the public should not be provided with [gas and electric] meter dials it can understand." If all the economic factors involved in the sale of electricity to the average domestic or commercial customer are in balance, then there should be absolutely no necessity for meter reading on the part of the customer. The customer should feel that he has received full value for the money he spent toward electric or gas service, and, therefore, not have any interest in how many kilowatt hours or cubic feet he has purchased.

Certainly on the Pacific Coast this balance must exist, at least insofar as electric sales are concerned. Very few customers feel the need of reading meters; I am willing to venture that many of them do not know whether this service is purchased in kilowatt hours, foot pounds or ergs.

I admit that it is at first a little more difficult for a professional meter reader to read a meter, due to the fact that the directions of the pointers alternate with each dial, but a meter reader reading anywhere from 200 to 400 meters a day

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quickly gets used to that. Actually the meter reader does not *read* a meter any more than one reads a clock by looking at the ciphers on the face. A glance to ascertain the relative position of the pointers is sufficient. That is what the meter reader does, and that is why a meter reader can read a meter from seemingly impossible distances. It is also the reason why utilities do not use cyclometric dials. If cyclometric dials were used, the meter reader would have to be very close to the meter in order to read the ciphers. This would entail additional footsteps and consume time. In addition, cyclometric dials impair the accuracy of the meter because of the additional drag they produce. Similarly a meter dial could be designed with all the hands running in the same direction, but there again the gear train would be much more complex than the present one and the accuracy of the meter would be affected.

G. C. DELVAILLE

Vice President
California Electric Power Company
Riverside, Calif.

Sirs:

As a lawyer, I find the problem of the man condemned to be executed within seven days ["Science and the Citizen," *Scientific American*, April] congenial.

I have in mind two solutions, which, despite my admiration for W. V. Quine, I consider more straightforward than his. The more logical of the two is the following:

At nine o'clock on the second morning, say, the prisoner receives the following message from the judge: "When I pronounced sentence, I knew perfectly well that you were interested in mathematical logic and therefore would reason as you did. Thus lulling yourself into a sense of security, you would not know that you would be executed on a given day; indeed, you would be convinced that you would not be executed at all. Today is the day. You may choose between hanging and shooting."

Incidentally, as far as I know, writers on logical paradoxes have never discussed the legal problem of *renvoi*, which actually has arisen in the field of "conflict of laws." A contract is made in Virginia, to be performed in New York, and suit is brought on it in New York. The law of New York is that a contract shall be construed as if suit had been brought on it in the state where it was made. The law of Virginia is that a contract shall be construed as if suit had been brought in the state where it is to be performed. Which law governs?

WEBSTER PETERSON

St. Paul, Minn.

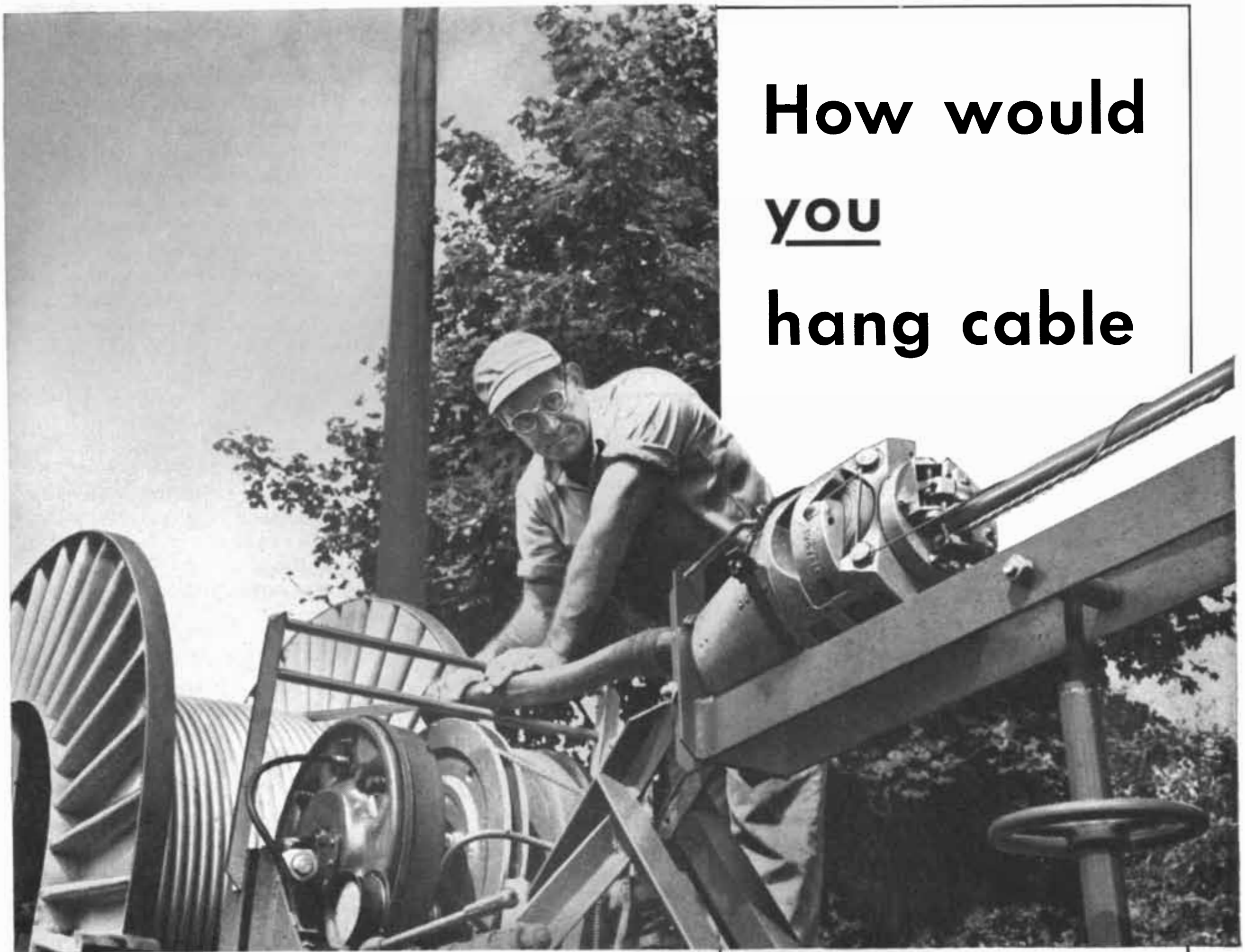
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1903: "Lord Rayleigh discusses the question: Does motion through the ether cause double refraction? He answers it in the negative. The question was suggested by the supposition of Fitzgerald and Lorentz that motion through the ether alters the relative dimensions of bodies. Such a change of dimensions might naturally be accompanied by a sensible double refraction, and as the beginning of double refraction can be tested with extraordinary delicacy, the author thought that even a small chance of arriving at a positive result justified a careful experiment. The experiment was made with an apparatus consisting of a tube containing a liquid and mounted in a north and south direction at noon. At that time, the motion of the surface of the earth is across the ether, and a beam of limelight may be used to detect any double refraction. The tube was mounted on a board which could be swung round into the east-west direction. Observations made upon bisulphide of carbon in a tube 76 cm. long failed to indicate the slightest shift of the band on rotating the board either at noon or at 6 p.m."

"There is every reason for believing that radioactive substances have been discharging positive and negative electrons and Röntgen rays into space for ages, and there is no sign of any diminution in the amount of energy which they give out. Physicists, imbued with the doctrine of the conservation of energy, have tried in vain to discover where the radioactive furnace gets its constant supply of fuel. Sir William Crookes accounts for the supply of energy by supposing that the radium atom has the power of absorbing the energy of the more rapidly moving particles of the atmosphere, and thus gets over the difficulty by endowing the radioactive atoms with the superhuman powers of Maxwell's 'demons.' Rutherford thinks the energy is derived from the shrinkage of the atom, much as the energy of volcanic eruptions is derived from the shrinkage of the earth. This would imply a transmutation into some other material, and Curie objects to this on the basis that the spectroscope has given no indication of such a change after an interval of several years. Curie himself thinks that radium utilizes an external energy

How would *you* hang cable



Cable lasher appears to right of workman. As the cable and supporting strand feed through, the machine rotates, binding them together with steel lashing wire. Meanwhile, a winch hauls the lashed cable into position.

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IT IS a job your telephone company faces every day. Thousands of miles of cable go up each year—all secured to steel strand running from pole to pole. The best way to secure cable is to *lash* it to the strand with a spiral binding of wire.

One way to do this is to raise cable and strand separately, then lash them together by a rotating machine pulled along by workmen on the ground. This produces a strong, tight support for the cable. But each pole has to be climbed as many as four times. So Bell Laboratories engineers devised an easier way.

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"Telephone lines are very much overburdened at present. Certain subscribers require a large number of communications (fifty perhaps) per day, while others desire but two or three; and yet all pay the same amount. It would be equitable to remedy such inequalities by adopting a charge for each communication. An automatic telephone that has just been invented by M. Henri Mager seems to lend itself very readily to the conditions required by the substitution of a charge per call for the subscription system. The person who wishes to telephone gives the handle several turns, and the central office answers. He then asks for the number of the person with whom he wishes to converse. As soon as his correspondent has answered, the operator notifies him of the fact. He then introduces the proper coin into the slot, and it is thereupon possible for the telephone to operate."

"The most effective way of testing an egg is to subject it to the light, but under the old plan, when the egg was held close to the flame of a candle it almost invariably happened that the shell was blackened. The use of electric light has, however, rendered conditions perfect for a thorough test of the eggs and the utmost speed in handling. A fairly expert tester will examine at least two hundred and fifty eggs a day."

"An interesting competition is to be carried out under the aegis of the Aeronautical Society of Great Britain, to ascertain the maximum height to which it is possible to fly kites. The contest is of an international character, so as to obtain considerable data relative to the utility of kites for meteorological operations, and the best type of kites with which to attain high altitudes. There is no stipulation regarding the size of the kites, but only single kites must be employed, and a height of 3,000 feet is fixed as the minimum. The duration of flight must be one hour. Each kite will carry a weight of two pounds to represent scientific instruments."

SCIENTIFIC AMERICAN

JUNE, 1853: "The stone masons in Glasgow, Scotland, acting on the advice of Dr. Allison, of Edinburgh, have commenced wearing mustachios as a preservative against the injury done to the system by fine particles of sand, while they are engaged dressing stones. Cus-

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tom may be against such natural preventatives; but if it is found that they are at all beneficial, we deem it the duty of some of our medical readers to recommend their adoption by millers, bakers and others similarly exposed."

"The French government has employed a party of gentlemen to explore the site of ancient Babylon. From reports received from them it appears that they have ascertained beyond reasonable doubt that the ruins beneath the tumulus called the Kasr are those of the palace-citadel of Nebuchadnezzar. They are in such a state of confusion and decay that it is impossible to form from them any idea of the extent or character of the edifice. They appear, however, to extend beneath the bed of the Euphrates, a circumstance accounted for by the change in the course of that river."

"In April, 1850, the *Atlantic*, the first of a new line of American steamships, left this port on her voyage to Liverpool to compete with the celebrated Cunard Line for the mastery of the seas. At intervals after that three noble consorts, the *Pacific*, *Arctic* and *Baltic*, were added to the line, all built after the same model. For the past two years they have made such voyages as have given them the supremacy over all the English steamships, both in point of speed and every excellent sea quality. This is manfully acknowledged by Captain McKinnon of the Royal Navy in a work recently published, entitled *The Resources and Settlements of America*. He came to the United States in one of the Cunard steamships, and went back to England in the *Baltic*, one of the Collins Line, respecting which he uses the following language: 'I am only doing justice to these magnificent vessels in stating that they are beyond any competition the finest, the fastest and best sea boats in the world. I am sorry to be obliged to say this, but as a naval officer I feel bound in candor to admit their great superiority. Their extraordinary easiness in the sea cannot fail to excite the admiration of the sailor. I never beheld anything like it. No sea ever came on board, there was no violent plunging; the steaming of the *Baltic* was the absolute poetry of motion.'"

"The time is not far distant when all our railroads will be compelled to stop using wood for locomotive fuel, and the sooner they set about preparing for the change so much the better. It will be a good thing for passengers when wood ceases to be used; the *spark punishment* now inflicted on travelers will then be abolished. As no wood is employed on the English railways, we cannot see how it is that the same fuel used there cannot be used here with equal advantages; the coke from the Cumberland coal may bring about the desired relief."

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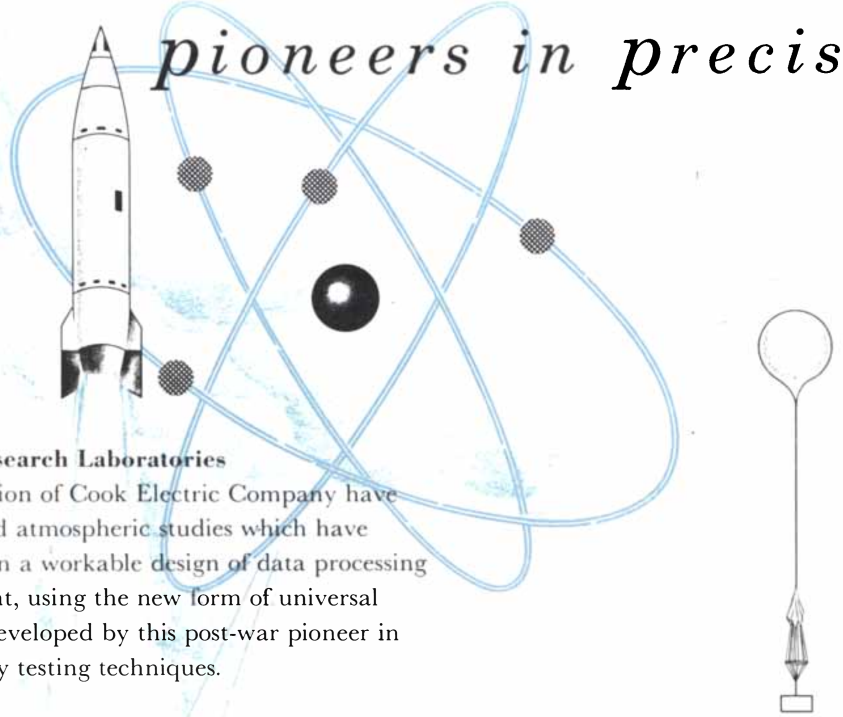

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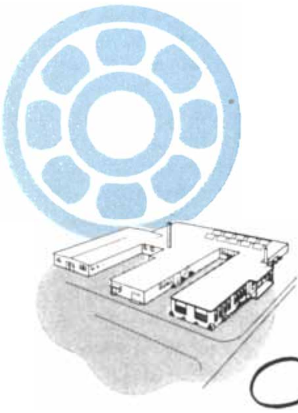

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THE AUTHORS

JACQUETTA HAWKES ("Stonehenge") is an archaeologist, a writer on science, a poet and a playwright. She was born in Cambridge, England, in 1910, the daughter of Sir Frederick Gowland Hopkins, pioneer biochemist and discoverer of vitamins. At the age of nine she wrote an essay expressing a determination to be an archaeologist, and at Cambridge University she won a first-class honors degree in archaeology and ethnology. She has specialized in the study of ancient Britain, and has written a number of books on the subject, one in collaboration with her husband, the archaeologist C. F. C. Hawkes. As archaeological adviser to the Festival of Britain in 1951, she organized its exhibit on the Origin of the People. For this she was awarded the Order of the British Empire. Her book *A Land*, a vividly written account of the formation and prehistory of the British Isles, was a best seller in England and in the U. S. During the past decade Mrs. Hawkes has become increasingly interested in creative writing. She has published collections of poems and is co-author with J. B. Priestley of a new play, *The White Countess*, which will be produced in New York next fall.

W. R. STAMP ("Underwater Television") is on the staff of the Admiralty Research Laboratory of the Royal Naval Scientific Service at Teddington, England. He entered the Service in 1945 directly from London University, where he had taken his degree in physics. For the next few years he worked on photographic research and the applications of photography to naval problems. In 1950 he was transferred to work on television on what he calls "the doubtful grounds of having built a home televisor." Stamp was the leader of the team that made the first practical use of underwater television in identifying the lost submarine H.M.S. Affray among the numerous wrecks lying at the bottom of the English Channel. He is married and finds outlet for his surplus energies in "domestic engineering, scientific instrument making and taking anything to pieces to find what makes it tick."

REIDAR F. SOGNNAES ("The Skin of Your Teeth") is professor of oral pathology and Associate Dean of the Harvard School of Dental Medicine. Born in Bergen, Norway, he "learned English and earned my first pennies as a horse-and-buggy tourist guide." After attending the Latin Gymnasium in Bergen, he went on to study dentistry in Leipzig and in Oslo, graduating *summa cum laude* in 1936. His dental research

Operator transfers evacuated retort from heating to cooling station of Stokes Vacuum Annealing Furnace, designed and built for the processing, annealing and other heat treatment of titanium, zirconium, hafnium, copper and other metals.

One of the uses for the complete custom-built installation of Stokes vacuum freeze-drying equipment in Pitman-Moore Company's new million-dollar plant at Indianapolis, Ind. is to produce gamma globulin to combat poliomyelitis. One of the steps is drying the material from its frozen state. Operators are shown removing trays of gamma globulin from Stokes freeze-dryers. Temperatures are as low as 40° below zero F. during part of the freeze-drying cycle.

Diesel locomotive armature being removed, after impregnation, from Stokes high vacuum impregnating tank in the San Bernardino, Calif., plant of Atchison, Topeka & Santa Fe Railway. Electric motors for the Santa Fe's "Chief" and "Super Chief" develop such excessive heat that ordinary insulation would swell or burst, causing the rotors to "freeze" in the mounting. By impregnating these rotors with protective resins under high vacuum in Stokes impregnators, each turn of wire is held in place, motors operate without interruption.

Installation of Stokes Rotary Vacuum Dryers used by Metals Disintegrating Co., Berkeley, California, for drying of aluminum powder. Highly oxidizable materials can be handled without any danger of combustion or explosion when they are processed under vacuum.

Vacuum at Work

Diesel locomotive motors, paper and metals, medicines, electrical parts, toys . . . are but a few in a wide range of products which are processed in vacuum for the good of mankind and the profit of business.

The application of vacuum engineering to industry is a major function with Stokes engineers. And naturally so, for it is at Stokes' that many of today's accepted procedures of vacuum processing had their inception during the last fifty years.

Stokes is FIRST in Vacuum . . . *first* in the design and manufacture of practical vacuum processing equipment . . . and Stokes engineers are available for consultation on opportunities to apply vacuum processing to your business.

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STOKES

STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages / Industrial Tabletting, Powder Metal and Plastics Molding Presses / Pharmaceutical Equipment started the following year, when he inspected the fabulously good teeth of the inhabitants of Tristan da Cunha, a lonely island in the South Atlantic, as a member of a Norwegian expedition to the island. Sognnaes came to the U. S. in 1938 to study at the Forsyth Dental Infirmary for Children in Boston. Then he spent two years at the University of Rochester as a Carnegie Research Fellow, receiving a Ph.D. in 1941. He spent the war years with the Royal Norwegian Airforce in Canada and in Europe, returning to this country in 1945 to take an appointment at Harvard.

GEORGE W. GRAY ("A Larger and Older Universe") is on the staff of the Rockefeller Foundation. His job takes him to universities, observatories and other research institutions over most of the Western Hemisphere, looking into and writing reports on projects supported by Rockefeller grants. Born in Texas, Gray entered the University of Texas and shortly found himself headed for a career in physiology. Within a year, however, he left the University because of illness. After his recovery he worked for the Houston *Post* and then went to Harvard University. He graduated in 1912 and joined the staff of the New York *World*. During the 1920s he turned freelance and began to concentrate on the natural sciences, contributing many articles to magazines, as well as writing a number of books. His present article is his 12th for SCIENTIFIC AMERICAN. One of them, "The Great Ravelled Knot," which appeared in the October, 1948, issue, won him the A.A.A.S.-George Westinghouse Science Writing Award for the best magazine article of the year. In his comprehensive article on "The Universe from Palomar" in our February, 1952, issue, he told about the beginning of the studies whose fruition he reports this month.

HAROLD F. WALTON ("Chelation") is associate professor of chemistry at the University of Colorado, in charge of his department's analytical division. He was born in Cornwall, England, and educated at Oxford University, where he took a doctorate in chemistry in 1937. He spent a year at Princeton University as a postdoctoral fellow and then went to work as a research chemist for the Permutit Company. From there he went to Northwestern University, where he taught for six years, and then to Colorado in 1947. His chief research interest is ion exchange, on which he wrote an article for the November, 1950, issue of this magazine. Walton is a member of the Colorado Mountain Club and leader of the Rocky Mountain Rescue Group.

KARL MARAMOROSCH ("A Versatile Virus") attributes his "taste" for

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the viruses described in this article to a background in zoology, botany and agriculture. Born in Vienna in 1915, he graduated in 1938 from the Warsaw Agricultural University, specializing in animal breeding and beekeeping. As a civilian internee in Rumania during World War II he did research on plant pathology at the University in Bucharest. In 1947 he came to the U. S., received his Ph.D. from Columbia two years later, and his citizenship in 1952. Since 1949 he has been at the Rockefeller Institute for Medical Research. For his studies of the aster yellows virus he was awarded the A. Cressy Morrison prize of the New York Academy of Sciences in 1951. In his spare time Maramorosch is an ardent photographer and has accumulated a large collection of candid shots of scientists.

HAROLD C. REYNOLDS ("The Opossum") has been studying this primitive marsupial for several years, first at the University of Nebraska, and since 1946 at the Museum of Vertebrate Zoology of the University of California, where he is now assistant curator of mammals. He has been breeding marsupials in captivity—a feat never before accomplished. He was the first biologist ever to observe the birth of a litter of opossums. This year he is lecturing at a U. of C. extension school in Japan. While overseas he will also spend some time in Australia studying marsupials.

GERARD H. MATTHES ("Quicksand") learned about his subject the hard way. As an engineer for the U. S. Geological Survey around the turn of the century he led a surveying party into the Far West. When a river had to be crossed, Matthes would ride into it on horseback to find a ford that could be negotiated by a heavy covered wagon drawn by four horses. He soon learned how to recognize and avoid quicksand and how to extricate mired men and animals. Matthes was born in Holland in 1874. His early interest in waterways was fostered by an uncle who was chief engineer for the country's dike and canal system. He came to the U. S. to study at the Massachusetts Institute of Technology and graduated as a civil engineer in 1895, specializing in hydraulic engineering. He has worked for various government agencies and for private power companies on irrigation, reclamation and flood control. As a War Department engineer in the early 1920s Matthes surveyed the Tennessee River and its tributaries. This comprehensive study, embracing problems of navigation, water power, flood control and mineral resources, was used in creating the TVA some 10 years later. During World War II Matthes was director of the U. S. Waterways Experiment Station at Vicksburg, Miss., and was awarded a medal for his services.

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New Mallory Products Speed Their Use

CHANCES are that in recent months you've read and heard about transistors—those mighty miniatures of electronic magic that offer great hopes of startling changes and improvements in many things used in our homes, offices and factories.

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Other commercial uses for the midget transistors are on the way—some just around the corner. A portable TV set . . . that wrist radio small boys dream about . . . less costly, more efficient electronic office and factory equipment.

When they do reach market, you'll find Mallory playing a vital role in the transistor field.

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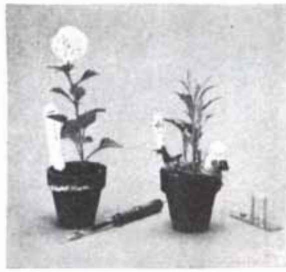

THE COVER

The plant at the right in the photograph on the cover is an aster afflicted with a disease called aster yellows (*see page* 78). The plant at the left is a healthy control. Aster yellows is caused by a virus which is transmitted by a tiny leafhopper. The interesting thing about the virus is that it multiplies in both its plant and insect hosts; this makes it one of the very few organisms that infect both plants and animals. In the laboratory the transmission of aster yellows is studied by bringing the leafhoppers in contact with the plant by means of a small plastic chamber. One such chamber is affixed to a leaf of the diseased aster; another may be seen at the right.

THE ILLUSTRATIONS

Cover photograph by David E. Scherman

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CUT OUT HERE

DESIGNING WITH ALUMINUM

This is one of a series of information sheets which discuss the properties of aluminum and its alloys with relation to design. Extra or missing copies of the series will be supplied on request. Address: Advertising Department, Kaiser Aluminum & Chemical Sales, Inc., 1924 Broadway, Oakland 12, California.

NO. 2

THERMAL CONDUCTIVITY, REFLECTIVITY

CONSIDER USE OF ALUMINUM ALLOYS WHERE HEAT CONDUCTION OR RADIANT HEAT REFLECTION IS REQUIRED

At first glance it may appear to be a paradox that aluminum is both a good thermal conductor and a good reflector of radiant heat, but two separate phenomena and properties are involved.

Conduction is the process of heat transfer through a material by kinetic energy. Radiation is the transmission of energy from a source to a receiver through space by electromagnetic waves; those chiefly responsible for heat radiation are similar to but of no longer wave length than those for light. When absorbed, the radiant energy increases the temperature of the absorbing body.

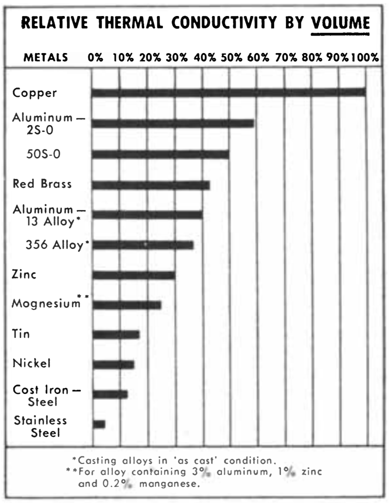
The possession of these two distinct properties—thermal conduction and radiant reflectivity—has proved of outstanding value in many successful applications of aluminum, especially as they are combined with such other properties of aluminum as corrosion resistance, light weight and strength, workability and economy.

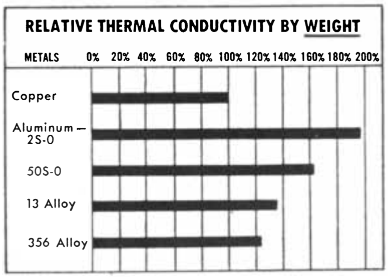
Aluminum best conductor on weight basis

Of the commercial metals aluminum ranks second only to copper in thermal conductivity on a volume basis. On a *weight* basis, however, aluminum has the highest thermal conductivity, with various aluminum alloys being superior to copper by a wide margin.

The relationship between some aluminum alloys and other metals with respect to thermal conductivity, as illustrated in the charts in the next column, shows why aluminum is worth considering where it is necessary to conduct or dissipate heat.

Localized "hot spots" resulting from use of a metal of inferior conductivity are troublesome and reduce efficiency, whether they occur in a cooking utensil or in a more complex application.





How aluminum's high thermal conductivity can greatly improve efficiency is demonstrated by its use in internal combustion engines, where one of the major problems is high temperature in the engine envelope. By dissipating heat rapidly, aluminum cylinder heads reduce temperature in the combustion chamber by as much as 100° F., thereby making it possible to obtain higher compression ratios by preventing detonation caused by a "hot spot." It has been found also that aluminum cylinder liners surfaced with hard plating have given a very considerable power increase over cast iron liners because of better heat dissipation.

More and more, the trend is toward greater utilization of aluminum to produce higher performance engines. In fact, power plants made almost entirely of aluminum are built not only for aircraft but also for marine application, tanks, trucks and such popular, work-saving products as power lawn mowers and portable chain saws. The light weight, corrosion resistance and workability of aluminum are beneficial as well in their design, manufacture and operation.

The thermal conductivity properties of aluminum also play a part in its use in torque converters (discussed in No. 1 of this information series, dealing with "Light Weight with Strength") by eliminating the need to make special provision for cooling to handle heat generated during operation.

An interesting specialized use of aluminum's conductivity, made practical because aluminum can be economically rolled to thin foil, is seen in cigarette-proof tables, desks and counter tops. A layer of foil just beneath the surface dissipates heat from the burning tip of a carelessly laid cigarette so rapidly that there is no scorching or burning.

Aluminum reflects short, long waves

Aluminum is highly reflective to both short wave (solar) and long wave radiant energy. Possession of this quality means also that aluminum is characterized by low absorption of solar heat and low emissivity, or radiation, of long waves.

PLEASE TURN TO NEXT PAGE ➡

In per cent, reflectivity plus absorption, or reflectivity plus emissivity, equals 100. Although polished aluminum surfaces such as bright aluminum foil have the highest reflectivity, up to 95% or 97%, even aged mill finish aluminum sheet retains this property to a marked degree.

The table below gives approximate values of these properties for aluminum in comparison to some other surfaces:

EMISSIVITY, ABSORPTION OF VARIOUS MATERIALS

	Long Wave Emissivity in %* (Radiation) 50-150°F New	50-150°F Aged	1000°F New	1000°F Aged	Solar Absorption in %* (Short Wave) New	Aged
Bright Aluminum Foil	3	5	5	10	5	15
Bright Aluminum Roofing Sheet	5	20	10	20	20	40
Mill Finish Aluminum Sheet	8	20	11	20	25	40
White Paint (Flat)	85	95	60	75	12	50
Colored Paint	85	95	..	..	65	88
Galvanized Iron	10	60	..	..	30	90
Black Non-Metallic Surfaces	87	98	..	..	85	98
Window Glass	90	95	..	..	Transparent**	
Wood	90	98	..	..	98	..
Steel Sheet	65	90	80	97	..	..

*Per cent reflectivity is 100% minus value listed.

**Actually reflects about 8% of sun's rays.

Reflectivity useful in varied ways

Inasmuch as radiant heat is frequently the major source of the total heat load, examination of these values shows why designers in various fields are making more use of aluminum to solve different problems.

It is obvious also how an aluminum roof makes a building cooler in summer—it reflects a high percentage of the solar heat, and only a small percentage of what is absorbed is reradiated by long-wave emissivity to the interior—and why aluminum foil makes excellent reflective insulation, whether new and bright or old and dusty.

Other ways in which the heat reflective property is being used with substantial benefit include reflective shields behind radiant heaters, radiant heat baffles in residential furnaces and radiant heat shields to protect workers who must tend high-temperature industrial furnaces.

Because of its low emissivity, a heating duct made of bare aluminum delivers more heat than other standard types of duct construction. Comprehensive tests (report available on request) between 12-inch diameter round ducts approximately 100 feet long showed that a duct made of new aluminum gave a temperature drop of only 43° F., as compared with a 61° drop for an asbestos paper covered galvanized duct.

It is possible, if so desired, to achieve directional radiation by painting or otherwise coating one side of aluminum and leaving the other side bare. When the metal is heated, the painted side will radiate heat but the bare side will emit little heat.

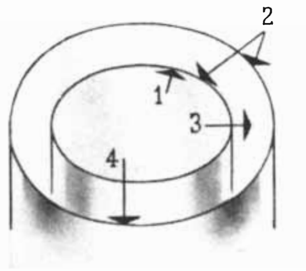
Better vent and flue pipe of aluminum

Use of aluminum in a double-wall construction, essentially an inner and outer pipe of aluminum sheet separated by a ventilated air space, has resulted in a highly efficient gas vent and flue pipe that fully meets Underwriters' Laboratories, Inc., Type B requirements without restriction.

The properties of aluminum as well as its design contribute to the value of this pipe. The inner pipe, being of small thermal mass (and of high conductivity, though that is of less importance), rises quickly to temperature when the gas appliance is turned on; it provides quick, strong draft, thorough removal of flue gases and elimination of condensation.

Maximum insulation is provided by the low emissivity of both inner and outer pipes in conjunction with the insulative properties of the air space between them. The result is that this type of pipe keeps adjacent wood surfaces from exceeding 90° F. above room temperature, the UL limit, even when flue gas temperature is at the American Gas Association-permitted maximum of 550° F. In other words, aluminum makes possible *a safer as well as a better operating construction* than other commonly used materials. Other advantages from the use of aluminum are light weight with easier installation, durability through freedom from cracking or breaking, resistance to corrosive influences, and economy.

HOW ALUMINUM VENT PIPE WORKS



1. Inner pipe heats rapidly.
2. Low emissivity of outside surfaces of both pipes provides minimum radiation.
3. Ventilated air space provides high insulation.
4. Inside surface of outer pipe reflects radiant heat.

Where heat flow occurs, investigate aluminum

If heat transmission or reflection is involved in a design and application problem, it will pay to investigate the use of aluminum alloys. Along with high conductivity or reflectivity, other aluminum properties will provide additional benefits.

Kaiser Aluminum engineers experienced in product design, development and fabrication will gladly assist you in getting the most from aluminum's unique combination of properties. Call or write any Kaiser Aluminum office, in principal cities. Kaiser Aluminum & Chemical Sales, Inc., Oakland 12, Calif.

SCIENTIFIC AMERICAN

Established 1845

CONTENTS FOR JUNE, 1953 VOL. 188, NO. 6

ARTICLES

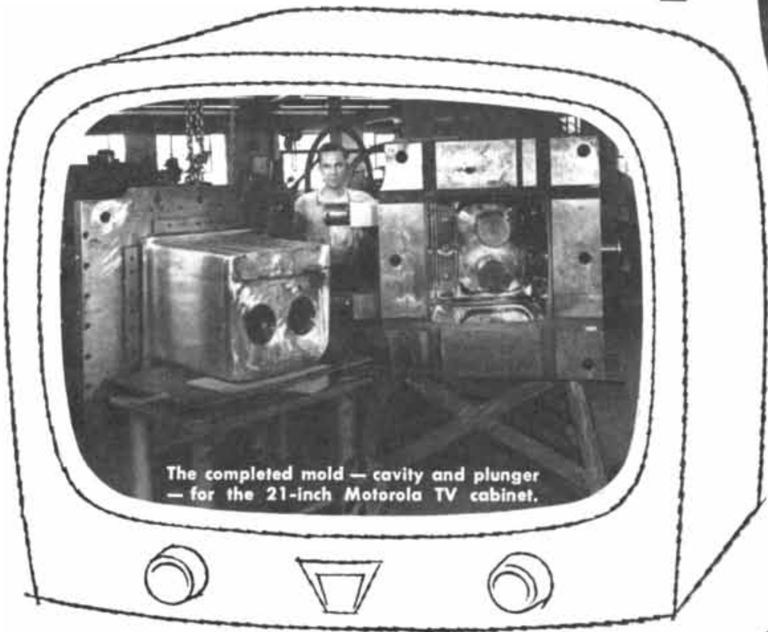
DEPARTMENTS

What's Happening at CRUCIBLE

about plastic mold steel

The production of mold steel for the plastics industry is not a new operation at Crucible. But to manufacture the special seven-ton mold used by Chicago Molded Products Corporation in producing 21″ Motorola TV cabinets presented a unique, though typical problem in the field of specialty steelmaking. The block from which the mold was machined is probably the largest mold steel forging ever produced in this country.

Crucible Plastic CSM2 Mold Steel in final forging stage.



The completed mold — cavity and plunger — for the 21-inch Motorola TV cabinet.

type of steel used

The steel used in making this mold was Plastic CSM2 — a Crucible special mold steel produced in accordance with tool steel standards. It is especially uniform in composition and structure to provide superior machining and polishing characteristics, dependable response to heat treatment and a high degree of dimensional stability.

forging the mold

The 14,000 pound forging required for the mold was produced from a 25,000 pound ingot. In the upsetting operation the 70″ axis of the cropped ingot was reduced to 28″ in a 1500 ton press. The heating, forging, and slow cooling phases took a total of 14 days. Seven more days were required in the annealing operation. The forging was then planed to its finished size of 40″ x 28″ x 43″.

engineering service available

To build a precision mold like this requires the combined skills and experience of several specialists. That's why Crucible maintains a staff of field engineers to help work out specialized metallurgical problems. If you have an application problem for mold or any other special purpose steel, don't hesitate to call in one of our engineers. And if you need mold steel, you'll be glad to know that it is carried as a stock item in Crucible warehouses conveniently located throughout the nation.

Two TV cabinets being molded in one operation.

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National Drawn Works, East Liverpool, Ohio • Sanderson-Halcomb Works, Syracuse, N. Y. • Trent Tube Company, East Troy, Wisconsin

SCIENTIFIC AMERICAN

JUNE, 1953 VOL. 188, NO. 6

Stonehenge

The strange monument is often attributed to the Druids of 2,000 years ago, but radiocarbon dating supports the view that it was started by a savage but aspiring people 2,000 years before that

by Jacquetta Hawkes

THE GREAT prehistoric sanctuary of Stonehenge stands among the sweeping curves of the chalk downland of Salisbury Plain. Not very many miles away on a more northern stretch of the Wiltshire downs is Avebury—another most remarkable though less famous stone circle. Around both Avebury and Stonehenge cluster vast numbers of burial mounds, many of them the graves of wealthy Bronze Age chieftains whose presence there is proof of the fame and sanctity of these circles in ancient times.

The architecture of Stonehenge is arresting in its strangeness. Nowhere in the world is there anything quite comparable to this temple, built not of masonry but of colossal rectangular blocks of stone. Plainly it is the handiwork of a people more barbaric than any of historic times, yet the careful shaping of the huge monoliths, the use of horizontal lintel stones, and above all the coherence of the whole as a work of architecture set it far above the usual megalithic building of prehistoric western Europe.

It is no wonder, then, that for the past thousand years Stonehenge has been so famous as to attract countless visitors and speculation of every kind. Among the many famous men who went there were Inigo Jones, Samuel Pepys, John Evelyn and William Wordsworth—indeed Wordsworth has enriched its literature with poetry of the first rank. James I knew it and was curious about its origin; Charles II, when he was sheltering at nearby Amesbury after the battle of Worcester, spent a day there counting and measuring the stones to pass the time and forget his anxieties.

Today more than ever Stonehenge attracts its visitors. Summer tourists go there in thousands, leaving buses and cars to buy tickets at a Ministry of Works kiosk and approaching this holy place of their forebears along a path flanked by neat waste-paper baskets. Even in these conditions, once inside the circle visitors surrender to the power of its stones. In spite of our familiarity with architecture on a vastly greater scale, there is something about these massive, weather-beaten monoliths which awes modern men with thoughts of a savage, primitive, yet mightily aspiring world.

We know that immediately after the Norman Conquest Stonehenge was rec-

HEEL STONE is seen from within the circles of Stonehenge. Sir Norman Lockyer tried to date the monument by computing that on Midsummer Day (June 24) in 1680 B.C. the sun rose directly over the Heel Stone.

ognized as one of the wonders of Britain. The fanciful 12th-century historian Geoffrey of Monmouth suggested that the stones had been fetched to Salisbury Plain from Ireland by the wizard Merlin in the days of Ambrosius, the uncle of King Arthur. Subsequently, he said, the circles were used as the burial place of Ambrosius and his brother, Uther Pendragon, Arthur's father.

This tale was believed all through medieval times and was repeated with variations by writers in Latin, French and English. By the 16th-century Renaissance scholarship was harshly and sometimes mockingly questioning Geoffrey of Monmouth and the whole glorious but improbable Arthurian legend. But the new scholars and antiquaries hardly knew whom to put in Merlin's place as the founder of Stonehenge. During the 16th, 17th and 18th centuries this baffling inheritance from the past was attributed to the Romans, Danes, Phoenicians and Druids. Most of these theorists recognized it as a temple, but one school of thought (the Danish) identified it as a crowning place of kings.

TODAY we are inclined to smile at all these notions; we can supply dates and attach archaeological labels that look convincing enough. The truth is, however, that we still have not explained the unique architecture of Stonehenge. Stone circles are a special feature of prehistoric Britain. They are found all the way from the south of England to the extreme north of Scotland, where there are fine examples in the Orkneys. Some of them are circles of free-standing stones; others are enclosed by a circular bank and ditch. These circles are all assumed to be holy places, and all can be said to have some relationship with Stonehenge. But how inferior they are! Even Avebury cannot compare with the architectural grandeur of Stonehenge.

It is not surprising that Avebury and Stonehenge, the two most imposing circles in Britain, should both be situated on the Wiltshire downs. As geographers have often pointed out, this region forms the hub of the uplands system of southern England, and it was on these uplands that prehistoric settlement was most strongly concentrated. Throughout almost the whole of prehistoric times the English lowlands were made largely uninhabitable and impassable by the heavy growth of oak forest. The early farmers sought the chalk and limestone hills, where the thin, light soil could readily be cleared to improve pasturage and make room for their small grain plots.

On the broad chalk plateau of Salisbury Plain and the adjacent Marlborough Downs many lines of hills converge—the Cotswolds and their northern prolongation up to Yorkshire, the Chilterns, North and South Downs, Dorset Downs and Mendips. The plateau therefore early achieved the dominance usual to centers of communication. Not only were the pastoral tribesmen of this area sufficiently prosperous to be able to afford the prodigious expenditure of labor needed to build Stonehenge and Avebury, but they were able to build them in places accessible to the whole of England south of the Pennines. They may have been able to draw labor or tribute from such a wide area, but whether or not this was the case we can be reasonably confident that the sanctuaries served as rallying points. At the most important seasonal festivals tribesmen must surely have traveled to them along the ridgeways of all the radiating hills. There is interesting evidence for such a gathering of peoples in the occurrence of grave goods of a kind characteristic of the north of England in at least one of the barrow burials lying close to Stonehenge.

LIKE MANY Gothic cathedrals, Stonehenge is a composite structure in which feature was added to feature through the centuries. This structure includes several important parts in addition to the circles of standing stones which are what most people mean when they speak of Stonehenge. Before going on to discuss the history of the monument it will be well first to describe its parts [*see diagram on page 30*].

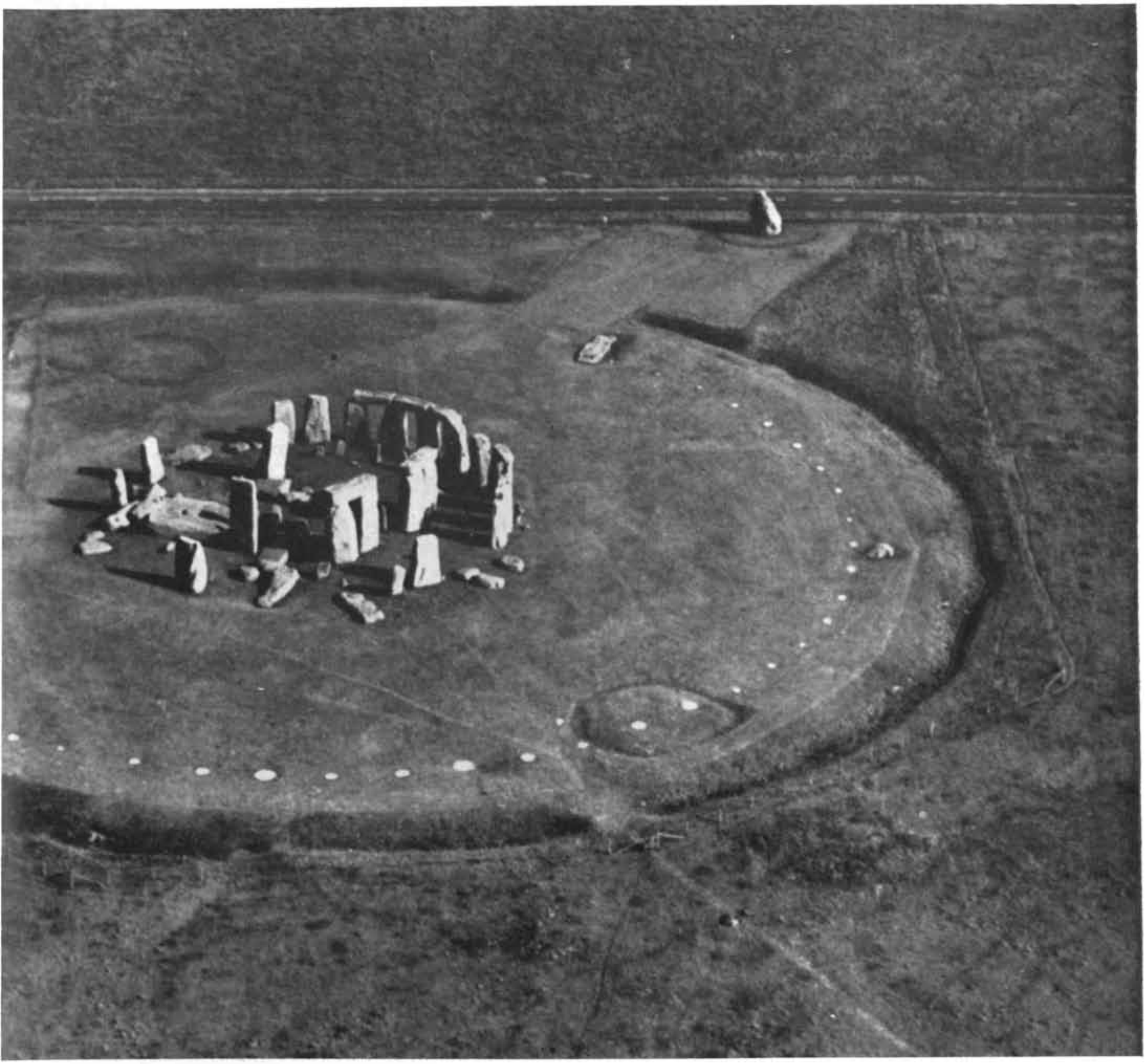
To the north of the sanctuary, stretches the great length of the Cursus, a very narrow embanked enclosure some 1¾ miles long. It owes its odd name to the 18th-century antiquary William Stukeley, who liked to fancy that it served as a course for chariot racing. It is easy to laugh at Stukeley's fantasy, but the actual purpose of this and the few other enclosures of the kind in southern England remains unexplained. What is of particular interest for an understanding of Stonehenge itself lies in a recent discovery made at the west end of the Cursus, at the point where the side banks appear to terminate against a long burial mound. In this area excavation and field survey discovered a strong concentration of chippings from the Blue Stones which now form a part of the sanctuary itself. It has therefore been suggested that these stones, known from other evidence to have been present in the area before they were erected in their present sockets, originally stood here at the west end of the Cursus.

The other important outlying earthwork associated with Stonehenge is the Avenue, which can be assumed to have been the main ceremonial approach to the sanctuary. It consists of two parallel lines of bank and ditch about 70 feet apart which, from the northeast side of the circles, run almost dead straight for 1,800 feet, then swing eastward and curve gradually toward the River Avon. The banks and ditches are now so nearly level as to be clearly visible only from the air.

AERIAL VIEW of the monument shows how its stones are encircled

A circular embankment about 320 feet in diameter encloses the sanctuary itself. Such an enclosing bank and ditch is the feature which is held to distinguish a "henge" from an ordinary free-standing stone circle. Immediately inside the bank is a ring of pits, named the Aubrey Holes after their 17-century discoverer. They are 56 in number and all roughly circular. Cremation burials, without urns and normally without grave goods, were found in many Aubrey Holes and also in a quadrant of the ditch and bank.

Between the Aubrey Holes and the



by a bank and a ditch. The small white circles within the bank mark those Aubrey Holes which have been excavated. At the upper right is the Avenue, which runs straight for 1,800 feet and then curves toward the Avon.

stone circles are two more rings of pits, long known to archaeology as the Y and Z Holes; the individual pits are oval and about six feet long.

AFTER THIS account of the earthworks and ceremonial pits associated with the monument, we can leave these painfully unspectacular but historically important features and approach the stones themselves. Those that first catch the attention are the immense sarsens, great monoliths of sandstone. The nearest place from which blocks of this size could have been obtained apparently is the Avebury region, miles away, and the transport of the some 80 sarsens at Stonehenge, running up to 30 feet in length and weighing an average of 28 tons each, was a prodigious effort, especially as the journey necessitated the crossing of a broad, soft-bottomed and overgrown valley. Presumably they were dragged on rollers by men hauling on rawhide ropes.

The sarsen architecture of Stonehenge has two parts: an outer circle about 100 feet in diameter and an inner horseshoe formed of five gateways. The circle originally had 30 columns, united by a continuous lintel of smaller blocks laid over their tops. The stones are all roughly squared, and the lintel stones are secured onto the uprights by tenons and sockets, and to one another by mortise joints. The chopping out of two tenons on the top of each upright and of the rails of the mortise joints is a remarkable achievement for masons working only with clumsy stone mauls. The largest sarsens of all are found in the inner horseshoe, which measures 44 feet across and 50 feet along the axial line. Its colossal central gateway is more than 25 feet high.

THE SARSEN peristyle and horseshoe setting astound us by their size and the unparalleled precision of their masonry; they please the eye, too, by their soft gray color and the richness of texture produced by the weathering of the sandstone. Yet it is the other element of this extraordinary monument that can claim the most fascinating and dramatic history. The plan of the outer circle and horseshoe of sarsens is repeated on a smaller scale by a circle and horseshoe of the so-called Blue Stones. These stones are very much smaller and they lack the architectural refinement of lintels. What is so astonishing about them is that they were made from rocks (mainly dolerites and rhyolites) which are found together only in the Presely Mountains in the extreme west of Wales. It is equally astonishing whether one thinks of the immense physical difficulties of their transport from Wales to southern England or of the sanctity which must have resided in them to prompt prehistoric men to undertake such a feat.

The question of the route by which the stones were carried has been much disputed. Perhaps the most satisfactory view is that they came by sea (probably from Milford Haven in the west of Wales) to the mouth of the Bristol Avon and were then conveyed across Somerset and Wiltshire by a series of rivers close enough together to require only short portages. This seems the easiest route—but even so the distance involved is well over 300 miles. Across the innermost tip of the Blue Stone horseshoe lies a single so-called Altar Stone. This supposed Altar Stone, which in fact may formerly have stood upright, is made of a variety of sandstone found near Milford Haven.

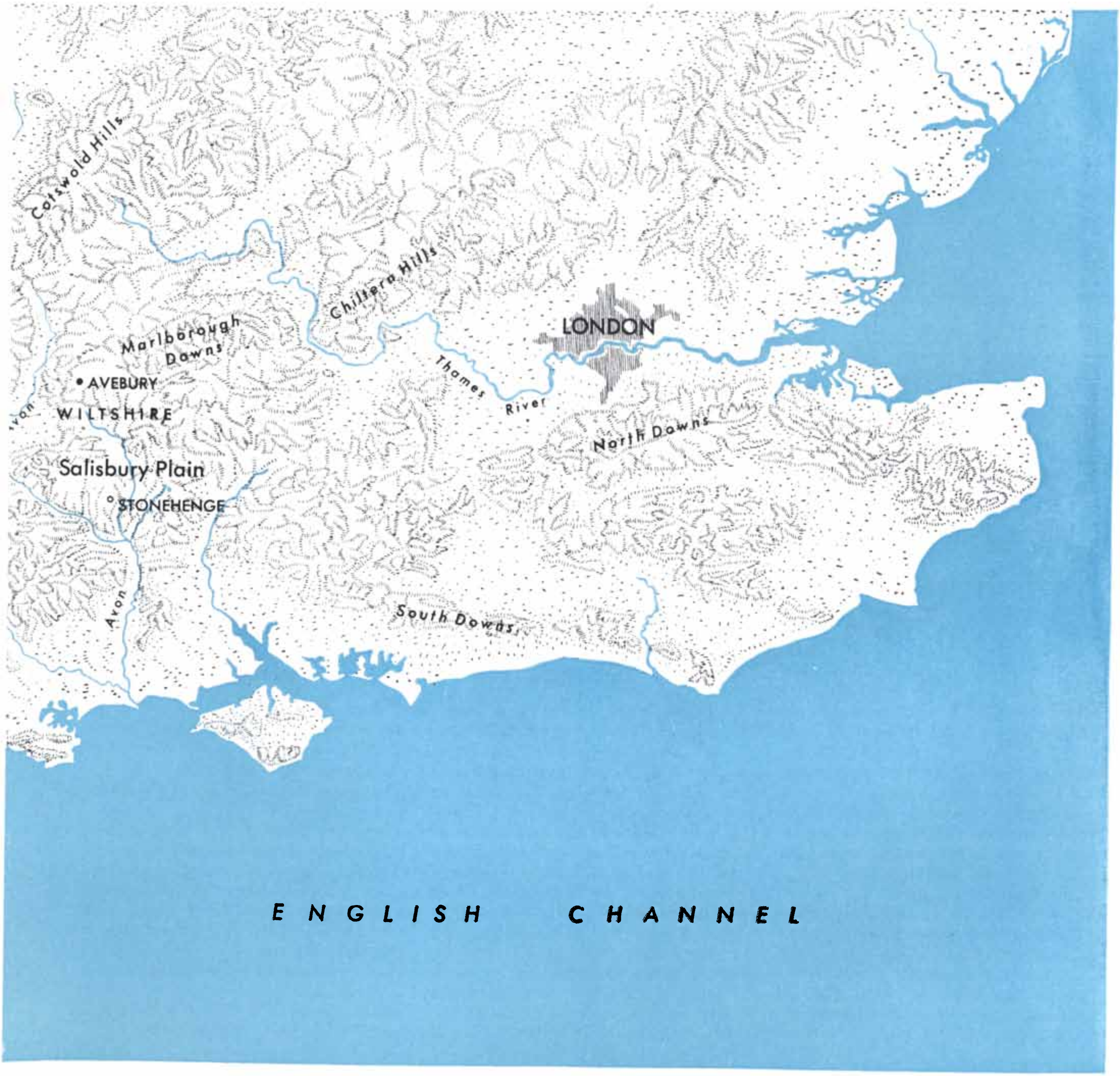
THE layout of the complicated sanctuary at once suggests different periods of construction for its parts. The enclosing embankment and the Aubrey

RELIEF MAP of southern England and Wales shows the geography which influenced the location of Stonehenge. When the monument was built, the English lowlands were covered with a thick oak forest; the early

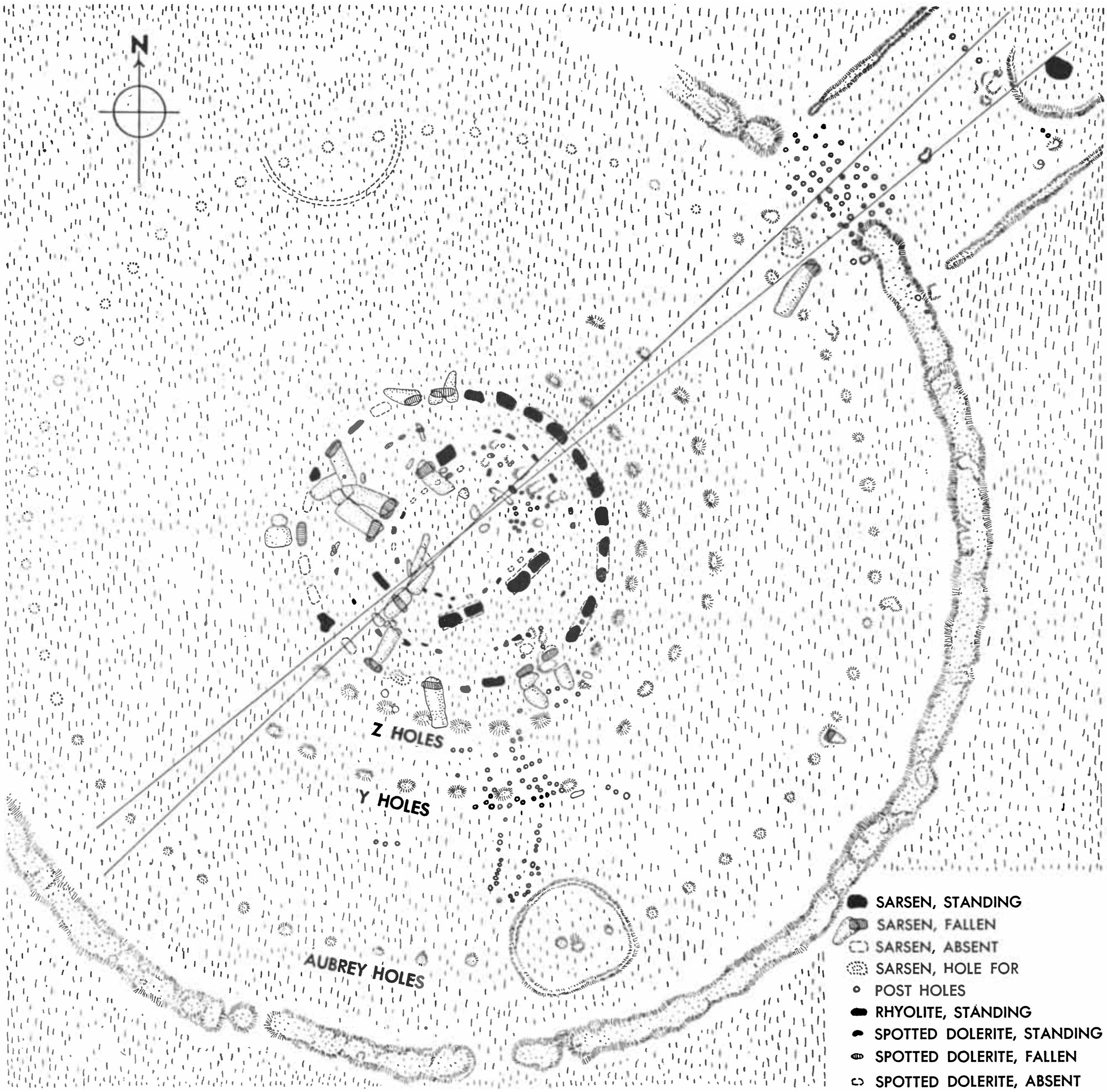
Holes have one common center, while the stone structure is very precisely centered on a different point, a foot or two from the center of the earthwork. The axis of the stone complex as marked by the horseshoes falls exactly along the center line of the Avenue but considerably to one side of the entrance causeway through the earthwork. As for the Y and Z Holes, they are set in irregular arcs as though the distances had been measured not from a true center but by estimation from the outer sarsen circle.

Thus the plan suggests that the enclosure and Aubrey Holes are of one age, the stone structure and the Avenue of a second, and the Y and Z Holes of a third. Excavation and analysis of many kinds have proved this division to be correct, and furthermore that this order in fact represents their correct chronological sequence. They have also shown that the Cursus belongs to the earliest period, being approximately contemporary with the enclosure and Aubrey Holes.

ALTHOUGH many difficulties and uncertainties still remain, years of digging and research have at last made it possible to give a coherent account of the long history of Stonehenge. The first building period is now generally recognized as belonging to a late neolithic culture. These tribesmen dug the long entrenchments of the Cursus, the enclosure ditch with its single entrance and the ritual pits within. Just before or after the making of these very humble earthworks they transported the Blue Stones and Altar Stone from Wales. As these stones must already have been imbued with a most compelling religious value, it can be assumed that they had formed part of a sacred monument in Wales. They were set up at some spot



farmers thus sought the thinly covered chalk and limestone hills of Wiltshire. Some of the stones for the monument came from the Presely Mountains in Wales by way of the Bristol Channel or around Land's End.



GROUND PLAN of Stonehenge shows its stones both in their present and original positions. The axes of both the large and small horseshoes are aligned with the Avenue, but the main entrance to the enclosure is not.

which may or may not have been at the western end of the Cursus.

During this earliest phase the neolithic peoples were already using the monument for cremation burials—a practice which seems to have continued unbroken into the second phase.

This first Stonehenge has been dated by British archaeologists as belonging to the centuries immediately after 2000 B.C. It was exceedingly gratifying to them to have their historical findings confirmed recently by radiocarbon dating of a piece of charcoal taken from one of the Aubrey Holes, which gave a date of about 1845 B.C., with a possible margin of error of 275 years.

The second period of Stonehenge, the period of its greatness, appears to have followed upon the first with no greater break than is implied between the Romanesque and Gothic phases of a cathedral. The enormous sarsen blocks were dragged from the Marlborough Downs, given their final shaping with stone mauls and set in position; the Blue Stone monument was dismantled and its pieces reassembled to enhance the sanctity of the new building. At much the same time the Avenue was laid out as a ceremonial way. Cremation burials continued to be made inside the sacred area, while outside it the wealthy and powerful men and women of the tribe were buried with their gold, their scepters of office and other precious possessions below the barrows which still ride so majestically upon many of the neighboring downs.

For the exact period and cultural background of the men of genius who designed this second Stonehenge there is no direct evidence. Certain elements which Stonehenge has in common with the relevant phase at Avebury suggest that this, like the more northern sanctuary, was built by beaker-using peoples who began to invade and settle in Britain in about 1800 B.C. On the other hand, it has been very tempting to assume that the building was done by the people of the Bronze Age Wessex culture, whose leaders lie buried in the richest of the associated barrow graves, and in whose time (about 1450 B.C.) the power and prosperity of the Salisbury Plain region was at its height.

As FOR the uses for which this great building was raised, there is no possibility of doubting that it was a sacred place, and little need, except for the excessively cautious or scholastic, to refrain from calling it a temple. There is no question, either, that its orientation was dictated by the position of the midsummer sunrise. The axis of the second Stonehenge points to the spot where the sun would have risen at the summer solstice during the first half of the second millennium before Christ.

If in its second phase the monument reached its glory, in its third phase it must have presented a melancholy picture of decay. It would hardly be possible to claim anything better for a period represented by the Y and Z Holes, and possibly by a single inhumed burial! It is not known for what purpose these Y and Z Holes were dug, for they appear never to have held either posts or standing stones.

That they were dug after the stone circle was already tumbling into decay is clearly shown by at least one piece of evidence. One of the big sarsens of the outer stone circle has fallen across the Z circle, and there is no hole beneath the stone, although the spacing of the Z Holes indicates that one should have been there. It seems plain enough that it could not be dug because the stone already blocked the way.

Pieces of pottery found in the pits suggest that the Y and Z Holes date from the Celtic Iron Age, probably from about the second century B.C. If this is so, it is more than likely that they represent a very limited attempt to restore the use of the sanctuary after a long period of decay covering all the latter part of the Bronze Age. This Iron Age revival makes it permissible to say that perhaps by good luck Stukeley may not have been altogether wrong when he spread the idea, still too widely held, that Stonehenge was the handiwork of the Celtic priesthood of the Druids. Build it they most certainly did not, but they may conceivably have officiated there before the ancient sanctuary was abandoned and left to turn into a noble ruin.

As WE have seen, the history of Stonehenge did not end with its abandonment. If we take a unified view of history, Stonehenge is no less important as a subject for countless chroniclers and many poets, as a place visited by Pepys and where Charles II whiled away an afternoon after the battle of Worcester, than it is as the greatest sanctuary of prehistoric Europe. Certainly we can say that if in the Bronze Age it was known throughout Britain, today it is famous all around the world.

VARIOUS ASPECTS of Stonehenge are shown by these photographs. The monument is seen from the east (*top*), southeast (*middle*) and northwest.

UNDERWATER TELEVISION

As a means of seeing beneath the surface, the image-orthicon camera has many advantages. It needs relatively little light and can be lowered to depths far beyond the range of divers

by W. R. Stamp

UNDERWATER television made a dramatic public debut in June, 1951, when it helped identify the wreck of H. M. Submarine *Affray*, 280 feet down at the bottom of the English Channel. The camera employed, which had been developed in the short space of three weeks after the tragedy of the *Affray*, was the first underwater TV camera to be built in Britain, and it was also the first to demonstrate the great possibilities of such an instrument. Its service during the survey and diving operations around the sunken *Affray* showed that underwater television was indeed a powerful new tool for gleaning information below the sea surface.

Several laboratories had already been working on this idea. In the U. S. the Cornell Aeronautical Laboratory had built and tested an underwater television system somewhat similar to the one developed for the *Affray*. The National Research Council of Canada had started developing a small image-orthicon television camera for underwater use, and the Scottish Marine Biological Association had begun experiments to determine the utility of television for marine research. The impetus given by the sinking of the *Affray* speeded developments, and there are now seven underwater television cameras in Britain. They are being used for many purposes by the Navy and other agencies.

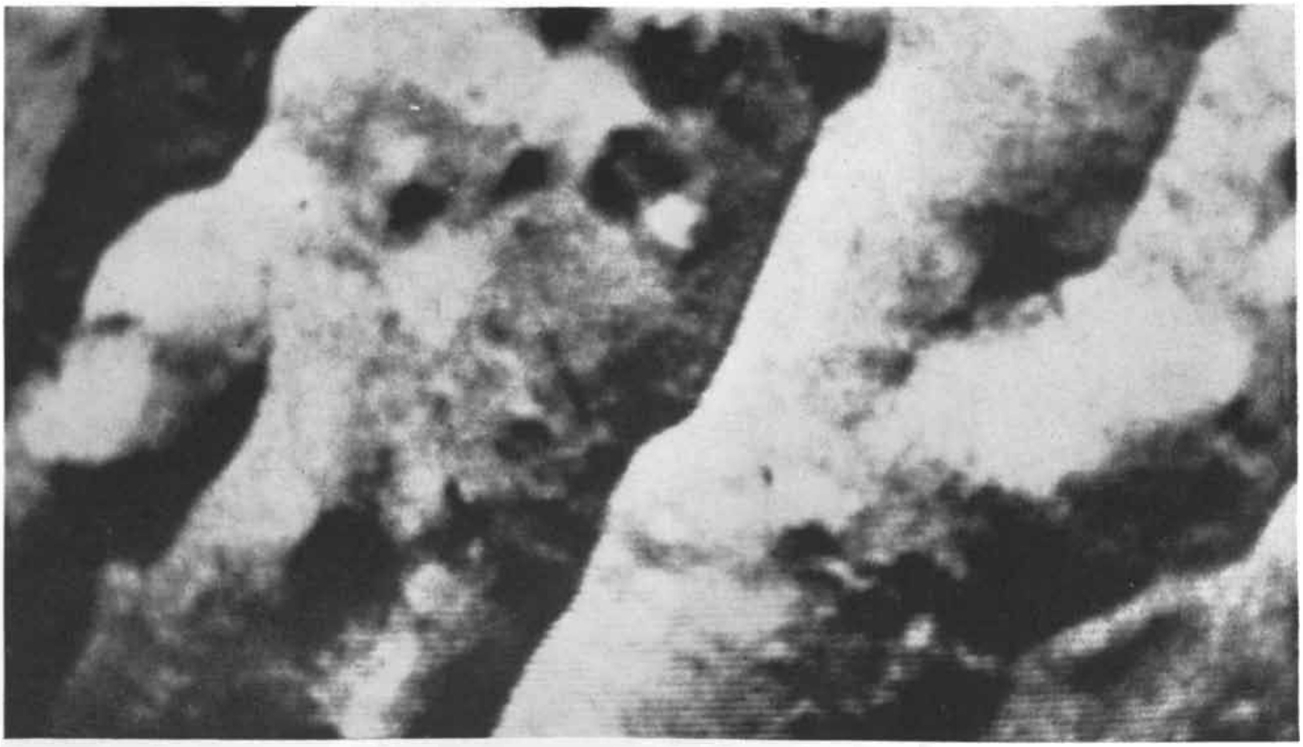
TELEVISION CAMERA protected by a heavy casing is suspended from the *Reclaim*, the British Navy's deep-sea diving and diving-research vessel.

Until recently the underwater world was the province of a privileged few—divers and expert swimmers—whose visual problems received little scientific attention. In the last decade, however, extensive work in underwater photography in France, the U. S. and Britain has brought a greater understanding of the problems and, to a limited extent, their solution. This work, particularly the Royal Naval Scientific Service's experience in making underwater motion pictures, is what made possible the rapid development of underwater television.

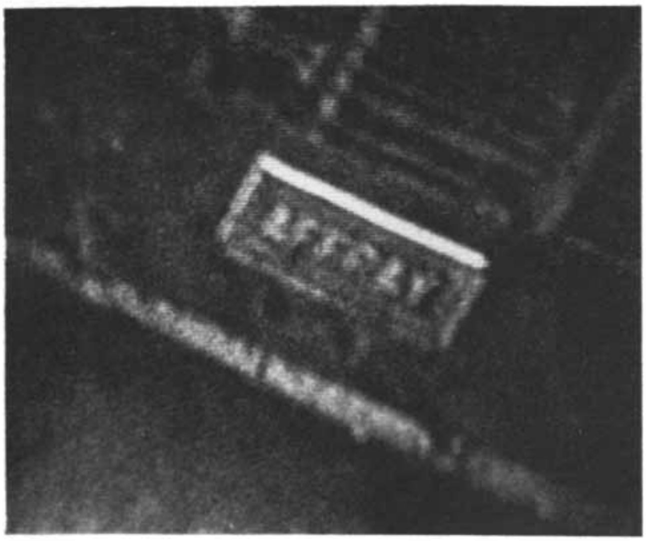
The fundamental difficulty is the turbidity of sea water, which varies greatly in different places. Turbidity is caused mainly by organic and inorganic particles in suspension. Turbid water resembles a dense fog in its light-scattering characteristics. In both, the particles causing the scattering are large in relation to the wavelengths of light. This means that light of all colors is scattered equally, and no help can be obtained from filters or special light sources, such as mercury or sodium discharge lamps.

In clear oceanic water light is scattered mainly by the molecules of water itself. They scatter blue light more easily than red, and this is what accounts for the intense, almost fluorescent blue of tropical waters, just as molecular scattering in the air makes the sky blue. Hence in very clear water a red filter or red light may help. Aside from spectral factors, television has a distinct advantage over photography in underwater

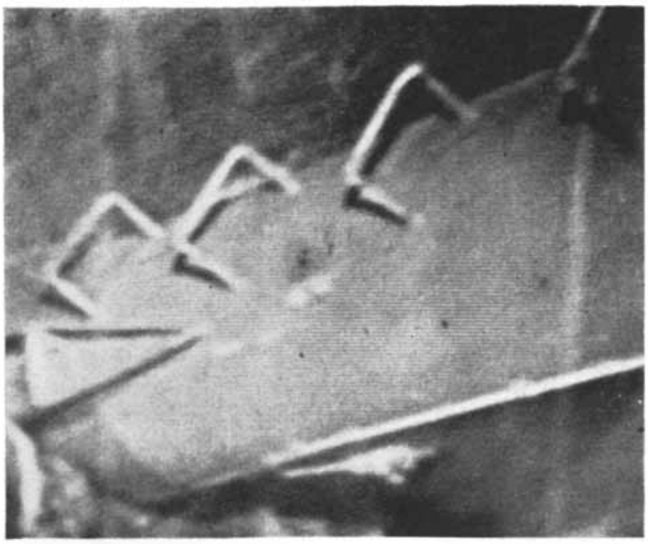
PROPELLER of R. R. S. *Discovery II* is viewed by means of a television camera lowered from the deck. In clear waters the television camera can be used to inspect damage to the hull or the stern gear of a ship.



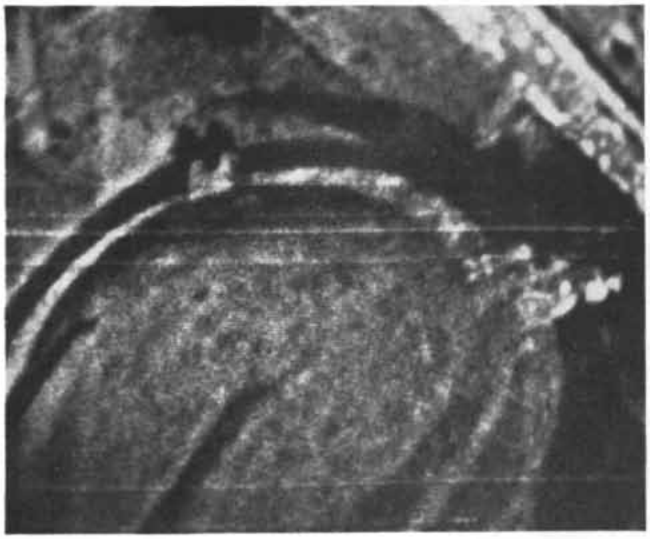
RIPPLES in the sand on the bottom also are made visible by the television camera. The form of the ripples can be analyzed to obtain information about such things as currents and wave motion close to the bottom.



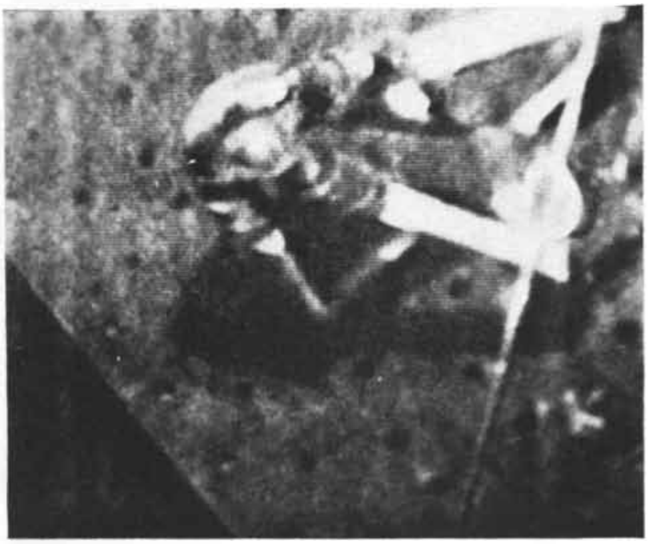
NAMEPLATE on the deck of H. M. Submarine *Affray* was viewed during the operations to salvage the vessel.



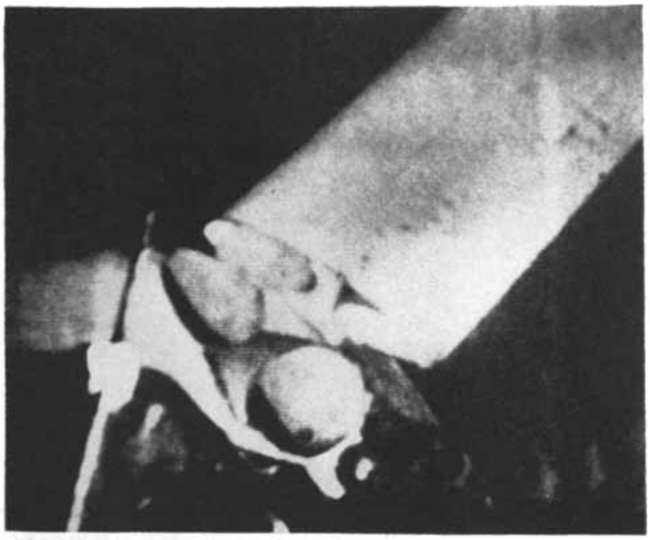
PERISCOPE STANDARD of the *Affray* was similarly viewed. Projecting from the standard are ladder rungs.



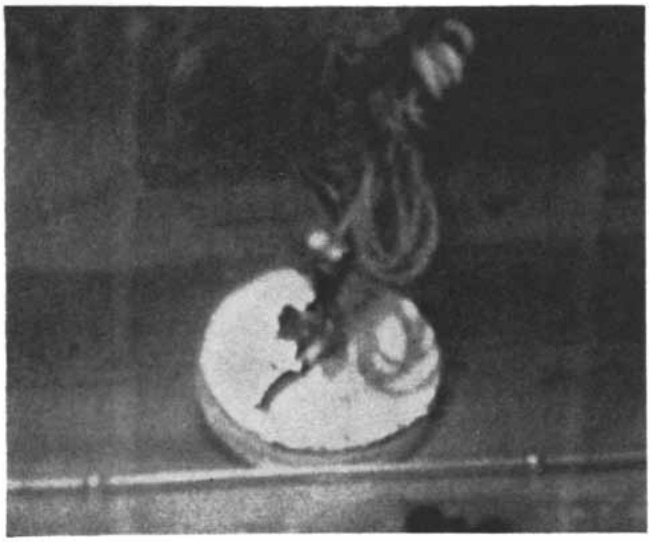
AFTER HATCH of the *Affray* is shown with its "salvage clips" unfastened. These permit divers to enter.



AERIAL of the radio direction finder was removed by dangling a hook below the camera and pulling it up.



SNORKEL of the submarine was found to be broken. The break appears toward the left side of the picture.



WEIGHT at the bottom of a diver's line was placed on the deck of the *Affray* with the help of the camera.

work, for while its definition is not as sharp, it gives a higher contrast between light and dark. But turbidity remains the main limiting factor, and the first step in dealing with it is to measure the turbidity of water. This is accomplished by an instrument called a hydrophotometer, pioneered by the German oceanographer Joachim Joseph. It measures the percentage of light transmitted through a short length of sea water by a beam of a certain diameter. By means of a number of such measurements taken in various waters, the hydrophotometer's readings have been related to the visibility range under various conditions. With this instrument a picture of the water clarity in a number of regions at various seasons and tidal states is gradually being built up.

The poorest visibility of course is encountered near estuaries and in any locality with a mud bottom stirred by strong tides or heavy weather. Indeed, the water in many river estuaries, docks and harbors is nearly opaque. Sometimes, when the object to be viewed under water is small enough, the difficulty can be overcome by interposing a bag of clear water between the object and the camera: one open end of the bag is attached to the camera lens and the other either is attached to the object being observed or has a window through which to look at it.

The best visibility is found along rocky coasts and in waters far enough from land to be away from its contaminating influences. In British coastal waters the usual visibility is about 15 feet, and under good conditions it goes up to 40 or 50 feet. The maximum range is much greater in the Mediterranean and in the open oceans. The record so far is 150 feet, attained on the Gettysberg Banks off the west coast of Spain.

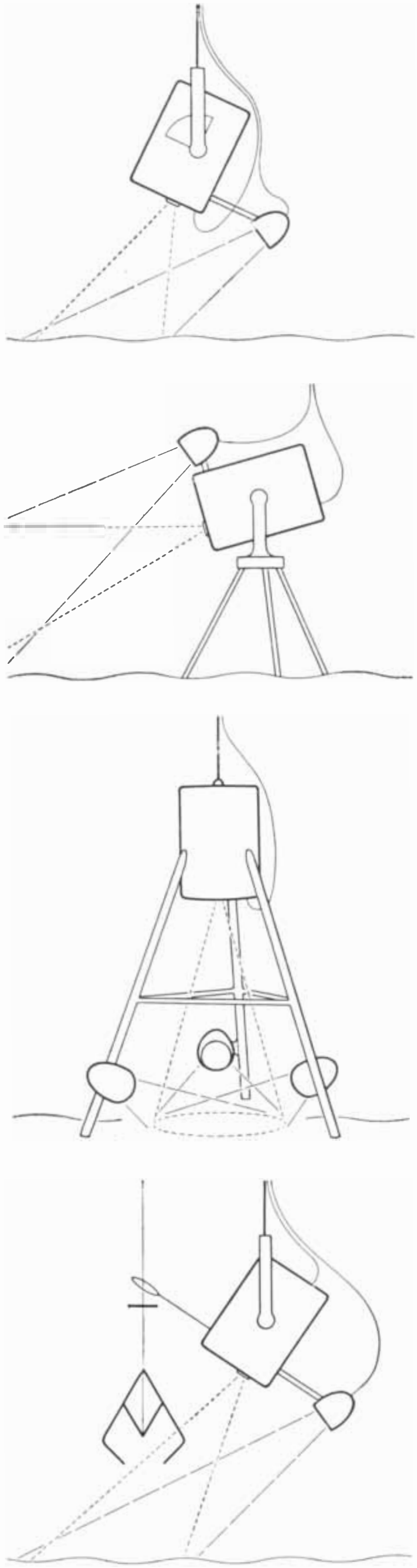
Generally one needs to provide artificial light even in daytime. For this reason the image-orthicon camera tube is the one most suitable for underwater television. It will register an image with only a few kilowatts of light. The light is usually built into the camera structure. Its positioning in relation to the lens is highly important. The best arrangement is to keep the water between the lens and the object as dark as possible to reduce the back-scattered light. Anyone who has driven a car at night in a fog will appreciate the necessity for this. The first lights used were ordinary divers' lamps, suitably shielded. Then various discharge lamps in different housings were tried. The simplest and most reliable arrangement found so far is to lower directly into the water ordinary tungsten-filament lamp bulbs, equipped with reflectors. The pressures a normal light bulb will stand are surprising: a 2,000-watt bulb of the type used for film-studio lighting is quite reliable to 600 feet depth and a good specimen will withstand 1,000 feet. Special bulbs, using a heavy filament in a comparatively small envelope, have been developed for regular operation down to 1,000 feet. Such a construction is possible because water immersion cools the bulb.

For very great depths a different form of lighting will be necessary. Housings to resist pressures at such depths are undesirable because they are optically inefficient and would be nearly as bulky and heavy as the camera itself. A possible new light source would be a small high-pressure mercury arc of the capillary-tube type. This would stand almost any pressures likely to be encountered. It has been tried with promising results.

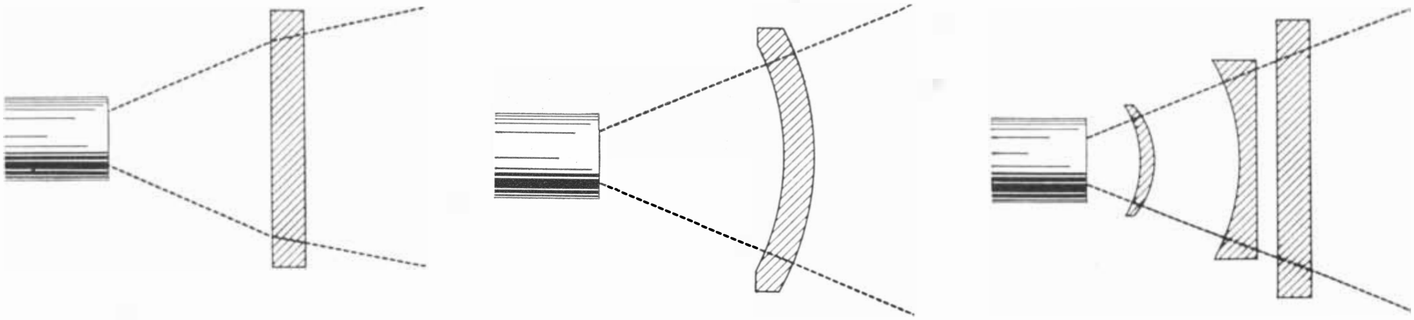
THE CAMERAS now in use are standard outdoor television ones, slightly modified and built into cylindrical steel watertight containers. The cameras' bulk and shape make the cylinders rather unwieldy, particularly if built for deep working. The first casing built was for a 200-foot working depth and operated down to 300 feet, its survival being accredited to luck. Subsequent casings have been more carefully designed and two are capable of 1,000-foot depths with a large factor of safety. The largest tips the scale at 2,000 pounds. The casings for various purposes differ considerably in design. Handling these heavy objects with their delicate contents at sea has been a difficult task at times. An attempt is now being made to produce a simplified camera of a more suitable shape which will fit in a casing about 10 by 22 inches that would weigh no more than 100 pounds even for 1,000-foot operating depths and could be made lighter for shallow working by a diver or from a small ship.

Since the slightest leak in these casings would be costly, great attention has been paid to the watertightness of joints, glands and windows. As an additional precaution, all possible sources of leakage are kept at the bottom or lens end of the casing; the camera is generally operated with the lens pointing downward. The casing is fitted with a leak detector, which gives an alarm on the surface before any damage can be done. The cable connecting the camera to the surface is identical with that used in television studios, except that its sheathing is doubled for extra mechanical protection. The maximum length of cable through which the camera will operate satisfactorily is 1,000 feet, and thus far the design of casings has been limited to that depth.

The television picture is reproduced in the normal way on the ship. It can be relayed to shore by a conventional microwave link. Occasionally the screen has been photographed; some of the pictures are reproduced with this article. The photographers do not do full justice to the television images, because of the improvised nature of the setup and the



SPECIALIZED RIGS have evolved for underwater television. Top: suspended camera with light attached. Second from top: camera on tripod with power-operated pan and tilt motions. Third: bottom-survey camera with lights attached to tripod legs. Fourth: suspended camera with light and attachment for guiding grapple.



LENS SYSTEM for underwater television has developed through these stages. At left in each picture is the camera lens. The first system has a smaller field of view in water than in air. The second has nearly the same field in water as in air, but has mechanical and optical disadvantages. The third has the same field in water

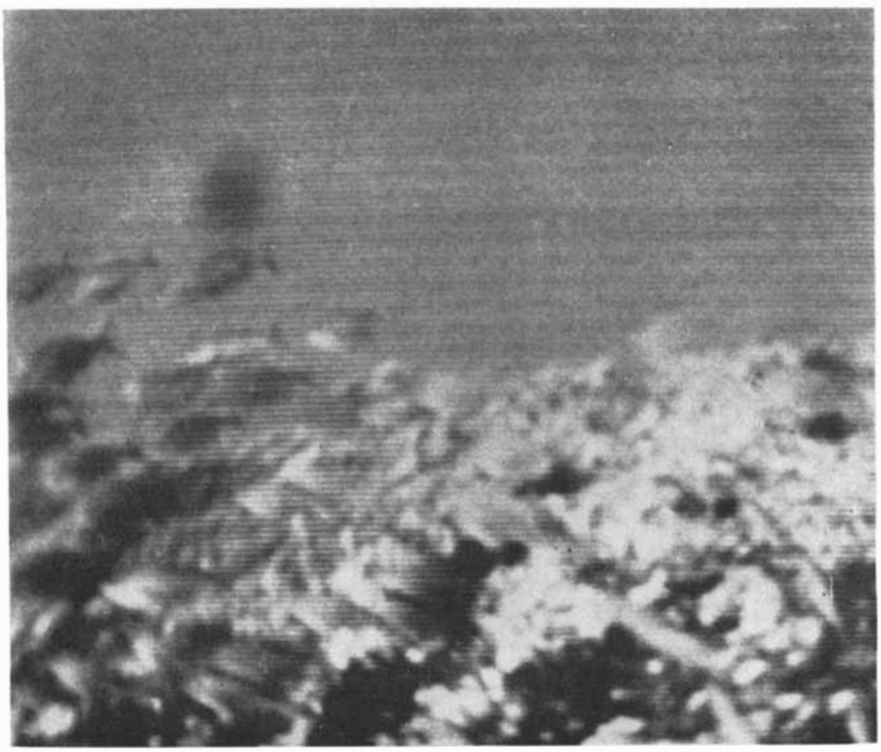
inherent difficulties in photographing a moving television screen. Motion pictures of the screen are not feasible either, because of the prodigious amount of film required. If really good underwater photography is wanted, it is best to fasten a remotely operated camera to the underwater television camera and use the latter as a viewfinder.

Both photography and television are complicated by the optical problem of looking from air into water. We cannot place a flat glass window in front of the camera lens to protect it because the glass would narrow the angle of view, due to refraction; we need the widest possible angle of view, as the camera has to be close to the subject. In photography the problem has been met by special lenses designed to work directly in water, albeit at rather small aperture. The television problem is slightly different: an aperture of at least *f*/4 is required to reduce the lighting to a reasonable power, and at the great depths at which television works the delicate optical surfaces cannot be in direct contact with sea water. In addition, television's high contrast will tolerate only slight vignetting. Designers have now developed a prototype lens which covers 75 degrees in water at *f*/4 through a flat window. This lens is a great advance over the original ones, which covered only 25 degrees. Several cameras have provision for changing lenses under water by remote control, and thus changing the angles of view. A typical survey camera can change its coverage from 65 to 35 degrees in this way, and a camera for marine biological studies, which needs less coverage, can change from about 30 to 10 degrees.

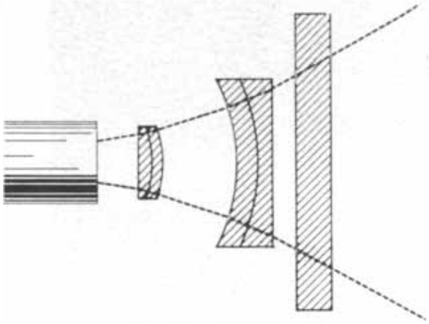
THE GREATEST single problem was how to maneuver the camera under water to train it on the target. There are three basic ways of doing it. First, a diver may handle the camera. This kind of operation may be valuable in salvage work. It allows experts on the surface to see an accurate picture of a wreck instead of having to rely on verbal descriptions by the diver (who is seldom a salvage expert). But of course the employment of a human carrier of the camera loses many of the advantages of television. For handling the camera by remote control there are two possibilities: one can maneuver it, like a puppet, by means of wires or even power-operated pan-and-tilt mechanisms, or one can simply lower it on a single wire and direct it by purely optical means.

It may not be irrelevant here to digress on the design of sea-going equipment in general. Many devices and arrangements which may seem very attractive on paper are unlikely to succeed at sea. The sea is crude and simple in its attacks on ships and their equipment, and crude and simple methods are apt to be most successful in combatting it. Obviously a present-day television camera is not such a simple device. Bolted firmly in a static housing, however, it becomes robust, and its handling is probably better accomplished by normal methods of seamanship, including wires, derricks and winches, than by more complex methods.

THE USES to which underwater television has already been put are manifold, and more are continually suggesting themselves. It was originally conceived as a rapid method of identifying wrecks, for which comparatively simple task it proved eminently suited. This was soon followed by its use as a salvage tool for deep operations to replace the observation chamber ordinarily used. For example, the wire-supported camera may be loosely shackled to and slid down the operating wire of a salvage grab. Watching the picture of the wreck on the screen, the salvage men can maneuver the grab more easily and accu-



SHOAL OF FISH hovers over weed-covered rocks. This picture was made by daylight. Daylight pictures have been obtained as deep as 400 feet.



as in air, and has a flat window. The fourth incorporates a flat window and a larger field in water than in air.

rately than when they have to depend on telephoned instructions from an observation chamber.

The camera was also quickly used as an aid to diving. A diver normally descends along a "shot rope"—a thick rope with a heavy weight at the end to anchor it on the sea bed. On reaching the bottom he may or may not be in the right place, since the shot rope was lowered by guesswork. In shallow working the diver is reasonably mobile and can walk off a considerable distance from the shot rope, holding on to a thin guideline. But in a deep dive he usually cannot leave it. Hence if he lands in the wrong place, he must be raised to the surface and dropped again. The return to the surface is a lengthy procedure and in tidal waters only one dive every slack water is possible. Furthermore, the diver's guess as to where he should be dropped on the second try may be inaccurate. With a television camera all this is changed. The weight is dropped first; the camera is slid down the shot rope to see whether the shot is in the right place, and the shot is then placed in the exact position required. The camera, while returning to the surface, can make sure that the shot rope is clear of all entanglement. While all this is going on the diver can be briefed in his job. This procedure led to the recovery of the *Affray*'s snorkel tube, which was lying on the sea bed in a very awkward position under the overhanging periscope standards.

Another simple application of the television camera is in surveying sea beds. This is perhaps the easiest and most straightforward use of the camera. Such surveys are of interest to geologists and physicists, to oceanographers and to marine biologists studying the behavior and distribution of bottom-living organisms. The camera used may be the freely suspended survey type, or it may be fastened to a tripod and stood directly on the sea bottom for a detailed picture of a small area. With the latter arrangement it is possible to locate the lighting to much greater advantage, and high quality pictures are obtainable even in coastal waters.

In the field of oceanography there is another basic application of television technique. This is in the remote reading of instruments. It is often simpler to have a television camera read an instrument on the bottom (*e.g.*, a pointer on a scale) than to use an instrument which transmits recordings to the surface. In some cases a very simple technique may make possible measurements unobtainable in any other way. For instance, the movements of small patches of dye in the water may be observed to measure the direction and speed of small currents very close to the bottom.

For the examination of dock walls, harbor works, ships' bottoms and the like, underwater television is less promising. The reason, of course, is turbid water. Sometimes the water is clear enough, as in Malta, where a survey of dock walls has been done by underwater photography. In turbid water an arrangement such as a clear-water bag may be used, but at these shallow depths television may offer no advantage over a direct optical instrument.

It is in the more inaccessible surveying problems that the television camera really comes into its own. Present development is concentrating in producing simpler and smaller cameras, better optics, lighting and cables, and a generally cleaner technique, so that the use of underwater television may spread into more and more branches of marine research.

EDITOR'S NOTE

This article is published with the kind permission of the British Admiralty.

SOLITARY FISH is viewed at 600 feet. The television camera may be used to estimate populations of fishes.

FISH ON THE BOTTOM is photographed at the great depth of 1,000 feet. Underneath the fish is its shadow.

ANATOMY OF A TOOTH is revealed by a vertical section photographed under ultraviolet light at the National Bureau of Standards. The light area is the dentin, striated by growth rings. The darker area at the top is the enamel, with a cavity in its crown. The darker area around the dentin at the bottom is the cementum.

The Skin of Your Teeth

It is enamel. Like hair and nails, this hard substance is made by epithelial cells. Once it was thought to be as inert as rock; now it is known to exchange its substance with the body fluids

by Reidar F. Sognnaes

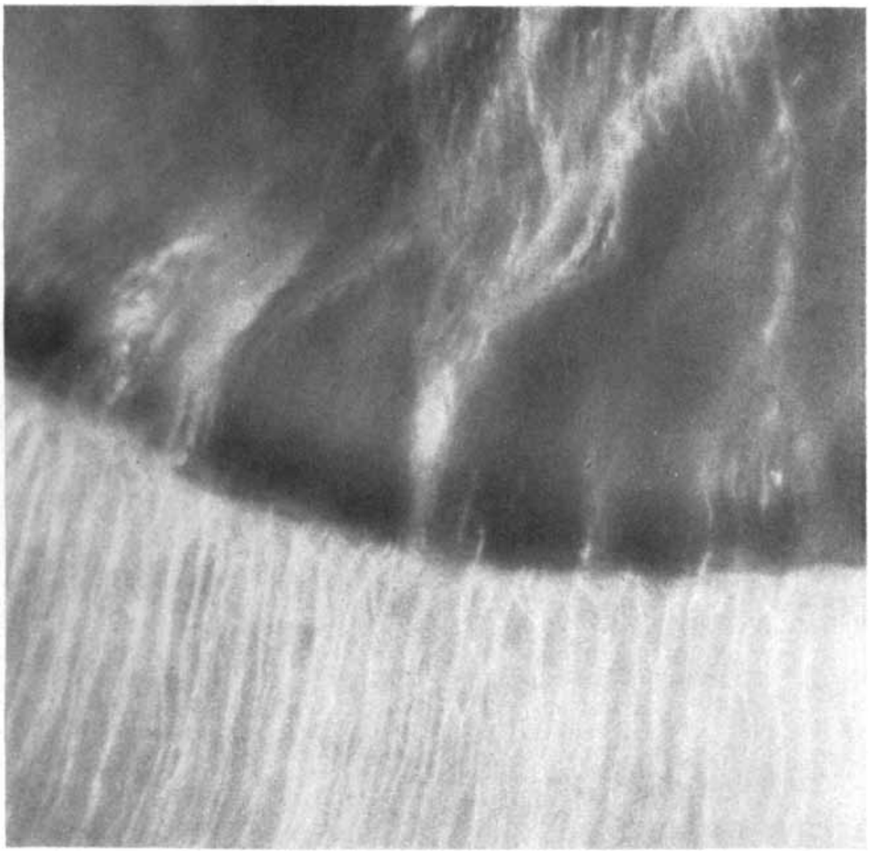
IT IS A CURIOUS fact that the teeth of man are the most durable part of the body after death and yet tend to go to pieces faster than any other organ during life. Buried in the ground they may last for thousands of years, long after the rest of the body has crumbled. But in the living body they are extremely vulnerable to decay.

Tooth decay seems to be an affliction peculiar to the human species. Man has always had sporadic cavities; even primitive human beings had less perfect teeth than the average monkey in the wild. Today there are few peoples in the world, primitive or otherwise, with truly healthy teeth. Tooth decay has shown a disquieting tendency to grow with civilization. A University of Minnesota study covering the last three decades indicates that the teeth of the U. S. population are steadily deteriorating. In Europe the trend has been the same, except for a temporary respite during the two World Wars, when people ate more primitively. If the trend of recent centuries continues, by the year A.D. 3000 Homo sapiens may not have any whole teeth left at all.

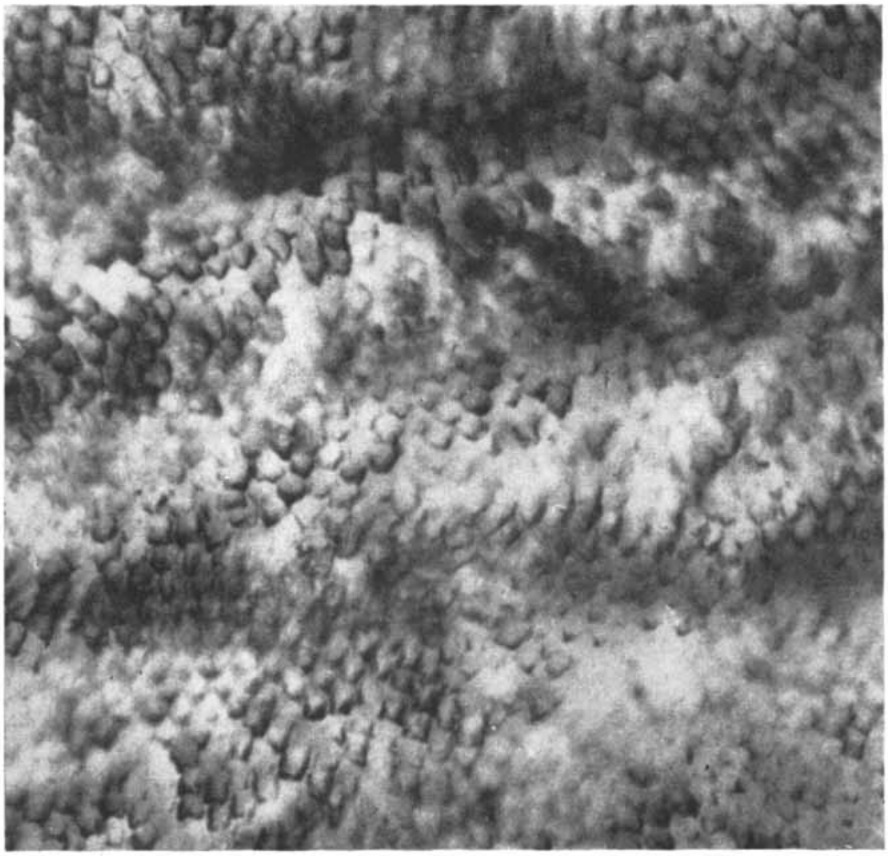
Even more discomfiting than the peculiar frailty of our teeth is the fact that we still do not know exactly why they decay. In the past century investigators have offered a number of theories, only to find flaws in all of them. The idea that "a clean tooth never decays" is more than 50 years old, but despite half a century of vigorous tooth-brushing the prevalence of the disease has increased. To find a rational solution to the problem, the only hope is to intensify our research on the teeth. In this research we now have the help of some important new tools, notably radioactive tracers and the electron microscope. With them we have already learned some facts that overthrow old notions about the teeth.

ESSENTIALLY the teeth consist of two types of hard tissue: the dentin or ivory core, and the enamel, or "skin" of the teeth, to which man owes his white smile or his cavities, as the case may be. The dentin is formed by connective tissue—the same tissue that makes bone and cartilage. The enamel is produced by skin (epithelial) cells—which also give rise to hair, nails, feathers, horns and so on. The enamel of the teeth is the hardest and strongest tissue of the body. If the dentin is a "super bone," the enamel is a "super skin." We shall concentrate here on the enamel—the most mysterious part of the teeth and the rampart that defends them against decay.

The building of a human being's teeth begins when the fetus is only about a month old and less than half an inch long. While the future jaws, tooth sockets and dentin are being formed by connective tissue, epithelial cells start to make the units of the enamel. In rhythmic fashion each enamel-forming cell (ameloblast) builds a tiny, pencil-shaped prism. The prisms are packed together lengthwise like fagots; their ends become the surface of the enamel and each prism is as long as the enamel is thick—a tenth of an inch or less. The prisms are so slender that there would be room for 100 of them within the thickness of a human hair. It takes some



DENTIN AND ENAMEL are photographed at larger magnification by the same technique as on opposite page. Dentin (*light area at bottom*) is produced by connective tissue cells; enamel (*darker area at top*), by skin cells.



SURFACE OF THE ENAMEL is composed of tiny "prisms." Each of these is a long, thin structure extending from the surface of the enamel down to the dentin. This photomicrograph enlarges the prisms some 500 diameters.

10 million of them to make the enamel crown of a molar tooth.

Because of their rhythmic growth, the prisms show growth lines like the rings of a tree. Their growth is extremely sensitive to disturbances in metabolism: an infection or nutritional deficiency interrupts their development and leaves a permanent imprint on the enamel in the form of an irregular growth line. Even the normal event of birth, with its change in metabolism, marks a so-called birth line in the enamel.

When the infant is born, not only are its baby teeth already calcifying but its permanent teeth have begun to form. At the age of three the child literally has a mouthful of teeth: the 20 baby teeth, which by now have emerged into the mouth, and 32 permanent teeth, which are buried in the jaw in various stages of formation and calcification. The permanent teeth replace the baby teeth between the ages of six and 13, and the wisdom teeth, if any, do not appear before 18. Thus the formation and calcification of the teeth cover many years, during which conditions are not always ideal for their construction. Yet to make perfect enamel each enamel-forming cell must stay healthy until the work is done, for the ameloblasts, unlike most other cells of the body, cannot reproduce.

For many years the completed enamel of the teeth was considered "dead as a doornail"—an inorganic, rocklike structure devoid of any organic matter. As a result it was treated as if it were independent of the body as a whole. Whereas the lining of an organ like the stomach has physiological defenses against its digestive acids, the enamel was thought to be a passive prey to its environment. The prevailing idea was that tooth decay was due simply to attack by acid formed by bacterial fermentation of carbohydrates in the mouth. This view guided much of the research on the problem.

We know now that the enamel is not purely inorganic. The early investigators failed to find any organic material because they lacked sufficiently refined methods for examining the enamel. When it was treated with acid, it disappeared; when thin slabs of it were examined under the microscope, only inorganic material was observed. The reason was that the slabs were much too thick, many times thicker than the prisms they were examining. The enamel prism itself is a mere five microns (one 5,000th of an inch) in diameter, and the spaces between the prisms are less than one micron wide.

WHEN, with the new tools of recent years, it became possible to slice much thinner sections of enamel and to explore the prisms and spaces at the submicroscopic level, a new picture emerged. Under the ordinary microscope it could be seen that the enamel was permeated with a sponge-like meshwork of organic matter which filled the spaces between the prisms. Under the electron microscope, and using still thinner sections (much less than a micron thick), investigators have discovered very recently that organic fibrils interlace not only the spaces between prisms but the core of the prism itself. These fibrils, so fine that they are invisible under the ordinary microscope, apparently surround the individual inorganic crystals.

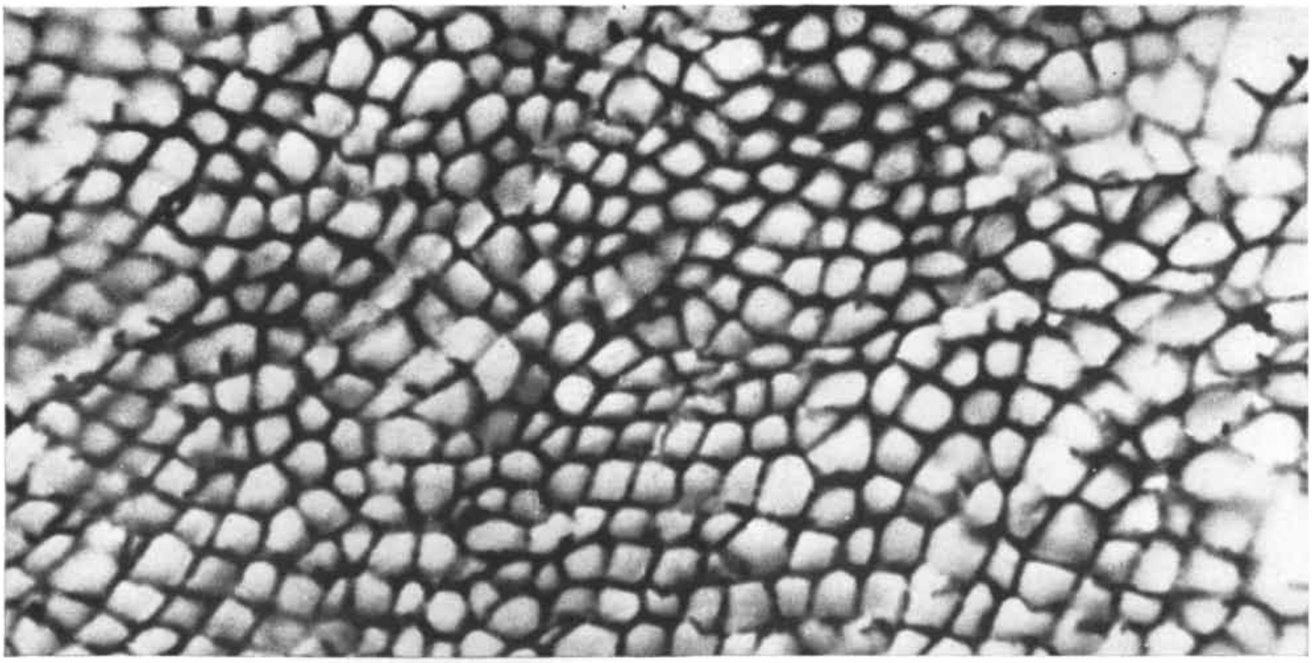
These discoveries make clearer what is involved in the decay of a tooth. The microorganisms that are believed to cause decay in the teeth are much wider than the individual crystal-and-organic units that make up the enamel. Hence before a microorganism can invade the enamel, both the organic and the inorganic matter (or the bond between the two) must be destroyed or weakened in some way.

The next problem is the chemical composition of the enamel. The prism crystals are made of tricalcium phosphate, magnesium phosphate and calcium carbonate—the same substances that occur in the dentin of the teeth and in bone. In addition, the enamel contains many trace elements, but it is not clear whether these are attached to the crystals or intermixed in some other fashion. One of the trace elements is fluorine. Studies of it suggest that it may enter into a chemical reaction at the surface of the crystals and form a relatively insoluble product, making the teeth more resistant to decay.

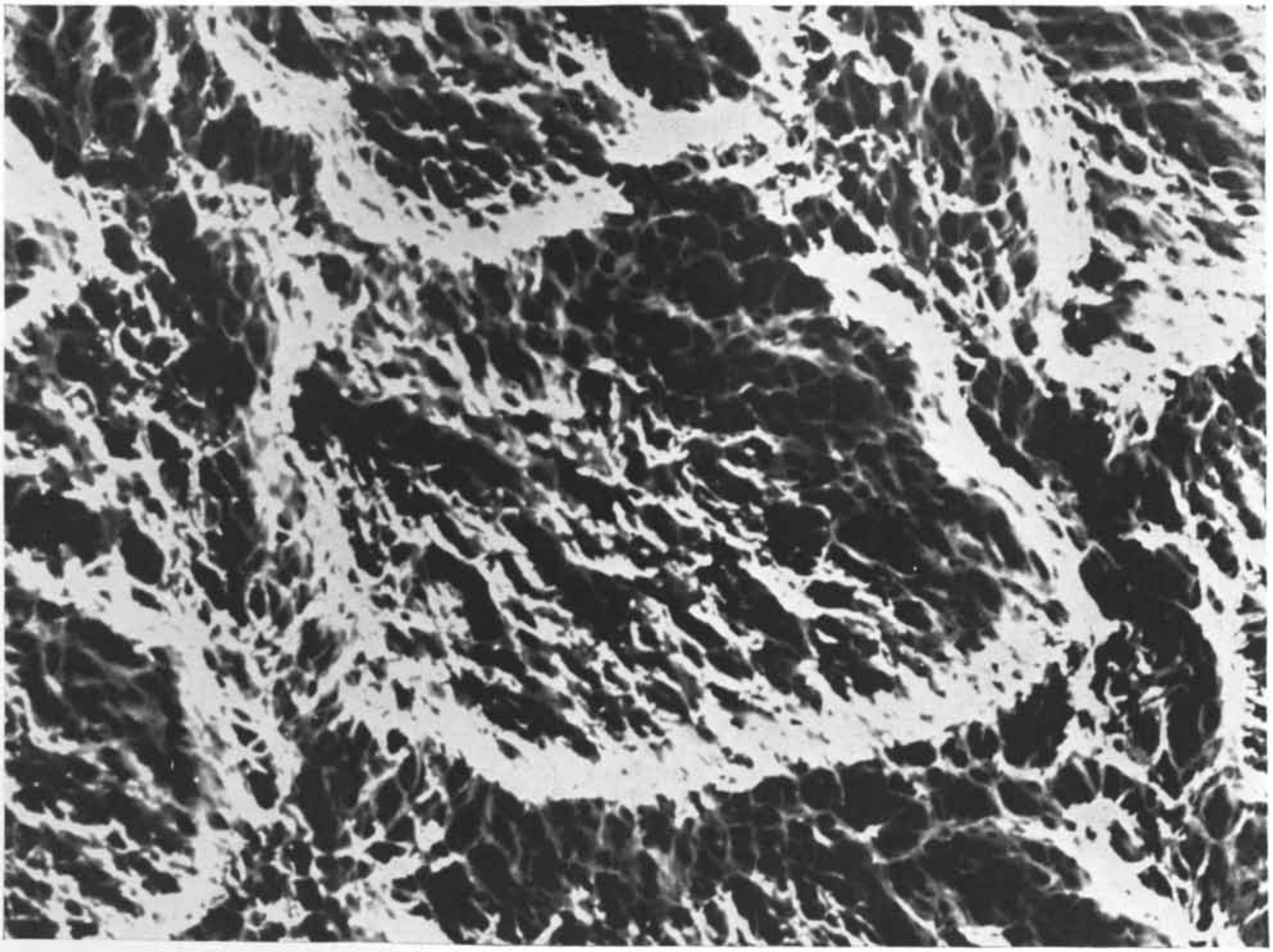
As for the organic fibrils in the enamel, analysis of their amino-acid composition indicates that they may be a keratin—the fibrous protein of skin and hair. Besides this fibrous protein, the organic matter also seems to contain a polysaccharide (a complex of protein and carbohydrate) which may serve as a coating of the fibrillar matter and as a bond between the inorganic crystals.

Thus it appears that the enamel of the teeth, like dentin and bone, is made up of three major components: (1) the inorganic crystals, which serve as bricks; (2) the polysaccharide, which acts as mortar, and (3) the fibrous protein, which form the reinforcing framework of the structure.

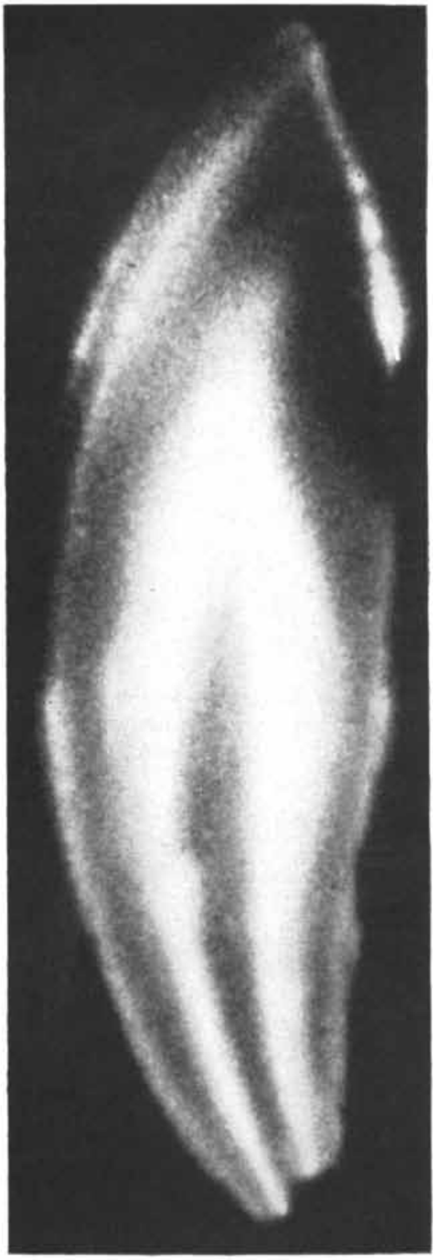
Yet enamel is unique among living matter in two respects; it has no cells or blood vessels. Is this strange tissue dead or alive? The question has been argued heatedly ever since the enamel was found to contain organic matter. Certainly enamel cannot reproduce itself, as living tissues usually do. But then, neither can some of the highly specialized cells of the body, such as the brain neurones. To investigate the question



ORGANIC FRAMEWORK of the enamel prisms remains when their inorganic content (tricalcium phosphate, magnesium phosphate and calcium carbonate) are dissolved with dilute acid. The organic material seems confined to the spaces between the prisms, which are enlarged some 1,000 times in this photomicrograph.



ORGANIC FIBRILS are revealed when a very thin section is enlarged 20,000 diameters by the electron microscope. The roughly circular structure is a single prism. The electron micrograph was made in collaboration with the author by David B. Scott, Marie J. Ussing and Ralph W. G. Wyckoff of the National Institutes of Health.



RADIOAUTOGRAPH of a monkey's tooth shows that teeth, like other tissues of the body, actively exchange some substance with the body fluids. The radioautograph was made by the following procedure. First 15 millicuries of the radioactive isotope phosphorus 32 were injected into a vein of the monkey. After nine days the monkey was sacrificed; the incisor tooth shown in the radioautograph was then removed and cut from top to bottom. The flat surface of the tooth was placed upon a piece of photographic film for 15 hours. When the film was developed, the radiation from the phosphorus had exposed it in the pattern shown here. The exposure is strongest on the surface of the enamel at the top and around the root canal, indicating that the tooth exchanged phosphorus with both the saliva and the blood.

whether the enamel is alive, or at least capable of change, radioactive tracers seemed a logical tool.

LET US CONSIDER the metabolic behavior of bone, second cousin to the enamel. Bone is an active participant in the body's physiology: it continuously rearranges its structure according to the body's needs; it stores calcium for the body's emergency demands. It gives up calcium by the process called resorption, which dissolves away part of the bone, in the presence of certain giant cells called osteoclasts and under the influence of hormones or of mechanical stress. Sometimes resorption may extend to the jawbone or even the bones that form the teeth sockets. Yet the teeth themselves are usually spared. (This is what makes it possible for orthodontists to straighten teeth; under pressure from the braces the socket bones are resorbed and rearranged, while the teeth remain intact.)

There is one perfectly normal process in which the teeth do submit to resorption. When the baby teeth are shed, the cementum that covers the root of the tooth, the dentin and often even the enamel are resorbed. Furthermore, as we have seen, developing teeth share in the general metabolism of the body. We must, however, make a sharp distinction between growing and adult teeth. Once the enamel has been fully formed, it seems to be independent of the body's metabolism—certainly of those metabolic influences that are transmitted directly through blood vessels and cells.

Does it exchange substances with the rest of the body in some other way? This is the question we undertook to explore with radioactive tracers. Tracer experiments had shown that deposits of bone and of fatty tissue, which seem stationary, are actually far from static and are constantly reworked by a give-and-take process—a turnover of the atomic building blocks. We used radioactive isotopes of phosphorus, calcium, iodine and other elements to find out whether such a turnover took place in the enamel. The experiments proved that it did. Some of the ions at the surface of the enamel crystals, including ions of phosphorus and calcium, are freely exchangeable with chemically similar ions in the surrounding fluid, the saliva. What is more, ions of such elements as phosphorus and iodine can penetrate through the enamel and dentin—and in both directions! They can move from the saliva into the internal pulp of the tooth and *vice versa*.

In short, the enamel is not as fixed or as dead as it seems. Like other hard tissues, it carries on a traffic with its environment, albeit without the aid of blood vessels or cells. What tissue fluid is to finished bone, in a chemical sense, the saliva is to finished enamel. As long as an equilibrium of intake and outgo is maintained, the composition of the enamel stays constant. But when the equilibrium is upset, the tooth substance may change—for better or for worse, from the standpoint of defenses against decay.

Saliva clearly is essential to the health of the teeth, for when the salivary glands are destroyed or removed, tooth decay becomes rampant. But considering the great variety of substances we take into our mouths and circulate *via* the saliva, we must be concerned about what the saliva is introducing into the enamel. Some of the substances that enter the enamel by this route may strengthen its defenses; some may weaken them. At the other end, a wrong-way traffic within the teeth themselves may be as dangerous to them as the microorganisms and food substances in the saliva.

PRACTICAL application of these findings to the prevention of tooth decay is not around the corner; the puzzle of what causes decay is still far from solution. Until we know more about the causes, we can only go on using the strategies we have at hand. Cleaning the teeth is demonstrably none too effective. It is perfectly true that a clean tooth—meaning a tooth completely free of microorganisms, their food and their products (acids and enzymes)—never decays. When rats are fed by stomach-tube, bypassing the mouth, or when animals are raised in a germ-free environment, their teeth do not decay. But in practice a clean tooth never exists, for a person who eats normally always has some microorganisms and food debris in his mouth, no matter how often he brushes. The most that can be said is that if we did not clean our teeth they would be worse than they are.

The second strategy is to fortify the teeth's defenses. This approach may be more effective. The most significant and useful step that has been taken in this direction is the fluoridation of drinking water. Fluorine helps most in preventing decay if it is built into the teeth while they are developing during childhood. The research that led up to this public health measure is a story in itself—a story of which the dental profession can justly be proud. However, this progress, while encouraging, should not lead to complacency in our fight against the deeper secrets of dental disease. Fluorine significantly reduces the extent of tooth decay; it does not abolish the disease.

Nonetheless the partial success of fluorine has underlined the importance of the developmental period in general, and of trace elements in particular, for the construction and maintenance of healthy teeth. It emphasizes that to find the causes of tooth decay we must investigate not merely the microorganisms in the mouth but the submicroscopic structure, the chemistry and the physiology of the teeth themselves.

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All prices quoted are subject to change without notice

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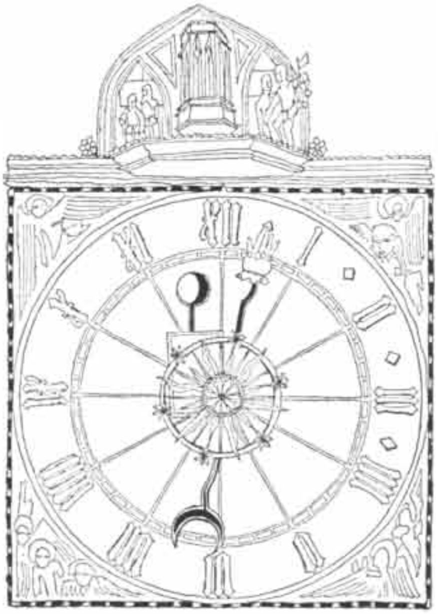


Atomic Power

AS this issue of SCIENTIFIC AMERICAN went to press, the Congressional Joint Committee on Atomic Energy had under consideration several proposed amendments to the Atomic Energy Act. *The Wall Street Journal* reported that President Eisenhower was "about to ask Congress to let private industry have a bigger share in the atom." The proposed changes in the Act, as outlined in a bill already introduced in the House, would license private companies to possess uranium and to produce plutonium and other fissionable materials, would permit the Government to make long-term contracts to buy plutonium from private manufacturers, and would allow companies doing research in atomic energy to patent their inventions.

These proposals have the support of a number of interested companies. Walker L. Cisler, president of the Detroit Edison Company, recently said that "the time has come when definite, full-scale commercial applications of atomic fuels must be considered and undertaken." Industry, he declared, is ready to "proceed with this development if it can do so on the basis of our competitive enterprise system." A consultant of Detroit Edison has estimated that industry could develop atomic power to compete with other fuels within 10 years. This calculation is based on the sale of plutonium produced in the power reactors to the Government for weapons. Charles A. Thomas, president of the Monsanto Chemical Company, believes that industrial power reactors might produce plutonium for sale to the Government at less cost than the Atomic Energy Commission's present reactors.

Not all sections of industry agree with this approach or accept such estimates. A leading exponent of the "go slow" school, Harry A. Winne, vice president of General Electric Company, stated last month that he saw "no need to get hysterical about the development of atomic-electric power." Winne argued that nuclear power "will be economically sound only when it can compete with conventional electric power without requiring a government-supported weapons market." He thought that it might be desirable to go ahead with one experimental reactor for the dual purpose of producing power and plutonium, but he estimated it would take "decades" to develop the "new tools and new knowledge" needed to build economical power plants.

In advance of the hearings there was little publicly expressed opposition to the proposed changes in the Atomic Energy Act. U. S. Senators John W. Bricker and Bourke B. Hickenlooper and General Leslie R. Groves were reported to head a group opposed to the changes on the ground of the security risk. Some members of Congress also believe that such changes are premature. They argue that truly competitive atomic power is so many years away that no large private funds would be ventured in it; that the companies which wish to build plants are primarily interested in selling plutonium, and any pilot plants would actually be subsidized by the Government directly or indirectly. They also believe that the Government should retain control of atomic energy in order to mitigate the impact of such a power revolution, when it actually comes, on the national economy. They favor merely widening industrial participation in government-owned research and development projects at this time.

Bureau of Standards

THE National Bureau of Standards was placed in a state of suspense last month. Confronted with the threatened resignation of a large part of the Bureau staff over the discharge of Director Allen V. Astin, Secretary of Commerce Sinclair Weeks temporarily reinstated Astin and appointed a committee of nine prominent scientists to review the Bureau's work and functions. He asked Astin to stay on until the investigation was finished. The committee is headed by Mervin J. Kelly, president of Bell Telephone Laboratories, and includes representatives of a number of scientific and engineering societies.

A few days after Weeks's appointment of the committee the Washington *Post* reported that he had already begun to curtail the Bureau's functions. At Weeks's request, said the *Post*, Secretary of Defense Charles E. Wilson issued an order stopping any further assignment of defense research projects to the Bureau of Standards or other Government agencies except on his specific approval. When the investigating committee learned of this, it asked that the order be rescinded until its inquiry has been finished.

Weeks, who had originally charged the Bureau with not being objective in its tests of a battery additive, said in his later statement "that at no time has there been any intent, implied or otherwise, to cast reflection upon the integrity of the Bureau or the professional competence or integrity of Dr. Astin." But he made clear that Astin would not be retained, whatever the findings of the investigating committee. Weeks declared he had differences with Astin over "administrative viewpoint and procedure."

Astin, agreeing to stay in his post regardless of "personal opinions or wishes," noted that "the professional integrity of the Bureau and my own integrity and competence have during recent weeks seemed to be in question. I am gratified that the Secretary has seen fit to reassure me and the Bureau on these particular points."

Astin's firing, remarked the New York *Times*, "mushroomed into one of the most embarrassing political incidents the Eisenhower Administration has yet faced." Scientists, congressmen and the press accused Weeks of political interference with scientific work, and some found disquieting a reported statement by Weeks that technical products should be submitted solely to "the play of the market place."

AD-X2, the battery additive which touched off the explosion, will be investigated by a committee to be appointed by the National Academy of Sciences. Meanwhile a few more details of its history emerged. Wallace R. Brode, of the Bureau staff, disclosed that the Bureau had been under "terrific pressure," including requests from 24 Senators, to report favorably on it. The Washington *Post* said that Keith J. Laidler, technical consultant to the Senate Small Business Committee and one of the chief critics of the Bureau's tests, was on the payroll of the manufacturer of AD-X2.

Attic Physicist

THIS is an age of specialism and big research establishments in science—an age in which the esoteric refinements of nuclear physics, for instance, are widely recognized to be too much for the untrained man. Still, untrained solo investigators are not always or altogether discouraged. Three years ago the Radiation Laboratory at the University of California received a long letter from one Nicholas Christofilos, then living in Athens, Greece. Mr. Christofilos had an idea which he thought would make it possible to build immensely bigger and more energetic synchrotrons.

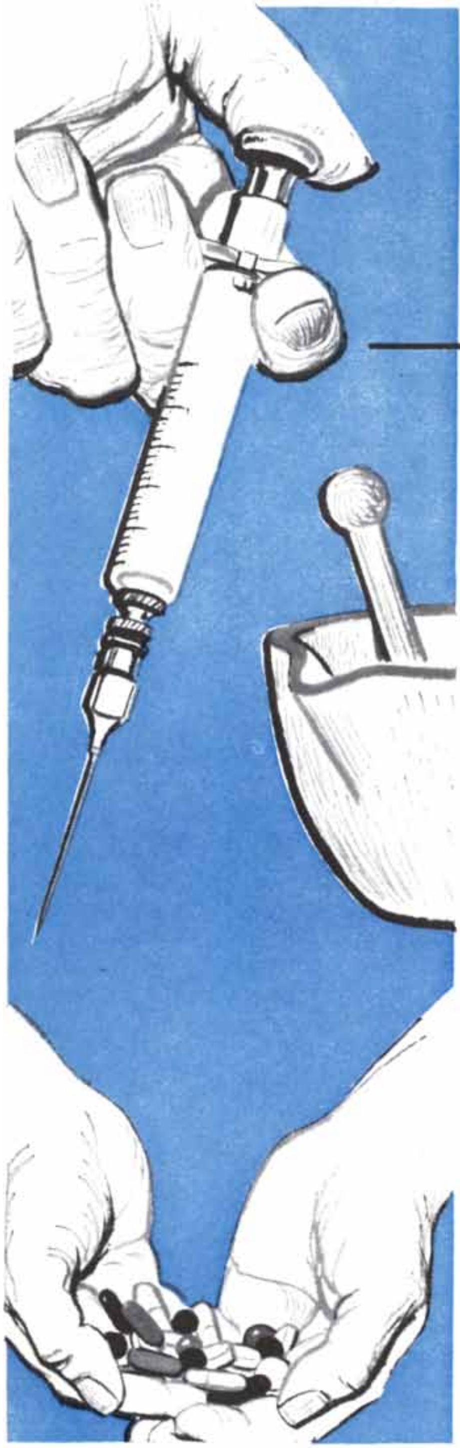
The California scientists considered the suggestion, were baffled by the unorthodox mathematics with which Mr. Christofilos ventured to explain it, and decided the idea would never work. Christofilos, undiscouraged, was so sure he was right that he applied for U. S. patents on his principle. His idea lay quietly buried in the Patent Office until a few months ago when a team of physicists at the Brookhaven National Laboratory, who had never heard of Mr. Christofilos or his suggestion, discovered independently after much high-powered labor that such a system would indeed work. What Mr. Christofilos had discovered was the principle of the strong-focusing synchrotron (see "A 100-Billion-Volt Accelerator," by Ernest D. Courant; SCIENTIFIC AMERICAN, May).

This verified story came to the attention of a number of leading U. S. physicists last month and created considerable interest in its hero. Christofilos, born in Boston, Mass., in 1916 of Greek parents, grew up in Athens, to which his family returned when he was a boy. He was educated as an electrical engineer in Athens and after graduation worked for an elevator manufacturer. In his spare time he studied atomic physics, and on his own he seems to have discovered the principle of the synchrotron itself. Then it occurred to him that the magnetic field which keeps the accelerated particles in their path might be split up into a series of alternate focusing and defocusing sections which would have a strong net focusing effect and keep the particles in a very narrow beam. Christofilos had no training in mathematical physics, but he improvised a crude mathematical handling of the problem which gave approximations close enough to satisfy him that the idea was sound.

Christofilos, now back in the U. S., has recently talked with physicists at Brookhaven and the University of California—and received a respectful hearing. He foresees important commercial applications for his discoveries in addition to their value in nuclear research.

Lie Gadgets

THE technological methods of lie detection appear to be losing favor among the experts. The Atomic Energy Commission has just issued a new policy directive on the use of the lie detector at Oak Ridge. It will no longer be used for periodic mass examinations of the several thousand employes assigned



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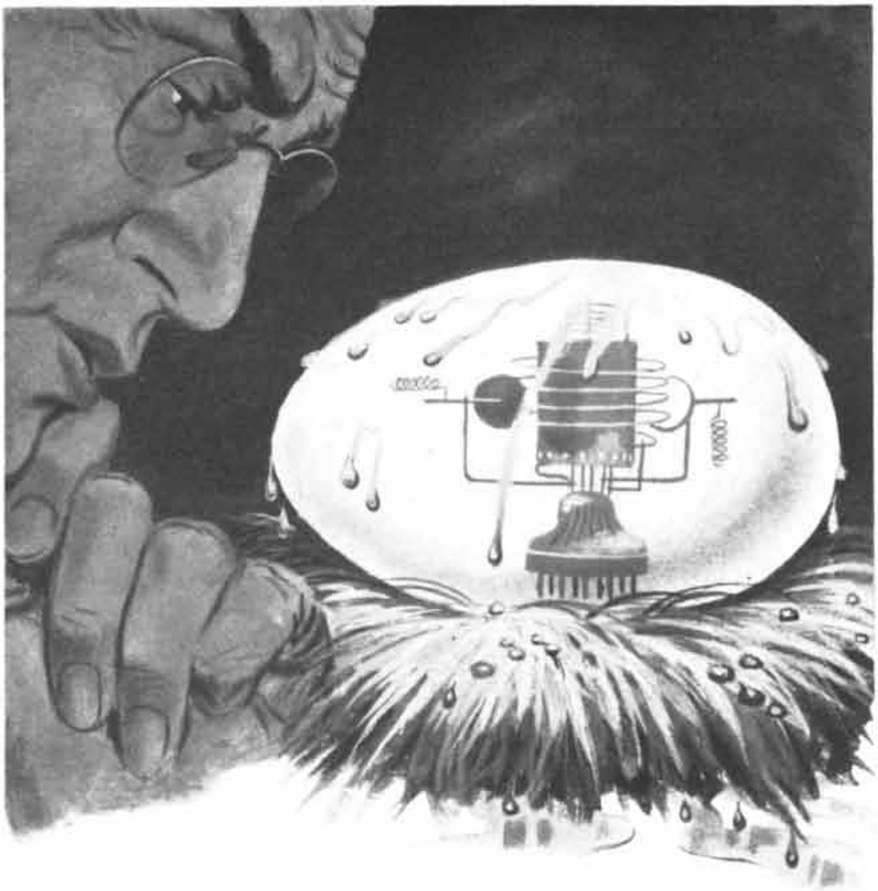

there to "sensitive" jobs. Future lie detector examinations anywhere in the AEC will be confined to specific cases and will be undertaken on a "voluntary" basis and only when authorized by the General Manager.

The AEC gives as reasons for limiting the scope of its quizzing machine that it offers only an "indeterminate marginal increase in security" beyond what is supplied by normal police methods, that it has not proved effective in ferreting out intent to commit sabotage or sympathy with subversive movements and that it has a bad effect on employe morale.

Two lawyers and two psychiatrists on the Yale University faculty recently issued a joint warning against the use of "truth serums" in criminal investigations. The psychiatrists, Frederick C. Redlich and Lawrence Z. Freedman, cited clinical evidence to show that "normal" subjects readily hide what they wish to hide when under the influence of one of these drugs (sodium amytal), and that "neurotic" subjects frequently confess to deeds of which they are innocent. The statements elicited by drugs, they said, are more apt to be symbolically significant than objectively true.

The lawyers, George H. Dession and Richard C. Donnelly, noted that truth drugs have been used by many police departments. They urged the courts to devise ways of protecting people held in police custody from this type of grilling and to rule out as evidence such involuntary statements. They held that if the drugs are to be used at all, they must be administered under court order and court supervision. The Yale report concluded that while truth drugs might sometimes be a helpful adjunct to the detection of crime, they "must be both mastered and controlled if we are to honor our belief in the dignity of the individual."

Growing Pains

An unexpected flaw in transistors "as they exist today" has caused Zenith Radio Corporation to stop production of a new transistor hearing aid. Because of the high humidity to which transistors are subjected when worn next to the body, they fail in hearing-aid service after a few weeks, the company said.

This "unexpected flaw" is only one of several problems with which transistor designers are wrestling. Engineers in the field compare the device today with the vacuum tube in 1915—a new development with high promise, but some years and many engineering refinements away from full usefulness. The big problem now is to find out what jobs transistors can do and to learn how to design different transistors, and circuits to go with them, that will meet a variety of

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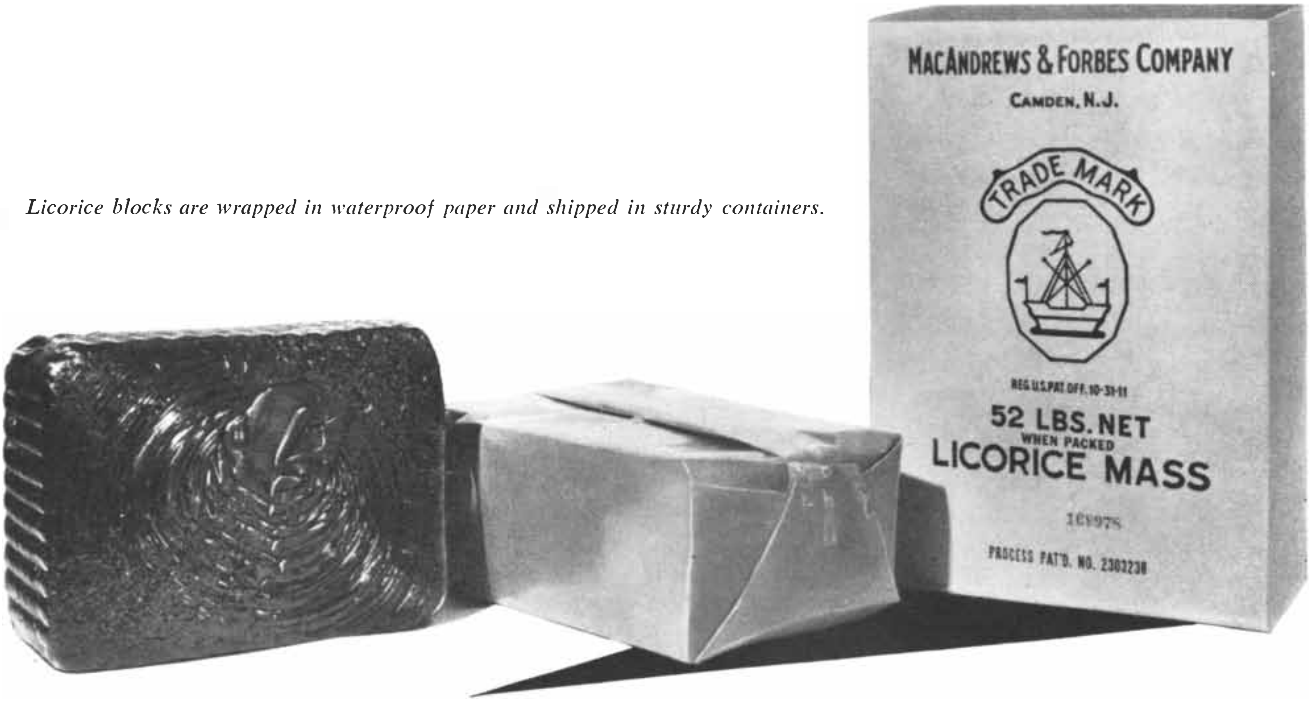

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Medical studies recently completed indicate a *yes* to the first question. *It's likely* would be the reply to the food manufacturer who failed to solve his problem with more familiar flavor components. *Don't know* would be the answer to the third query—almost anything, it seems, can happen with licorice. The fourth: at this moment, a question mark!

Centuries ago someone introduced a new, flavorful candy by adding licorice to his recipe. Pharmacists also started using licorice extract to mask the bitterness of certain medicines. More recently, extract of the "sweet root" came to be employed as a conditioner and mellowing agent in tobacco products. Next, experiments revealed that licorice helps produce a tough foam structure, one that has been put to valuable service in extinguishing fires.

The listing at the right still further suggests that you should not overlook licorice in your search for new products or for ways to improve what you are already making. We don't have all the answers, but we do have the licorice and the licorice derivatives, plus the know-how, to help you find them.

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specifications. On this job, the engineers say, they are barely started. There are also other flaws. Transistors are still cranky things, each with its own characteristics. They are expensive to make (present cost \$7.50 to \$20 apiece), unstable and sensitive to moisture, temperature and aging.

Engineering improvements, however, are coming fast. Among recently announced developments are:

A hermetically sealed transistor made by the General Electric Company which "has licked the high-temperature and humidity roadblocks," according to the Company.

A new method of making germanium wafers for transistors which will cut production costs. Also announced by G.E., the method is said to get as many as 100 slices out of a six-inch germanium ingot instead of the present one or two.

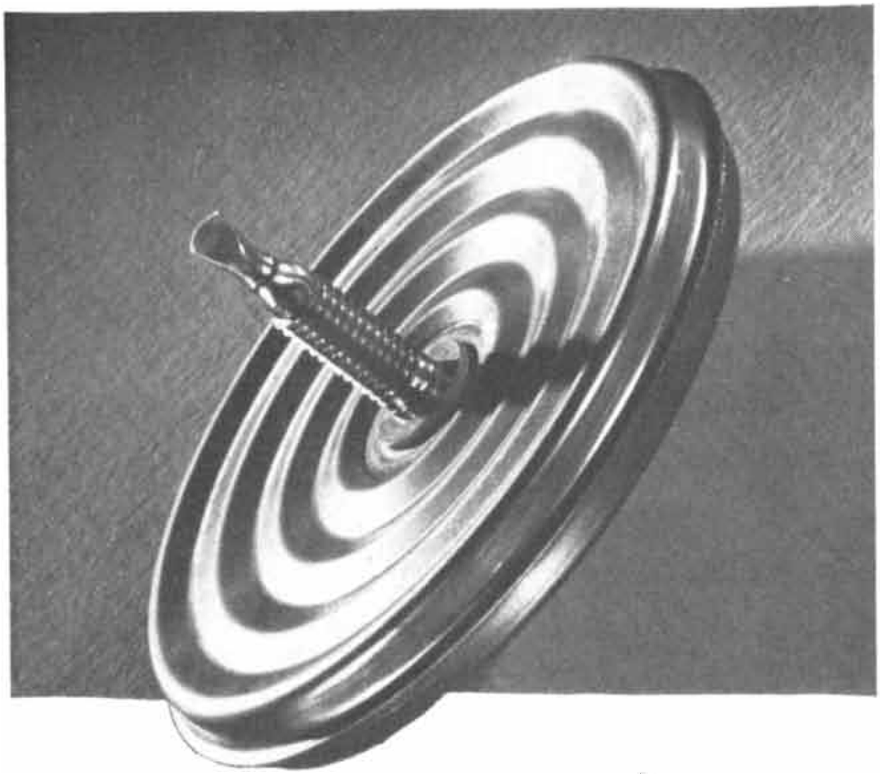
The "distinct possibility" of using aluminum instead of germanium was announced by the Battelle Memorial Institute. Aluminum would be cheaper and might be better for high-temperature operation.

Gamma Globulin for Polio

ABOUT 1,300,000 doses of gamma globulin will be available this summer for prevention of poliomyelitis, according to the most recent estimates of The National Foundation for Infantile Paralysis. Since this falls far short of enough to protect the 46 million children and adolescents whom doctors would like to protect, the entire gamma globulin supply has been placed under the control of the Office of Defense Mobilization for allocation. The ODM has announced that it plans to distribute 57 per cent of the stock to state health officers in proportions based on past and current polio incidence, to hold 33 per cent for mass prophylaxis in severe epidemic areas and to reserve 10 per cent for "unusual or special situations" and "special investigations."

Each state officer is to be responsible for distributing his allotment to individual physicians and for deciding on the way it is to be used. The ODM recommends that the 57 per cent be given to all persons under the age of 30, and to all pregnant women, in whose households there has been a proved case of polio and who have not yet developed symptoms of the disease themselves. In areas of heavy incidence the injections might be extended to non-household contacts and perhaps to contacts of suspected cases.

The National Foundation objected to this allocation, observing that many contacts of cases of poliomyelitis will become paralyzed even though they receive gamma globulin. It recommended that the major portion of the stock be used for mass immunization and that a small part be reserved for research on



its effectiveness when given to contacts.

The ODM plan, however, is in line with the suggestions of William McD. Hammon, who directed the gamma globulin studies, and his associates in their final report on the field tests. "With gamma globulin in such limited supply," they wrote in *The Journal of the American Medical Association*, "mass prophylaxis cannot be recommended under conditions less severe than those encountered in the Utah and Iowa-Nebraska tests, where the total annual morbidity rates were from 160 to 427 per 100,000 for all ages. Such rates, it should be recalled, almost never occur in large cities." A city such as Houston, Tex., they said, would require almost the entire national supply of globulin. Last year 16,000 injections of gamma globulin there appear to have prevented only eight cases. They added that inoculations of families of diagnosed cases "should prevent more disease and disability" than mass injections "in most epidemic areas."

Hammon and his collaborators concluded from the survey of last year's results that gamma globulin is an impracticable means of polio prevention, because of its cost (prevention of eight cases in Houston cost $224,000), and the short duration and incompleteness of protection. Immunity is high for five weeks, drops off during the next two, and disappears after eight weeks.

Hammon feels that the most valuable result of the field trials has been in demonstrating the full possibility of immunization with vaccines. Before the tests scientists did not believe that an antibody level as low as that produced by the gamma globulin injections would protect man from the disease. The fact, now proved, that such low levels do give protection means that vaccines can be made with less virus than had been thought necessary, thus making them safer and easier to produce in quantity.

Joseph Stokes, Jr., of the Philadelphia Children's Hospital, has suggested a procedure which might greatly increase the supply of gamma globulin. He proposed that only the gamma globulin fraction of blood be taken from donors. With a new machine developed at the Harvard Medical School, whole blood could be withdrawn, the gamma globulin separated, and the corpuscles and remaining plasma fractions reinjected into the donor, Stokes said. Only seven per cent of the protein in the withdrawn blood would be permanently removed in this procedure. A donor therefore could make more frequent donations. Furthermore, it might be possible to make the donated gamma globulin very rich in antibodies by inoculating the donor with polio vaccine, as soon as even small quantities of it are available. If the method proves feasible, a comparatively small number of donors could supply as much gamma globulin as is

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Flowmeter

A NEW instrument which can measure the rate of liquid flow in closed tubes, the speed of a boat moving through the water, minute air currents in a still room or the blast of a wind tunnel has been developed by the National Bureau of Standards. Unlike previous devices for measuring flow rates, this meter places no mechanical device in the stream and so does not interfere with the quantity it is measuring. It operates by sending sound waves through the fluid.

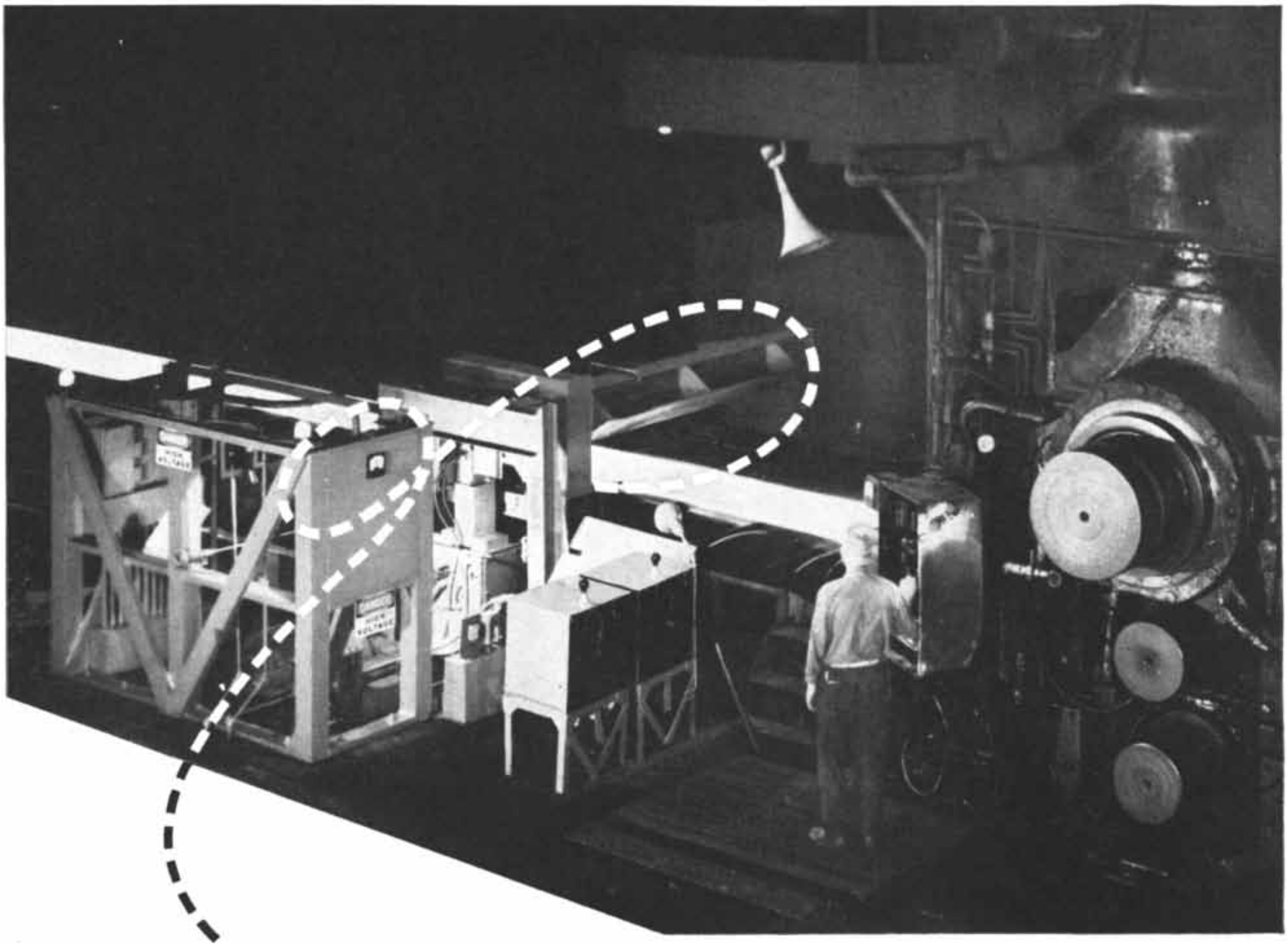
The instrument consists of a sound transmitter and receiver, placed a short distance apart along the line of the current to be measured. The speed of the current is computed by finding the difference between the actual speed of the sound transmission from the transmitter to the receiver and what the speed would be if the fluid were stationary. The speed is recorded as a phase difference between the sound waves at the receiver and at the transmitter.

Some of the applications suggested for the flowmeter include measurements of blood flow in veins and arteries, river-water flow and air currents in air conditioning systems.

Gone Goose

A CRIPPLED Canada goose last month made its northern migration *via* commercial airline. It will spend the summer in an Ontario bird sanctuary, wearing a 14-karat gold-plated leg band with which the Canadian Consul General in New York personally adorned it. The flight marked the end of several weeks of notoriety for the goose and of a near-crisis in relations between Canada and the State of Connecticut.

Early this spring the goose attempted to take off for the north from Long Island Sound. Amos L. Horst, executive secretary of the Wild Life Restoration Foundation, happened to be present, and he swears that when the crippled bird failed to rise, two healthy geese lined up on either side of it and tried to help it into the air. The story, though greeted in some quarters with skepticism, aroused Canadian goose fanciers to arrange transportation for the bird. The Connecticut State Board of Fisheries and Game made a gallant but vain attempt to keep the bird, contending that it was one of a group which summers not in Canada but at Bantam Lake in Connecticut. But the Board was finally overruled by the intervention of the Canadian Consul General and the Governor of Connecticut. The goose was helped (or shanghaied?) to Canada by Trans-Canada Airlines.



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A LARGER AND OLDER UNIVERSE

The principal discovery made with the 200-inch telescope so far is that the yardstick by which we measure distance outside the Milky Way is twice as long as we had thought

by George W. Gray

IT IS NOW a quarter of a century since George Ellery Hale wrote his memorable request of February 14, 1928, to Wickliffe Rose—the letter which resulted in the Rockefeller International Education Board's grant of $6 million for the construction of a 200-inch telescope and led to the establishment of Palomar Observatory. Never before had anyone seriously proposed investing so huge a sum in an instrument of scientific research. Hale argued a strong case for the unprecedented gift. He focused his argument on three unsolved problems of nature: the evolution of stars, the structure of the universe and the constitution of matter.

The great telescope, with its light-gathering power of a million human eyes, was finally completed and dedicated to Hale in 1948—10 years after his death. The instrument has now been in operation for four years, and with its aid thousands of photographs have been taken of distant stars and of even more distant nebulae. While it has turned up many bits of new evidence bearing on the three problems which occupied the primary place in Hale's thinking, the telescope's major contribution so far has been not new astronomical discovery but a correction in a most basic concept: the yardstick for measuring the vast distances of the universe. The Hale telescope has shown that the yardstick which had been accepted and used by astronomers for more than 30 years is twice as long as was thought. It is as though the oceanographers had suddenly discovered that the fathom, instead of being six feet long, is really 12; the effect would be to double all measurements of ocean depths.

Since this astronomical yardstick, the cepheid variable star, is the principal measure for plumbing the depths of space outside the Milky Way, it follows that all the outside distances which astronomers had previously determined must be multiplied by a factor of two, if indeed the yardstick was wrong by that factor. For example, the Andromeda Nebula, the nearest of the great outside spiral systems of stars, is at least two million light-years from us, instead of one million. So says the evidence of the Hale telescope. Moreover, it adds, the Andromeda spiral is twice as large as the pre-Palomar estimates had led us to believe and appears to be larger than our own galaxy, the Milky Way.

Over the years more and more remote clusters of spirals had been discovered: one in the constellation Virgo at six million light-years, one in Pegasus at 23 million, another in the Big Dipper at 85 million, and a still more remote cluster in Gemini the Twins at 135 million. Now if we apply the new yardstick, their distances, too, must be doubled.

Two Billion Light-Years

Thus the immediate effect of the Palomar findings is to enlarge the realm of outer space that we already knew. It is a vaster universe, not because we have discovered more distant objects, but because the already known and charted galaxies and clusters of galaxies are more remote and more widely dispersed than we had supposed.

Another consequence of correcting the yardstick is to increase our respect for the optical instruments that we already have. A pair of sharp eyes can see the faint haze of the Andromeda Nebula without the aid of lens or mirror—which means that the naked eye can look through two million light-years of space. In Hale's day the 100-inch reflector on Mount Wilson, then the largest telescope in the world, was estimated to have a range of 500 million light-years, and the new 200-inch was supposed to be able to photograph objects 1,000 million light-years distant. But now the reach of all telescopes is doubled. With the Hale telescope the Palomar observers have already photographed objects which they estimate to be more than 1,600 million light-years away. And they expect to reach 2,000 million as the auxiliaries to the telescope are improved—such devices as correcting lenses, photoelectric eyes and the like.

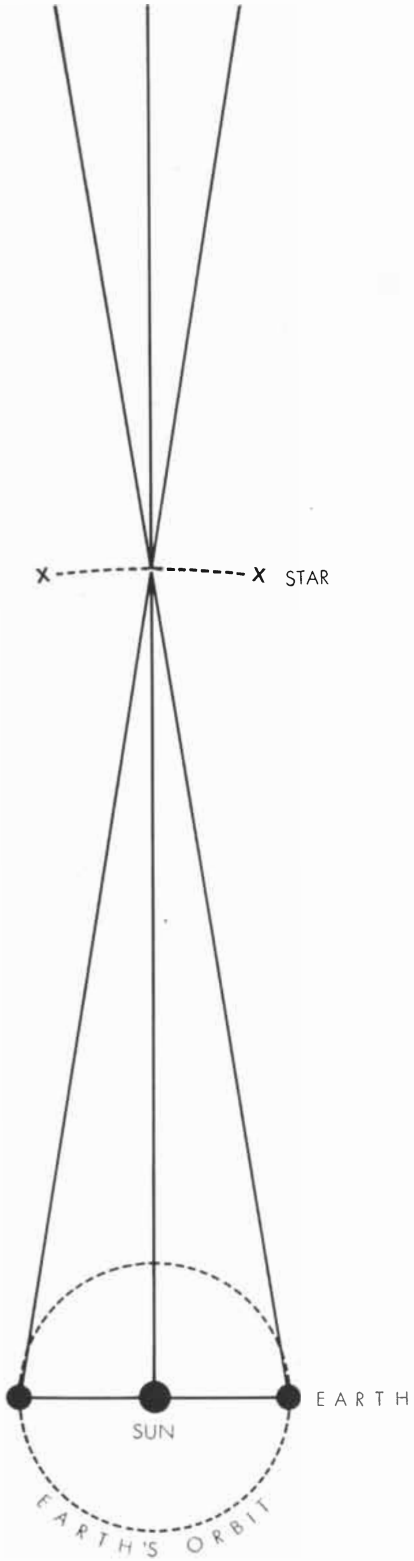
Yet optical and electrical accessories can only collect the light of luminous bodies and record the behavior of their rays under the conditions which the astronomer has set up. It takes the mind of man to interpret the meaning of this behavior. Fundamental to his interpretations are the yardsticks, or distance-indicators, by which the remoteness of a source of light is evaluated. No matter how right the theory, how perfect the seeing or how powerful the telescope, if the distance-indicators are incorrectly calibrated, the interpretation will be wrong.

This first big contribution made by the new instrument was publicly announced by Walter Baade, of the Mount Wilson and Palomar staffs, at the meeting of the International Astronomical Union in Rome last September. It created something of a sensation among the group, which was made up of leading astronomers of all nations. And indeed its importance cannot be overestimated. "These new determinations will, without much question, be the most important result to come from the Hale telescope in the first few years of its operation," said Ira S. Bowen, director of the Mount Wilson and Palomar Observatories. "In fact," he added, "the recalibration of cepheid variable stars is fundamental to all research on that second problem in Hale's list—the structure of the universe."

Cepheids

Opposite the Great Dipper, on the other side of the North Star Polaris, is

GREAT NEBULA IN ANDROMEDA is photographed by the 48-inch schmidt telescope on Palomar Mountain. Above and below the spiral are its two satellite systems. Studies of the Andromeda Nebula with the 200-inch telescope indicate that it is at least two million light years away instead of one million, as formerly thought.



TRIANGULATION is used to measure the distance of nearby stars. As the earth moves from one side of its orbit to the other, a distance of 186 million miles, the apparent position of the star changes with respect to the background of stars much farther away. Here the change in the apparent position is greatly exaggerated.

Cepheus the King. This constellation is faint and inconspicuous, and the early stargazers would probably have given little attention to Cepheus had it not been for the peculiar behavior of one of its members. This star, which is marked on the sky chart as Delta Cephei, alternately brightens and dims with remarkable regularity. It takes five days and eight hours to pass from its brightest phase down to its faintest and then back to its brightest. The change, more than a stellar magnitude, is noticeable to the naked eye. When telescopes were turned on Delta Cephei, they disclosed the object to be actually two stars—a large yellow one and a smaller companion which showed a blue tinge.

There are numerous double stars, known as eclipsing binaries, which alternately wax and wane in brilliance. To the eye they appear as single stars, but through the spectroscope they reveal themselves as a pair. Their changes in luminosity are due, as the instrument shows, to one star passing in front of its close companion as they revolve around their common center of gravity. It was at first thought that some such eclipsing mechanism was responsible for the variability of Delta Cephei. But observation after observation failed to detect any evidence for this. Neither of its components was ever found to pass in front of the other, and astronomers were forced to recognize that the brightening and dimming of Delta Cephei was something inherent in the giant yellow star which the telescope showed to be its major component. It was apparently a pulsating star, which increased in brilliance as its surface area enlarged, and then sank to fainter luminosity as it collapsed to smaller size.

Meanwhile astronomers had found other non-eclipsing stars which behaved in the same fashion as Delta Cephei, some with longer periods of variation and some with shorter. For example, the North Star Polaris, was shown to be pulsating with a variation of 3.97 days. Its change in luminosity was only one tenth of a magnitude from maximum to minimum—hardly enough to be recognized by the casual sky-gazer. And so with many other stars, some visible to the naked eye, others so faint that they could be seen only with a telescope. In the constellation Gemini a pulsating star with a period of 10 days was recorded. In Cygnus the Swan another with a little over 16 days for its period was found. In Carina the Keel, a constellation of the Southern Hemisphere, a red star pulsated with the long period of 35 days and 12 hours.

Hundreds and eventually thousands of such stars were catalogued, each with its characteristic change in luminosity. Since they appeared to be of the same general type as Delta Cephei, they were named "cepheids." They were found in all parts of the Milky Way—many blue, others yellow, some orange, still others red. In the 1890s Solon I. Bailey, of the Harvard College Observatory, discovered numerous short-period cepheids in the globular clusters of the Milky Way. These clusters are huge swarms, some containing hundreds of thousands of stars of many types, but it was the frequent occurrence of short-period cepheids that caught Bailey's attention. What impressed him was the fact that each had a period of less than a day. He called them "cluster-type variables," and the name was adopted by others who prospected other globular clusters and found again and again these cepheids with periods ranging from six to 18 hours.

The Magellanic Clue

A decade after Bailey had reported the cluster-type variables, Henrietta S. Leavitt, an assistant at the Harvard College Observatory, began a study of the Magellanic Clouds. The two Magellanic Clouds are galaxies outside the Milky Way, and are visible only in the Southern Hemisphere. They are so named because the explorer Magellan sighted them on his famous voyage around the globe. Harvard's southern station, which was then in Peru, had started an extensive photographic survey of the Large and Small Magellanic Clouds, making nightly exposures with a telescopic camera. A collection of these photographs reached Cambridge in 1905, and they were turned over to Miss Leavitt for examination. She soon spotted numerous variable stars, which later were recognized as cepheids. She concentrated her inquiry on 25 in the Small Cloud and made detailed measurements of their apparent brightness and variability. They showed a wide range of periods, some taking four days to pass through their cycle, others 10, still others 17, and a few up to 127 days.

As she examined the images of these Magellanic stars, Miss Leavitt noticed a systematic relationship among them. All were faint. Not one could be detected without the aid of a long photographic exposure through the telescope, but some appeared brighter than others and there was a curious orderliness in their degrees of luminescence. In every instance, the longer the period of the star, the brighter it was. Thus stars with 10-day periods were about four times brighter than those with four days, and 17-day stars were twice as bright as the 10-day ones.

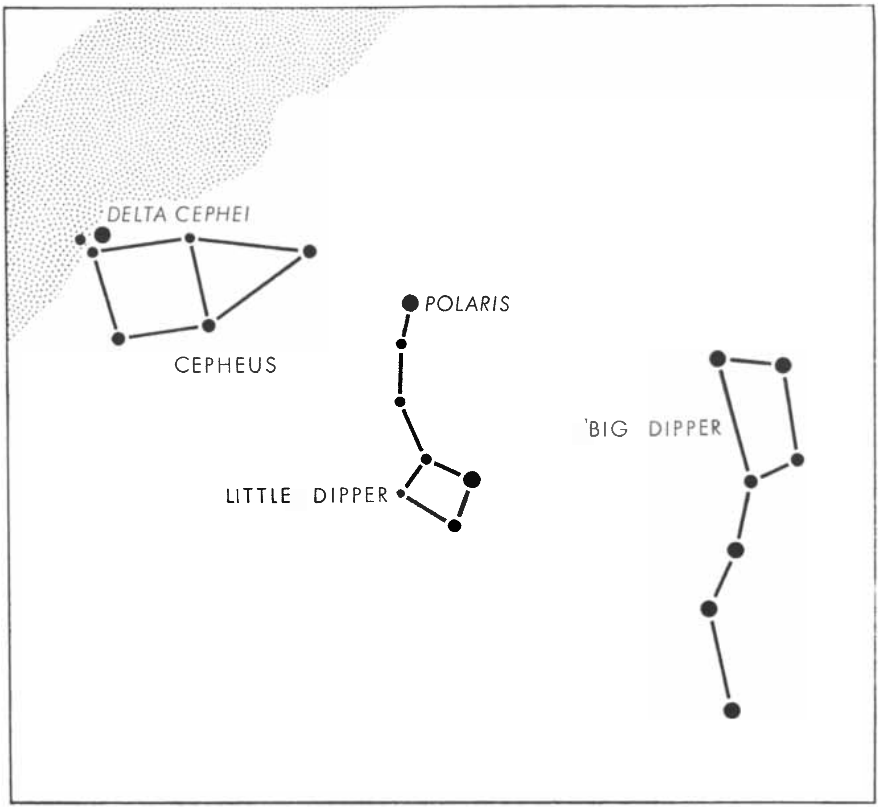
The cepheids strewn about in the Milky Way are at varying distances from us. But here in this little galaxy of the Small Magellanic Cloud, a separate island universe distinct from our system, presumably all the stars in the Cloud were roughly the same distance away. And since at that uniform distance the cepheids of longer period appeared brighter than those of shorter period, was it not reasonable to conclude that they were actually brighter?

At the time of Miss Leavitt's study the measurement of astronomical distances was a very fragmentary science. For nearby stars fairly good determinations had been made by triangulation. That is, the position of an object in the sky was measured precisely at two times six months apart, when the Earth was on opposite sides of its orbit. From the angle thus projected the distance could be calculated. This trigonometric method gave dependable results out to about 100 light-years. But for objects beyond that the angle of displacement was too slight for measurement, and astronomers had resorted to various stratagems.

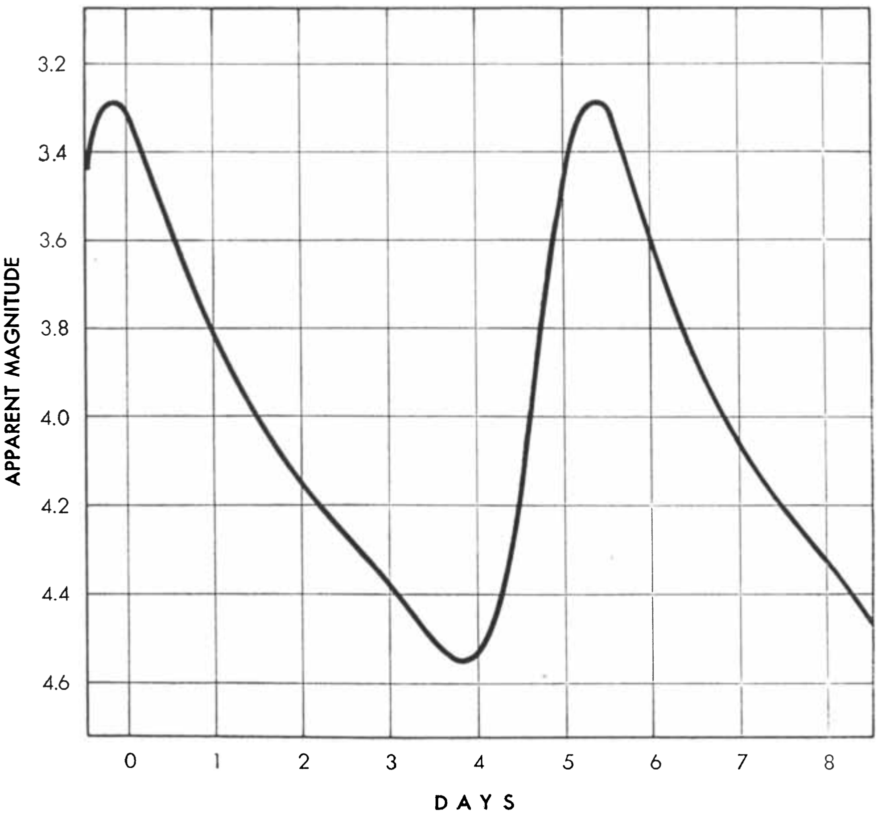
One scheme used the motions of the stars. The motion of every star can be separated into two components—one across the sky, called the proper motion, the other a motion of approach or recession, known as the radial velocity. The spectroscope measures the radial velocity very accurately, and it is possible to translate its reading directly into miles per second. The proper motion, on the other hand, is extremely slight, even over an interval of many years. But by prolonged photographic observation the proper motions of numerous stars had been recorded, and the evidence indicated that the slower the motion, the more distant was the star. By combining the radial velocity with the proper motion, and submitting the results to statistical analysis, astronomers were able to determine the distances of stars out to about 3,000 light-years.

Light dims with distance according to a fixed ratio. Therefore, if you know the actual distance of a star, you can, by applying the ratio to its apparent brightness, calculate its real brightness. Or if you are ignorant of the distance, but can arrive at a value for its real brightness, you can calculate how far away the star is. These various efforts to estimate stellar distances by motion studies, and to estimate stellar magnitudes from signals of the stellar temperature, were expressions of the search for beacon stars to use as standard candles. But for the most part the estimates were built on inferences, and astronomers yearned for a direct yardstick that would reach clear across the Milky Way and enable them to measure the dimensions and distances of the most remote objects that telescopes could photograph.

At the turn of the century the most generally accepted estimate of the diameter of the Milky Way was 7,000 light-years. In 1915 Sir Arthur Eddington raised the guess to 15,000 light-years. These dimensions seemed vast then. To recall them now, when the Milky Way is reckoned in diameters of 75,000 to 100,000 light-years, is to give



DELTA CEPHEI is the prototype of the cepheid variables. This pulsating star is located at the edge of the Milky Way on the opposite side of the Pole Star from the Big Dipper. Here its magnitude has been exaggerated.



LIGHT CURVE of Delta Cephei shows the character of its pulsation. In a period of five days and eight hours its apparent brightness gradually decreases more than a full magnitude and then quickly increases again.

a measure of how far astronomers have come in their thinking.

Miss Leavitt plotted her observations of the 25 Magellanic cepheids in a curve, and this provided the groundwork for a period-luminosity relationship. By means of this relationship an astronomer could tell how much brighter one Magellanic cepheid was than another. He could not say how much brighter it was than the Sun—for there was then no measure of the distance of the Magellanic Clouds. But the clue did offer an enticing possibility. It suggested that if the distance of one cepheid were determined, an astronomer by applying the relationship could calibrate the absolute brightness of all cepheids, wherever found. Then, whenever one of these blinking stars was spotted in a cluster or galaxy, its absolute brightness should indicate how far away the cluster or galaxy was. Thus the cepheids might be employed as standard candles, or optical yardsticks, with which to measure vast distances.

Shapley's Measurements

The first to use this opportunity was Harlow Shapley, then a young astronomer on the staff of Mount Wilson Observatory. He had set himself the task of measuring the dimensions of the Milky Way. It occurred to him that the surest way to measure the length and breadth of our galaxy would be to determine the distances of the globular clusters which surround it. It would be like surveying a city by measuring the distances out to its adjoining suburbs. The clusters showed no appreciable proper motions, so nothing could be gained by motion studies of them. But Shapley seized on the cepheids as a possible means of spanning the distances to the globular clusters.

The first requirement, of course, was knowledge of the real brightness of a few cepheids—for Miss Leavitt's curve was based entirely on apparent brightness. Through motion studies within our neighborhood of the Milky Way, Shapley obtained values for the distances of 11 nearby cepheids. They ranged in period from 1.9 days to 10.2 days, and by striking an average he derived a mean value of 5.96 days. Then, having the distance and apparent magnitude, he calculated that a cepheid of 5.96 days shone with the absolute magnitude of –2.3. This means it had 690 times the brightness of the Sun. From this fixed point Shapley proceeded to recalibrate Miss Leavitt's apparent magnitude curve in terms of absolute magnitude, and thus to work out the period-luminosity relationship for cepheids. His curve ranged from cepheids with periods of half a day (cluster-type variables) up to those with periods of more than 100 days. The period-luminosity relationship indicated that all cepheids were giant stars—some of them thousands of times as bright as the Sun. Even the short-period cluster-type variables were each the equal of a hundred Suns.

In this way Shapley obtained not just one standard candle but a whole series ranging over a wide scale of luminosities. With cepheids in the globular clusters he measured the distances of these encircling star groups. This was accomplished in 1917. Some years later, after he had transferred to Harvard as director of its Observatory, Shapley used cepheids of longer periods to measure the distances of the Magellanic Clouds. Astronomers hailed these demonstrations of the usefulness of the blinking giants. At last, it seemed, there was a dependable device for bridging the abyss of intergalactic space.

Hubble's Measurements

Still farther out in space, beyond the Magellanic Clouds, whirls the Andromeda Nebula. Nobody knew how far it was. Telescopes which readily resolved the Clouds into stars were unable to resolve the great Andromeda spiral. In the early 1920s Edwin Hubble decided to explore this luminous whorl with the new 100-inch telescope on Mount Wilson. In the spiral arms he found hundreds of pin points of light which betrayed themselves as stars—and among them were 12 cepheids.

Cepheids in Andromeda! Here were yardsticks to measure its distance. The Andromedan cepheids were of various periods, ranging from 17 days to 50, and by applying the period-luminosity curve to them, Hubble estimated that the Nebula was close to a million light-years away.

Like the Milky Way, the Andromeda Nebula has an encircling halo of globular clusters. Hubble next turned the 100-inch telescope on them. He was not able to resolve any of these clusters into individual stars, and so never spotted any cepheids, but he noticed one puzzling fact about them. The globular clusters of Andromeda appeared to be from one to one and a half magnitudes fainter in absolute luminosity than those of the Milky Way.

This discrepancy was the first intimation that the distance-indicators might be at fault. "Among ourselves we discussed possible interpretations of the disparity at the time," Hubble recalled recently. "The lack of correspondence between our galaxy and the Andromeda could mean that the cepheids were brighter than we had supposed when we used Shapley's calibration for the cepheids. Or it could mean that the globular clusters were fainter than we had thought. At that time we were inclined to suspect that the trouble would be located in the clusters. There was then no 200-inch telescope, but we agreed that here was a problem which was waiting for attack as soon as such an instrument was built."

Baade's Discovery

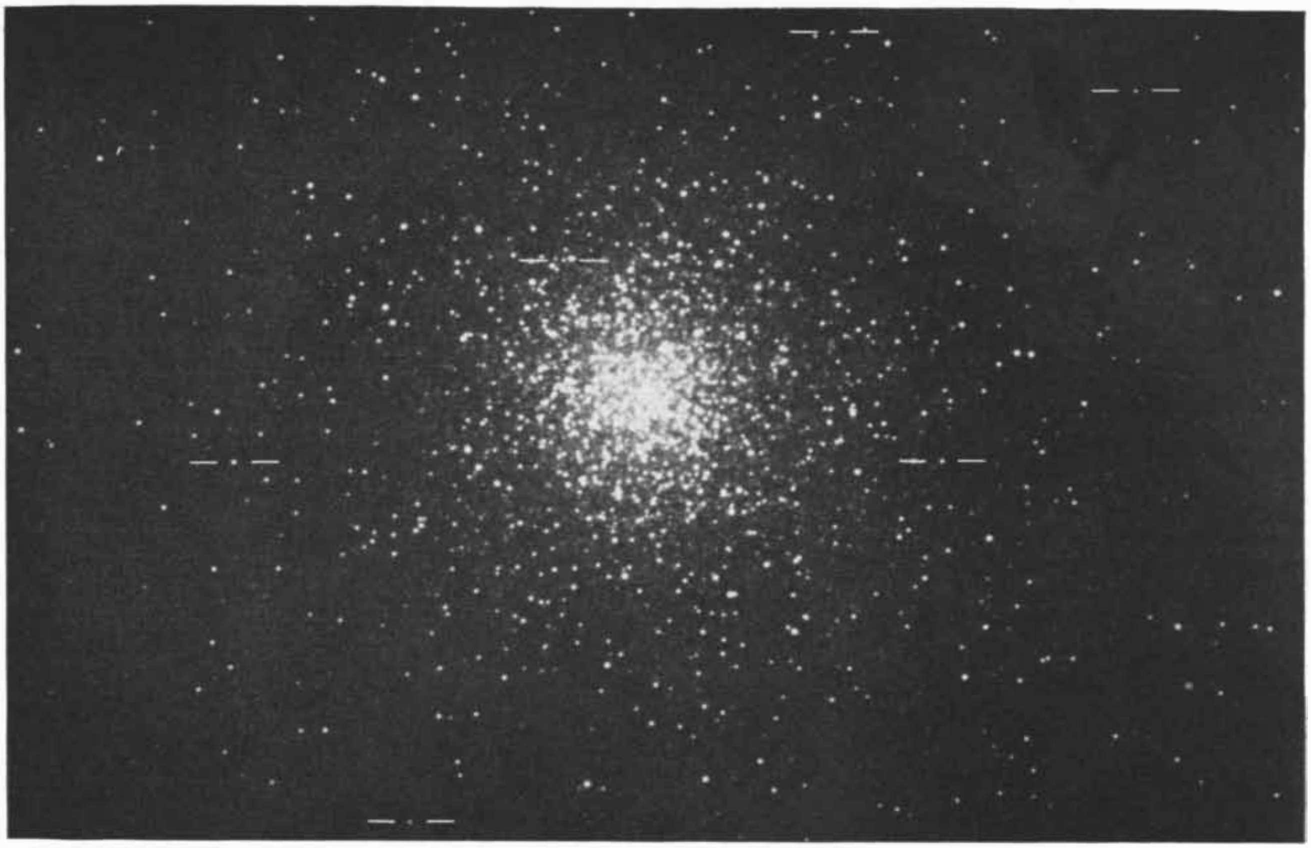
Even before the completion of the 200-inch, Walter Baade made a major discovery which was to have a direct bearing on the problem. Baade, a German-born astronomer who had first visited Mount Wilson in the 1920s on a Rockefeller fellowship and later had been called to join the observatory staff, began his history-making study of the Andromeda Nebula in the winter of 1941-1942. Photographing the great spiral with the 100-inch telescope, he found that all its stars were separable into two types or stellar populations.

"Good luck contributed to the success of my undertaking," explains Baade. "The first fortunate circumstance was the blackout of city lights which our entrance into the war imposed on Pasadena and Los Angeles, for this sky glow often has interfered seriously with the photography of faint objects from Mount Wilson. The second circumstance was the acquisition of a new type of photographic plate which was extrasensitive to red light.

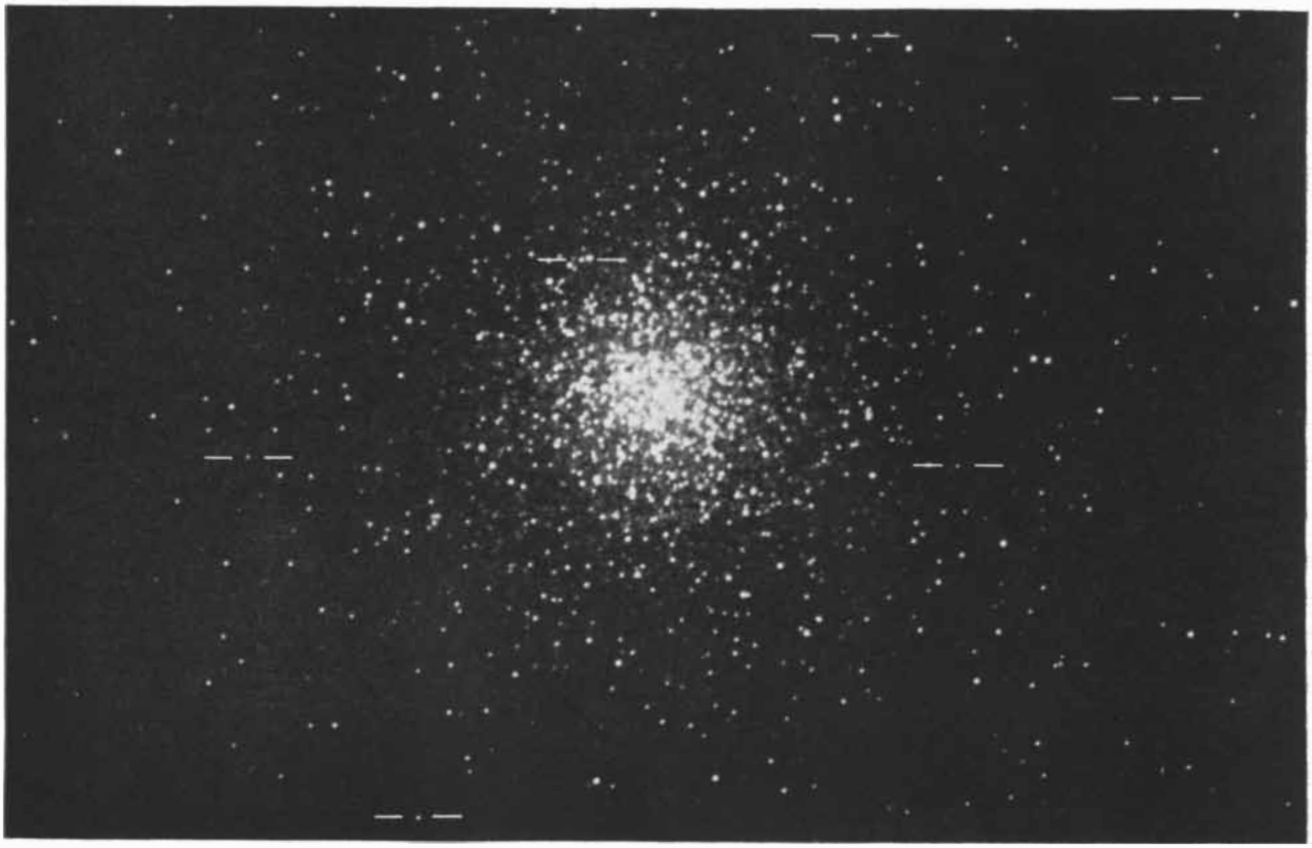
"I was not looking for the two populations. I was looking for individual stars in the central disk of the Andromeda Nebula. It was only in the spiral arms that Hubble had found stars. When he tried to resolve the central area, which appeared in all photographs as a solid, luminous mass, he could get no separate pin points of light such as had rewarded him in the spiral arms. My purpose was simply to see whether, under the improved photographic conditions, the central disk might be resolved.

"At first I wasted time with blue-sensitive plates. Hubble had found blue supergiants in the spiral arms, and it was natural to expect that the brightest stars in the central area, too, were blue. But I couldn't find any, and it was only after all the schemes for spotting blue stars had been exhausted that I turned to the red-sensitive plates to see if, perchance, the brightest stars were red. On the new photographs hundreds of tiny star images showed where none had been distinguishable before. They were red giants. As I turned the telescope to other regions of the Nebula, moving from the center outward, the pattern of prominent stars changed from red giants between the spiral arms to blue supergiants in the arms. It looked as though the central area and the regions between the arms were populated by one kind of star, whereas another kind predominated in the arms themselves."

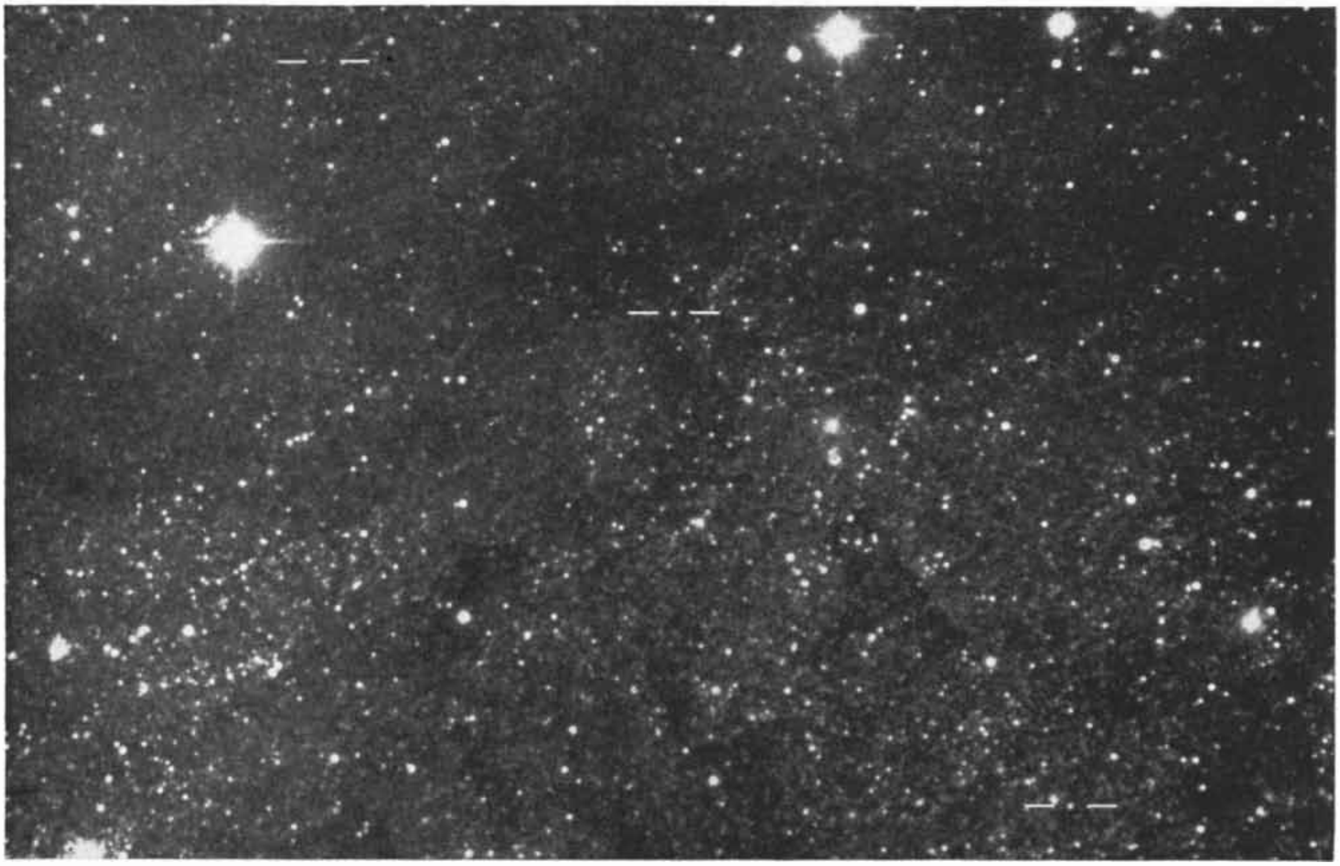
Two smaller nebulae accompany the Andromeda, one close to the big spiral on one side, the other farther out on the opposite side. Baade extended his survey to these midget systems, and found their



GLOBULAR CLUSTER Messier 3 is photographed by the 100-inch telescope on Mount Wilson. This cluster contains more than 200 cepheid variables. Six, each centered between a pair of horizontal lines, are marked.



SAME CLUSTER is photographed 18 hours and 43 minutes later. The variation in the marked stars is slight but perceptible. The marked variable above the center of the cluster is the middle member of a group of three.



SMALL SECTION of an arm of the Andromeda Nebula is photographed by the 200-inch telescope. The two stars located between the horizontal lines at upper left and lower right are variables. The star in the middle is a nova.

SAME SECTION of the Andromeda Nebula is photographed later by the 200-inch telescope. Both stars at the upper left and lower right have increased in brightness. The nova has faded so that it is virtually invisible.

stars to be of the same type as those he had photographed in the central disk of the Andromeda itself. Again the brightest stars were red.

It was these findings that led to the classification of all stars into Population I and Population II. Both populations include stars of all colors, but the most luminous members of Population II are red, while the most luminous of Population I are blue and are more than 100 times brighter. There are differences in the composition of the two types, the Population I stars being richer in metals. Apparently, too, they are younger than those of Population II.

Some stellar systems are made up entirely of Population II stars; examples are the two companions of the Andromeda Nebula and the globular clusters. Large spirals, such as the Andromeda and presumably our Milky Way, embody both types, with Population II concentrated toward the center and Population I in the spiral arms. Inasmuch as our Sun, with its family of planets, is in a spiral arm of the Milky Way, most of the stars in our immediate neighborhood, including the Sun and practically all the others that can be seen with the naked eye, are Population I.

"When we came to appraise the cepheids," says Baade, "we found the same division into two clearly separate groups. There are striking differences between the cepheids of the Population I which we observe in the spiral arms of our galaxy, and the cepheids of the Population II which we find in the globular clusters. Delta Cephei and Polaris, for example, are Population I stars, while the cluster-type variables with periods of less than a day are found only in Population II. The fact that the cepheids were of two distinct classifications immediately raised a question. Could stars of such different types be properly calibrated on the same period-luminosity scale?"

"What does the 200-inch telescope say on this question?" Baade was asked.

"The present data indicate," he answered, "that throughout the range of cepheids, those of Population I are about one and a half magnitudes brighter than their counterparts in Population II. This means that they are four times brighter. The former calibration of the period-luminosity relation seems to apply correctly to the Type II cepheids. But the old calibration is in error for Type I—these cepheids are one and a half magnitudes brighter than they were credited with being."

Revisions

Now the cepheids Shapley had used to measure the distances of the globular clusters were of the cluster type; that is, cepheids of Population II. These stars were calibrated at a magnitude which represents 100 times the brightness of the Sun; their values remain unchanged, and it follows that the former measurements made with cluster-type cepheids are correct.

But it was cepheids of Population I that Hubble had used to determine the distance of the Andromeda Nebula. Indeed, he had not been able to find any cluster-type stars in the Nebula. Among the 12 cepheids that he photographed, the faintest had a period of 17 days. According to the then accepted calibration, this meant that its real brightness was 2,700 times that of the Sun, and reckoning from its apparent brightness in the photograph, Hubble estimated the distance at about a million light-years. But the new determinations indicate that a 17-day cepheid has a brightness of about 10,800 times the Sun's luminosity. Calculation shows that for a 10,800 Sun-power star to appear as faint as that cepheid did, it would have to be approximately two million light-years away. And so with each of the other cepheids. When their luminosities were revised upward by one and a half magnitudes, they all pointed to the same distance—two million light-years.

But, you ask, how did the 200-inch telescope show this?

It was a question of magnitude range. The instrument was powerful enough to reach certain stars, if they were of a certain luminosity at a certain distance, and when the telescope failed to do this, the astronomers knew at once that something was wrong. The scale of apparent magnitude begins with the brightest-appearing stars, which are rated as of the first magnitude or less, and the scale goes on up to the sixth magnitude, which is the faintest that the eye alone can see. The telescope brings to view fainter and fainter objects, especially when aided by long photographic exposures, until finally it reaches a limit beyond which it cannot collect enough light from an object to form an image. For the 100-inch telescope this limit is the 21st magnitude, which is the luminosity of a candle at a distance of 6,800 miles. Now at the million light-years distance which Hubble had calculated for the Andromeda Nebula, the cluster-type cepheids would appear as of the 22.4 magnitude. That is too faint for the 100-inch telescope to reach, and so when Hubble directed this telescope at the globular clusters of the Andromeda Nebula 20 years ago, he did not expect to find any short-period cepheids. What surprised him was the apparent faintness of the Andromedan clusters as a whole.

The 200-inch telescope, however, can reach the 22.4 magnitude, and there was every expectation that it would detect the Andromedan cluster-type cepheids. Yet not one showed up, though there were repeated exposures to the limit permitted by the optical conditions. Some giants brighter than the cluster-type cepheids were found, but they were uniformly one and a half magnitudes fainter than they should have been when rated from comparisons with similar stars in nearby Milky Way globular clusters.

"This suggested," says Baade, "that in the Andromeda Nebula cluster-type cepheids would be found at magnitude 22.4 + 1.5, or 23.9—which is beyond the reach of the 200-inch telescope."

Moreover, 23.9 is the magnitude at which cluster-type variable stars would appear at a distance of two million light-years—or, more precisely, 1,964,000 light-years. The fact that all the brightest Andromedan stars of Population II were also one and a half magnitudes fainter than they should be at a million light-years was further evidence for the greater distance.

Baade next searched one of the small companions of the Andromeda, and in this miniature nebula, made up of Population II stars, he found that all the brightest giants were one and a half magnitudes fainter.

The Evidence Piles Up

The final test of the calibration of Population II stars was accomplished last year. It was a procedure which Baade had first proposed in 1948 as a means of determining the real brightness of the cluster-type variables without resorting to statistical methods. Baade's idea was to make two diagrams. First, plot according to color and apparent magnitude the stars of a particular globular cluster. Then make a corresponding diagram of representative stars of the Milky Way which are near enough for their distances to be measured trigonometrically. With their distances known, it would be possible to determine the real brightness of these nearby stars and thus to plot the second diagram in terms of absolute magnitude. Now the cluster stars are all of Population II and the nearby Milky Way stars are Population I, and each population describes a quite distinctive diagram for all except its dwarf stars. Fortunately for Baade's test, the dwarfs of both populations fall along approximately the same line when plotted according to color and magnitude. The possibility thus was opened of superposing one diagram on the other, and thereby converting the apparent magnitudes indicated by the diagram of cluster stars into the absolute magnitudes indicated by the diagram of nearby stars.

It happened that Allan R. Sandage, a graduate student in astrophysics at the California Institute of Technology, was looking for a subject for his doctoral thesis. Baade suggested that he study a globular cluster, and Sandage went to work on the Milky Way globular cluster known as Messier 3. He obtained photographs made with both the 100-inch

CLUSTER OF GALAXIES in the constellation Coma Berenices is photographed by the 200-inch telescope. This reproduction enlarges a section of the original plate made by the telescope a little more than three times.

telescope and the 200-inch, and from the images of individual stars he proceeded to make a stellar diagram of Messier 3.

Meanwhile, at the Lowell Observatory in Arizona, an independent study of nearby stars had been made by Harold Johnson. Since the stars were in our neighborhood of the Milky Way, Johnson was able to plot them by their absolute magnitudes and colors, while Sandage could plot his stars only by their apparent magnitudes and colors. When superposed, the dwarf section of Johnson's diagram fitted neatly over the dwarf section of Sandage's. As was expected, the apparent magnitudes of all of Sandage's stars were instantly converted into their corresponding absolute values. The position of the cluster-type variables on Sandage's curve, which was at the level of the 15th apparent magnitude, was shown by this device to be at zero absolute magnitude. Now zero absolute magnitude is equivalent to the brightness of 100 Suns, and this was the absolute magnitude assigned to cluster-type variable stars in the original period-luminosity curve. Thus again the calibration of these Population II stars was confirmed.

Further evidence was added by Olin Eggen of the Lick Observatory, who had made a similar survey of nearby stars somewhat earlier. Eggen's plot too, when the Sandage diagram was superposed, declared that a cluster-type variable star is the equal in luminosity of 100 Suns.

"The mistake, as we now see, lay in calibrating Population I cepheids on the same scale with those of Population II," says Baade. "These recent determinations tell us that two curves are necessary. The old curve, Shapley's period-luminosity curve of 1917, remains good for Population II cepheids. But for cepheids of Population I we have to describe an entirely new curve, on which the stars are systematically brighter by one and a half magnitudes.

"You cannot say that astronomers were foolhardy in making the assumptions that they did 30 or 40 years ago, and accepting a classification which placed all cepheids on a single curve. It was a calculated risk, and to move forward science must take risks. Sometimes, as in the present instance, the assumption proves to be wrong, or partly wrong. But if the risk had never been taken, we would have made no use of cepheids as distance-indicators, our ventures into intergalactic space would have been more timorous, our resulting concept of the universe would have been more restricted. Even a half-length yardstick is better than none."

Since Baade announced the new determinations at the Rome meeting last September, several other astronomers have reported observations pointing to the need of recalibrating the classical cepheids. At the meeting of the American Astronomical Society in Amherst, Mass., last December Shapley presented the sixth in his series of papers on the Magellanic Clouds. In it he gave new estimates for both the sizes and distances of these outside stellar systems. He extended the estimated distance of the Clouds to 150,000 light-years and their estimated sizes to a diameter of 30,000 light-years for the Large Cloud and of 20,000 for the Small.

Another Magellanic Cloud surveyor is A. D. Thackeray of the Radcliffe Observatory at Pretoria, South Africa. At the Rome meeting last September, following Baade's announcement, Thackeray reported the study of a globular cluster of the Small Cloud in which he found that its cluster-type cepheids were one and one half magnitudes fainter than was to be expected on the old scale—thus arguing for a great distance. Since then Thackeray and his associate, A. J. Wesselink, have extended the measurements to short-period variables in two globular clusters of the Large Cloud, and in the April 18th *Nature* they give their preliminary estimate of the distance of the Clouds as nearly double the former accepted value.

What Makes Them Pulsate?

Before we consider the effect of these findings on the runaway behavior of the outside nebulae, a word needs to be said about their effect on the cepheids themselves. We describe cepheids as pulsating giants, but the internal mechanism which produces and regulates their clock-like variations has long been a puzzle. The late Sir Arthur Eddington was the great authority on the internal constitution of stars. He developed the mass-luminosity law, by which one could interpret from the luminosity and mass of a star its nature and behavior.

"According to Eddington's theory," Martin Schwarzschild of the Princeton Observatory explains, "the speed of stellar pulsation depends on the star's density, but in the case of the cepheids, and particularly the long-period cepheids,

MORE DISTANT CLUSTER of galaxies in Corona Borealis is also photographed by the 200-inch. The enlargement is the same, showing how the average size of galaxies can be utilized to estimate their distance.

the stars were too dense to pulsate as fast as they did. We simply could not get anywhere with the problem without abandoning well-established principles which worked satisfactorily for other stars. The situation had become terribly frustrating."

"How could you know the density of these stars?"

"We started with the period of variation," said Schwarzschild. "That gave us the luminosity—or at least was supposed to. From the luminosity we computed the mass by applying Eddington's mass-luminosity law. Density is mass per unit of volume, and if we can determine the star's diameter, we can estimate its volume. Diameter can be calculated from luminosity and surface temperature. So it is a series of steps, each built on the preceding ones. We determined the masses and volumes, and from them derived densities. Then we compared densities with the observed periods of variation—that is, of pulsation. And this relation between densities and periods did not agree with theory. It was very discouraging.

"But now, with Baade's discovery that the long-period cepheids are brighter, the whole outlook for cepheid theory has taken a new turn. Higher luminosities mean more diffuse gases, which is what the theory calls for. Now we can recompute the densities and get a new period-density relation. It looks as if the new values will agree very closely with the theoretical requirements."

The Distant Nebulae

Twenty million light-years is about as far as the 200-inch telescope is able to resolve a nebula into individual stars—which means, of course, that this is the limit of usefulness of cepheids as standard candles. How, then, can an astronomer reach farther and measure the claimed distances of hundreds and thousands of millions of light-years?

The first task has been to determine the dimensions of the nearby nebulae—those in which cepheids or other familiar giant stars can be detected. Within 20 million light-years of the Earth there are hundreds of galaxies. They are of various sizes and luminosities. Some galaxies measure up to 75,000 light-years in diameter, others only 1,500, and there are assorted sizes between. But by measuring the distance of each and calculating from its apparent brightness its absolute luminosity, the astronomer can strike a mean and arrive at the average brightness of a spiral. In previous surveys, before the new calibration was indicated, the average galaxy had the luminosity of about 100,000 million Suns.

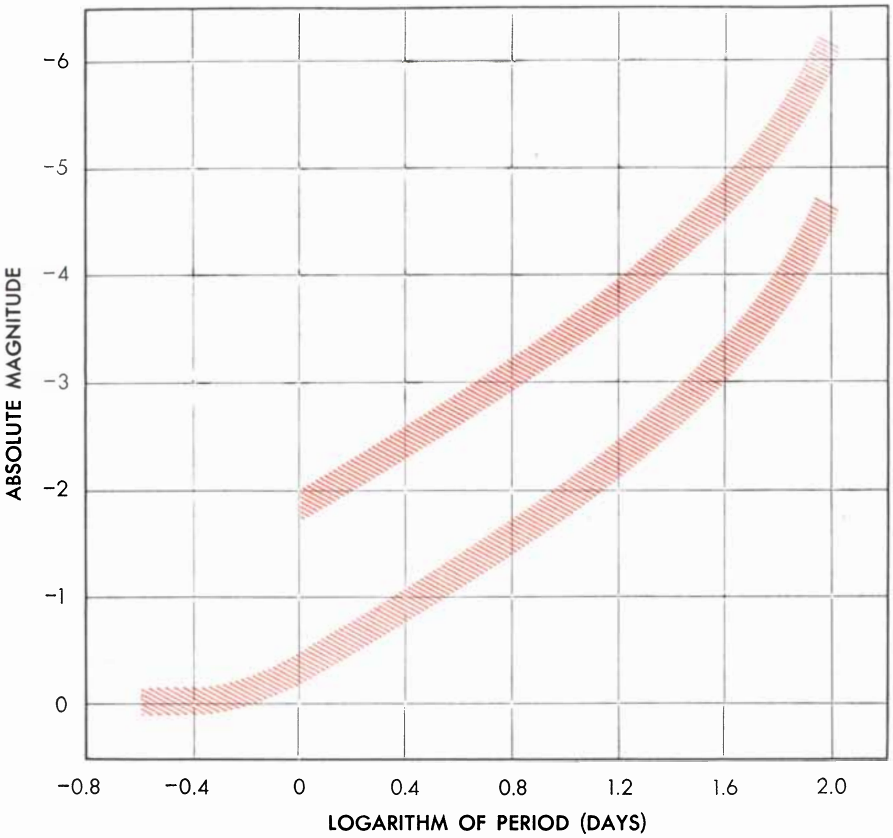
This average galaxy then became the yardstick. As the telescope reaches nebulae which cannot be seen as separate stars but only as blobs of luminosity, their distances are roughly estimated by calculating how far an average galaxy would have to be to appear that faint. For clusters of nebulae, statistical analysis is applied. Noting the proportion of large spirals to small ones in our neighborhood, the astronomer reasons that a similar distribution is probable for more distant neighborhoods.

The galaxies themselves thus serve as the standard candles when multitudes of nebulae scattered through a wide range of distances are involved. But since the calibration of the galaxy as a distance-indicator is based on the calibration of cepheids and other individual stars, the new determinations affect both stars and galaxies. On the new reckoning the average galaxy would approximate the brightness of 400,000 million Suns.

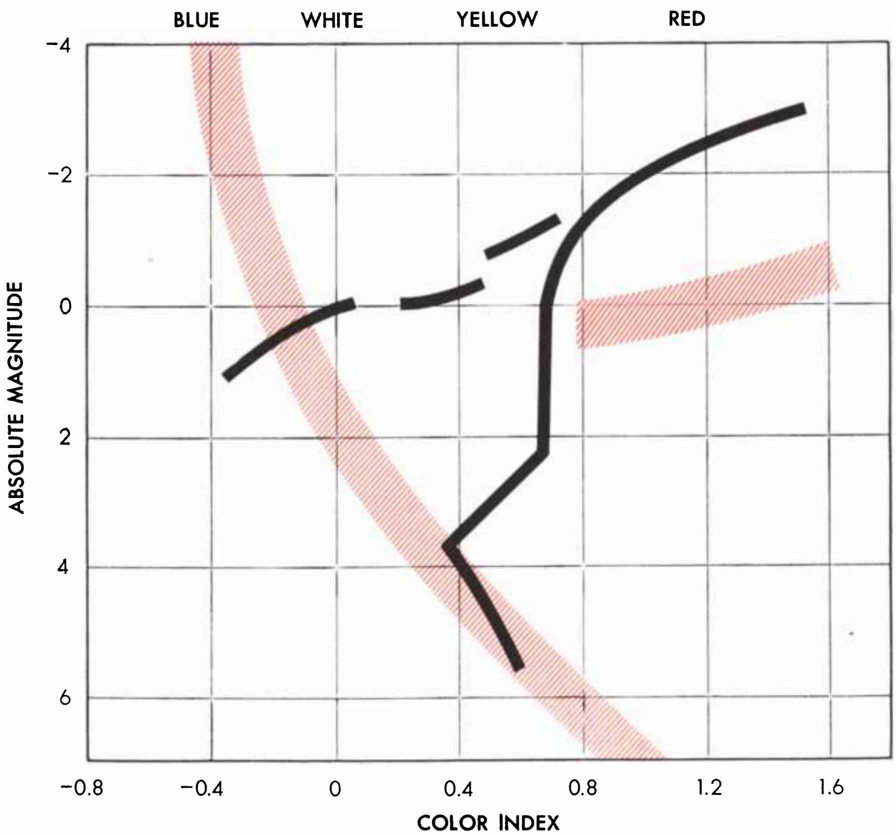
Doubled Time

Not only space but time is affected by the new calibration. For the age of the universe is calculated from the speed at which the galaxies are receding—an almost unanimous outward movement of nebulae as though they were running away from our part of the heavens. It is of course the well-known red-shift of spectral lines in the light received from these outside bodies that provides a measure of their motion.

Hubble, who has devoted the last 20 years to an intensive study of this evidence, found that the more distant the nebula, the greater was the redward shift of its light, and therefore the greater was its speed of recession. Nebulae at a distance of six million light-years were found to be receding at about 700 miles a second, those at 45 million light-years at 4,200 miles a second, and those at 135 million at 15,000. Thus there was an increase of about 100 miles a second for each additional million light-years of distance. Hubble calls this relationship between speed and distance "the law of the red-shifts." And the law held with remarkable consistency out to the most distant objects for which a spectrum could be obtained—a group of nebulae estimated to be 360 million light-years



PERIOD-LUMINOSITY RELATION of cepheid variables was formerly thought to be limited to the bottom curve. Now it is known that Population II variables are on the bottom curve; Population I variables, on the top.



COLOR-LUMINOSITY RELATION confirmed the correction depicted in the diagram at the top of the page. The diagram for nearby stars (*red*) provided a base for a diagram of the cluster Messier 3 (*heavy black line*).

away, for which the red-shift indicated a speed of 38,000 miles a second.

But if, as now appears, all these distances must be doubled, the ratio of speed to distance will be halved. That is, instead of the speed increasing at the rate of approximately 100 miles a second for each million light-years of distance, the rate of increase would appear to be only about 50 miles a second. On this basis it has taken twice as long as was formerly supposed for the nebulae to recede to the positions which they now occupy.

"The law of red-shifts," Hubble explains, "has been established by measurements of spectral lines out to the present limits of observation—lines which correspond to velocities of approximately 38,000 miles per second, or a little over one fifth the velocity of light. If the law continues to apply to objects beyond the limits of our present observations, then the age of the universe, on the old scale of distance, would be about 1,780 million years. On the new scale, it would be double that, or around 3,500 million years."

These speculations bring us to the shadowy frontiers of the unknown, and Hubble wisely counsels caution. He notes that the data received from the most remotely photographed spectra show a possible tendency to bend in the direction that one would expect them to take if the rate of expansion of the universe were slowing down. Unless this indication is disproved as additional precise photometric records accumulate, the maximum age of the universe will be sensibly reduced below the tentative revised estimate of 3,500 million light-years. "The time-scale is still an uncertain and disturbing feature," he says, "unless we drag in the idea of rapid evolution of such a sort that the nebulae appear systematically brighter the farther away they are—brighter because they were younger when the light left them on its journey to us.

"I believe," Hubble concludes, "that we can determine from observations whether or not red-shifts necessarily mean expansion, and I consider this a highly important project, because even the extended 'age of the universe' is no greater than the current estimates of the age of rocks in the crust of the Earth. The essential clues to the nature of the universe are: first, the law of the red-shifts, and second, the distribution of matter through space, which involves counts of nebulae, the luminosity function and masses. The law of red-shifts will be placed on a definitive basis in the course of a year or two. But the distribution of matter will require from five to 10 years for final solution. Meanwhile, it is unwise to be dogmatic and it is wise to distinguish carefully between topics of conversation and subjects for dissertations."

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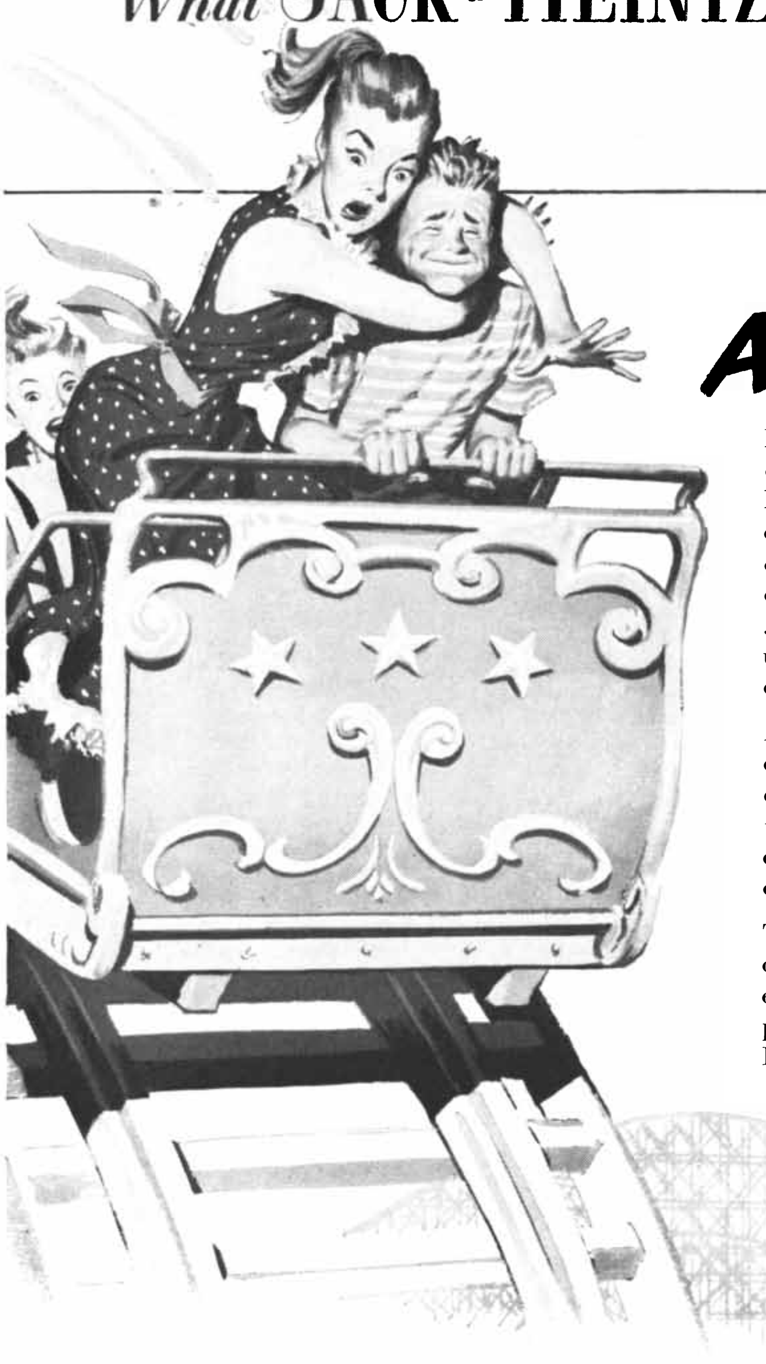

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CHELATION

It is a chemical process wherein the atoms of a metal in solution are "sequestered" by ring-shaped molecules. Chelating agents have now become important tools of analytical chemistry and technology

by Harold F. Walton

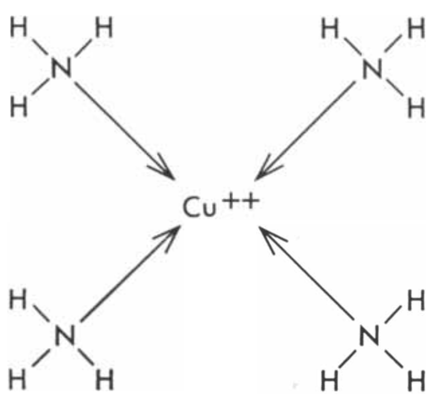
THE MOST USEFUL tool of the chemist's trade is the cabalistic scribble of letters and connecting lines with which he pictures a molecule. When, some 90 years ago, the German chemist Friedrich August Kekulé first visualized a molecule as a group of little balls (atoms) joined by sticks, he gave chemistry something much more important than a convenient scheme for writing chemical formulas. Kekulé's visions (one of his discoveries, the benzene ring, actually was suggested to him by a dream of a snake chasing its tail) provided the beginning of our understanding of how a molecule is constructed and of the bonds between atoms. And today the diagram with which a chemist represents a molecule on paper carries a great deal of meaning: it is, in fact, a prediction as to how the substance will behave chemically.

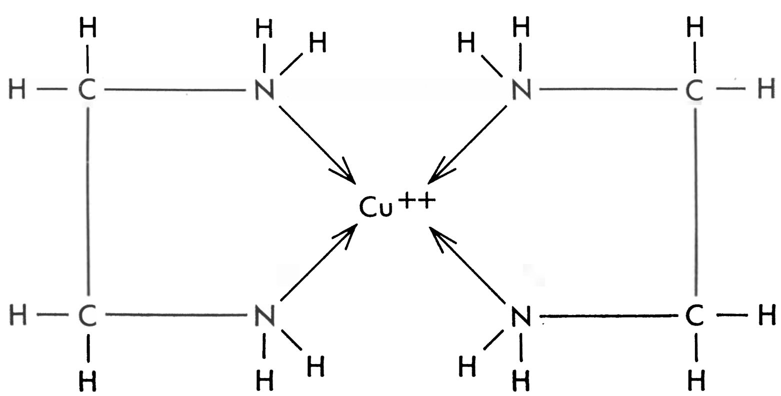
Within the past year or so wide interest has developed in a new branch of chemistry which gets its name from the symbols used to picture its peculiar type of molecule. The chemist's formula for this kind of compound shows rings of atoms in which arrows, representing a special kind of chemical bond, grip a central atom like a claw. The structure is called a chelate ring, from the Greek word *chele*, meaning claw. Chelation is not a brand-new discovery: there are many chelate compounds in nature, among them the hemoglobin of blood and the chlorophyll of plants. But new ways to use chelation are being found, and there is now rising a flourishing industry which produces made-to-order chelate compounds for many purposes, from softening water to dissolving kidney stones. Chelation also is revolutionizing chemical analysis in the laboratory.

The various uses of the chelate compounds all depend on one fascinating property: the ability of the crablike claw to seize and sequester atoms of metal. A chelate compound will hunt down traces of any given metal in a liquid. It is as if we sent a posse of crabs into a mixed population of flora and fauna with instructions to seize and swallow all the left-handed snails.

TO UNDERSTAND how chelation works we must examine the nature of a chemical bond. According to the modern theory of valence, the atoms in a molecule are bound together by electrons, the charged particles that surround every atom. The bond may be established in one of two ways. An atom may transfer one of its electrons to its neighbor. In that case the atom that loses the electron also loses its electrical neutrality and becomes positively charged, while the atom that receives the electron becomes negatively charged. These two "ions" then are held together by the electrical attraction of their opposite charges. The other way in which two atoms may be bound together is by sharing a pair of electrons—as if two persons were held together by a pair of ropes that belonged not exclusively to either individual but to both together. This is called a covalent bond: the chemist represents it by a single line joining the two atoms. Usually each of the two joined atoms supplies one of the two binding electrons. But sometimes one atom supplies both, and that kind of link is called a coordinate bond. The chemist's symbol for such a bond is an arrow pointing toward the atom which has received the electrons.

Now a chelate ring is simply a group of atoms linked into a ring with one or more coordinate bonds. The atoms that donate the electrons are usually oxygen, nitrogen or sulfur; the acceptor atom, grasped in the claw of arrows, is nearly always a metal. In such a ring the metal atom is gripped more firmly than if it were merely attached to atoms in independent molecules. Another way of saying this is that a metal atom is much more prone to unite with two donor





COORDINATION COMPOUNDS of the cupric ion (Cu^{++}) sequester copper. The arrows denote coordinate bonds. The compound at right is chelated; the one at left is not. The chelated complex is more stable.

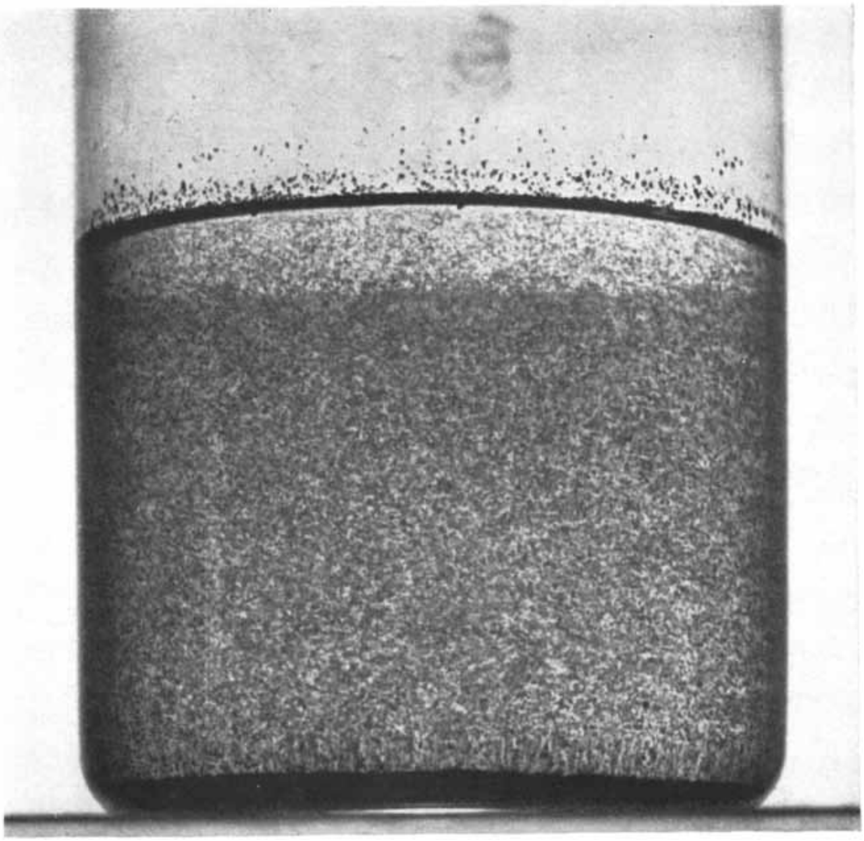
atoms in a ring-forming molecule than with the same atoms in two separate molecules. The mechanics of the situation make clear why this is so. To become attached to two separate molecules, the metal atom must capture a donor atom in each molecule separately, and this depends on chance contacts. But when the metal atom becomes attached to one end of a molecule that can form a ring around it, it easily links up with the other end, for the latter is tethered and cannot range far afield.

What kind of molecule do we need to form a chelate ring? In the first place, the molecule must contain at least two atoms that can attach themselves to a metal ion. Secondly, if we are to have a strain-free, stable ring, the atoms forming it must join in such a way that their valence bonds are at their natural angle. The natural angle of the bonds in the carbon atom, which determines the structure of most chelate rings, is slightly more than 108 degrees, and this is the size of the angles of a pentagon. Hence the ideal number of atoms to make a chelate ring is five. There are many known chelate rings with six atoms, but very few have fewer than five or more than six.

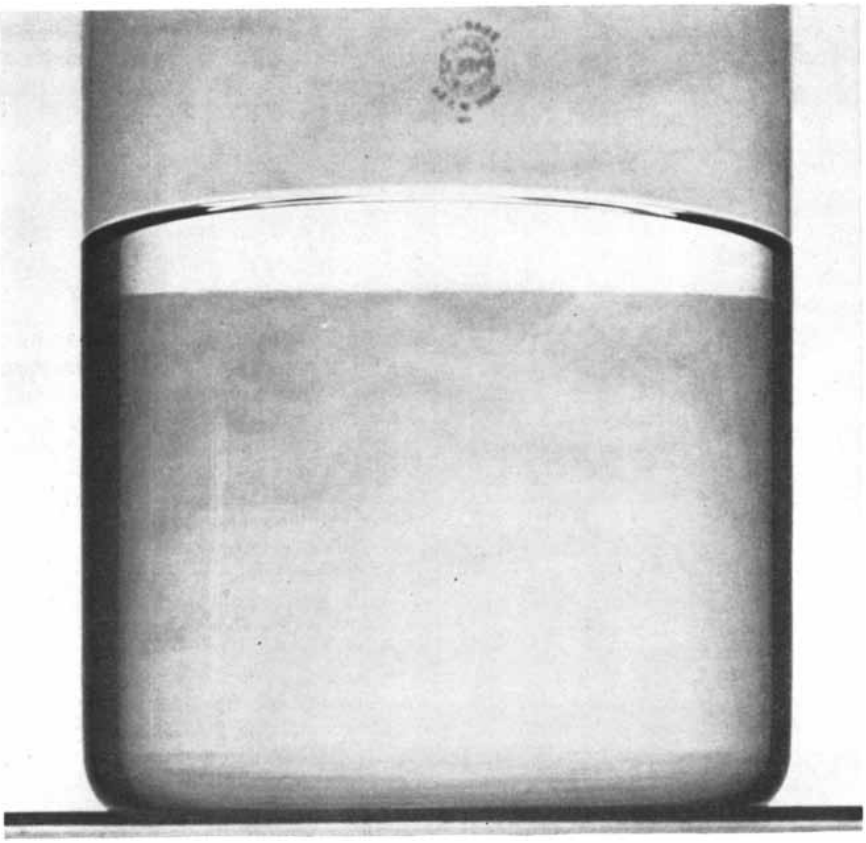
One of the best chelating compounds is a chemical with the imposing name of ethylene diamine tetraacetic acid, called EDTA for short. The atoms in this molecule are spaced just the right distance apart to give strain-free chelate rings with five atoms apiece. What is more, the molecule has no fewer than six atoms (two of nitrogen and four of oxygen) that can donate electrons to metals. It will grip an atom of iron with not one but five or six chelate rings: the molecule might fittingly be called an octopus rather than a crab [*see diagram on page 72*].

It is this kind of molecule, capable of forming several chelate rings at once, that has created the chelation industry. Studies of EDTA and similar chelating agents were begun about eight years ago by the Swiss chemist Gerold Schwarzenbach and have now been taken up in the U. S. by Arthur E. Martell of Clark University and other chemists. Already in commercial production are several chelating compounds, known variously by the trade names Versene, Sequestrene, Nullapon and Trilon.

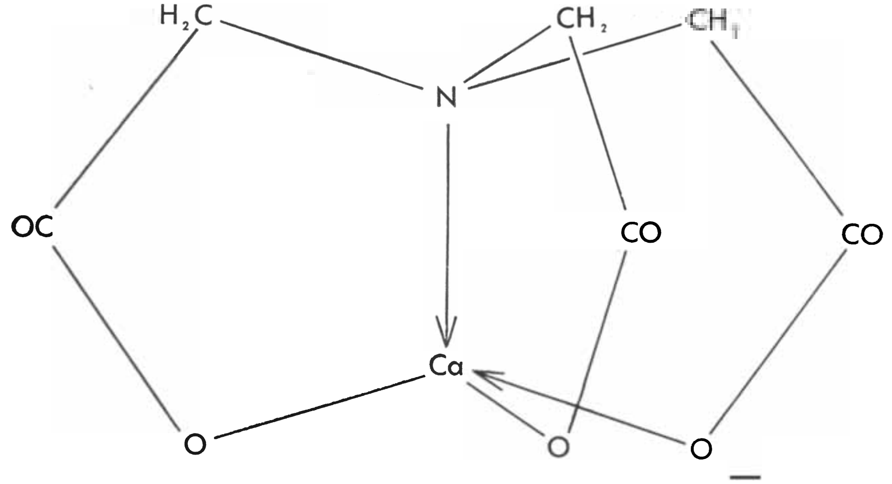
CHELATION can be applied to any problem in which the presence of metal ions causes trouble. Suppose, to take a common example, that our water supply contains dissolved salts of iron. The iron forms a sediment on standing; it discolors bathtubs and linens; it spoils the taste of tea. On the domestic scale it is very difficult to remove. Thanks to chelation, however, we do not need to remove it to prevent its ill effects. We may,



BEAKER CONTAINING IRON is photographed in the laboratory of the Bersworth Chemical Co. The iron is in the form of an insoluble compound.



BEAKER IS CLEARED by the addition of a chelating agent. The iron is still there, but it is sequestered by the rings of the chelating agent.



AMMONIATRIACETIC ACID sequesters calcium (Ca) in several chelate rings. The complex is an ion carrying one negative charge (*bottom right*).

instead, add EDTA to the water. Now the iron will leave no stains, form no sediment: the water becomes sparkling clear. The iron is still there, yet it cannot be detected even by sensitive chemical tests. It is tightly imprisoned and hidden away—"sequestered," in the poetic language of chelation technology—by EDTA's chelate rings.

The softening of water so far has been the largest use of chelation. The chelating compounds combine readily not only with iron but also with the calcium and magnesium ions of hard water. They are too expensive for large-scale use, but are ideal for adding to shampoos, soaps and detergents. Unlike some other water-softeners, chelates of the EDTA type do not lose their strength on prolonged contact with water.

EDTA also is added to dyes to get rid of traces of iron and other metals which may modify or weaken colors or even leave rust stains on the fabric. The metals spoil dyes, incidentally, by forming chelate rings with the dye molecules.

Another field where traces of metal do a lot of damage is in food preservation. Even one part per million of metal ions catalyzes atmospheric oxidation, and this is what makes cut apples turn brown, fats and oils go rancid, orange juice lose its vitamin C and most of its flavor and green vegetables spoil. The addition of one hundredth of 1 per cent of EDTA improves the keeping qualities of such food enormously. EDTA helps preserve rubber latex and high-energy rocket fuels also.

A large dose of EDTA will reduce the concentration of free metal ions in a solution to the vanishing point. With a moderate, calculated dose we can hold the concentration at any level we wish, just as we control the concentration of hydrogen ions, or the acidity, of a solution. EDTA is used in this way to regulate the deposit of metal in electroplating, assuring a smooth, adherent coat.

EDTA can dissolve insoluble salts of metals as well as prevent their formation. This makes it a useful decontaminant for radioactivity: it will wash off invisible films of radioactive metal salts where soap and water will not.

THE SAME property enables EDTA to help dissolve kidney stones, decalcify bone and rid the body of poisonous heavy metals, notably lead and plutonium; EDTA offers almost the only hope of treatment for plutonium poisoning. In such applications it is fed as the calcium salt, so that calcium will not be removed from the blood or bones. On the other hand, EDTA also is useful where we want to take calcium ions out of the blood to prevent clotting. Recent tests have shown that EDTA makes it possible to preserve whole blood nearly twice as long as does the citrate solution which the Red Cross now uses to keep blood from clotting before it is processed.

Citric, malic, lactic and tartaric acids are among nature's chelating agents. They keep metal ions from precipitating in body fluids, much as EDTA prevents precipitation of iron from well waters. The root hairs of plants secrete chelating acids which dissolve such compounds as ferric oxide and calcium carbonate and make the iron and calcium of the soil available to the plant. Humus assists this process, for it, too, contains chelating agents. Soils deficient in humus can be improved by adding EDTA.

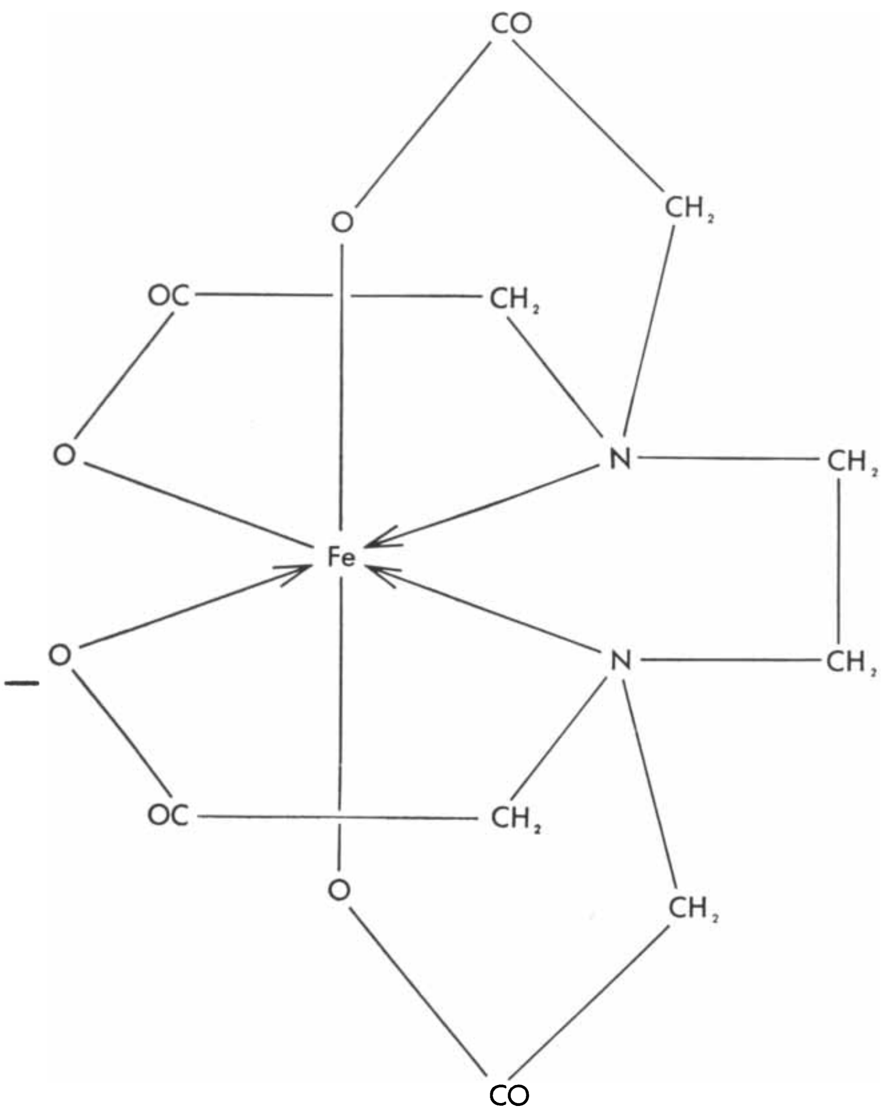
Chlorophyll and hemoglobin are chelated compounds of a very special type. They contain the "porphyrin ring": a complicated arrangement of rings within rings which is flat and has four nitrogen atoms placed at the four corners of a square. In the middle of this square is a metal atom gripped by the four nitrogens. In hemoglobin the metal is iron. The iron atom fits very nicely, for it is about the right size, and what is more

important, the normal arrangement of the bonds by which it is gripped is flat and not tetrahedral. In chlorophyll the situation is different. Its metal, magnesium, has bonds that normally angle toward the four corners of a tetrahedron. Consequently in the chlorophyll molecule these bonds are strained and the chelate ring is less stable. It is something of a mystery that chlorophyll should contain magnesium rather than some other metal. Once we get chlorophyll out of the living plant cell, its magnesium can be displaced by almost any other metal. To stabilize commercial chlorophyll preparations the magnesium is generally replaced by copper.

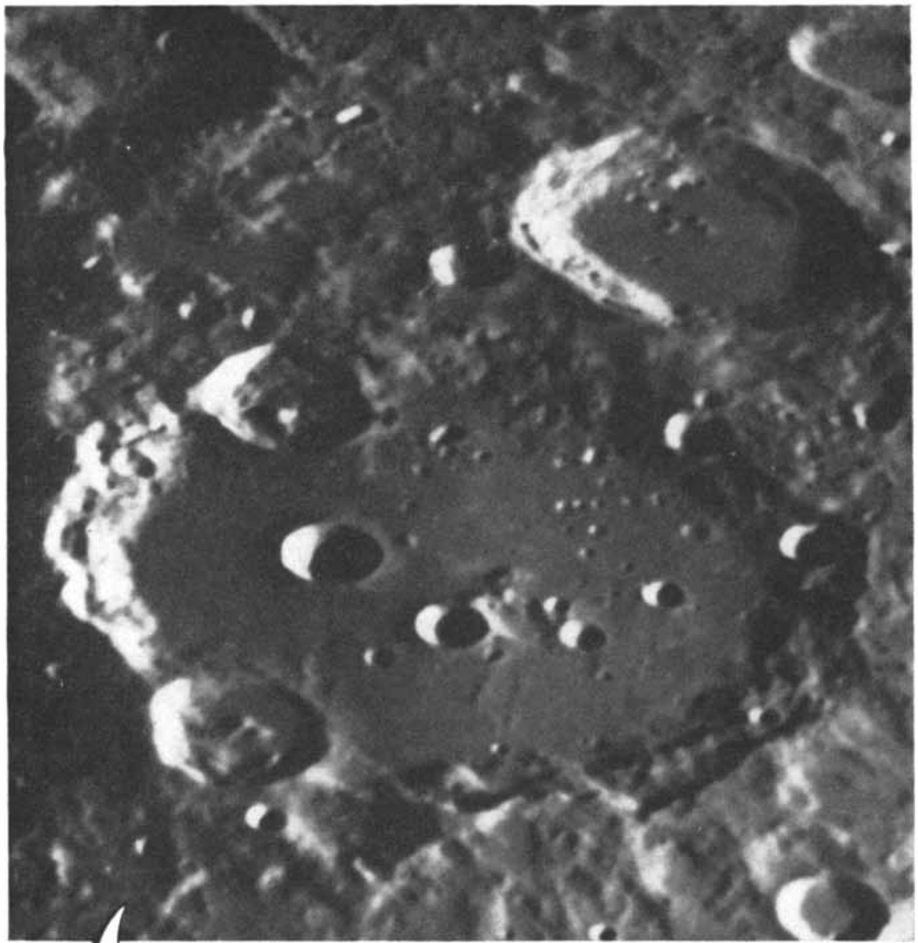
FROM ALL THIS it is obvious how chelation becomes a tool of chemical analysis. A chelating agent can be used like a pair of forceps to pluck out a specific kind of atom or ion from a complex mixture. Its selectivity comes from the fact that a given chelating agent grips some metal ions more tenaciously than others. We can apply this selectivity in two ways. Either we hold one metal in solution by chelation while we precipitate or extract another, or we use the chelating agent to make the metal we want insoluble so that we can extract it. The second method is the sharper tool.

Let us examine one particularly vivid example. Every analytical chemist knows that when the chelating agent dimethylglyoxime is introduced into a dilute ammonia solution containing nickel ions, he will get a beautiful scarlet precipitate—so brilliant in color that it has been used in lipsticks. The reaction is an analytical chemist's dream. Of the 98 known elements, only nickel is completely precipitated by this treatment! No other test is so specific for one metal.

The structure of the chelate compound explains this specificity. The molecules of the dimethylglyoxime chelate that holds the nickel are electrically



ETHYLENE DIAMINE TETRAACETIC ACID, or EDTA, sequesters iron (Fe) in more rings than ammoniatriacetic acid. It also is negatively charged.



Close-up of the moon taken through the famous Hale telescope at Palomar Mountain, Calif. Sharp detail shows 150-mile wide crater known as Clavius (center). The glass for this 200-inch mirror was supplied by Corning.

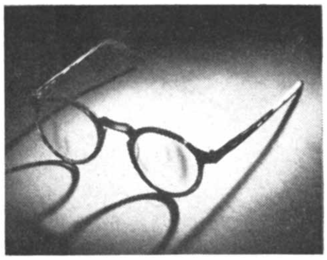
Looking for the moon?

If you are looking for the moon, glass is a most logical material to use. Whether you use binoculars, a home-made telescope or a giant reflecting telescope like the 200-inch glass mirror of Palomar, Corning can produce a glass to meet your exact requirements.

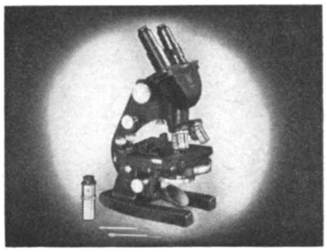
Glass was used for the Palomar Mountain telescope because it could be polished to precision tolerances that could be maintained over wide temperature ranges. Corning has also developed glasses for many other optical uses—mass-produced glass to exacting specifications for eyeglasses, microscopes and camera lenses, glasses that protect the eyes from harmful rays of the sun and filters that control light in many types of scientific instruments.

So whether you are looking for the moon or something more earthy, glass can help. If your problems involve corrosion, electrical properties, heat resistance, hermetic enclosure or smooth surfaces we would like to bring you up-to-date on how glass can help you.

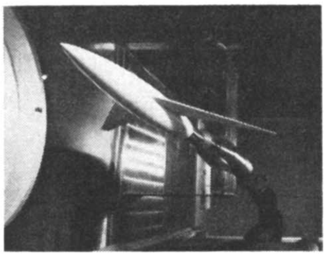
For that purpose, we have prepared some factual material about glass by Corning that your engineering department should have. We would be happy to send you all or any part of it. Check and return the coupon.



Everyone who needs eyeglasses today can depend upon excellent vision, thanks to the consistent optical purity of glass by Corning.



The glass for microscope lenses must be of high optical quality. Corning mass produces glass that more than meets this standard.



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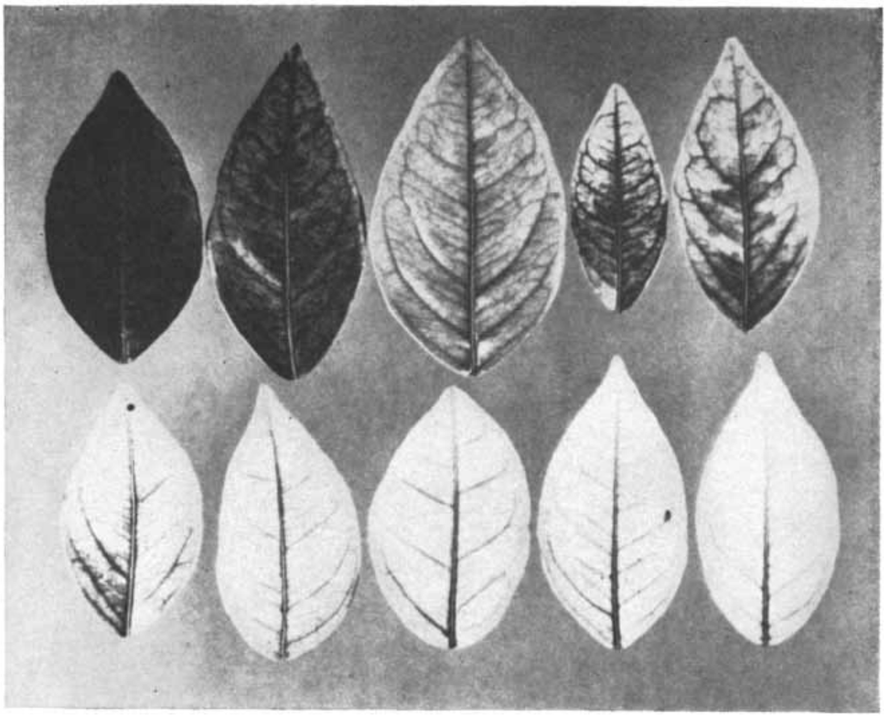
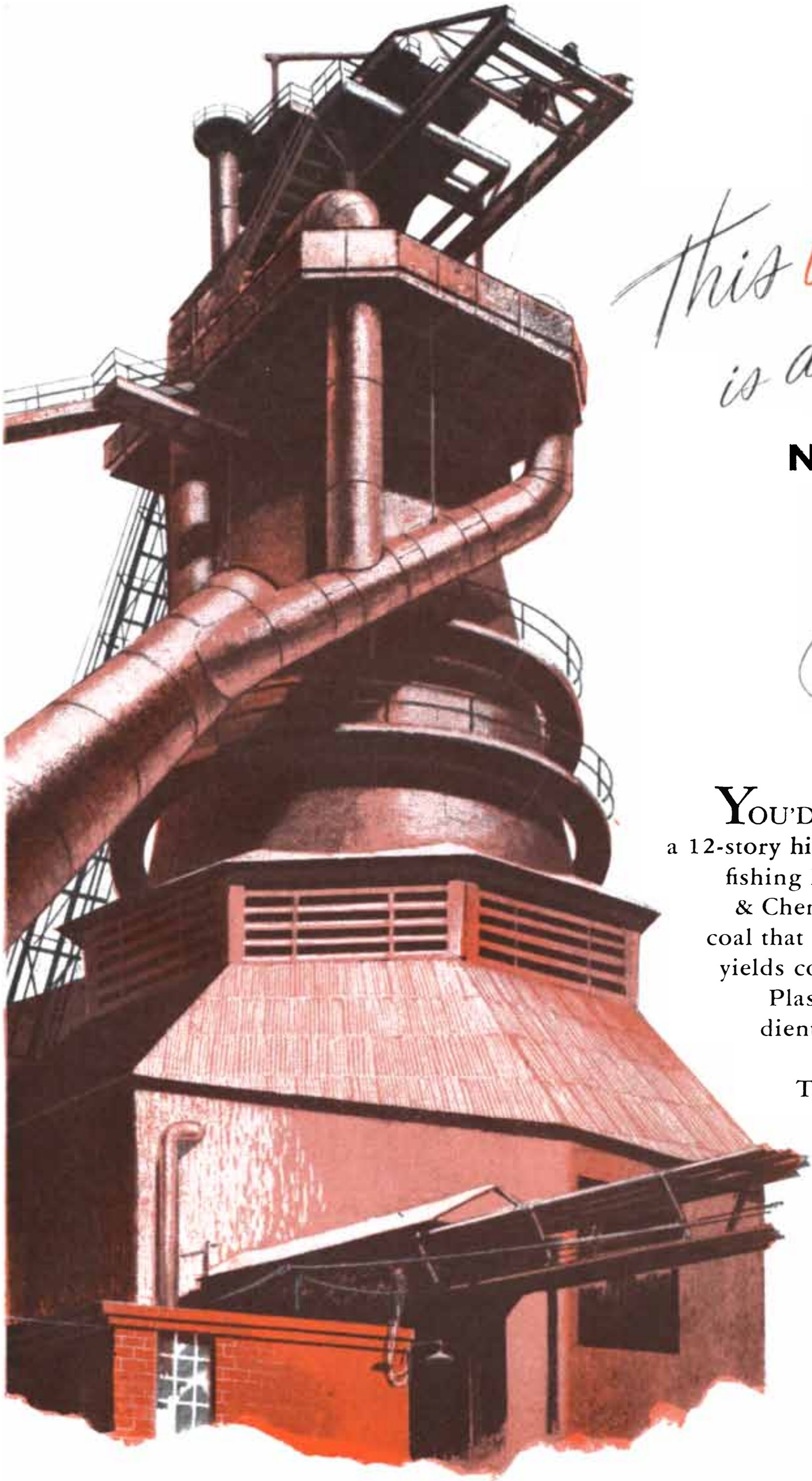


BLEACHED LEAVES of a citrus plant suffer from chlorosis, a disease caused by a lack of soluble iron in the soil. The condition can be corrected by adding to the soil a soluble chelated complex of the metal.

neutral and completely flat—so flat that they can be stacked up together like a deck of cards to make a compact crystal. Each molecule contains two dimethylglyoxime units, one on each side of the central nickel atom. To form this flat, symmetrical molecule four distinct requirements must be met. First, if the molecule is to be neutral, the metal ion must have a charge of plus two, so that when it combines with the two dimethylglyoxime units no electric charge is left over. Second, it must readily accept electrons from the donor nitrogen atoms. Third, since each dimethylglyoxime contains two nitrogens, the metal ion must join with four nitrogens, and these must lie at the corners of a square, not of a tetrahedron. Finally, the metal ion must be the right size. These requirements are like the tumblers of a lock: to open the lock, the key must fit them all. Nickel is the key that fits this lock. Its ions have a charge of plus two; they coordinate easily with nitrogen; their valence bonds are in one plane and not tetrahedral; the ions are the right size. The ions of copper have almost exactly the same combination of properties as nickel, and they will form a chelate with dimethylglyoxime. But what makes nickel unique here is that the copper chelate is soluble, whereas nickel precipitates out of the solution.

DIMETHYLGLYOXIME is one of hundreds of organic reagents for metals used in modern chemical analysis. Nearly all of them form chelate rings. None is quite as selective as dimethylglyoxime and its homologues, or gives quite as beautiful a color as the dimethylglyoxime-nickel reaction. But many do form strongly colored compounds. The combination of color production with selectivity is just what we need for the analysis of complex mixtures. By looking at the colors we can tell what metals are there, and by using a photoelectric colorimeter we can tell how much of each metal is present. One of the best reagents for this kind of analysis is a sulfur-containing chelating agent known as dithizone. With certain metals dithizone forms red or orange chelates which are so intensely colored that as little as a 10-millionth of a gram of the metal can be detected. This method is as sensitive as the spectrograph, and a lot less cumbersome. Dithizone is used to check the content of trace elements in soils and to look for minerals by analyzing the water in streams that flow near the ore beds.

A good way to use chelating agents in analysis is to set two of them against each other in a chemical tug-of-war. The National Bureau of Standards employs this device to measure traces of copper in steel. The elements to be separated are iron and copper; the chelating contestants are EDTA and sodium diethyldithiocarbamate. Neither of these agents is sufficiently selective to separate iron and copper by itself. But EDTA grips iron a trifle more strongly than it does copper, while the other reagent is more partial to copper. When the two reagents are used together, the EDTA gets all the iron (also chromium, cobalt and nickel if they are present), and the sodium diethyldithiocarbamate gets all the cop-



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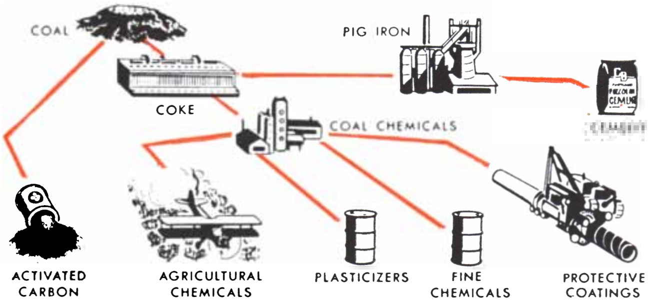

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X-RAY PHOTOGRAPH of a rabbit demonstrates the use of a chelating agent to make not only the bones but also the soft tissues visible. The animal was fed chelated lead, sequestered from its usual toxic action. The lead makes the internal organs relatively opaque and is eliminated.

per and nothing else. This copper chelate is intensely colored. It is extracted with an organic solvent—a common practice with metal chelates—and the color is measured with a suitable instrument.

One more example will show the usefulness of these reagents to the analytical chemist. Often he wants to know exactly how much of a dissolved substance is present, by volume, in a liquid; for instance, he may want to measure precisely the total hardness of a sample of water, meaning the sum of its calcium and magnesium ions. He adds to the water a solution of EDTA of exactly known concentration. He drips in the solution a little at a time, as he wishes to shut it off at precisely the moment when the EDTA has swallowed all the calcium and magnesium ions. To determine that point he uses a certain purple-red dye, itself a weakly bound magnesium chelate, which is torn apart by EDTA and changes abruptly from purple-red to sky blue when all the calcium and magnesium ions are gone. Now, from the amount of EDTA solution that was needed to swallow up the ions, he can calculate exactly how much calcium and magnesium was in the water.

From the laundry tub to the analytical laboratory, the versatile chelating agents justify their description as "chemistry's most precise chemicals."

A Versatile Virus

A disease of asters is caused by a virus that multiplies in both the plant and the insect which infects it. This makes the virus one of the few pathogens common to the plant and animal kingdoms

by Karl Maramorosch

ABOUT 30 years ago a mysterious disease blighted China asters in the New York area. The tracking down of this disease, called aster yellows, has been a classic piece of scientific detection. More than that, it has opened up a new field for the study of virus diseases. Aster yellows was found to be due to a virus transmitted by an insect to plants. It was one of the first known cases of a virus infecting both a plant and an animal. The research on this virus has gone far toward settling the long-disputed question as to whether viruses are living organisms.

Plants provide virus investigators with a peculiarly convenient laboratory tool. Many can be grown from cuttings to produce successive generations of plants genetically the same as the parent. Thus hundreds of virtually identical individuals can be grown and tested in a uniform way—a control condition ideal for experiments but hardly available in animal research. Many studies have shown that plant, animal and human viruses have many basic aspects in common and may profitably be studied together.

The story begins in 1922 when Colonel William Boyce Thompson saw the prize asters on his estate in Yonkers, N. Y., succumbing to the plague. The disease stunted the plants, deformed the

CHINA ASTER suffering from aster yellows is in the pot at the left. Its flowers are distorted; its upper leaves are deformed and their veins yellow; it is stunted. In the pot at the right is a healthy plant of the same age.

flowers and destroyed their seeds or made them sterile. After futile inquiries as to a cause or a cure, Thompson decided that here was a great gap in knowledge. A determined man, he hired several plant scientists and created the Boyce Thompson Institute for Plant Research. One of the men he hired was Louis Otto Kunkel, a young plant pathologist just returned from three years' work for the Hawaiian Sugar Planters' Association.

While in Hawaii Kunkel had discovered that a virus causing a corn disease was transmitted by an insect. In Yonkers, therefore, he collected and segregated the types of insects that feed on asters, tested them on healthy seedlings in a greenhouse, and soon discovered that aster yellows was transmitted by leafhoppers—those tiny, triangular insects one commonly sees hopping about on the foliage in a field on a summer's day. They feed by sucking juices from a plant through a slender, jointed beak, so fine that it can penetrate deeply into the plant's food-carrying cells without injuring the plant. Kunkel showed that one, and only one, of all the species of leafhoppers feeding on asters carried the disease agent. It was the gray leafhopper *Macrosteles fascifrons*. He also proved that the infecting agent was a virus.

KUNKEL was immediately confronted with a puzzle. The aster, an annual, does not live over the winter in the Northeast. Neither does the adult leafhopper. When the plant's seeds germinate and the insect's eggs hatch in the spring, they are free of virus. Where, then, does the virus spend the winter? He decided it must live through in some other host, probably a biennial or perennial plant. Investigation soon showed that plantains and daisies harbor the virus. Eventually it was learned that leafhoppers could transmit the same virus to members of more than 40 different families of plants. It causes diseases called "carrot yellows" and "spinach yellows" and a disease of lettuce known as "white heart." A serious disease of celery on the West Coast is caused by "California aster yellows" virus. The California virus, which is reported to be transmitted by many species of leafhoppers, last year made its appearance in Florida, where it had been carried in some gladiolus bulbs.

Kunkel eventually found, during Colonel Thompson's lifetime, measures to prevent the aster yellows disease. Insecticides were ineffectual, because a single surviving leafhopper could spread the disease widely; but screening could protect the asters, and it is now extensively used by commercial growers.

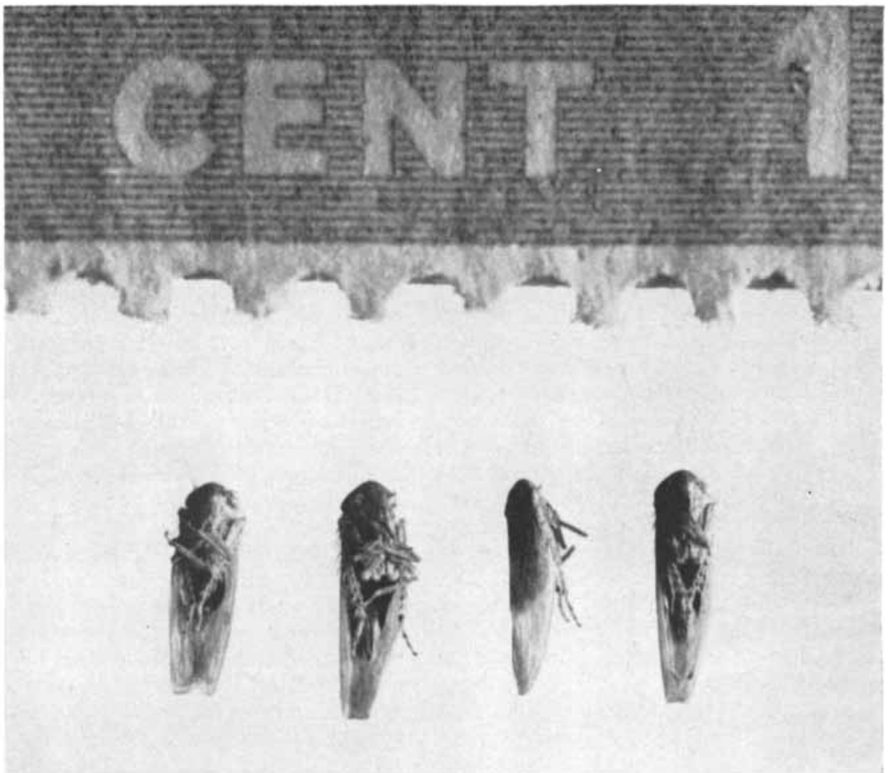
However, the virus itself, and its hosts, soon became the main interest of the investigators. For 10 years at the Boyce Thompson Institute, and after 1932 at the Rockefeller Institute for Medical Research, Kunkel and many colleagues pursued an intensive investigation of various plant viruses. Along with the experiments on aster yellows went studies of the tobacco mosaic virus, which eventually led to the first isolation and crystallization of a virus by the Nobel prize winner Wendell M. Stanley. The work on these plant viruses paralleled and aided studies of animal viruses, notably the virus of yellow fever, which was found to lurk in various species of mosquitoes and monkeys and in other animal hosts, just as the aster yellows virus infects many kinds of plants. At the Rockefeller Institute many specialists, including plant pathologists, chemists, crystallographers, parasitologists and microbiologists, have worked together on the virus diseases of animals and plants.

THE RELATIONSHIP of the aster yellows virus to its insect carrier was carefully studied. Experiments showed that leafhoppers may become carriers of the virus after feeding on diseased plants for a short time, sometimes less than an hour, but it takes from nine days to three weeks for the virus to incubate in the insects sufficiently so that they can transmit the virus. Leafhoppers that have fed on diseased plants for two weeks all become carriers, but some are less effective transmitters than others. Once a leafhopper has incubated the virus, it remains infective throughout its lifetime, which averages about 65 days. A few good transmitters can spread aster yellows over a large area in a short time.

Now it is obvious that a plant virus such as aster yellows must be able to multiply in the plant. But that the same virus could also multiply in its animal carrier had been a matter of much dispute up to this time. The first evidence that the aster yellows virus actually did multiply in the leafhopper came from certain studies of the effects of heat.

From the beginning it had been evident that the virus was sensitive to heat. Aster yellows usually appears about two or three weeks after asters are set out in the spring, spreads rapidly for four to five weeks, and then, beginning in June, slows down until September, when it spreads rapidly again. This behavior does not jibe with the activity of leafhoppers, which are relatively scarce in spring, become most numerous in summer, and begin to decline in September. The changes in temperature were found to be responsible for the decline in spread of the disease during the summer. At about 75 degrees F. leafhoppers readily transmit the disease, but at 90 degrees F. they soon lose the power to infect plants. The insects are more sensitive to heat than the plants, because they are much smaller and therefore more quickly warmed to the temperature of the air.

After a few days of hot weather, a fall in temperature may restore the insects'



LEAFHOPPERS which transmit the virus are compared with the edge of a postage stamp. The first and third are male; the second and fourth, female.

infectivity. However, they need an incubation period, ranging from a few hours to two weeks, for their surviving virus to reach the same infective level again. When the hot spell lasts for two weeks or more, the leafhopper permanently loses its infectivity. Now it must feed on a diseased plant again to become infective. Experiments with varying periods of heat demonstrated that the longer the heat treatment, the longer it took the insects to regain infectivity. This certainly seemed to show that virus multiplied in the leafhopper; obviously the longer heat treatment had destroyed more virus and it took longer for the remainder to multiply to the infective level. The heat treatment was applied as a cure for this and several other virus diseases.

Further evidence that the aster yellows virus multiplied in the insect soon followed. It was made possible by the development of a mechanical method of infecting the leafhopper. As early as 1920 the Polish scientist Rudolf Weigl had succeeded in injecting typhus rickettsia, organisms not much larger than some viruses, into lice by means of a very fine needle. But animal and plant virus research were so far separated that plant pathologists did not adopt this technique until the English investigator H. H. Storey discovered in 1933 that he could inoculate leafhoppers with a corn virus by means of a fine hypodermic needle. He demonstrated his technique at the Rockefeller Institute, and there Lindsay M. Black (now at the University of Illinois) applied it to inoculating the aster leafhopper with aster yellows virus.

He ground up the bodies of infected insects and by centrifugation obtained a fluid containing virus. Then he injected the fluid into virus-free leafhoppers. The number that became carriers of virus served as a measure of the virus concentration in the fluid. Black found that the concentration increased with the length of incubation of the virus in the original insects which had donated the fluid. Here, then, was another indication that virus multiplied in leafhoppers.

A few years later we showed in our laboratory that when measured amounts of virus are injected into leafhoppers, the time it takes them to become infective to asters varies with the amount of the injection. A large injection (either in volume or in concentration of the virus) makes them infective in a short time; the smaller the injection, the longer it takes. The period of incubation ranges from 11 to 38 days. This experiment makes clear that a leafhopper must develop a certain minimum amount of virus to become infective, and therefore that the virus must multiply in the insect. The method also afforded a convenient new measure of virus activity.

In experiments using specially constructed chambers kept at a constant controlled temperature, we found that reduction of the temperature to 40 degrees F. arrested the incubation of the virus.

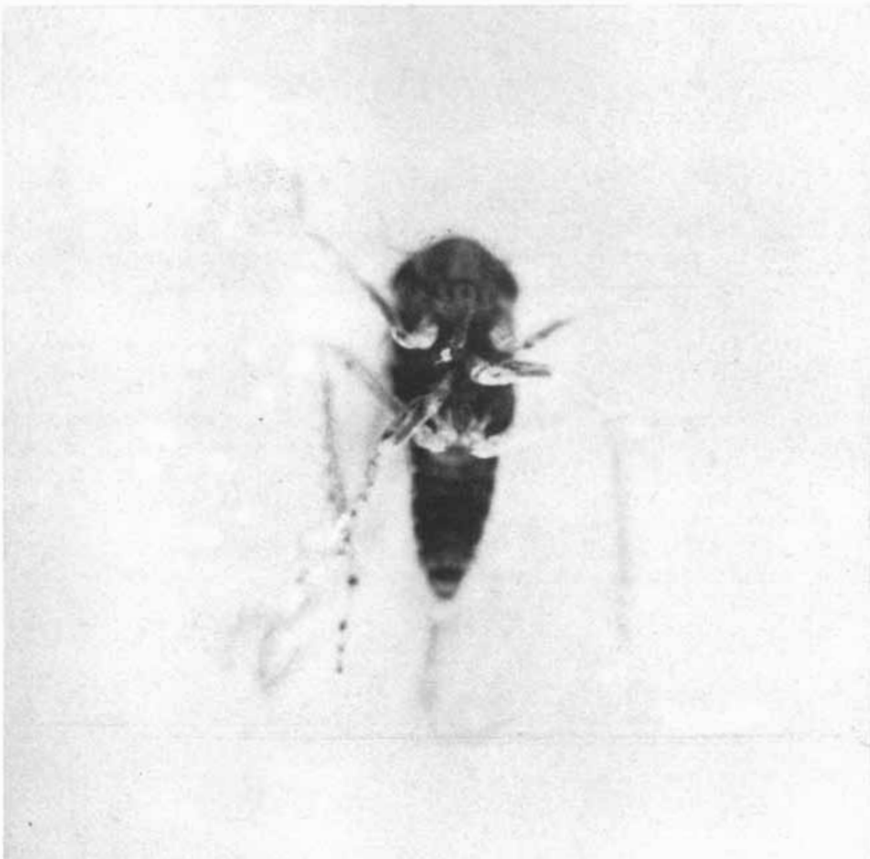
Another test in this laboratory provided final proof of multiplication of this

virus in the insect. The virus was passed by injection through 10 successive groups of leafhoppers. After the virus had incubated in one group for 30 days or more, the bodies of the insects were ground up and a saline solution was added to dilute their juice to one part in 1,000. Small measured amounts of this diluted juice were injected into the next group. By the 10th group the original virus should have become diluted to one part in many, many billions—far too little to make them infective. Yet the tenth group turned out to have as much virus as the second! Plainly the virus must have reproduced itself in the successive groups of leafhoppers.

No artificial method of injecting yellows viruses into plants has yet been found. Man-made hypodermic needles, far coarser than the leafhopper's proboscis, injure the plant cells. Besides this, the virus is obtainable only in low concentrations and is soon destroyed in the extracted juices. But there is a parasitic plant called dodder which can transmit the aster yellows virus: grown on an aster, it takes up the virus and then can be transplanted to another plant to pass it on. Dodder is useful for transmitting aster yellows to plants only distantly related to the aster and to those that are poisonous or unpalatable to leafhoppers. It also provides a way to infect a convenient host for storing the virus. The host most commonly used is a perennial periwinkle of tropical Madagascar. By dodder transmission aster yellows in recent years has been transmitted to many plants never found infected in nature.

Apparently the reason why only one known leafhopper species in the Eastern U. S. transmits aster yellows is that this is the only species in which the virus can multiply. Many viruses, animal and human, show a similar specificity in transmission. Some of the studies on aster yellows may help in part to explain such specificity. We have tried to induce the aster leafhopper to transmit a virus which causes corn-stunt disease, and similarly to induce the leafhopper that carries the corn virus to transmit the aster yellows virus. But all our attempts to make a corn leafhopper into a vector of aster yellows virus, and *vice versa*, failed. Moreover, when we passed the virus of one leafhopper species through successive groups of the other, the virus soon disappeared. This demonstrated that a given insect's ability to incubate a certain virus may be a necessary condition for specific biological transmission of that virus. Thus the spread of a virus may depend on its finding a suitable intermediary for multiplication.

Studies of transmission of aster yellows have been confined to leafhoppers. This is due not only to a lack of success in



LEAFHOPPER magnified 25 diameters is seen from below in macrophotograph. The tiny white spot that appears slightly to the left of the center of its body is a bit of jelled saliva ejected from thin proboscis it inserts into plants.

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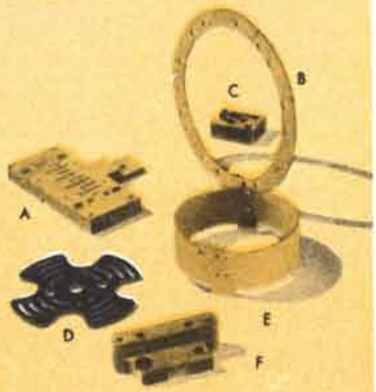

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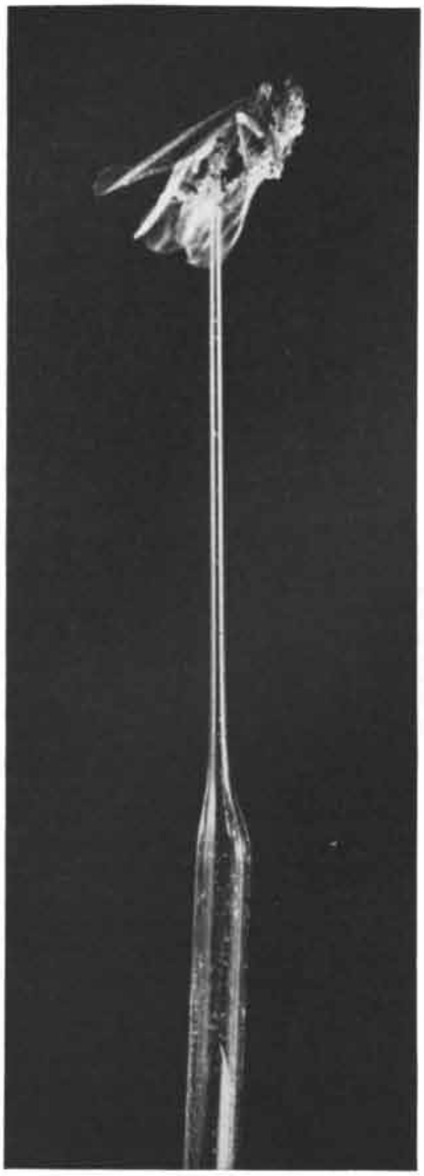
LAMINATED PLASTICS



FINE GLASS NEEDLE is used to inject the virus into a leafhopper. At the bottom is the tip of a steel hypodermic cemented into the glass.

transmission by other insects but also to the fact that in general only one group of insects will transmit a given plant virus. If a virus causes a mosaic disease, we expect the vector to be an aphid; if the disease is a true yellows type, we feel certain we should look among the leafhoppers. So far Western Europe is the only part of the world in which no plant diseases transmitted by leafhoppers have been reported, but from the general evidence it seems a fair guess that at least two diseases there are leafhopper-borne: a hop-nettle disease in England and a stone-fruit disease recently described in Switzerland.

How do viruses originate? There is no shred of evidence that they spring up spontaneously. Their geographical isolation, which is very similar to that of plant species, suggests that they are

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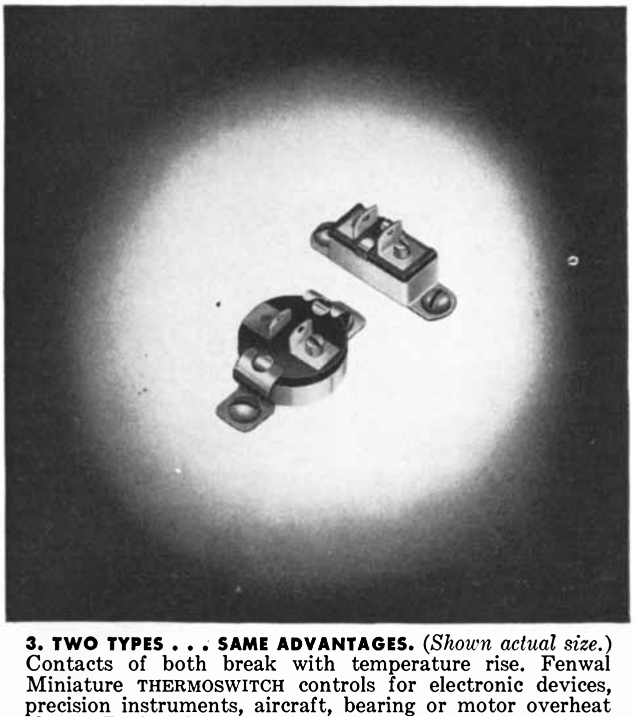

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products of evolution, like higher organisms. In the past 30 years more than 200 "new" virus diseases of crop plants have been discovered, but they may very well have come from wild plants, where their presence is not easily detected. Many such plants may harbor latent or masked viruses which show no visible symptoms until they infect new hosts. Similarly many species of insects may carry viruses which will cause more damage as they become more widespread. We are unable to estimate the number of potentially destructive viruses that remain hidden. In view of the many and often alternate hosts of viruses that have been uncovered by investigations into animal and plant diseases, it is only natural to fear that some of them, by combinations of chance and circumstance, may give rise to new virus diseases in man.

Did the yellows viruses arise first in plants or in insects? Years ago the great U. S. bacteriologist Theobald Smith observed that parasites which have lived a long time with their hosts generally reach an equilibrium in which they do not seriously damage the host. The yellows-type viruses apparently have reached such an equilibrium with the leafhoppers, which indicates a long, intimate association and makes it likely that these viruses originated as animal viruses. An adaptation permitting them to multiply in plants may possibly have come about as a further step in evolution.

IN ANY CASE, the ability of these viruses to multiply in such diversified hosts as plants and animals throws serious doubt on the once prevalent idea that viruses are formed from large molecules already present in the host. It seems highly unlikely that the same large molecule precursor would occur in two hosts so unrelated as asters and leafhoppers. Thus we have strong confirmation of the idea that viruses are living organisms. Kunkel stated the case cogently in a recent paper on the yellows viruses:

"They are the most efficient parasites that we know anything about. . . . They get themselves injected into cells by some of the finest and most efficient hypodermic syringes known to man, the proboscises of insects. . . . The viruses pass quarantine lines very simply in masked carrier hosts. If they get into trouble because some plant they try to invade is immune, they mutate to produce a virus strain that can attack this plant. . . . The plant viruses have wings to take them where they wish to go, wings that are guided in their flights by the appetites of insects. . . . When you add to all of these advantages the property of being invisible except under an electron microscope, you have what are truly superb parasites. Can anyone believe that such well-adjusted and well-equipped parasites are of recent origin or belong in that level of organization characteristic of lifeless molecules?"

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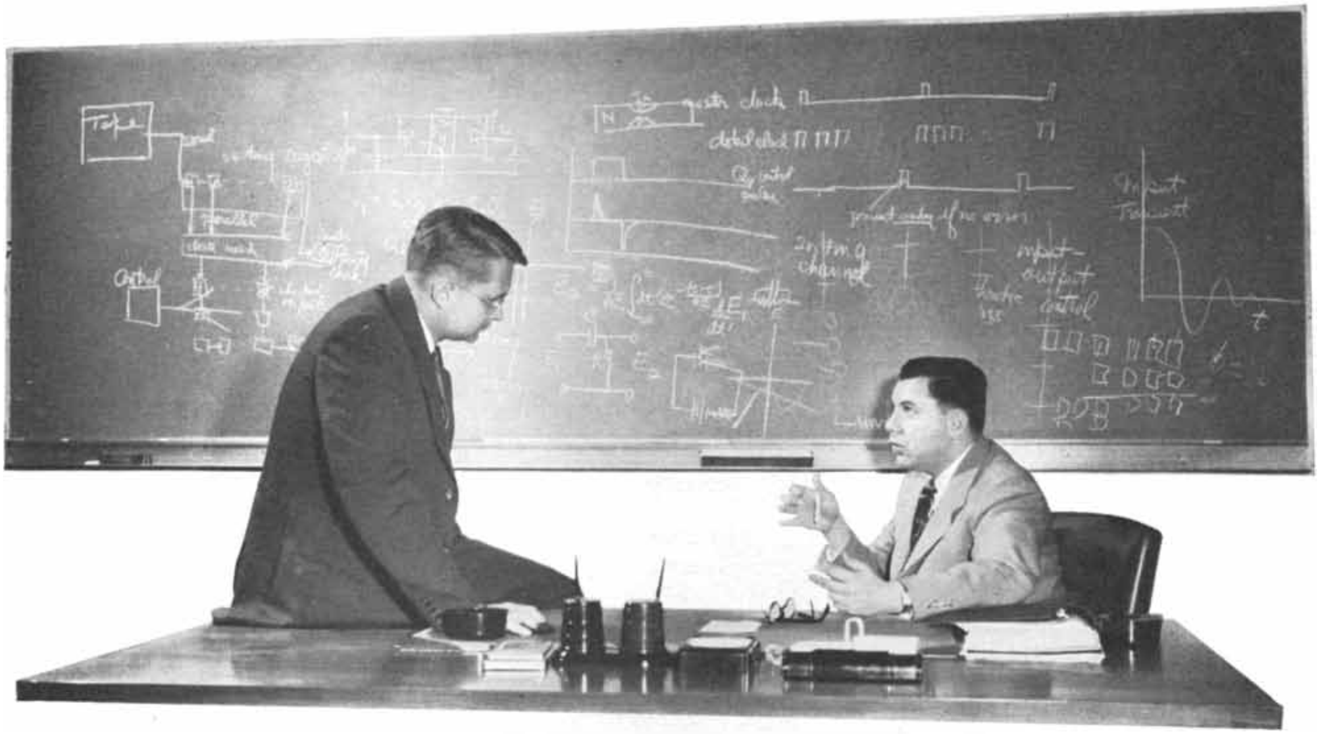
The complexity of modern air defense—extreme aircraft speeds, highly complex weapons, new combat strategies, the advanced state of today's technology—poses serious problems for the scientist and engineer.



One significant solution lies in the extensive use of airborne automatic equipment, including electronic digital computers, to augment or replace the human element in aircraft control.

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Dr. E. C. Nelson (left), Head of Computer Systems Department, and J. H. Irving, Head of Systems Planning and Analysis Department, discuss a problem in the systems planning and analysis stage.

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The Opossum

The pouched mammal is adaptable, clean, unintelligent, weighs less at birth than a paper match, gives rise to as many as 25 young in one litter and only occasionally devours its own tail

by Harold C. Reynolds

THE OPOSSUM is probably the oldest living native mammal in America. It has been living here since the time of the dinosaurs, some 80 million years ago. It has survived all its early contemporaries, including the dinosaurs. Thriving in the American environment, early marsupials overran the continent and developed into a variety of forms—at least 11 genera. Then as higher mammals appeared and the competition became more rigorous, the opossums were reduced in North America to the single genus that now survives: *Didelphis.*

Except for its larger size, the opossum of today is almost exactly the same as its earliest ancestor. Despite the millions of years that have elapsed, it has remained generalized in form and habits. This sets it apart from other living marsupials (mammals that carry their young in a pouch) of South America and Australia and from the higher mammals. As the most primitive of America's mammals it is often referred to as a "living Cretaceous fossil."

The white colonists in America found the opossum (as the Indians of Virginia had named it) unlike any creature known in the Old World. The English travel historian Samuel Purchas wrote in his *Pilgrimages* in 1616: "The Opassum hath a head like a Swine, a tayle like a Rat, as big as a Cat, and hath under her belly a bag, wherein she carrieth her young. . . . It hath the bodie of a Fox, handed and footed like a Monkey."

Today's opossum is, in fact, about the size of a house cat, weighing at most about 10 pounds. It has very primitive teeth and a primitive opposable thumb on the hind feet, somewhat like a monkey's. Its prehensile, almost hairless tail is scaly, very much like that of a rat. Generally gray, it has three other color phases—black, tan and white.

As might be expected from the size of

FEMALE OPOSSUM is photographed outside a hollow log with her young clinging to her back. Hollow logs are a favorite home of opossums. The photographs that are used to illustrate article were made by the author.

its brain—only about a fourth that of a house cat—the opossum is an extremely stupid animal. Its intelligence might better be compared with that of the reptiles, beyond which it does not seem to have evolved very far. Comparison of brain cases between the oldest known fossil and the present-day opossum indicates that it is probably no more intelligent than its earliest ancestors. It is even too stupid to make an interesting pet.

The opossum is nocturnal. It goes abroad at dusk and returns to its den at daybreak. It is a solitary animal and rarely dens with one of its own kind even in captivity. Though it is regarded as extremely primitive, the opossum has an effective body-temperature control mechanism, which maintains its body heat at about the same temperature as man's. No hibernator, it is active all winter long. In cold climates males are more active during winter nights than females, but in neither sex has body temperature been found to fluctuate more than five degrees, even in the cold of a Nebraska winter's night.

This ruggedness, plus its generalized living, feeding and breeding habits, have given the opossum great and increasing range. It is found all over the eastern half of the U. S. and recently has spread into Canada. In doing so it has returned to its original home, for the oldest fossils of opossums are in the north country. Man has also introduced opossums into California and Oregon, and they are thriving there.

OPOSSUMS live in almost all conceivable places, including the business districts of large cities. Their favored habitat, however, is a wooded area on the edge of a stream, pond or lake. They are usually found, in my experience, within 750 feet of water. For an opossum's den almost any dark, dry hole or crevice will do: a rocky cavern, a trash heap, a squirrel's or wood rat's nest, a hollow log, a niche under the floor or in an attic. It lines whatever nest it finds with large quantities of dry leaves, paper, cornhusks and other material. It picks up and carries this material in a curious manner, stuffing it into a loop on its tail. The opossum does not dig a hole of its own. If no ready-made den is available, it may build a nest on the ground or in a tree, using as a foundation the abandoned nest of some other animal. Though opossums go to great trouble in building a nest, most of them do not remain in it long; they seem to be predominantly nomadic, and few establish a permanent home.

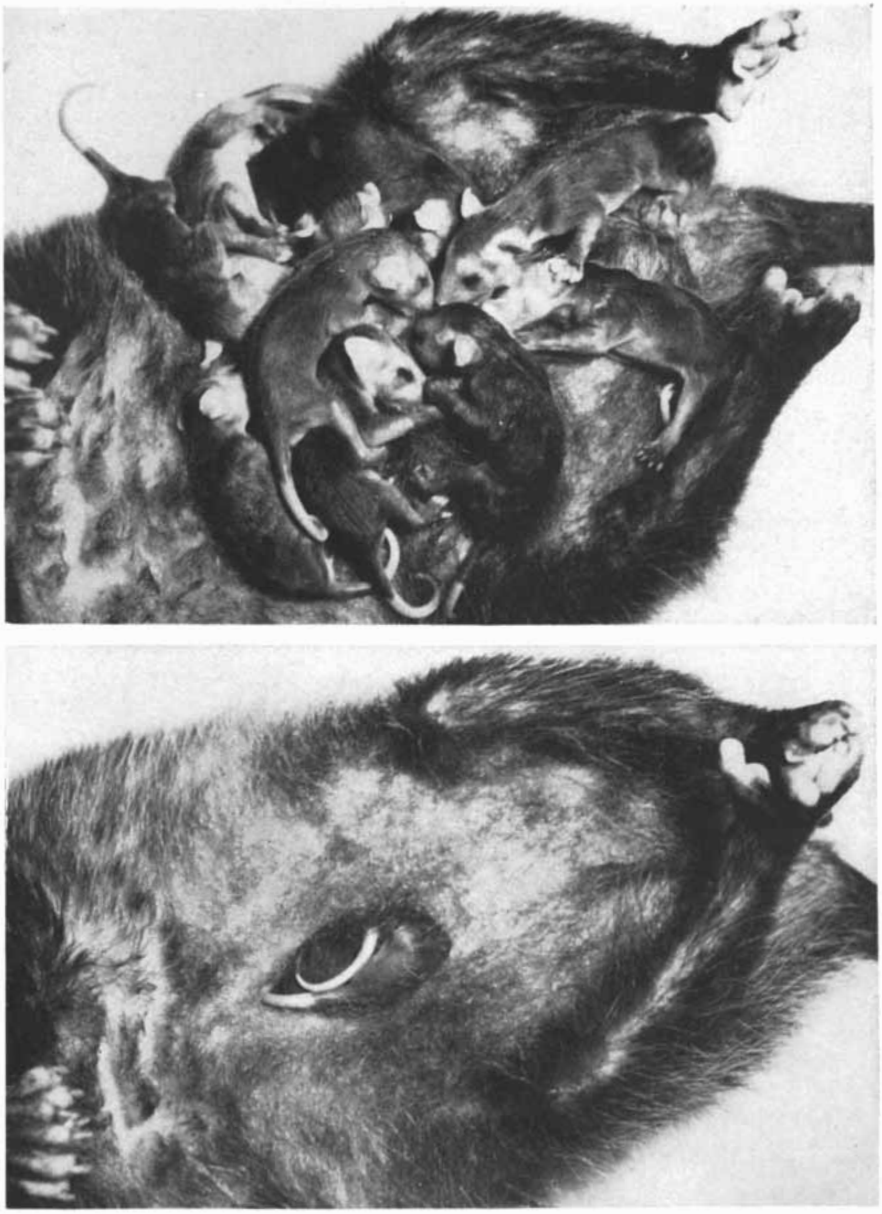
The opossum's choice of food is almost as generalized and catch-as-catch-can as its living quarters. Its chief diet is insects, but it will also eat almost any other animal material available, including snails, fish, frogs, lizards, snakes, birds and the flesh of dead mammals

YOUNG OPOSSUMS are photographed in the pouch. In the first picture they are a day old; in the second picture, 46 days old; in the third, 64 days.

such as cows, horses, cats, dogs, raccoons and skunks. Some opossums develop a taste for chicken eggs and even for the hens, but this is rare. They may also eat fruits, berries and, in winter, corn and acorns. The opossum has the reputation of being highly cannibalistic, but this is false. Although they occasionally eat one another or even chew off their own tails, they do so only when they are starving or have a dietary deficiency. I once raised 74 opossums together in a pen 14 feet square with no occurrence of cannibalism or tail chewing whatsoever.

THE opossum's most distinctive feature is its method of reproduction, the most primitive found among American mammals. Breeding begins in January or February, the time varying with the latitude. The breeding season lasts from eight to nine months, during which most females rear two litters. The female is in fertile mating condition for a period of only about 12 hours at monthly intervals. The male woos her with a peculiar clicking sound. If he smells another male nearby, he may do a fighting dance, twisting and kicking his hind feet while dragging his tail on the ground. After the mating the male and female go their separate ways.

The gestation period in opossums is very short. The embryos are not equipped with the highly developed placenta and umbilical cord for transfer of nutrients and wastes found in higher mammals; they complete their natal development in the mother's exterior pouch. According to my observations the gestation period is 13 days, plus or minus six hours. Contrary to an old mistaken idea which still appears in some zoology texts,



TEN OPOSSUMS 60 days old are shown outside their mother's pouch in the top photograph. In the bottom photograph they are all inside the pouch.

OPOSSUM'S NEST was photographed by the author in Missouri. Suspended from the branches of a tree, it was four and a half feet in length.

the mother does not place the newborn young in her pouch. They crawl there by themselves. Inasmuch as opossum birth is an unusual phenomenon, it is worth some detailed description. I have closely observed the birth of four litters.

After labor pains begin, the mother opossum folds her ears against her head, draws her tail forward between her legs and sits in this posture, balancing herself on one extended foreleg and her spread hind legs. Within two and a half to 12 minutes she gives birth to the entire litter, varying from four to as many as 25 young. A newborn opossum is tiny—only about half an inch in length and about the weight of a paper match. If a human baby at birth were as small in proportion to its mother, it would have about the weight of a nickel.

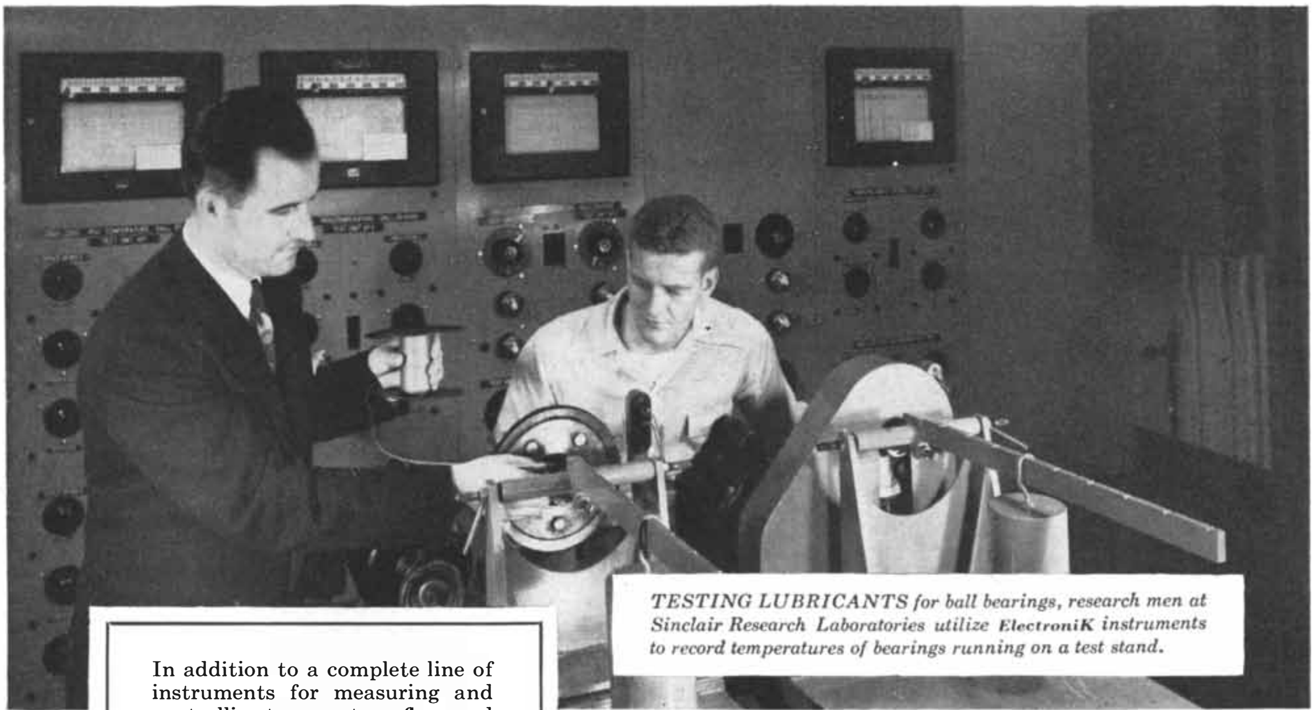
Blind, hairless, without a normally functioning mouth, tail or hind legs, the baby opossum at birth has a well-developed pair of forefeet, equipped with sharp claws for the important function of pulling itself up into the mother's pouch. The emerging young swing their forelimbs like swimmers, grabbing at the first thing they touch. For the fortunate ones this is the mother's hair. Their forefeet are so small that they can grasp only a few hairs at a time. Pulling themselves hand over hand, they climb rapidly up the mother's belly to the pouch. Because of the mother's sitting position, they have only a short distance to travel—only four or five centimeters, about three or four times their own length, from vulva to pouch. Nonetheless, the speed with which the blind infants make the journey is remarkable. I timed one with a stop watch: it made the trip in 16.5 seconds. Sometimes two of the newborn opossums advance side by side, almost as if they were racing to the pouch.

But the start of the journey is a critical point. Some of the newborn are entangled in the fetal membranes and fail to reach the pouch. When several are born simultaneously—and they may emerge in groups of as many as six or eight at a time—they get in one another's way and attempt to grab each other instead of the mother's hair. In one case all of six young emerging together fell to the ground. Of the 57 young born to the four females I observed, only 34, or 60 per cent, reached the pouch. Those that failed to do so were lost.

The mother apparently gives the climbers no help. Sometimes she licks them as they climb, but this seems to slow them down rather than help them. Occasionally she may lick the ones that have fallen on the floor, but she makes no attempt to pick them up.

Even after the young have reached the pouch, they are still in peril. Of the 13 nipples that most female opossums possess, apparently only seven to ten are usually functional. A nipple can support only a single infant. The reason is that the nipple soon becomes enlarged in the mouth, and, like a ball in a socket, it "buttons" the infant to the mother. There the young opossum remains for about 40 days, and no other individual can get to the nipple to take a turn at nursing. Hence if there are more young than

How many research hours in a day?



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functional nipples in the pouch, the surplus must perish. In the birth of 25 that I observed, eight became attached to nipples even before the entire litter had been born. Of the 19 that reached the pouch, 11 never succeeded in locating nipples. One of these survived for 14 hours after birth.

THE FEEDING young grow rapidly, but it is two months before they attain a stage of development comparable to that of most higher mammals at time of birth. The young opossums cannot even open their mouths properly until they are at least eight weeks old, and the eyes of some do not open until they are more than 10 weeks old. After their eyes and mouths have opened, they may lie outside the pouch if the den is warm enough, but they crawl back into the pouch at night before the mother leaves the den to feed. A mother that carries a large litter can hardly walk now. She must tolerate this, however, until the young are about 12 weeks old, because their delayed development of body-temperature control would result in chilling if they were left alone in the den.

After 12 weeks the young nurse from outside the pouch. They stay at home in the den at night unless the mother signals to them to come with her on her nocturnal forays. If she makes a clicking sound, they go along, riding on her back or running beside her. The clicking is a behavior pattern which apparently holds the family together.

After weaning, which takes place at about 14 to 15 weeks, young opossums may remain with their mothers for some time, seemingly of their own volition. They must fend for themselves, however. I have never seen a mother bring her young food or show them where to get it. On the contrary, females often take food away from their young.

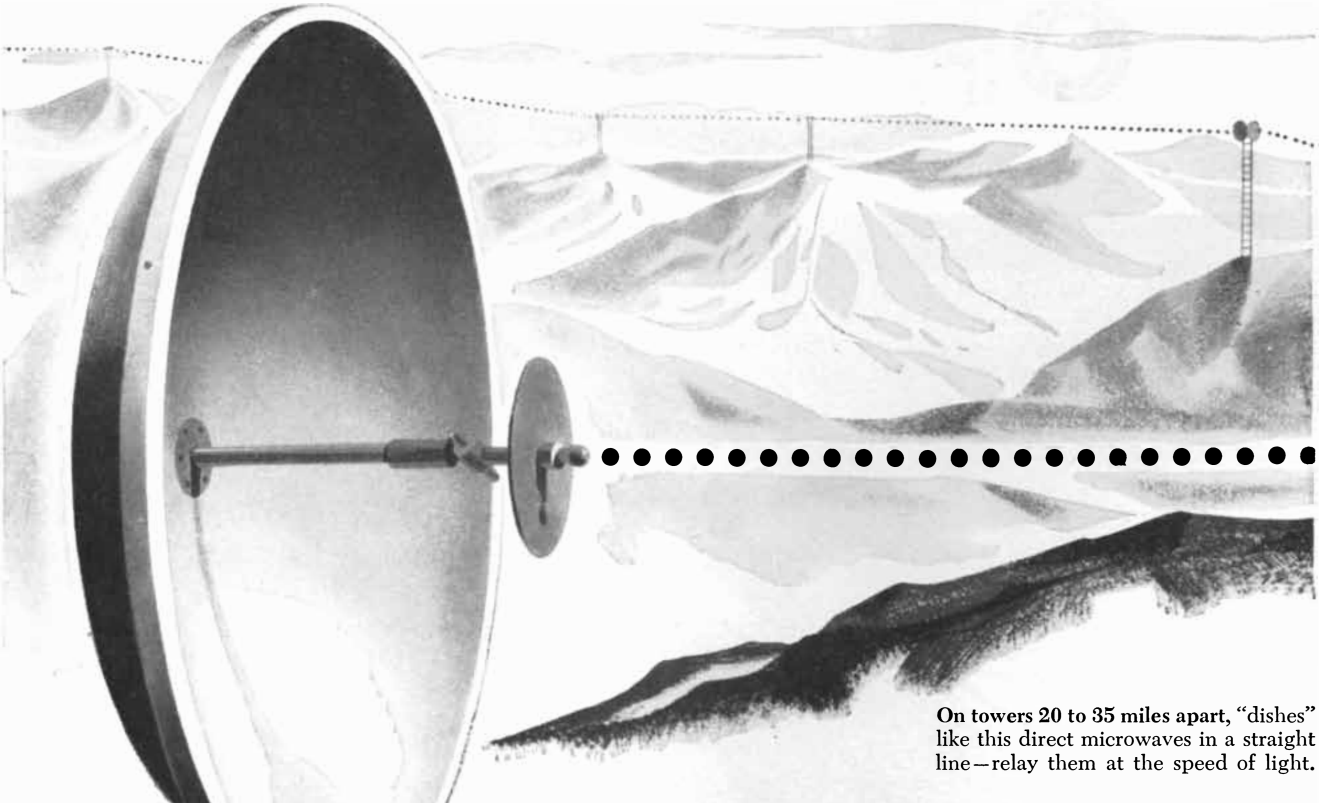
Unlike other young mammals, young opossums behave like miniature adults from the time they are able to walk. Among some 200 opossums I have raised I have never seen anything that might be interpreted as play. They are all business from the start. At weaning the young are about the size of large laboratory rats, and thenceforth show a variable rate of growth. Females may begin bearing young three months after they themselves are weaned, but males are not sexually mature until about eight months of age.

NO OTHER mammal has inspired more folklore (most of it erroneous) than the 'possum. Contrary to popular belief, opossums do not sleep or feed hanging by their tails from limbs of trees, nor do they swing from branch to branch by the tail. They do use the tail while climbing to catch a branch momentarily if they slip. Sketches of young opossums and even mounted museum specimens often show them with their tails wrapped around their mother's, but they have never been seen in that attitude in nature. The notion that the young are born through the mother's nose or grow out of her nipples is sheer fable. Opossums are accounted to be extremely dirty and smelly animals, but actually under favorable conditions they keep themselves as clean as a house cat. At one time I kept 125 opossums just outside the windows of a home-economics cooking laboratory with no complaints. While opossums do have a distinctive odor, it is no more pronounced than that of dogs or most other mammals.

The question often arises as to why most marsupials have become extinct in competition with placental mammals, and why the opossum, which has remained practically unchanged down the ages, has been so successful. The usual answer to the first part of the question is that the marsupial type of reproduction is inferior to the placental form. Actually there is no proof that marsupial reproduction, as illustrated by the opossum, is inferior so far as survival value goes. Although the young are born at a premature stage and many are lost in migration to the pouch, the survival rate of an average of seven to nine per litter is nonetheless high. Moreover, the pouch acts as an incubator, its flap has the ability to stretch and cover the young as they grow, and it offers mechanical protection, even allowing the mother to swim without wetting the young. The opossum's early breeding age and its ability to rear two litters a year give it a high reproduction rate.

The opossum has been favored by other gifts for survival. It can neither run fast nor fight well, nor is it an agile climber, but its habit of feigning death ("playing 'possum") when attacked protects it. Moreover, its flesh apparently is unpalatable to predators. I have yet to find a single animal that consistently feeds on opossums. A common statement is that not even a starving dog will eat one.

In my opinion the most important factor contributing to the opossum's survival is the fact that it has remained generalized. It has not become specialized in choice of habitat, dens, foods or in other behavior patterns. As a result the opossum has been able to withstand any competition it has encountered with other animals, including man. Had it become specialized for a particular type of habitat, den or food it probably would have been forced into competition with some more intelligent placental mammal that had specialized in the same way. By remaining generalized it has avoided any serious competition. Other North American marsupials may have become specialized and therefore lost out in the race. But the opossum, though stupid, has survived and probably will continue to do so.



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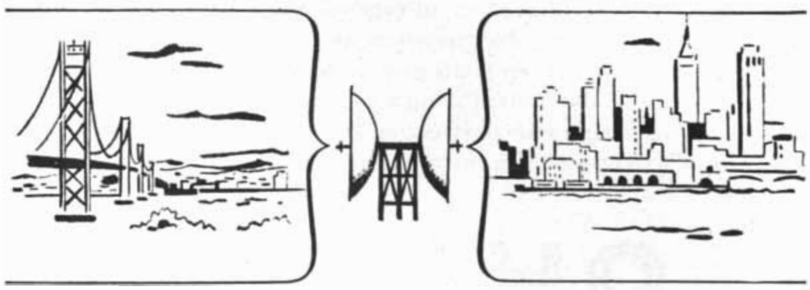

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QUICKSAND

A brief account of where it occurs and how to get out of it. The principal point to remember when mired: lie down on your back so as to float atop the sand as you would on the water

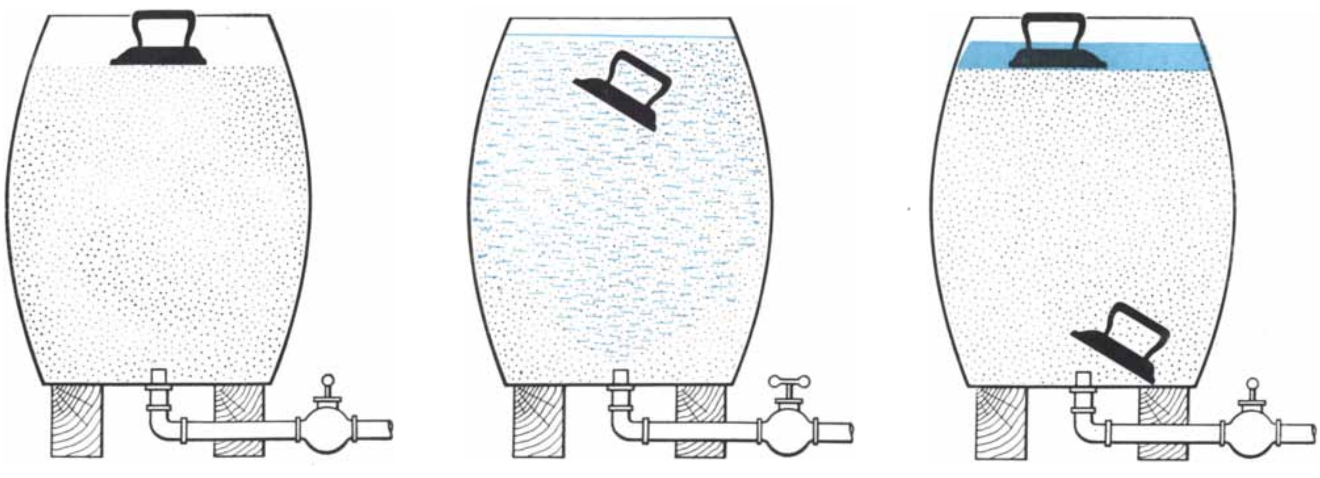
by Gerard H. Matthes

QUICKSAND is not a word that one hears often nowadays. The malevolent phenomenon figured prominently in the landscapes of 19th-century romances (where it was frequently a convenience to authors needing to dispose of unwanted characters) and in the pioneering of the U. S. West. In our day of the automobile and paved roads few people ever encounter it. Yet quicksand is as prevalent as it ever was and may be the more dangerous for being less familiar. As a scientific study it offers many points of interest, not the least of which is the correction of some of the romantic misconceptions about it.

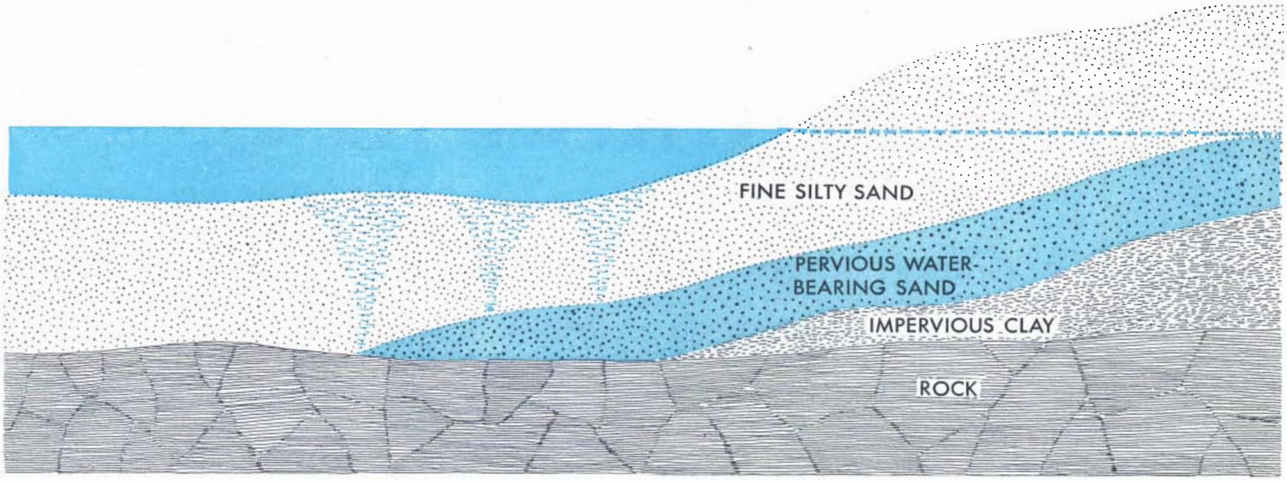
I shall discuss here the most common form of quicksand, that found along the shores and in the beds of rivers. It is simply sand supersaturated with water under pressure from beneath, as from a spring. A model of it can be made in a tub fitted with a water pipe leading into the bottom of the tub. The water flowing into the sand permeates the spaces between the sand grains and, by separating them slightly, makes the sand's bulk swell. When the water pressure from below equals, or a little more than equals, the weight of the sand, the sand becomes "quick." The grains, being suspended and frictionless, will not support a weight, and any object placed on the surface at once begins to sink. How fast it sinks will depend on its weight and the extent of its surface area, as well as on the kind of sand.

It was long believed that only sand composed of round, small, uniform grains could form quicksand, but this is not so. Any kind of sand, even with coarse, angular grains, can be quick when it is saturated with water under pressure from below. Sands composed of fine, rounded grains do, however, become quick more readily than coarser types, because the spaces between the grains are more uniform and slower to lose water to the surrounding mass of firm sand.

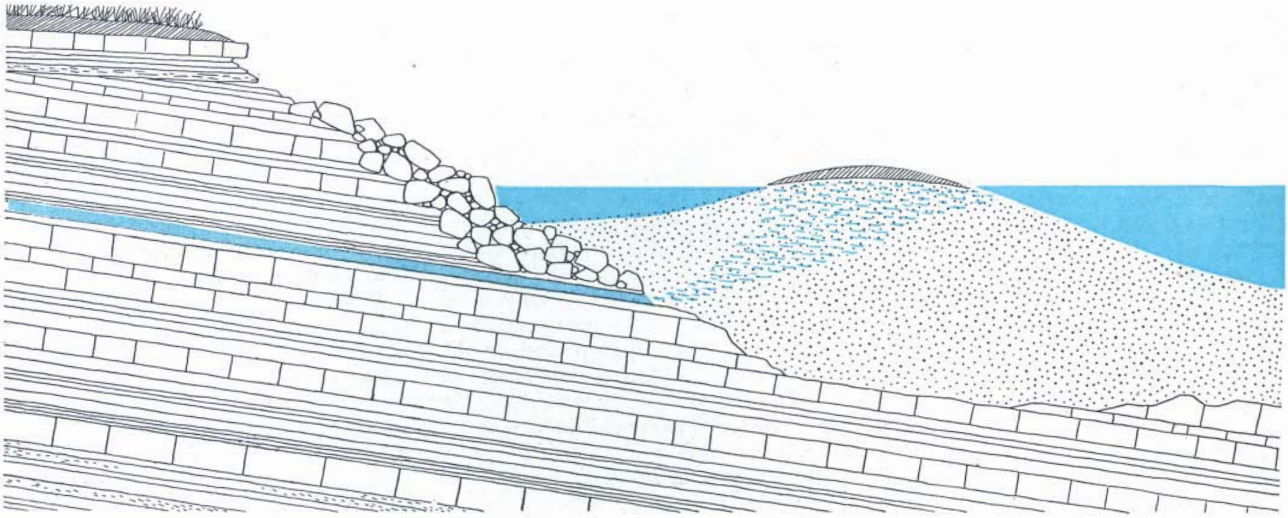
Quicksand is nearly always confined to a relatively small area where the underlying spring maintains pressure. In a sandy river bed the water drains away from the quicksand area through the surrounding sand. Extended quicksand areas are found only where spring water, under weak pressure, issues from a fissure in the side of a cliff extending for



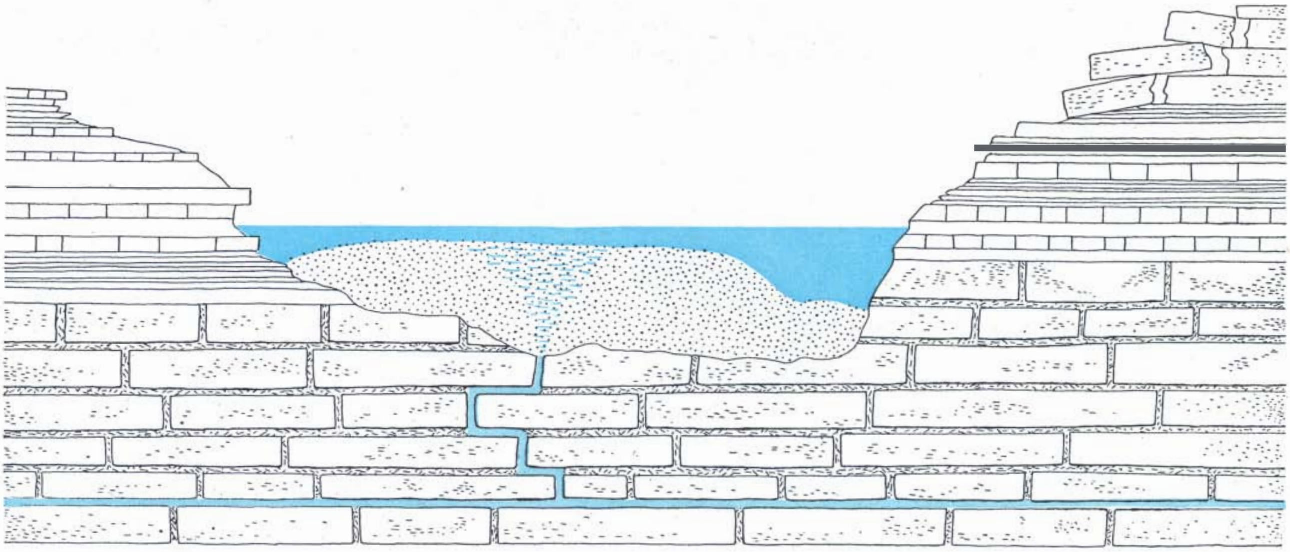
QUICKSAND EXPERIMENT shows how ordinary sand becomes quicksand. A barrel full of sand is fitted at the bottom with a water inlet. When the water is off, the flatiron rests securely atop the sand (*left*). When the water is turned on and a weak pressure maintained, the sand swells and its grains separate; the flatiron sinks (*center*). When the water is turned off again, the sand settles and squeezes the water to the surface; though it is wet and slightly larger in volume than before, it readily supports a second flatiron (*right*).



Quicksand is formed by spring water issuing from a pervious stratum



Quicksand is formed by spring water issuing from a rock stratum. The sun bakes a thin crust on the sand



Quicksand is formed in the middle of a river bed by artesian flow from water-bearing rock below some distance parallel with the stream. Quicksand cannot exist where the water inflow is large in volume or under high pressure. In such cases the bed sand, instead of becoming "quick," is washed away and deep holes are formed in both the bed and the bank.

Quicksand is uncommon in flat country, where there is too little gradient to produce springs. It is also rare in rivers that run in gorges or canyons through hilly country. Deep cuts of that sort permit the ground water, which might otherwise collect in the rocks and build up spring pressure, to drain directly into the stream. Quicksand is likely to occur in hilly country, especially where the rocks are limestones and dolomites. These formations harbor caverns and channels and are notorious producers of springs. Rivers cut through any rocks are apt to contain springs in their banks and beds. Quicksand will form along their courses in three situations: above water level along the shores of streams of all sizes; under water, usually near a bank but occasionally in midstream; occasionally in the bed of an apparently dry river. The diagrams on the opposite page show these typical quicksand formations.

HOW DOES one detect quicksand? It cannot be done by the eye alone, for a sand which is to all appearances perfectly firm may suddenly collapse and trap anyone who ventures out on it. This is particularly true when the top sand has become dry and crusted in the sun. In such cases a fast walker can sometimes get across, but anyone following in his footsteps is almost certain to be caught. The only way to be sure is to test the sand before walking on it. Anyone who walks along the edge of a sandy lake or along a sandy river course where the sand may be quick should carry a pole or long stick (a cane is useless) for test probing. This precaution is especially important when a stream is to be forded, for one almost instinctively chooses a spot where a pleasantly smooth stretch of sand interrupts an otherwise rocky or muddy channel. Repeated stamping with the feet will help to determine the limits of the danger area, though this method may cause you to reject a route which is in fact safe. Any thoroughly wet sand, especially one composed of small, round grains, will quake a little when sufficiently stamped upon, but it may be perfectly fordable. It is not easy to distinguish such a sand from the quick variety. By far the most satisfactory method of detection, particularly when a more or less permanent path is being mapped, is to drive long stakes into the sand with a maul. Pronounced quaking will identify it as quickened.

Certain clues are a help in doubtful cases. If there is clay in the sand, the footing will be safe. A clayey sand may mire a vehicle but can be crossed with impunity by a pedestrian. Swiftly running water also is evidence that a stream bottom is sound. Here, however, the traveler may encounter a "near quicksand." When a layer of coarse sand overlies a layer of fine and thoroughly saturated silt, the spaces between the grains of sand sometimes fill with the silt and form a crust. Anyone who walks on it will break through the crust and through the silt beneath. Although the sensation is alarming, the drop to firm bottom is rarely more than a foot, usually a matter of inches.

In true quicksand a trapped pedestrian soon sinks to the depth of his knees and will sink further if he stands still or struggles wildly. He must act promptly and with purpose. He should at once lie on his back and stretch out his arms. If a companion is at hand to help him out, his situation is not usually serious. Contrary to popular notion, quicksand does not suck objects down, and even at its worst it will support a great deal more weight than water alone.

Rescuers may build a platform on the sand from which to extricate the victim. For this almost any material at hand will do: boards, fence rails, brush, branches, a large piece of canvas or a ladder. In arid regions sagebrush offers good support because of its sturdy branch system. The mired person must be pulled out slowly and gently, for the sand holds its prey tightly and he may be badly injured.

A SOLITARY traveler who stumbles into quicksand is in a more awkward situation, but even his case is not desperate if he knows what to do. Attempts to force a way to shore will prove worse than useless; standing still and yelling will be fatal unless help arrives soon. The trapped man's first move must be to drop his pole behind him, if he is foresighted enough to have one, and fall back upon it, meanwhile stretching his arms out at right angles to his body. In this position he could float in water and he will certainly float on sand if he gets rid of any heavy object he may be carrying. He may now call out for help. If there is no prospect of help, the victim may begin to rescue himself. The first step in this operation is to get the pole at right angles to the body beneath the shoulders and then work it down until it is supporting the hips. It is difficult work, but once done the individual is in a position to pull his legs out of the mire, one at a time. He should do this slowly and with frequent rests. Once his feet are out, he looks about and selects the shortest route to solid ground. He then begins rolling toward his goal. Rolling is the easiest—and indeed the only—way of getting off the soft area. It can be done in short stages, but rests must be taken on

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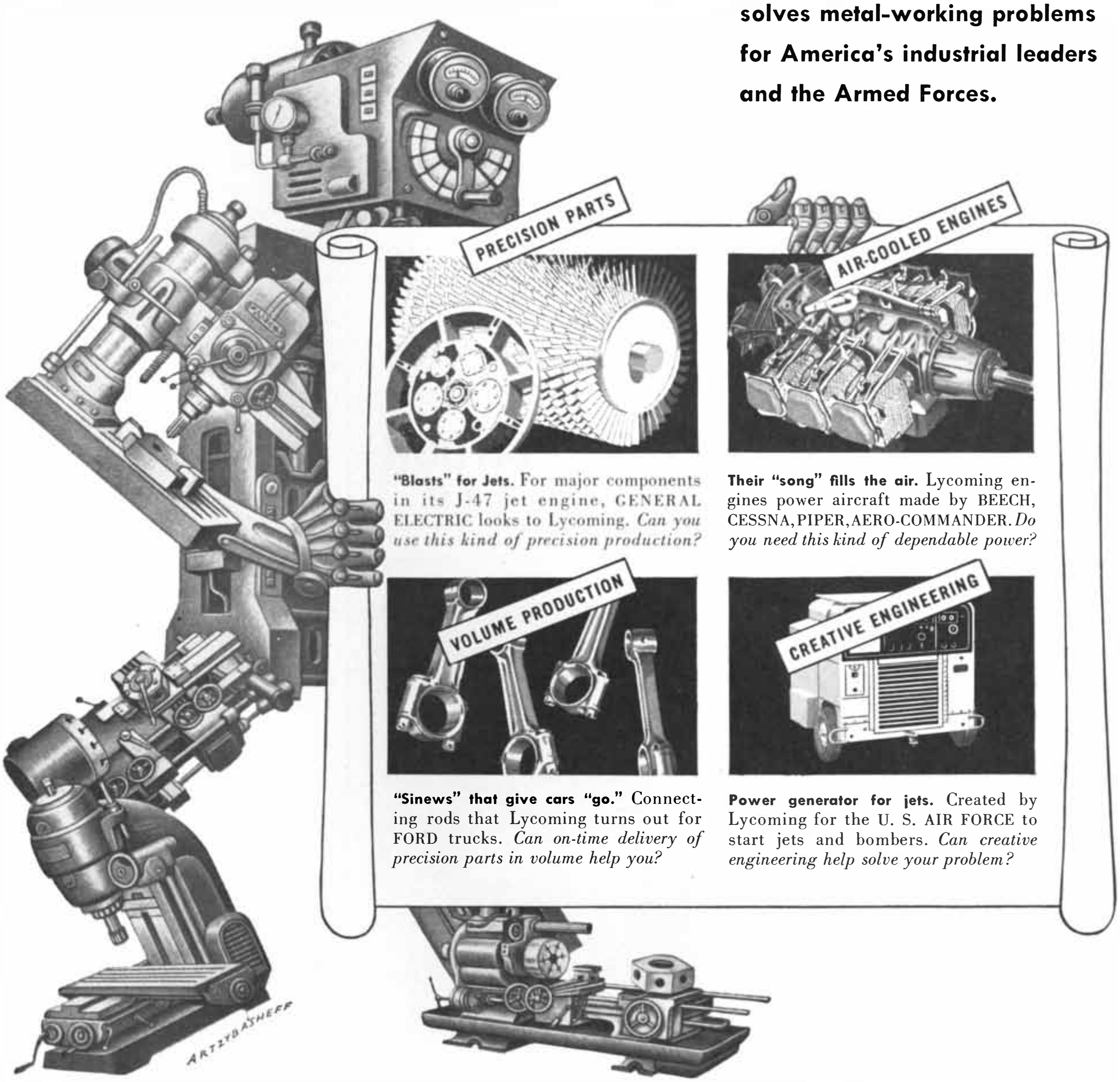

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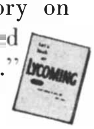

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AIR-COOLED ENGINES FOR AIRCRAFT AND INDUSTRIAL USES • PRECISION-AND-VOLUME MACHINE PARTS • GRAY-IRON CASTINGS • STEEL-PLATE FABRICATION the back with arms outstretched or he will begin to sink again. The pole is pulled along and used for support.

When the quicksand is under water, one can usually swim to safety, provided the water is deep enough for swimming. It is not too hard to pull the legs out of the quicksand, because the water helps to loosen it. But when the water is less than a foot deep, the victim is in virtually the same position as if the quicksand were at the surface.

Animals caught in quicksand often do not get out by themselves. A dog generally succeeds, but it must be encouraged to work hard and not wait for its master's help. A horse will usually fight its way to safety, making frantic, rabbit-like jumps. The rider or driver must know where to guide it, however, for it can soon become exhausted and then rapidly sink in the sand. A loaded or harnessed mule will lie down on its belly with its feet tucked under as soon as the ground gives beneath it. In that position the animal will not sink. The mule's hooves are so small and narrow that it cannot struggle if it is at all weighted down. Once freed of any equipment, it can usually be urged to get itself out of the morass. It is a good idea to station a horse, preferably a mare, on the nearest firm land as a guide and further inducement.

Cattle invariably panic in quicksand. The only sound way of rescuing them is to tie a rope around their horns or necks and pull them out, very gradually, with a steady team or a tractor. Unlike horses or mules, which seem grateful for assistance, cattle are apt to charge their rescuers as soon as they emerge. It is wise to have a knife handy for cutting the tow rope. When animals are found sunk to their necks and with their eyes bulging from the pressure on their bodies, they are best put out of their misery with a bullet. They cannot be saved, and the death that awaits them is agonizing.

THROUGHOUT the West there is a dangerous relative of quicksand known as the alkali bog. It is formed by spring-water seeps containing salts leached from a soil rich in alkaline salts. Such bogs are far more treacherous than quicksand because they are apt to occur in unexpected places—on a hillside as well as in or near a river—and because they contain clay or colloidal matter which gives them the consistency of soft soap.

Most alkali bogs can be recognized by the white efflorescence of salts along their edges or over their surface. A man or animal mired in an alkali bog sinks more rapidly than in quicksand, and quick work is required to get out of one. There are bogs in the West which are littered with the bones of animals that did not move promptly enough.

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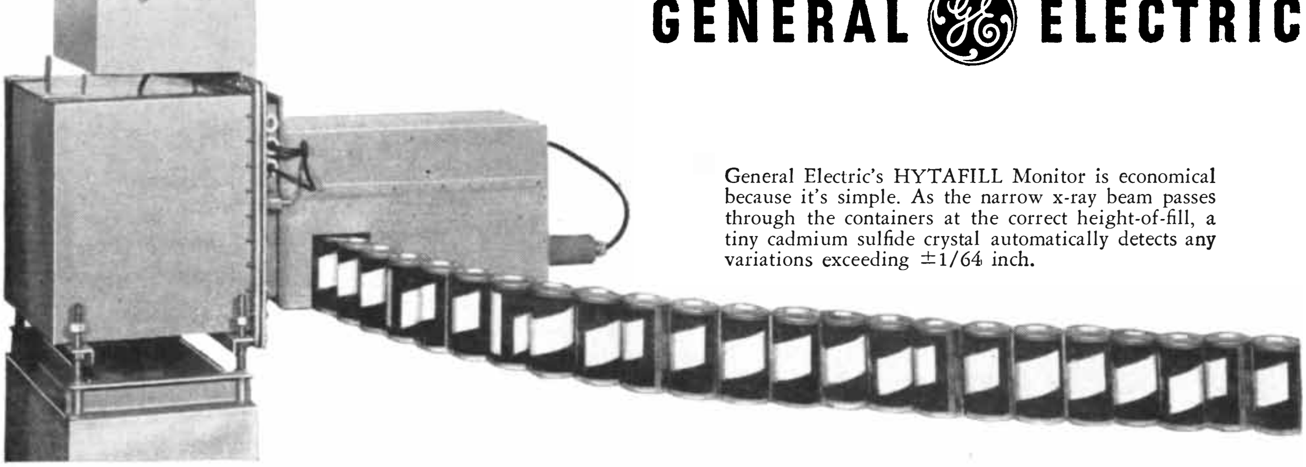

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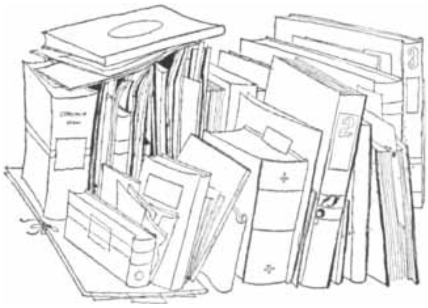

BOOKS

The fabulous life of Jerome Cardan, pioneer in the study of probability

by James R. Newman

CARDANO, THE GAMBLING SCHOLAR, by Oystein Ore. Princeton University Press ($4.00).

THE LIFE of Jerome Cardan (Gerolamo Cardano) of Milan, physician, mathematician, astrologer, philosopher, gambler, is a melodrama too improbable even for the Italian Renaissance. His fortunes, from infancy to old age, fluctuated wildly, so that he was alternately poverty stricken and held in wretched contempt, or rich, influential and fervently admired. Untiring in his quest for knowledge, immensely industrious, restless in imagination and creativity, he was an incredibly prolific writer: his works fill 7,000 pages of folio, and no one knows how much more was lost. Cardan was an ambitious, dishonest, hot-tempered, quarrelsome, conceited and humorless man, but capable of generosity, kindliness and merciless self-revelation. During much of his life he suffered from ill health, physical and mental. His parents were an abominable pair; his favorite son was executed for murder; his other son was a scoundrel who managed to escape the gallows but brought Cardan nothing but unhappiness and disgrace. In his old age Cardan was stripped of his honors and high position and imprisoned for heresy; nevertheless he ended his days peacefully as a pensioner of the Pope. He was a genius, a fool and a charlatan who "embraced and amplified," as the English literary historian Henry Morley said, all the superstition of his age, and all its learning.

It is understandable that Cardan has not lacked biographers, yet none has succeeded in giving both a convincing portrait of the man and a dependable appraisal of his scientific achievements. Morley published in 1854 a biography of Cardan in the spacious two-volume Victorian tradition: moralistic but not unsympathetic, rich in details and background, amply stocked with quotations, elevated and flowing in style. It provides excellent reading, but it does not make its hero wholly believable nor is it the book to consult for an informed assessment of his labors in science. The less interesting but in some respects more disinterested appraisal written by W. G. Waters in 1898 also is unsatisfactory as regards Cardan's mathematical discoveries. The book I review here, by Oystein Ore of Yale University, is limited in scope, but within the area of its primary concern it is a first-rate contribution to the history of science.

Ore's account of Cardan's life is scarcely more than a pedestrian recital of the unpedestrian facts. His long analysis of Cardan's quarrel with the Italian mathematician Niccolò Tartaglia adds little to what has already been said on that subject. But the great merit of his book is in explaining Cardan's remarkable researches in probability. Here for the first time a mathematician has taken the trouble to disentangle and elucidate Cardan's obscure text on games of chance, a poorly printed work of 15 folio pages called *Liber de Ludo Aleae* (The Book on Games of Chance). Other biographers have scolded Cardan for being a gambler but have shown not the slightest comprehension of the fruits of his devotion to this naughty practice. Historians of mathematics also have failed to appreciate the full extent of his achievement in this sphere. Isaac Todhunter's *History of the Mathematical Theory of Probability* acknowledged Cardan's solution of certain simple problems of dice games but overlooked the principal insights of the *Liber de Ludo*. Moritz Cantor in his monumental *Geschichte der Mathematik* pointed out that Cardan was the first to answer correctly several basic questions in probability; but the examples Cantor gave were meager and unenlightening. Ore, with the help of S. H. Gould of Purdue University, a classical scholar trained in mathematics, has deciphered Cardan's little book and analyzed its contributions to the theory of probability—that

A contemporary picture of Cardan

great branch of mathematics, the "very guide of life," which owes its origins to the gaming table. Ore shows convincingly that Cardan's treatise formulated a number of fundamental probability principles, more than a century before Pascal and Fermat are supposed to have developed the theory of probability in their famous correspondence about the wagering problems of the French rake the Chevalier de Méré. Cardan's work gave the correct chances on dice, the so-called power law for the repetition of events (combined probabilities), a suggestion of the law of large numbers and several other important probability concepts. Ore's work in interpreting this first text on probability is of capital importance in the history of mathematics.

Cardan was born in 1501 in Pavia. His father was Fazio Cardano, a doctor in law and medicine and a geometrician. His mother was a widow, Chiara Michena, with three earlier children—a fat, dumpy woman with an ugly temper whose sole attraction for Fazio seems to have been that she was much younger than he. Fazio saw no reason to marry her, before or after Jerome's birth, but finally resigned himself to doing so shortly before his death at 80. Jerome's early years were filled with sickness and misery. His mother (whom he sentimentalized in his autobiography) spared no effort to make him feel unwanted, to remind him that he was an abiding source of shame and sorrow. When she grew tired of tormenting the child with words, she beat him—a sport in which her sister and Fazio were delighted to join. When Cardan became old enough to carry his father's bag through the streets of Milan, it was decided to give up beating him, to avoid any injury that might make it necessary to hire a servant to carry the bag.

At the age of 19 Jerome was permitted to enter the University of Pavia to study medicine. Fazio agreed to this step reluctantly only after Chiara, for once unaccountably supporting her son, raised a hideous commotion. Cardan completed his medical education at Padua and then applied for admission to the College of Physicians in Milan. When he was turned down—partly because he was a bastard, partly because his aggressiveness and other disagreeable traits had already gained him a crop of enemies—he settled as a country doctor in the little village of Sacco, a few miles outside Padua. It was a quiet, pleasant existence. "I gambled, played musical instruments, took walks, was of good cheer and studied only rarely. I had no pains, no fears . . . it was the springtime of my life." At 30 Cardan married Lucia Bandarini, the daughter of an innkeeper who was captain of the local Venetian militia. It was a reasonably happy union, although from his 20th to his 30th years Cardan had been impotent and convinced that he would remain so. Considering the character of the children he produced, continued impotence would not have been an unmitigated misfortune.

His writings during this period included an essay on palm-reading, a book called *The Method of Healing*, another on the plague, and two treatises, on "spittle" and on venereal diseases, which were destroyed, according to Morley's decorous euphemism, by "the misdeed of a cat." "*Hi libri corrupti sunt,*" wrote Cardan, "*urina felis.*"

Poverty forced Cardan to abandon country-doctoring and seek his fortune in Milan. At first matters went so badly that he and his family had to find shelter in a poorhouse; then suddenly his luck changed. He was appointed to a lectureship in mathematics once held by his father; he published several books, among them *The Practice of Arithmetic and Simple Mensuration* and *On the Bad Practice of Medicine in Common Use*; finally, with the help of prominent sponsors, he was elected a member of the College of Physicians.

Within a few years Cardan became the rector of the physicians' guild and the most prominent practitioner in Milan. "Before he was 50 years old he was second only to Vesalius among European physicians and was overwhelmed with flattering and magnificent offers for his services." Since a court physician was apt to keep his head only so long as the royal patient kept his health, Cardan generally stayed away from the highest places. But he could not resist a financially tempting call to go to Edinburgh to treat John Hamilton, the Archbishop of Scotland, who suffered from "suffocating attacks of asthma." This turned out to be a most profitable errand of mercy. After observing his patient carefully for a month, Cardan prescribed a sensible regimen of hygiene and the usual farrago of potions and ointments. In addition, he specifically recommended that the Archbishop substitute silk for feather mattresses and linen for leather pillow cases. The entire course of treatment would have made a modern allergist happy, and, more important, it actually made the Archbishop well. His health improved rapidly and in gratitude he lavished on Cardan an enormous fee of 1,800 gold crowns and various gifts.

On his journeys to and from Edinburgh Cardan passed through Lyons, Paris, London, Antwerp, Cologne and Strasbourg. In each of these cities the learned and the noble accorded him a festive reception. Henry II of France desired that he should "kiss hands" and accept court service, with a considerable pension. The 15-year-old Edward VI of England—whom Cardan described as "a marvelous boy"—requested his presence and conversed with him in polished Latin about various abstruse matters such as the motions of the stars and the causes of the rainbow. Edward also asked Cardan to calculate his horoscope. The great man was pleased to comply and prophesied, in some detail, a fairly long and sickly life for the delicate young monarch, including the specific prediction that at the age of 55 years, 3 months and 17 days "various diseases would fall to his lot." Edward was inconsiderate enough to die the following year, aged 16. Cardan was thereupon moved to write a dissertation wherein he explained (a) that he had been compelled to cast the horoscope against his better judgment, (b) that he had done so hastily and had therefore miscalculated, (c) that he had suspected the King had not long to live, (d) that the King had been poisoned.

Cardan was now at the summit of his fame as a physician, philosopher, astrologer and writer. His practice was prospering; he was in reasonably good health, and his favorite son, Giambatista, was completing his education for a medical degree. His books continued to pour from the presses at an incredible rate. In a single year, 1543, he published 53 separate works; altogether, as he himself reckoned, he published 131 books and left behind him in manuscript 111. He wrote on mathematics, astronomy, astrology, metoposcopy, physics, horoscopy, chess, gambling, the immortality of the soul, consolation, the uses of adversity, marvelous cures, dialectics, death, poisons, seven-month parturition, air, water, nourishment, dreams, urine, teeth, the plague, Galen, Hippocrates, Socrates, Nero, the Blessed Virgin, wisdom, morals and music. This list is representative, not inclusive. His popular scientific and philosophical books were widely read and many times reprinted, sometimes pirated by printers. Cardan's book on consolation was well known in England as the source of Hamlet's famous remarks on sleep and death.

The decline in Cardan's fortunes began with Giambatista's marriage to a young trollop named Brandonia Serono in December, 1557. The night before the messenger arrived with the bad news, Cardan had a premonition of evil: the house trembled "so that it was noticed even by the servants." He would not have the young couple in his house, but supported them financially. From the beginning Giambatista quarreled violently with his wife and her family. They exploited him shamelessly, and Brandonia bore three children in rapid succession, none of whom, she openly boasted, was genetically linked to her husband. Giambatista decided to settle the score by feeding his wife and several of her relatives a cake generously sprinkled with arsenic. The in-laws survived but Brandonia did not; nor did Giambatista. He was executed, after torture and the striking off of his left hand, on April 10, 1560.

Cardan never recovered from this

ghastly happening. "He reproached himself, wrote elegies to his son, brooded and relived the tragic events incessantly." The disgrace led him to relinquish his professorship at Milan, but in 1562 he yielded to his friends and took the chair in medicine at Bologna. Unfortunately he was accompanied by his son Aldo, who was, if anything, a scurvier specimen than his departed brother. Aldo gambled for outrageous stakes and managed to be jailed for sundry misdeeds no fewer than eight times within a couple of years. The father finally tired of rescuing him and had him banished from Bologna and its surrounding territories. But he continued to support Aldo and even provided for him in his will.

In 1570 Cardan was arrested and imprisoned for heresy. The causes of the indictment have never been adequately explained, but it is reasonable to suppose that he was a victim of the Counter-Reformation. He had expressed so many opinions on so many subjects that officials had no difficulty in proving that he was a heretic. Nevertheless, the inquisitors were disposed to be merciful: he was not tortured or required to recant publicly in the shirt of the penitent but was merely stricken from the university rolls and forbidden to lecture and to publish any more books. He journeyed to Rome seeking leniency. With the help of influential friends he gained membership in the College of Physicians and was permitted a limited consulting practice. The Pope, strangely enough, granted him a pension. Together with the income from his remaining personal means, it enabled him to live in comparative comfort. It was not to be expected that the interdict against publication would stop Cardan from writing. His last manuscript was an autobiography, *De Propria Vita,* in which he combined apologies, boasts, confessions, "sorrows and joys, successes and failures." Cardan died September 20, 1576, and was buried in the Church of the Augustins in San Marco.

Cardan's fame rests mainly on his mathematical inventions, and this is what Ore reassesses. His *Ars Magna,* a pioneer work on algebra, was published within two years of two other history-making books in science: Nicolaus Copernicus' *De Revolutionibus Orbium Coelestium* and Andreas Vesalius' *De Humani Corporis Fabrica.* The *Ars Magna* set forth the theory of equations, including the solution of the cubic and the biquadratic, not previously known. It established the author as a creative mathematician of the first rank. Yet Cardan is entitled to small credit for its two major innovations in the "cossick art," as algebra was long called in Europe–from the Italian word *cosa,* for "thing" or the unknown quantity x. The method of solving a biquadratic equation was discovered by a pupil of Cardan named Ferrari, and the solution of cubic equations by the unhappy stutterer Tartaglia.

The quarrel between Tartaglia and Cardan is one of the great Italian operas, rich in ridiculous and tragic interludes. In 1539 Cardan sent his bookseller to Venice to ask Tartaglia to disclose his rule for the solution of the cubic equation $x^3+bx=c$. Tartaglia refused. Cardan responded with an insulting letter. But after several furious, baiting exchanges, Tartaglia allowed himself to give up his precious discovery. He went to Milan and there extracted from Cardan a most solemn oath not to publish or divulge the secret; Cardan swore that he would write down Tartaglia's discovery in cipher so that even after his death no one could understand it. Having obtained the secret, Cardan proceeded to publish it in the *Ars Magna.* There were mitigating circumstances. For one thing, Cardan's book acknowledged the value of Tartaglia's work. For another, Cardan learned that Tartaglia's discovery had been anticipated by the Italian mathematician Scipio Del Ferro about 1515. Furthermore, Cardan carried the cubic problem well beyond Tartaglia's rule: he solved the third degree equation in its most general form where all the powers of the unknown are present; he used imaginary numbers to extract all the roots; he employed approximations in his solution and exhibited a grasp of the relations between the roots and the coefficients of the equation. These circumstances do not excuse his offense, but they lighten its hue.

Tartaglia did not take Cardan's betrayal lightly. The feud was long and acrid, marked by many challenges, appeals to the public conscience and mutual denunciations. Mathematics was a serious business in those days. Cardan delegated to his brilliant and hot-headed pupil Ferrari the responsibility for upholding his colors. The skill and ferocity of the pupil exceeded the master's expectations. Not only as a mathematician but as a name-caller Ferrari was unexcelled. The final act was a public mathematical joust between Tartaglia and Ferrari. The older man lost his temper and was defeated. The contest proved nothing, but it was a sad ending to an absurd dispute. Tartaglia is one of the outstanding victims of secrecy in science, a secrecy which he himself had imposed.

Cardan's treatise on probability did not appear in print until the publication of a 10-volume edition of his complete works in 1663, and even then it attracted scant attention. Yet the mathematical sections of the *Liber de Ludo* are perhaps even better proof of Cardan's creative abilities than his considerable achievements in algebra; moreover, here the originality of his ideas is without shadow. The *De Ludo* is first of all a gambling manual, based on the experiences of a veteran gambler. There are chapters on false dice, marked cards, strategic kibitzing, the card game Primera (resembling poker) and the board game Fritilla (resembling backgammon), and many other interesting items. Cardan admits gambling to be an evil but calls it "a natural evil." The law recognizes that it is a solace as well as an evil and permits gambling to those who are sick, "in prison and condemned to death." Cardan, giving advice on play, is skeptical of most gamblers' superstitions, but suggests that it is advisable to sit facing the rising moon.

In the technical sections of the book he discusses equiprobability, mathematical expectation (the correct amount to bet when a player has a probability p of winning some amount P), reasoning on the mean, frequency tables for dice probabilities, additive properties of probabilities and what a century later came to be known as "de Méré's problem": *i.e.*, how many trials are required to give a player an even chance to win, for example, to throw a given point in dice. In some of his investigations Cardan sets off in the wrong direction, arrives at an incorrect result but then a few pages later discovers his mistake and corrects it. An excellent example of this curious procedure is his treatment of compound probabilities. After several false starts he demonstrates his mathematical ability by establishing the power formula $p_n = p^n$ for obtaining n successes in n independent trials. Cardan did not have enough mathematics to express the so-called law of large numbers in a formula, but used the law in the following sense: "When the probability for an event is p, then by a large number n of repetitions the number of times it will occur does not lie far from the value $m = np$."

Even without his work in algebra, the *Liber de Ludo Aleae* would assure Cardan of a place in the company of the great mathematicians. The situation has its ironic side. Of the mountain of scribblings poor Cardan left, it turns out that this tiny gamblers' manual, which he did not consider worth publishing and a large portion of which he burned in manuscript, is his firmest claim to immortality. He said in his autobiography: "I gambled . . . at chess more than forty years, at dice about twenty-five; and not only every year, but—I say it with shame—every day, and with the loss at once of thought, of substance, and of time." Yet it is for a by-product of these misspent hours that Cardan deserves to be remembered.

THE WORLD OF ELI WHITNEY, by Jeannette Mirsky and Allan Nevins. The Macmillan Company ($5.75). The year 1793 is one which U. S. school children are required to remember because it is the date of the invention of the cotton gin. They are usually spared further details, either as to the true measure of the gin's contribution to the social and economic development of the South or as to what Whitney accomplished after he invented the gin. Miss Mirsky and Professor Nevins, relying principally on unpublished materials, have written a comprehensive biography portraying the man and his career: as a student at Yale, an inventor, promoter, businessman, manufacturer, lobbyist and litigant. They have also provided an interesting history of the technological and agricultural scene of his period, 1750-1825. In a rather overblown style the authors attempt to make of Whitney a genius and a sympathetic figure; the facts they present contradict their judgment. Undoubtedly he was a shrewd, practical, skilled and imaginative mechanic, but nothing he invented was markedly original, not even his manufacturing processes involving interchangeable parts. His success sprang from his indomitable determination and zeal, and from the fact that his product was often a little better than his competitor's. He was a covetous, lonely and gloomy man without much human sympathy or understanding. He called Tom Paine, whom he met only once, merely a "filthy old sot." The sound scholarship of Mirsky and Nevins is a corrective to their extravagant estimate of Whitney's talents and virtues; the reader is presented with the material to make his own estimate.

WEBSTER'S NEW WORLD DICTIONARY OF THE AMERICAN LANGUAGE. The World Publishing Company ($5.00). A new dictionary is an event; the *Webster New World* is a gratifying event. It has been freshly compiled with emphasis on the language as actually used; it is the largest dictionary of its kind, intelligently conceived, skillfully executed and built for hard use. The editors have made a point of giving full etymologies and of including as many as possible of current idiomatic expressions, colloquialisms and slang; they sprinkle the pages generously with biographical references. There are some minor blemishes. The illustrations are of indifferent quality and —like most dictionary pictures—often serve no discernible purpose. Robert Hutchins, we are misinformed, is chancellor of the University of Chicago; there is an entry for Harold Urey but none for P. A. M. Dirac, for Erwin Schrödinger but not for Werner Heisenberg, for Lillian Russell but not for Ernst Mach, for Knute Rockne but not for Evariste Galois, for Button Gwinnett but not for Simon Newcomb, for Babe Ruth but not for William Gilbert, the father of electricity. Occam is here but not his razor, *hotfoot* but not *roman à clef.* To paraphrase an ancient warning: be hep, be hep, be not too hep.

TORNADOES OF THE UNITED STATES, by Snowden D. Flora. University of Oklahoma Press ($3.50). "Out of the south cometh the whirlwind." When a mass of polar maritime air collides with tropical maritime air from the south or southwest, the conditions are ripe for the formation of the most violent and spectacular of all whirlwinds, the tornado. In this book a retired U. S. Weather Bureau meteorologist who has made a lifelong study of catastrophic storms and floods gives an account of every aspect of tornadoes: their causes and structure, their distribution and frequency, the tragic damage they cause and their freakish results. In the 34-year period ending in 1949, not one of the 48 states escaped tornadoes. Nevada was struck once, New York 24 times, Texas 461 times, Kansas 587 times. Oklahoma had 389 tornadoes causing 664 deaths and the greatest property damage: $52 million. Illinois suffered 911 deaths and almost $48 million damage. If you own a square mile of land in Iowa the chance is one in 1,203 it will be struck by a tornado. Most tornadoes occur between 4 and 7 p.m. This is a fascinating book, adorned by stunning photographs from Flora's own collection.

SCIENCE AND THE SOCIAL ORDER, by Bernard Barber. The Free Press ($4.50). This book by a Barnard College sociologist is an attempt at a full-scale analysis of the social relations of science. The job has been done before, notably by Marxist disciples, but Barber's study is free of these preconceptions. Its basic method is to examine science as a social activity, as "a set of behaviors taking place in human society." It considers the effect of political circumstance on science and how the practice of science is promoted or retarded by various aspects of social structure and cultural ideals. It also treats of the place of science in U. S. society, the scientist in universities, industry and government, the social nature of the processes of invention and discovery, the social control and planning of science, the social aspects of the social sciences. Barber is not an exciting thinker. The merit of this study lies neither in profundity nor in virtuosity of presentation; at times, indeed, it is hard for the reader to remain attentive. But Barber is a competent writer and a careful student, covers a wide, difficult field and asks many useful questions.

ANTHROPOLOGY TODAY, prepared under the chairmanship of A. L. Kroeber. The University of Chicago Press ($9.00). AN APPRAISAL OF ANTHROPOLOGY TODAY, edited by Sol Tax, Loren C. Eiseley, Irving Rouse, Carl F. Voegelin. The University of Chicago Press ($6.00). In June, 1952, there was held in New York an international symposium on anthropology under the auspices of the Wenner-Gren Foundation, formerly the Viking Fund. These books are a record of the conference. The first consists of 50 papers written for the meet-

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ings; the second presents a report of the discussions. No one can fail to be impressed by the sheer bulk of the inventory volume or by the names of the contributors. The papers deal with a great variety of problems, such as long-range dating in archaeology, the biological basis of human behavior, prehistory, New World culture history, linguistics, experimental methods, social structure, the contribution of genetics to anthropology, culture and personality, physical anthropology, applied anthropometry, applied anthropology in medicine, industry and government. Like all symposia, this one is of uneven interest and merit. The incidence of high-flown jargon is terrifying. Anyone who supposes that this great, sprawling book, granting the excellence of several of its parts, will give him a coherent picture of its sprawling subject will be disappointed. The second volume, the *Appraisal*, is a disservice to social studies. It is a book edited without imagination and without sympathy for the reader, as if it were put out merely to provide the participants in the conference with a handsome memento of their deliberations. The discussions as here reported are scrappy and disjointed and often sound like a half-hour television discussion of the philosophy of Aristotle or relativity. Fortunately the book entitled *An Appraisal of Anthropology Today* is not an appraisal of anthropology today.

FLYING SAUCERS, by Donald H. Menzel. Harvard University Press ($4.75). If you think you have seen a flying saucer, it is not necessary to have either your eyes or your head examined. Flying saucers exist, but they neither fly nor are they saucers. The paradox is fully explained in Menzel's book. The saucers which honest, unhysterical men have seen and reported are natural phenomena. They are not mysterious Soviet missiles or vehicles for strange little men from other planets. They are only "patterns of light," no more substantial than the square of sunlight falling on the floor next to your window. Many of them are images formed by lenses of air, focused far above the ground. "Since the lens is imperfect and shifts with the breeze, the image flies erratically about—and finally disappears." Flying saucers are one of many different kinds of celestial phenomena observed since ancient times. Menzel's discussion includes aerolites and siderites (incandescent meteoric masses); superior, inferior and looming mirages; green and blue flashes; sundogs, auroras, rainbows, mock suns, moondogs, sun pillars, mock moons, subsuns, St. Elmo's fire, atmospheric dispersion and refraction, foo-balls and foo-fighters. This is a carefully reasoned and interesting book. It shows that there are more things in heaven and earth than are dreamt of in the philosophy of flying-saucer addicts.

THE AMATEUR SCIENTIST

About an ingenious electronic seismograph and the observation of changes on the moon

Conducted by Albert G. Ingalls

THE GRAPH on the opposite page shows how the earth jiggled a seven-room house in Alexandria, Va., last New Year's morning between 10:33 and 10:37 a.m. The record was made on a novel seismograph designed especially for amateurs by E. W. Kammer, an instrumentation specialist for the U. S. Navy. As may be seen, quite a lot was happening during those four minutes. The thickness of the trace line, particularly at 10:35, was caused by traffic streaming into and out of Washington, D.C., a few miles away. Similar nearby traffic disturbances account for some of the small, sharp peaks. The gentler, over-all modulation represents an approaching area of low atmospheric pressure. The longest rises and falls reflect a violent storm building up at sea off the Carolinas. Some 12 hours later its full fury struck and drove the recording pen off the sheet.

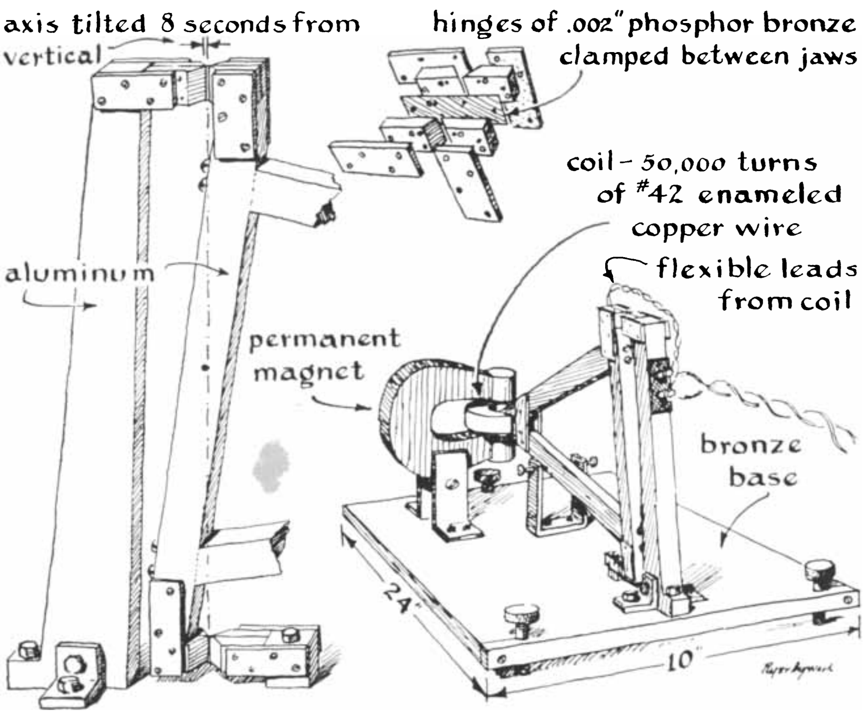
These waves are called microseisms. They are minute vibrations endlessly rippling through the earth's crust in response to the interplay of myriad forces, both natural and man-made. They are so faint that it is unlikely anyone in Alexandria other than Kammer was conscious that the earth was shaking last New Year's morning.

Earth waves are to the seismograph what light waves are to the telescope. Just as the telescope reveals cosmic details too dim or far away for the eye to see, the seismograph enables scientists to catch glimpses of the earth's internal structure. And as the telescope reports new comets and exploding stars, so, too, the seismograph provides a running account of unusual activities: sudden spurts in the growth of new mountains, readjustments of internal forces in response to surface erosion, the collapse of subterranean caverns, the interplay of stresses set up by tides and shifting air masses. Thus the seismograph is an instrument for investigating from a safe distance some of the most awesome spectacles staged on earth, as well as the only known tool for studying the planet's interior beyond a depth of six or seven miles.

It is regrettable that amateurs thus far have not been much attracted by seismology. Thousands of telescopes have been built by laymen, but the number of amateur seismographs in existence is very small. Professional seismologists have appealed repeatedly for amateur cooperation. To make a really detailed plot of the earth's interior, something still to be achieved, science must assemble observations from a closely spaced network of seismological stations.

Our present knowledge of what lies beneath the earth's surface is vague and indistinct. In general, it is believed that the granite crust extends down about 30 miles. Then, like the progressively thicker rings of an onion, comes a layer of basalt and glassy rock to a depth of about 420 miles, and below that to some 1,800 miles a layer or "mantle," probably composed of metallic oxides. The core, roughly 4,100 miles in diameter, is believed to be liquid, but its exact consistency is unknown. Some theories call for convection currents in this plastic mass, supplying the forces that build mountains. But these are only informed guesses and must remain so until seismology assembles enough facts to bring into clear focus the picture of what lies such a relatively short distance beneath our feet.

Kammer believes that three mistaken impressions have discouraged amateurs from taking up seismology. First, most laymen think that nothing much happens to a seismograph until an earthquake comes along; and judging by accounts published in newspapers, quakes seem to be few and far between. Second, laymen look upon seismograph records as a rather dull succession of squiggles which earthquakes convert into a hopeless scramble. Finally, the instrument strikes most laymen as a formidable piece of machinery. The few on public display feature massive frameworks anchored to concrete piers set in bedrock. The amplifying levers pivot on sapphire jewels. Finely wrought clocks drive precision drums carrying cylinders of smoked paper that look messy to handle. Certainly such an instrument lies beyond the pocketbooks and home-

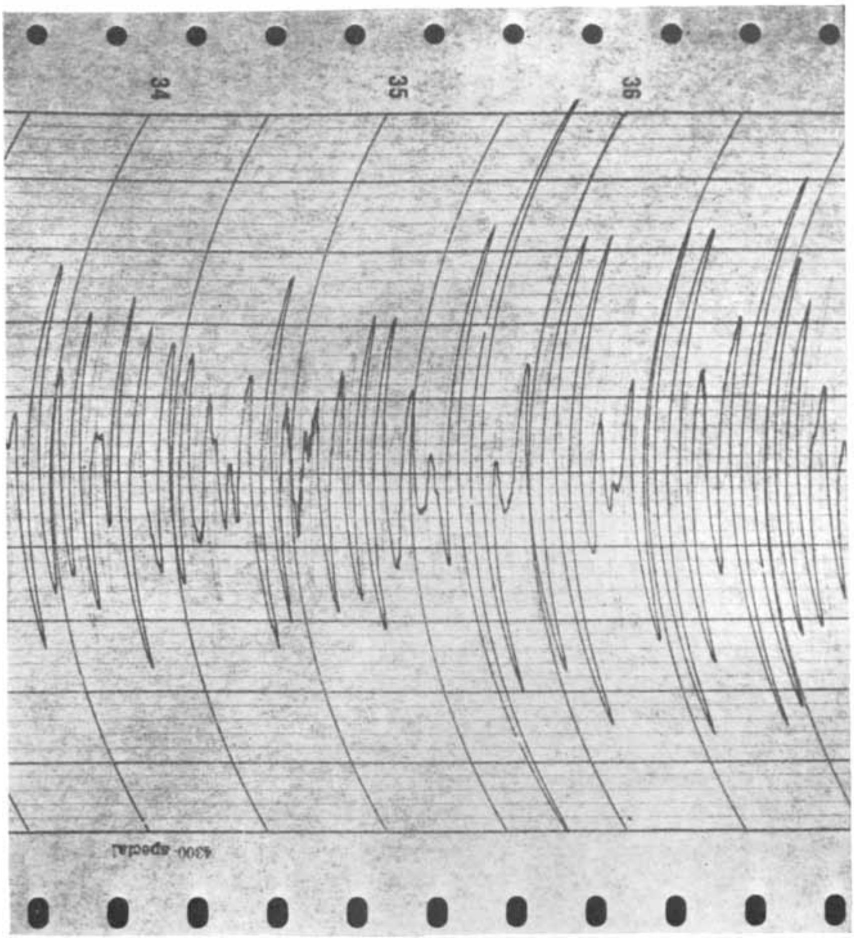


Details of an electronic seismometer

workshop capabilities of most amateurs.

Kammer admits that seismology owes most of its interest to earthquakes. Their waves do a lot of bouncing around on the layers inside the planet before registering on the instrument. That is why earthquake waves carry so much information about the places they have been. Contrary to lay notions, however, earthquakes are not rare. One occurs in some part of the earth on an average of every two hours and 27 minutes. Hence the analysis of quakes alone can become a full-time avocation.

But as shown by Kammer's chart of the microseism on New Year's Day, the seismograph is by no means idle during intervals between earthquakes. The surface of the earth quivers endlessly in response to waves that rush at miles-per-second speeds in all directions. "A television set gives you far less action for your money," says Kammer. "With a little experience the records become not only easy to read but exciting. You can tell at a glance whether a quake originated on the other side of the globe or only a few thousand miles away, whether it was a disturbance at the surface or a readjustment of deep forces. What seem meaningless wiggles become to the experienced observer images of a coastal region sinking beneath the sea, a distant storm center, the birth of a volcano—or merely a tell-tale trace that follows your wife as she walks from the kitchen to the living room."



A seismograph record showing microseisms

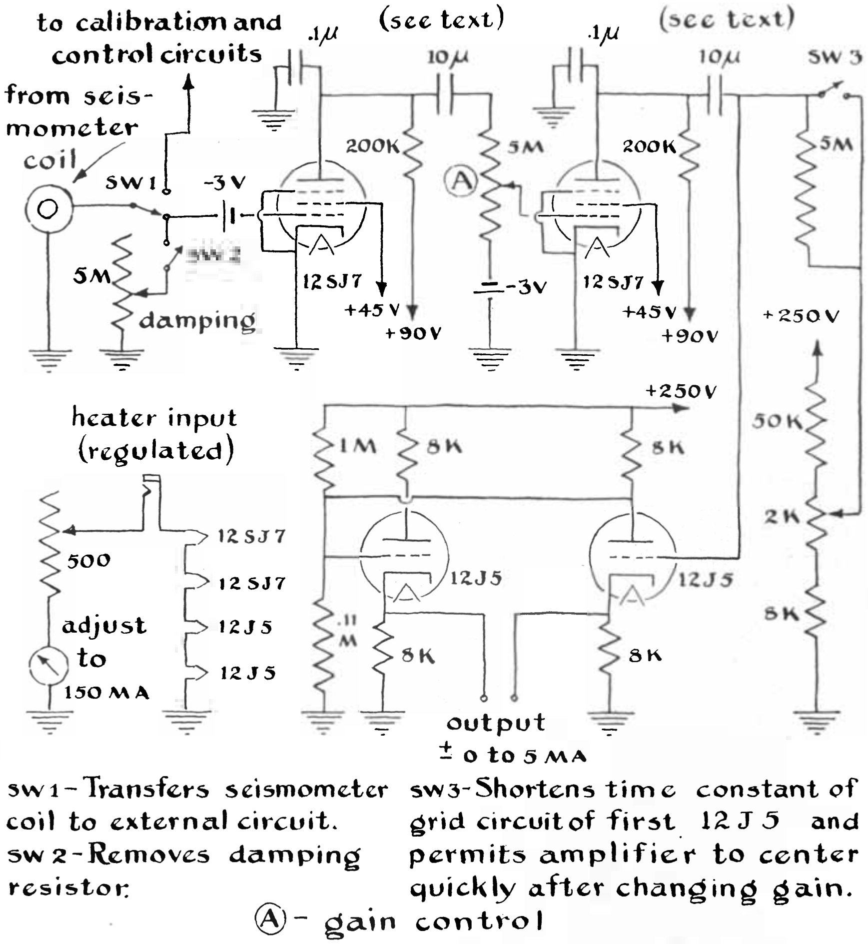
Kammer says that if he had to use one of the old museum-type seismographs his enthusiasm for seismology would probably dwindle. "I don't think I could work up much zest for a steam-driven bench saw today, either." Fortunately in our electronic age all engines have shrunk in size and cost, including the seismograph. The instrument Kammer has designed for amateurs sits on a plate only 20 inches long by 10 inches wide [*see Roger Hayward's drawing on the opposite page*]. It consists of three units: a seismometer, an amplifier and a recorder. A horizontal beam, pivoted at one end, carries a coil of insulated copper wire at the opposite end which swings between the poles of a permanent magnet. This pickup or seismic coil serves as the bob of the seismometer's pendulum. Flexible leads connect the coil with a line leading to the amplifier, which, if desired, may be located a mile or more away from the seismometer. The amplifier drives an electrical registering pen. Kammer uses a standard 5-0-5 milliampere Esterline-Angus recorder which he purchased on the war-surplus market.

In addition to permitting the seismometer to be located at a remote point favorable to it, the design has other advantages over old-type seismographs. Because it contains no delicate parts, the unit may be moved without the risk of disturbing its adjustment. The equilibrium position of the seismic coil is not critical, nor, for that matter, is the position of any of the parts with the exception of the Cardan-type hinges. These must be in good alignment or unpredictable forces will be set up when the pendulum is near its zero position. The builder is free, therefore, to modify the design and "make do" with such parts as his junk box or the surplus market affords. Kammer's pickup coil is scramble-wound with 50,000 turns of number 42 B-S gauge enameled copper wire, but both the number of turns and wire size may be varied. The coil swings between the poles of a war-surplus magnetron magnet. An electromagnet would serve as well. The size of the air gap between the poles and the thickness of the coil is unimportant as long as adequate clearance is maintained.

Kammer says that it is desirable to increase the voltage output from the seismometer by increasing the number of turns in the seismic coil until critical damping can be obtained by connecting a resistance of several megohms across it. The increased signal level permits the use of fewer stages in the amplifier. The unit is fitted with a cover to shield it from stray electrical and magnetic effects. The circuit is so arranged that a small battery can be switched momentarily across the seismic coil, thereby driving it as a motor and deflecting it from its normal position of equilibrium. Upon disconnecting the battery, the coil is again connected across the input to the amplifier. In this way the free period of the undamped seismometer oscillation as well as the proper value of damping resistance can be determined without disturbing the cover.

Perhaps the chief advantage of Kammer's instrument is the control it gives the observer over the character of the record. Unlike instruments that employ optical levers and record on photosensitive papers, the electronic seismograph's records can be observed continuously as they are being written. Faint, closely spaced microseisms can be enlarged at a twist of a knob to show as much detail as desired, while large-scale disturbances can be reduced, thus preventing the pen from swinging off the record sheet.

As presently designed, the instrument has only one questionable feature. It is a "velocity" type seismograph; the electrical output of the seismic coil varies in proportion to the *velocity* of



Circuit diagram for the seismometer amplifier

the pendulum rather than its *displacement*. Professional seismologists are interested in the shape of the displacement wave—the amount of the earth's excursion on either side of the point of equilibrium—rather than in the velocity of the excursion. Velocity graphs can be converted to displacement by performing a single integration, easily accomplished with one of the commercially available integrating devices or by feeding the output of the amplifier into an electronic integrating circuit of the type recently developed for electronic analogue computers. These circuits are simple to build and the parts do not cost much. But Kammer says it is surprising how much you can learn from a straight velocity graph. He does not use an integrator.

The most remarkable of the three units is the amplifier, which responds to frequencies extending from three cycles per second down to one cycle in twenty seconds. Kammer deliberately reduced the response of the amplifier to frequencies above three vibrations per second in order to suppress the effects of man-made disturbances such as motor traffic.

Most long-period amplifying devices are troubled by a gradual drift of the zero or neutral recording position. Kammer's amplifier [*see diagram at top of this page*] obtains long-term zero stability by means of capacity-resistance coupling between the stages. The five-megohm grid leak (damping resistor) across the first of two special 10-microfarad condensers gives the unit a 50-second time constant. Hence it is possible to observe typical seismograms containing vibrations up to a period of 30 seconds. Gradual changes in the characteristics of vacuum tubes or battery voltages do not occur rapidly enough, according to Kammer, to develop bothersome potentials across the grid resistors. The two 10-microfarad condensers are the only critical parts in the amplifier. They must be of the best quality and have at least 1,000 megohms leakage resistance. Condensers of this type are currently priced at about $10 each. (They are available from Condenser Products Company, Chicago.)

The output stages consist essentially of a bridge circuit similar to those used in vacuum-tube voltmeters. The first tube of the bridge acts both as amplifier and phase inverter—note the one-megohm resistor between the plate of the first tube and the grid of the second—to drive the final tube's grid. This increases the unit's sensitivity. Current to drive the recorder is taken from across the cathodes of the bridge tubes. If desired, voltage can be tapped from across the plates to operate a cathode-ray oscilloscope or other voltage-actuated device. Kammer made his gain control of fixed resistors that diminish by half-value steps from grid to ground, each tapped by a rotary switch. The positive action of the switch generates less noise than the potentiometer which has been substituted for simplification in drawing. The .1-microfarad capacitors, connected between the plates and ground, limit the upper-frequency response of the unit. Without them, nearby vibrations would unduly thicken the trace.

A well-regulated power supply may be substituted for battery operation. The heaters of the tubes are connected in series directly across the high-voltage supply through a dropping resistor which limits the current to 150 milliamperes. Plate and screen voltages for the pentode stages are derived from batteries, even though a power supply is used. Batteries improve the stability of the unit and, since the current drain is small, they will last their rated life.

The arrangement of the amplifier parts is not critical, though Kammer suggests some protection from vibration to eliminate microphonic disturbances originating in the vacuum tubes. In using this amplifier it is important, he warns, to be aware of phase shift introduced by the coupling networks when signals from several seismometers are being correlated. When studying microseisms from simultaneous recordings of three instruments—the so-called "tripartite" arrangement—signals being compared have the same period and hence experience the same amount of phase shift if the amplifiers are nearly identical. This condition, Kammer explains, is easily achieved and can be tested by connecting the inputs of all amplifiers in parallel, driving them from one signal source and comparing the records on separate recorders.

Although this remarkable amplifier was designed to operate from a velocity-type seismometer, it should perform equally well when driven by other long-period voltage sources. It takes little imagination to conceive of seismometers that would produce voltages proportionate to either pendulum displacement or acceleration. Beyond the field of seismometry, the amplifier should find wide application in stellar photometry and in other studies which require the recording of very low frequencies.

ANOTHER unusual amateur seismograph is operated by Elmer Rexin, maintenance superintendent of the Nunn-Bush Shoe Co. in Milwaukee. It is as permanently based as Kammer's instrument is mobile. It is a well-water oscillation seismograph. Although Rexin's instrument is not without precedent, it is, so far as we know, the only one of its type now being operated by an amateur.

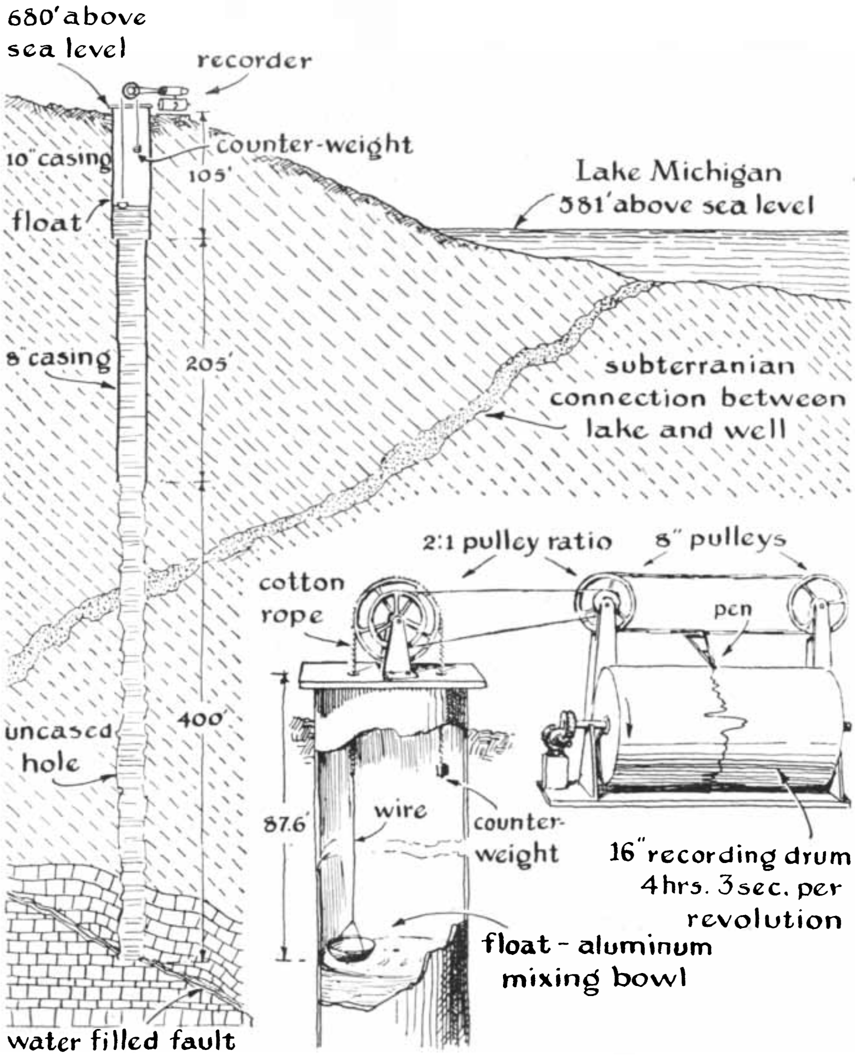
Heavy earthquake shocks often cause water to squirt from the ground in some regions. Small mounds of sand, resembling the craters of volcanoes, frequently mark the spots where underground water has erupted under pressures generated by the quake. The flow of artesian wells and the general level of water in wells in the vicinity are disturbed by these quakes. Many wells have been equipped with apparatus for recording water level, as well as hydrostatic pressure, and some of the resulting records have shown typical earthquake waves.

We are indebted both to Mr. Rexin and to *Earthquake Notes*, journal of the Eastern Section of the Seismological Society of America, for the following account of the Milwaukee well:

"In 1925 the Nunn-Bush Shoe Company added to its water supply by drilling a well to a depth of 380 feet and clearing it to 400 feet with a shot. The well was used until 1945, when gas contaminated the water. The casing was then plugged. In 1946 the United States Geodetic Survey received permission to install a water-level recorder in the hole. Shortly after the instrument went into operation, groups of closely spaced, vertical lines appeared on the charts.

"These lines aroused my curiosity," Rexin writes, "and I consulted the head geologist of the Geodetic Survey of Wisconsin about them. We suspected that earthquakes might cause them. He requested reports from Washington, D. C., and when the cards arrived about three weeks later our guess was confirmed. The reported quakes coincided with the records made by the well. With our curiosity thus satisfied, we dismissed the subject and I paid no further attention to the well.

"Then, on the afternoon of May 7, 1947, something happened that was to make a radical change in the way I use my off hours. An official of the company rushed into the maintenance shop at 3:38 and told me that the whole boiler room was shaking and that he had heard a deep, rumbling noise. Within seconds the chief engineer rushed in with the same story. Although I had felt or heard nothing, I wondered if the disturbance could be caused by an earthquake. So the three of us went down to the well, and sure enough there were the lines—big ones! I telephoned our newspaper office and the reporter tried to convince



A seismograph that utilizes an abandoned well me that the shock came from a big explosion on the southwest side of the city. But while I was speaking with him another reporter yelled that Father Joseph Francis Carroll, chairman of the department of physics at Marquette University, had just reported a local earthquake. From that day forward I have been an earthquake enthusiast.

"The next day I met Father Carroll and told him about the well. He was interested immediately and with his encouragement I decided to equip the well with an improved recorder, one that would make an enlarged chart of the waves. In this new device [*see drawing on preceding page*] the motion of the water is transferred from the well to the record sheet by means of a float and a counterweighted line which passes over a pulley above the well. This pulley is belted, in turn, to a pair of matched pulleys that carry an endless belt to which the pen is attached. The oscillation of the matched pulleys causes the pen to move back and forth in a straight line. The record sheet is carried beneath the pen by a motor-driven drum. The drum makes one revolution in about four and a half hours.

"The new recorder worked even better than we expected. The first markings to appear were not earthquake waves but extremely long curves, two every 24 hours, in the shape of perfect sine waves. Previously Father Carroll and I had discussed the tides of Lake Michigan, and I now consulted the library of Milwaukee's meteorologist. An early report by the U.S. Army Corps of Engineers showed that in spring the combined lunar and solar tides would amount to about two inches. When I made a check of the well against the predicted tides, and took measurements of them at the beach, all three corresponded.

"Then I noticed that other curves were appearing on the graph. I suspected that variations in barometric pressure might be causing some of them. A microbarograph borrowed from the Johnson Service Company of Milwaukee proved that this was a good guess.

"On May 29, 1947, the water rose and fell six tenths of a foot over a period of six hours, in addition to changes accounted for by the tide and barometric pressure. The following day I learned that a tidal wave had swept in on this side of the Lake with a great loss of property. So I had to add tidal waves to the growing list of events that disturb the well.

"Earthquake waves were being impressed on the record right along, of course, and it was necessary to unscramble these other curves in order to interpret the quake records. While learning to do this I first observed a curious effect. As areas of high barometric pressure moved out over the Lake, the water level in the well would rise instead of going down. By this time I had learned to distinguish the small seiches caused by abrupt changes in barometric pressure during severe lightning storms. The seiches, tides, tidal waves and changes in barometric pressure at the Lake all appeared to operate in reverse of the well. When the water in the Lake rose, that in the well fell, and *vice versa.* Father Carroll and I discussed this with Father James B. Macelwane, head of the Geophysics Technology Institute of St. Louis University. We reached the conclusion that the well is connected with the Lake by a natural tunnel of some sort. Hence the effect we observed is the normal functioning of a U tube—with the well forming one arm of the U and the Lake the other.

"The sensitivity of the well to earthquakes is probably accounted for by a water-filled fault that connects with the well at the 400-foot level, but until now we have not devised an experimental method for checking this theory. If our guess is correct, the action would be much like that of a syringe, with the fault serving as the rubber bulb. Pressure created by quakes would compress and expand the fault, thus forcing water into the well and sucking it out again. As a seismograph, the well is quite sensitive, and I have little trouble distinguishing primary and secondary waves of even low-magnitude quakes.

"At present I am interested in setting up apparatus for measuring short-period pressures that may be created in the well. The apparatus will consist of a waterproof microphone which will drive an electrical recorder through a high-gain amplifier. I once sank a microphone to a depth of 160 feet and detected a regular pattern of pressure waves, but the seal broke where the lead entered the water-tight container, and you can guess what the record showed after that."

ONE TEST of the quality of a telescope is to photograph the moon with it and note how much the photograph can be enlarged without loss of sharpness. The amateur telescope maker Henry Paul has made a photograph of the moon at the focus of his 10-inch, $f/9$ reflector, where the image was eight tenths of an inch in diameter, which he was able to enlarge 20 times, giving an image of the moon 16 inches in diameter, before loss of sharpness became apparent. Usually a picture begins to be fuzzy with anything over a fivefold enlargement. Thus Paul beat par by four times.

The photograph, enlarged five times, appears on the opposite page. In the photograph the moon is eight days old, or near its first quarter. The edge of darkness crosses the lofty Apennines, the finest range of mountains on the moon. Near their eastern (right-hand) end, isolated in black shadows as the moon rotates westward, is a tiny cusp

The moon with the crater Eratosthenes near the terminator

of light. This is the eastern rim of the crater Eratosthenes peeping out of the night at first dawn. (On the moon the sun rises in the west.) At left on the next page is another photograph, taken one day later, which shows the entire Eratosthenes crater, 37 miles in diameter. The outer ring of the crater rises about a mile above the surrounding plain. The crater floor is more than a mile below the level of the plain. The central mountain rises to the level of the plain.

It is easy to see the shape of a lunar crater as long as its parts cast shadows, but when the sun is high in the sky and they are illuminated on both sides, no shadows are cast. Even as large a crater as Eratosthenes can then so nearly vanish that an observer who has watched it and drawn it again and again at the telescope eyepiece may have difficulty in finding it. The right-hand illustration on the next page reveals the same area as its left-hand companion, photographed at lunar noon, sun directly overhead, full moon from the earth. Without the aid of the companion illustration it would be far from easy to find this crater amidst the camouflage that surrounds it. Other craters put on similar disappearing acts each month.

The commonest method of becoming familiar with the moon's topography is to keep observing along the dark edge, because there the shadows easily interpret the relief. By doing this throughout the month, night after night as the day-night borderland creeps to the east then retreats to the west, the whole visible face of the moon is surveyed. Here many telescope users stop, and thus miss seeing changes on the moon that were long ago minutely described by the American selenographer W. H. Pickering and others. Let us ferret out some of these changes.

When the left-hand photograph was taken, the sun's altitude in the lunar sky was approximately equal to that on earth at 6:20 a.m. Close comparison with the right-hand illustration yields practically no correspondence between the light and dark areas. The reason is that the dark areas in the first are the shadows of objects, while those of the other are not, for the sun is near the noon angle and shines down on all sides of all prominences. The dark areas seen in the right-hand photograph appear monthly in and around the crater between the 9 a.m. and 2 p.m. positions of the sun and keep shifting their position. What these patches are is unknown; they are not related to the moon's topography. The bright areas consist partly of streaks, best seen in the illustration through nearly closed eyelashes, and rounded plats where the streaks meet. These streaks and plats shift in position each month, in approximately the same cycle. Most interesting is the fact that the behavior of the dark and bright areas varies from month to month in minor respects that are unpredictable.

Pickering found it easier to observe Eratosthenes with a small telescope than Mars with a large one; the apparent diameter of Mars at its nearest is but half that of Eratosthenes, and Eratosthenes contains far more detail than Mars. To show that the major changes on Eratosthenes can be observed with a six-inch telescope anywhere in the U. S., he made drawings of it with only a three-inch telescope and a magnification of 90 from his home on the high plateau of the tropical isle of Jamaica, British West Indies, where the seeing is good. He systematized the study of the monthly changes by charting the eight fields in Eratosthenes as shown in the drawing on page 122. The following is his summary of the more marked changes that may be expected to be seen each month. The times given are not for a single day but simply indicate the angle at which the sun is shining on the moon at the time of observation. At 6:30 a.m. the summit of the central peak becomes visible.

At 6:40 a "canal" (streak of brightness) joining the SC and SE fields may appear.

At 7:50 fog begins to form within the crater, increasing till 10 a.m.

At 7:55 canals appear in the SE field.

At 8:00 the eastern side of the NW field darkens.

At 8:20 the northern part of the bird-shaped NE field begins to fade and the southern part to extend.

At 8:40 two dark spots in the E field unite.

At 9:20 the central field begins to narrow at the northern end [*see drawings on page 122, corresponding respectively with SC and C fields at 8:30, 9:30 and 10:30 a.m.*]. The northern field crosses the crater rim from the outside and begins extending inside the crater.

At 9:40 the SE field crosses the rim of the crater.

At 10:00 the SC field darkens and a canal sometimes begins joining the SC and SE fields, while the southern part of the NE field begins to fade.

At 10:40 the EC field darkens; at 1:30 it is conspicuous, and at 5:00 it is lost in the shadows.

At 10:50 the E field joins the NE, which soon begins to shrink.

At 11:00 the two arms of the SE field begin to curve inward.

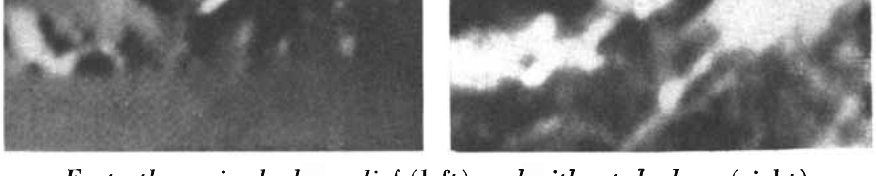
At 1:00 the SC field becomes notched at the south (upper) end and at 3:20 it fades out.

At 2:00 the NE field begins to fade.

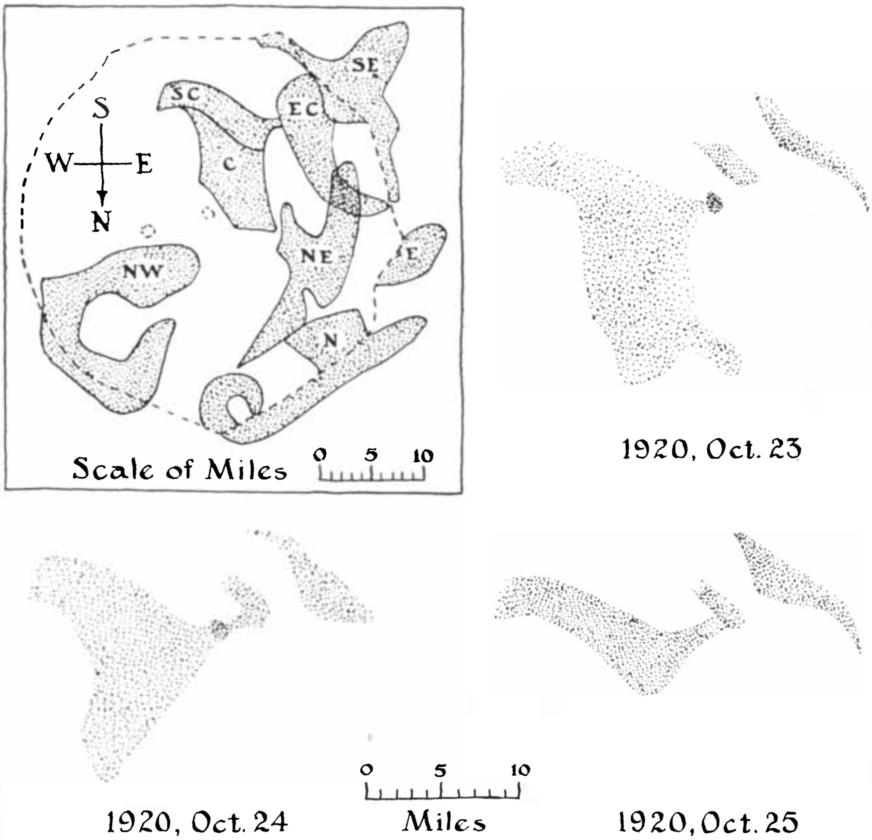
These are only the major changes. There are so many minor ones that the principal difficulty of the selenographer is to sketch them as fast as they occur.

The "canals" are streaks of brightness a mile or two in width—about one 200th the width of the Martian canals as seen at about 200 times the moon's distance. Pickering called these lunar streaks canals because they resemble the streaks on Mars that are called canals, though no water has ever been seen in them. The plats at their intersections resemble the lakes of Mars and, like some of them, shift in position.

The fogs mentioned by Pickering occur in craterlets usually less than one mile in diameter. These emit a brilliant white circular glow after being warmed by the sun. They remain conspicuous until sunset. Other selenographers have seen fogs in craterlets within Eratos-



Eratosthenes in shadow relief (left) *and without shadows* (right)



Changing areas on Eratosthenes and examples of change

thenes. The British selenographer Patrick A. Moore calls them mists. He says their existence "cannot be questioned, as the evidence is overwhelming; various craters have at various times been seen mist-filled."

Pickering argued that because the markings on the moon and on Mars are neither shade nor shadow they must be either changeable surface discolorations or something growing or something moving over the surface—"mineral, vegetable or animal." He found that the "vegetation" in general is gray, like sagebrush; in places near the moon's equator it is purplish black, like lichens. Eratosthenes is one of a number of oases in the desert waste of the moon's surface. The "vegetation" is often associated with minute craterlets within large craters. Its growth and decline must be very rapid.

After Pickering published his findings in *Popular Astronomy* (November, 1919; August-September, 1921; May, 1922; February, 1924; May, 1924; August-September, 1924) critics dismissed the alleged changes as due merely to the shifting of shadows and the changing angle of illumination. Pickering replied: "If so, why do they always appear at full moon? How explain dark markings that advance *toward* the setting sun?" He denied that he had said that terrestrial vegetation would be possible on the moon. The lunar "vegetation" must be very different from that of the earth and we know nothing about what it is like. The same would be true, he said, if the dark areas were swarms of ant-sized insects migrating.

After Pickering had published his articles, the Italian selenographer Mentori Maggini spent several days discussing the moon and Mars with him and later made drawings of Eratosthenes with a 13-inch refractor in Sicily. He verified nearly all the details of Pickering's drawings. He, too, saw the canal-like streaks and noted they were continuously visible, unlike those of Mars, which peep out for no longer than one fiftieth of a second or at most a second. He said they resembled the lines of Mars and asked, "Does this similarity lead us to believe that we have to do with the same phenomenon, an optical one?"

Maggini's optical interpretation of the moon's changes was this: "The glimpsed details, or invisible ones, are gathered together and integrated into linear sensations or into spots. From the point of view of the optical theory these lines and spots are the means by which the eye of the observer, who always wishes to see something, succeeds in representing fleeting detail. In the region of Eratosthenes it has seemed to me that a great number of lines have their origin in the contrast between two bright areas; when two bright regions form, one can see between them a dark line. And the optical theory explains the displacements of the fields and canals by a change in the maximum distribution of elementary spots scattered over a region."

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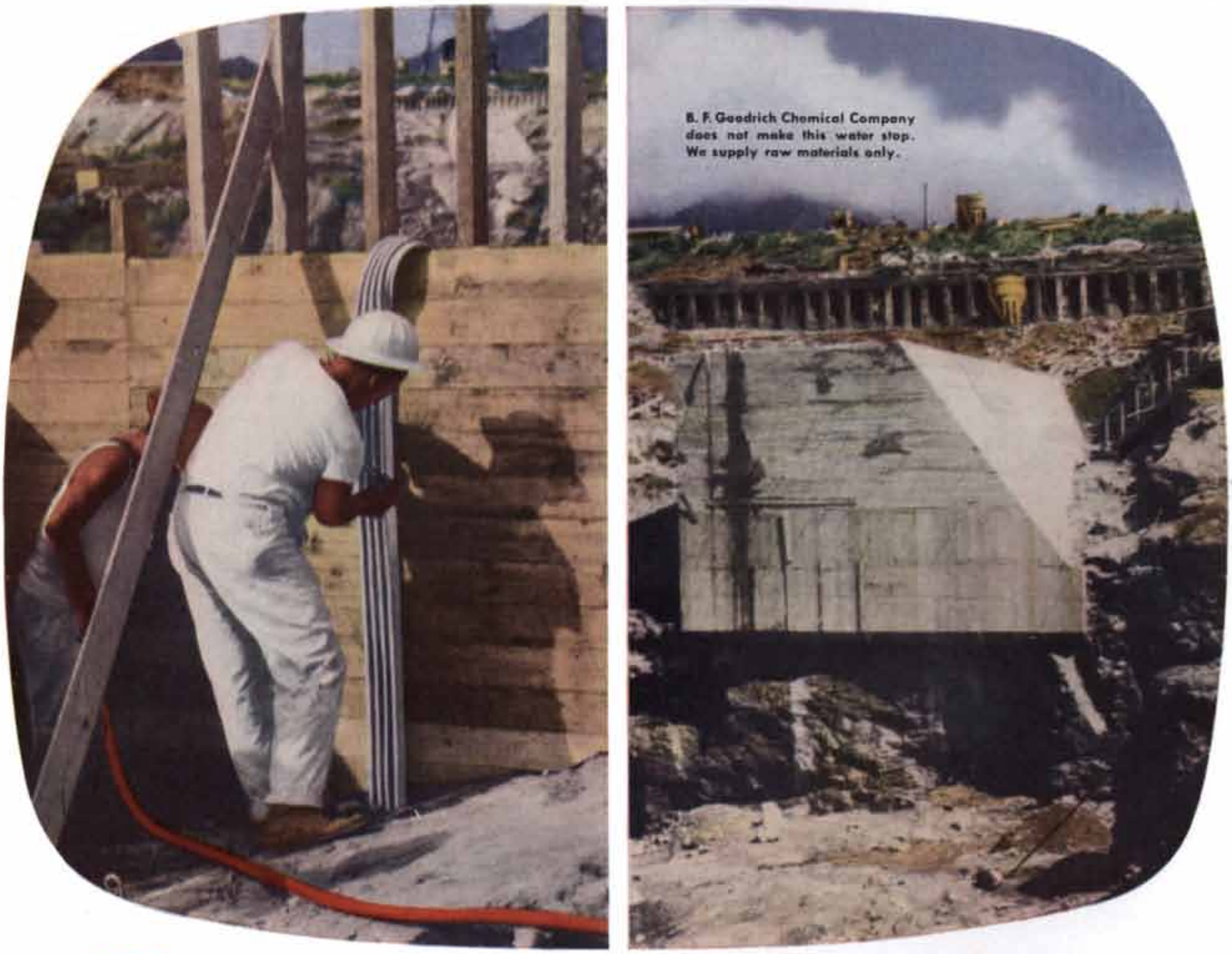

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