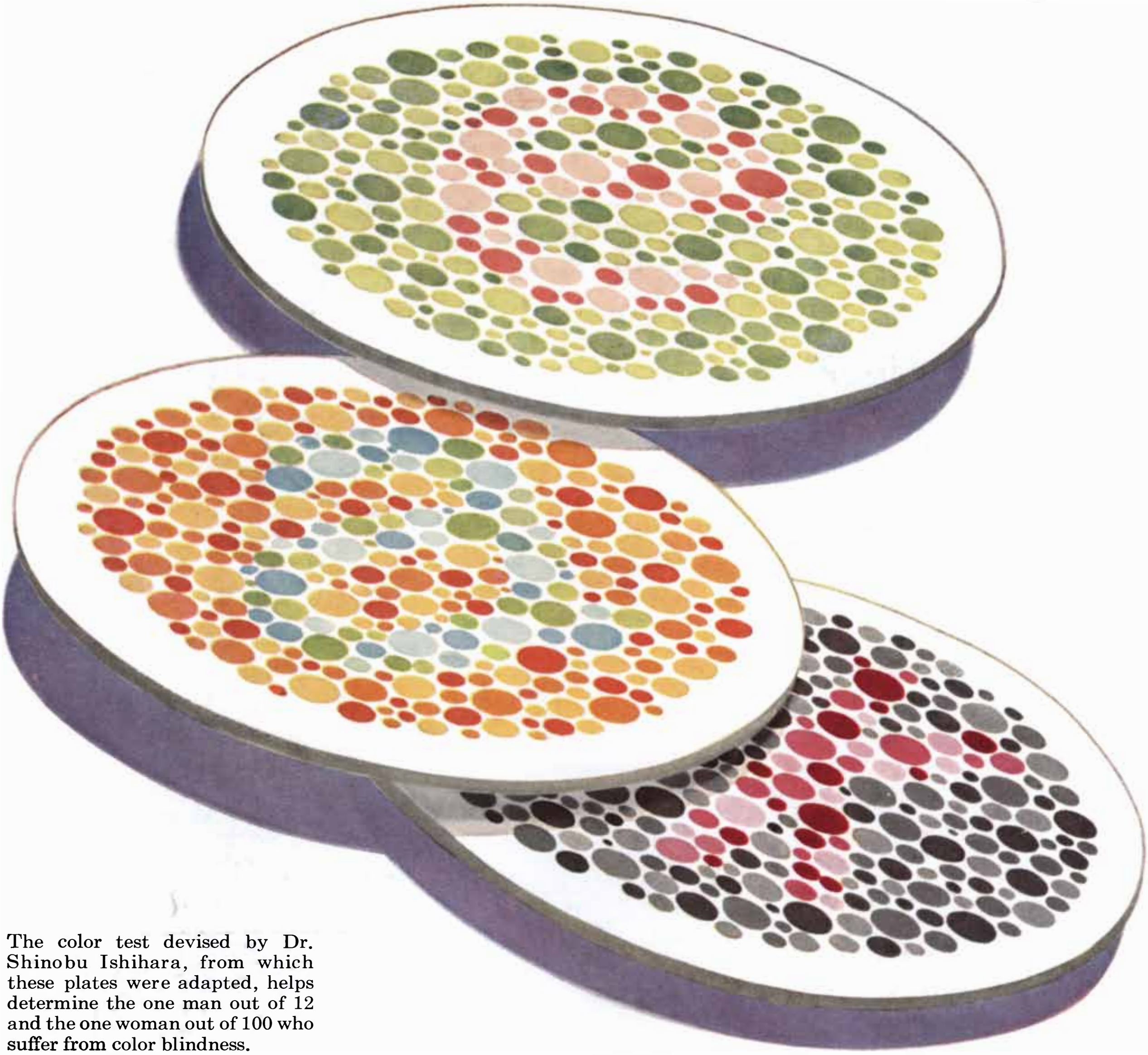
SCIENTIFIC AMERICAN

SALAMANDERS IN THE LABORATORY

FIFTY CENTS

October 1958



The color test devised by Dr. Shinobu Ishihara, from which these plates were adapted, helps determine the one man out of 12 and the one woman out of 100 who suffer from color blindness.

What's your color I.Q.?

ANYONE with a good eye for color can pick out the letters E-A-K. But go to the head of the class if you know how EAK (ethyl amyl ketone) and the rest of the ketone family of Shell solvents bring more color into your everyday life.

Because of their tremendous appetite for nitrocellulose and other resins, Shell ketones work more effectively than most other solvents. They make possible more and better colored finishes for today's automobiles and furniture.

The continuing search for better solvents in Shell Chemical laboratories has led to improved quality and lower cost in a wide variety of coatings for industrial and consumer products.

Shell Chemical Corporation

Chemical Partner of Industry and Agriculture

NEW YORK

Leonardo da Vinci...on experiments

"I shall begin by making some experiments before I proceed any further; for it is my intention first to consult experience and then show by reasoning why that experience was bound to turn out as it did. This, in fact, is the true rule by which the student of natural effects must proceed: although nature starts from reason and ends with experience, it is necessary for us to proceed the other way around, that is — as I said above — begin with experience and with its help seek the reason. Experience never errs; what alone may err is our judgment, which predicts effects that cannot be produced in our experiments. Given a cause, what follows will of necessity be its true effect, unless some external obstacle intervenes. When that happens, the effect that would have resulted from the cause will reflect the nature of the obstacle in the same proportion as the obstacle is more or less powerful than the cause."

—Notebooks, circa 1500

Missiles designed to soar out of this world
...*are sped by liquid oxygen from* LINDE

Oil, kerosene, and alcohol "burn" by combining chemically with oxygen from the air. But it takes pure oxygen with these fuels to speed rocket planes faster than sound . . . to drive missiles beyond the earth's atmosphere.

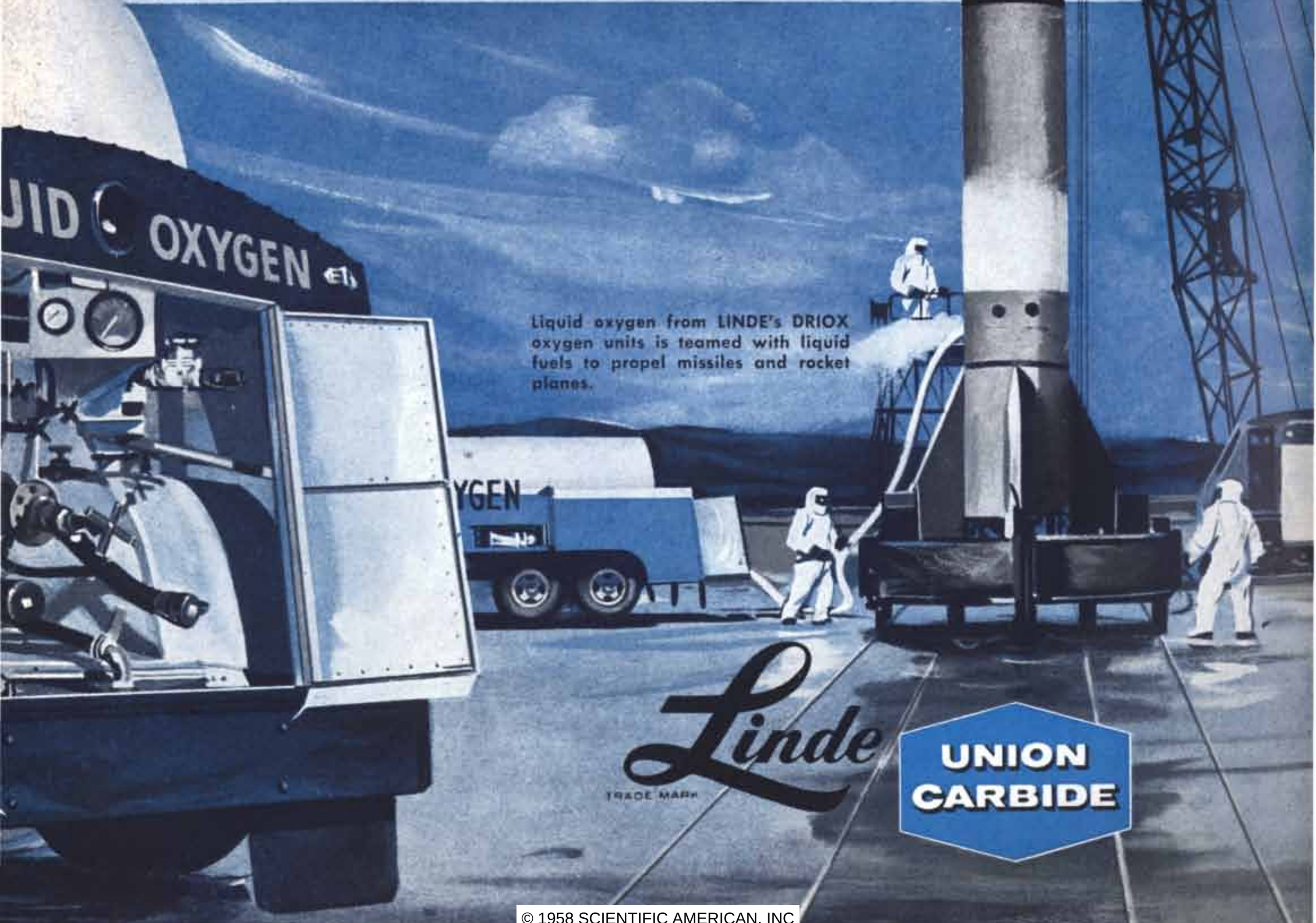
Liquid oxygen, vital to today's rocket engines and many types of missiles, was being produced by LINDE as long as 25 years ago. In fact, LINDE has been supplying oxygen to industry for more than 50 years. LINDE pipes oxygen directly to industrial users from nearby oxygen plants built and operated by LINDE. The user makes no capital investment, and pays only for the oxygen consumed —at a price guaranteed by LINDE.

LINDE also developed methods for transporting liquid oxygen efficiently, in large and small amounts, at 300 degrees below zero F. You can get LINDE oxygen in just the quantity you need, at the exact time and place you want it, as a liquid or a gas.

For detailed information about LINDE oxygen, write Dept. R-10, LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y. Offices in other principal cities. *In Canada:* Linde Company, Division of Union Carbide Canada Limited.

***When you need Oxygen—call* LINDE!**

The terms "Linde," "Driox," and "Union Carbide" are registered trade-marks of Union Carbide Corporation.



Liquid oxygen from LINDE's DRIOX oxygen units is teamed with liquid fuels to propel missiles and rocket planes.

Linde
TRADE MARK

UNION CARBIDE

Established 1845 SCIENTIFIC AMERICAN October, 1958 Volume 199 Number 4

ARTICLES

DEPARTMENTS

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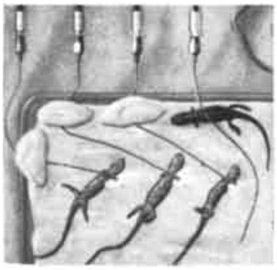

THE COVER

The painting on the cover shows part of an experiment on the regeneration of amputated limbs by the salamander (*see page* 79). The experimenter seeks to answer the question: How are nerve fibers implicated in the process of regeneration? The experiment involves amputating both forelimbs of a salamander, and then (by means of one of the syringes at the top of the painting) injecting into the early growth of one limb a tiny amount of a drug which inhibits nerve action.

THE ILLUSTRATIONS

Cover painting
by John Langley Howard

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HAYNES Alloys Solve the *Tough* Corrosion Problems

Resists HOT SULPHURIC ACID...

Saves $5000 Annually

The use of HASTELLOY alloy C in ore charging baskets has eliminated a costly corrosion problem. Each basket, loaded with a ton of ore, is submerged in a solution containing 19 per cent sulphuric acid at 170 deg. F. The acid salts formed during the process are oxidizing and reducing. Yet the corrosion rate on the HASTELLOY alloy parts is less than 0.004 in. per year! It is estimated that the alloy C parts will last for 20 years at an annual maintenance saving of $5000 per basket . . . An overall saving of 100,000 dollars!

For complete information on the physical, mechanical and corrosion-resistant properties of HASTELLOY alloys, ask for our newly published 104-page book. Address Haynes Stellite Company, Division of Union Carbide Corporation, General Offices and Works, Kokomo, Indiana.

Corrosion resistance plus high strength makes HASTELLOY alloy C the ideal choice for use in ore charging baskets. They carry a ton of ore and are expected to last 20 years.

HAYNES
ALLOYS
HAYNES STELLITE COMPANY
Division of Union Carbide Corporation
Kokomo, Indiana

UNION CARBIDE

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ADVANCED INERTIAL GUIDANCE

Complete systems or components for aircraft, missiles and spacecraft

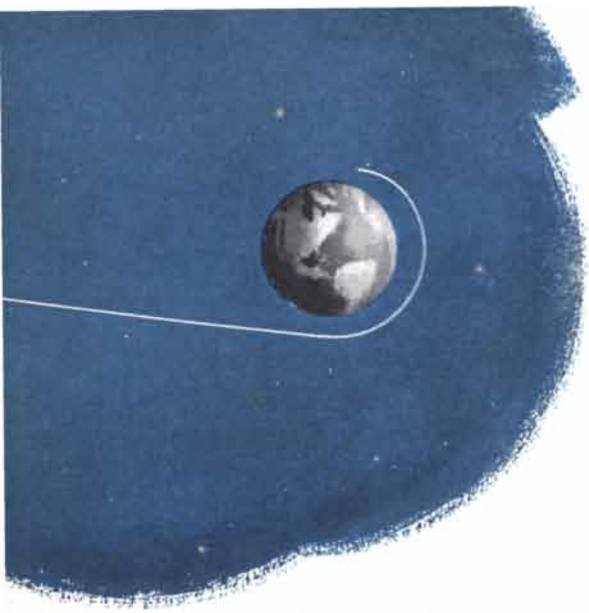
To design and produce extremely accurate inertial guidance systems requires a complex combination of engineering and manufacturing skills. Each component must be developed to meet the accuracy needed for the system's mission.

The long background in gyroscopics, electronics and computation has made it possible for Sperry to design and produce advanced inertial systems for some of our country's most modern weapons of defense. Other Sperry inertial systems will, one day, allow man to explore space.

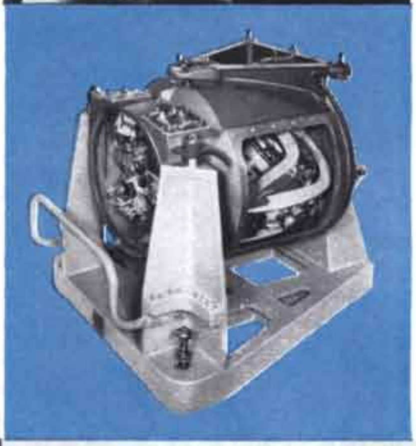
On these pages are highlighted some of Sperry's recent achievements in inertial guidance. If you have a systems problem or are interested in individual components, write our Air Armament Division for further information.

CONVAIR'S B-58 HUSTLER with Sperry inertial navigation system will be able to navigate undetected for thousands of miles to exact target. Most nearly automatic airplane yet developed and requiring only a 3-man crew, the B-58 will fly faster than sound at altitudes well over 50,000 feet.

HYPERSONIC, ROCKET-POWERED X-15 manned research aircraft by North American is designed to explore near space. Sperry inertial system, developed for USAF, will give pilot data for navigating and maneuvering the NACA-sponsored X-15 with extreme accuracy at speeds of one mile per second.



UNDER MICROSCOPE, Sperry employee assembles floated gyros under specially-designed hood and in sealed pressurized room. Since even dust speck might cause serious error in a long-range mission, every precaution is taken in the production of these critical units.



COMPACT Sperry stable platform mounts three advanced floated gyros. Nerve center of the inertial system, platform serves as fixed space reference in flight for maintenance of prescribed course.

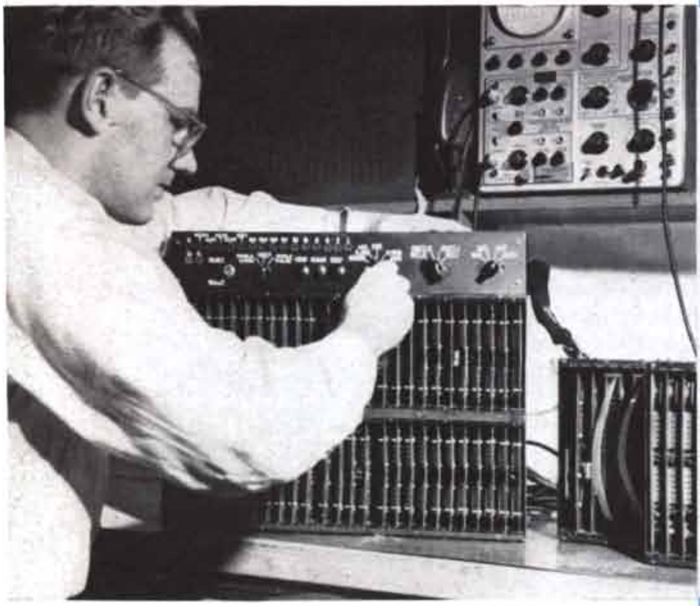
NEW linear integrating accelerometers weigh only 1½ lb., measure exact velocity of aircraft or missile in any direction. New sensing mechanism moves in straight line, eliminating errors inherent in previous types.

AIR ARMAMENT DIVISION

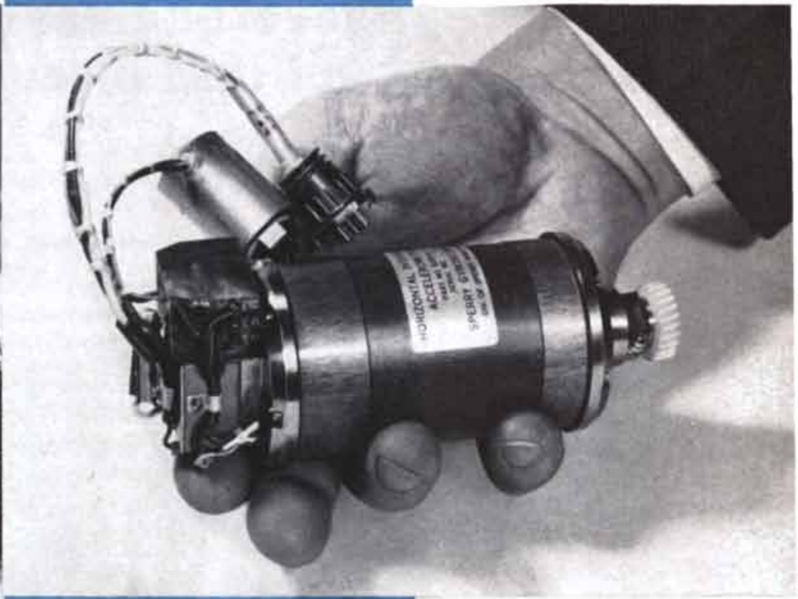
SPERRY GYROSCOPE COMPANY

Great Neck, New York

DIVISION OF SPERRY RAND CORPORATION



ENGINEER TESTS new airborne digital computer designed by Sperry. Computer accepts data from stable platform's gyros and accelerometers, gives instructions for automatic corrections in flight path. Closely related operator displays permit inflight monitoring and control.



ULTRA-SENSITIVE floated gyroscope minimizes random drift, assuring high performance for inertial system over long periods. These production gyros withstand shock and vibration many times the force of gravity.

LETTERS

Sirs:

Donald R. Griffin's article in your July issue, describing the highly developed echolocation systems used by bats for navigation and for locating their prey, was extremely interesting to some of us engaged in the development of military radar systems. However, it appears that the "echolocation efficiency index" used in the comparison of bat radar *v.* man-made radar is not valid. The radar sets compared would be crude indeed if the bat's system were a million million times more efficient.

In any echolocation system, the maximum range attainable is proportional to the *fourth root* of the product of the energy content of the transmitted pulse, times the transmitting antenna gain, times the receiving antenna effective area, times the target effective area, divided by the minimum energy detectable by the receiver. This implies that it is necessary to increase transmitter power, receiver sensitivity, or target effective area 16 times in order to double the range. Hence a comparison of two systems should include all these factors, raised to the appropriate power. But working only with the data available from the table in Dr. Griffin's article, a more valid echolocation efficiency index would seem to be range divided by the product of the fourth root of transmitter power times the square root of target diameter. The echolocation efficiency in-

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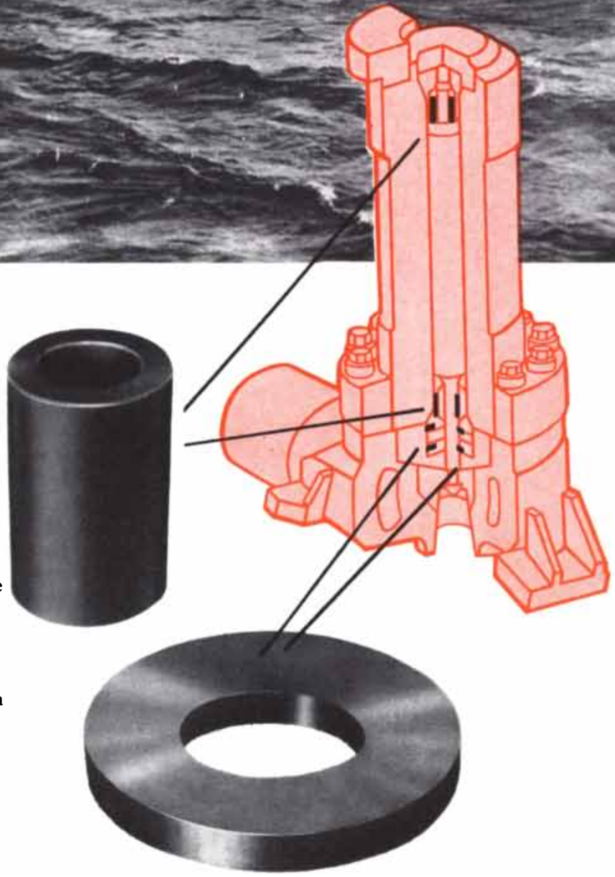


Working closely with the Atomic Energy Commission, the Westinghouse Electric Corporation designed and built the power plant for the NAUTILUS, first atomic-powered submarine. The soundness of every engineering principle, every individual part—including the GRAPHITAR pump bearings—has now been proved by the more than 50,000 miles the submarine has steamed, approximately half was submerged. These Westinghouse-designed pumps are hermetically sealed within the integrated pump and drive motor. All leakage past the pump seal is contained within the flooded motor while the purely electrical elements are contained in "cans" to exclude the water.

The GRAPHITAR pump bearings in the power reactor of the Nautilus have withstood high speeds, extreme temperatures, and great pressures, and have come through this test-period with a perfect performance record . . . their only lubricant, radioactive hot water!

This same GRAPHITAR that has proved its ability to help harness the power of the atom is available for use in performing equally tough jobs in your product, too . . . why not get full information today.

226

THE UNITED STATES GRAPHITE COMPANY

GRAPHITAR® CARBON-GRAPHITE • GRAMIX® POWDERED METAL PARTS • MEXICAN® GRAPHITE PRODUCTS • USG® BRUSHES

DIVISION OF THE WICKES CORPORATION, SAGINAW 6, MICHIGAN dex should be dimensionless, but in the above cases cannot be, because of the missing factors of receiver sensitivity and receiving antenna effective area. Equipment weight should not be included in the echolocation efficiency index, since weight does not determine echolocation efficiency. Weight depends more on the success of the designer in achieving miniaturization, and may be evaluated separately in a power-to-weight ratio comparison.

Calculated echolocation efficiency indices based on the above method, using Dr. Griffin's data, are as follows:

Bat (*Eptesicus*)	356
Radar (SCR-268)	4,030
Radar (AN/APS-10)	4,620
Sonar (QCS/T)	225

Calculated power-to-weight ratios for the bat and for the AN/APS-10 radar (the only other "airborne" equipment) are as follows:

Bat (*Eptesicus*)	.001 watt per kilogram
Radar	100 watts per kilogram

The above figures might indicate that the bats have not yet reached the end of their evolutionary research and development program.

GORDON LARSEN

Fairchild Guided Missiles Division
Wyandanch, N.Y.

Sirs:

The principal question raised by this stimulating letter is whether the customary radar equations are applicable to all forms of echolocation, natural and artificial. I am not certain that the assumptions underlying these equations are valid for all types of bats. For instance, F. P. Möhres states that the emitted sound level of the horseshoe bats falls off with distance more slowly than the inverse square law predicts, and some bats certainly detect wires, and perhaps insects, that are below one tenth of a wavelength, so that the echo intensity falls off very rapidly with decreasing target diameter (Rayleigh scattering). My echolocation efficiency index involved compromise approximations in attempting to compare systems adapted for such widely different kinds of energy, media of transmission, tar-

Miniature Directional Signal. A foraging bee brings home one drop of nectar. His fellow workers sniff it like bloodhounds, and from the scent know just where to go for more. This tiny droplet is nature's miracle for keeping bees on the beam.

Miniature Selector Switch. Missiles stay on course when controlled by complex selector switch. Two MPB bearings on its shaft make frictional torque practically negligible, keep total weight down to .42 ounce. It's a man-miracle in miniaturization.

Man With Miracles. This is Hank Eckert, one of MPB's Sales Engineers. He helped the selector switch people find exactly the right type of MPB radial retainer bearing to hold friction to a minimum, give dependable service and assure operating precision.

Designers' dream world Miracles in Miniaturization

BEARING ACTUAL SIZE

New Miracles. Today's industrial scientists are pioneering a whole new world of man-made miniaturization. With MPB miniature bearings and experience it is a wide, wide world on a tiny scale. For in miniaturization, bearings are one of the most critical considerations.

MPB makes miniature bearings ⅜″ O.D. *down* (specials on request). In stock—over 500 types and sizes. Consult MPB when you are embarking on a miniaturization problem and/or write for new MPB catalog. **Miniature Precision Bearings, Inc.,** 1210 Precision Park, Keene, N. H.

MPB

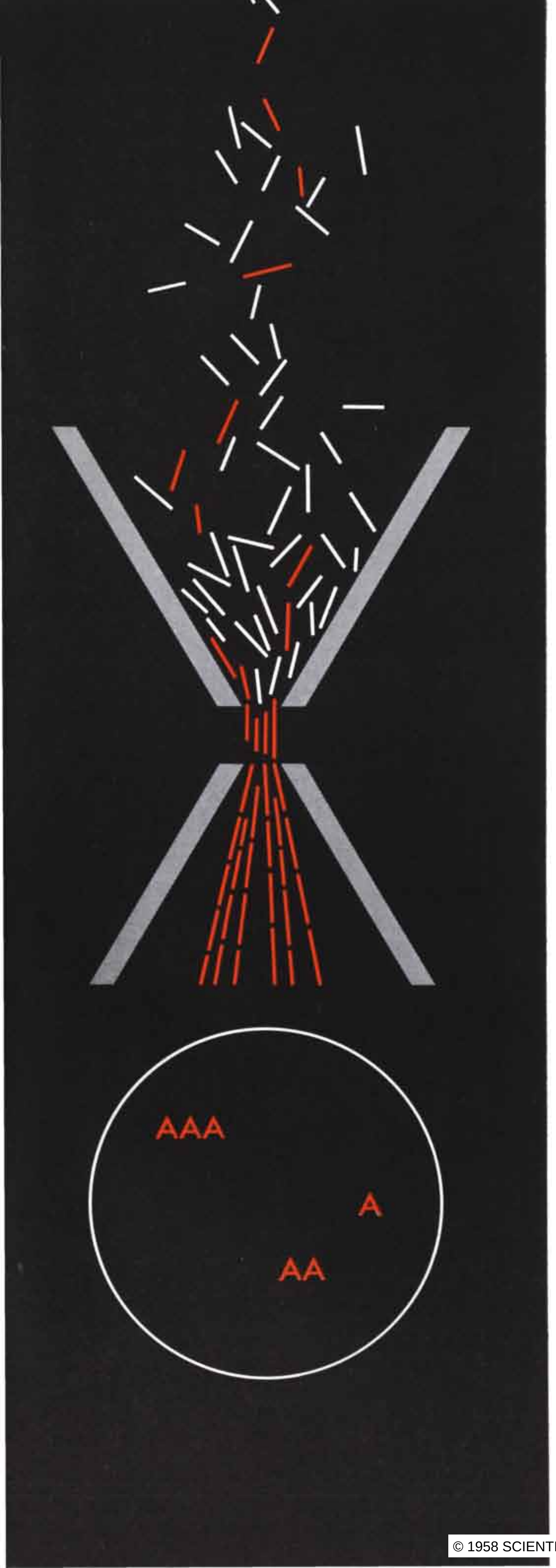
Helps you perform miracles in miniaturization gets, and distance ranges. It has served its purpose in helping to call attention to the wide variety of successful systems for echolocation.

The usual concept of antenna gain may not be strictly applicable to bats, except perhaps the horseshoe bats which scan with narrow beams of constant-frequency sound. The "FM bats" use a broad beam and appear to detect insects even when they are 60 to 90 degrees to one side. This may waste power (though microwatts are of minor concern even to a bat), but it eliminates the need for scanning movements of the body, head, ears or nose leaf. Hearing in all mammals is both broadly sensitive to sounds from almost any direction and at the same time highly directional in determining the angle from which sound waves are arriving. Should one estimate the receiving-antenna gain from the broad angle of good sensitivity or from the much narrower angular discrimination demonstrated by sound localization? Comparison within the brain of signals derived from the two ears undoubtedly facilitates localization of sound sources, and probably also reduces the effective noise level of the bat's receiving system in those portions of the brain concerned with binaural interactions. Pulse durations of the FM bats are much longer than in radar, but should not some allowance be made for the much smaller number of individual waves? Radars often emit hundreds or thousands of pulses during the time needed to locate a target, but bats intercept elusive insect prey with many fewer pulses.

Comparisons of efficiency in the broadest and most meaningful sense must certainly take account of compactness, reliability, self-repair and maintenance, as well as economy of power. Nor does my simple index reflect the multiple functions performed by the same organs and tissues—to say nothing of the speed and precision with which information from faint echoes is processed to guide complex flight maneuvers. Finally I should point out that the figure for the bat's weight was that of the entire animal, since I could see no way to estimate accurately the small fraction of its total body devoted exclusively to echolocation. Should the comparison perhaps be based on the weight ratio of a bat to a radar picket plane?

DONALD R. GRIFFIN

Harvard University
Cambridge, Mass.


AAA
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A Report on the

Ten basic attributes that can help you satisfy both design and production needs.

The properties of copper alloys are a handbook in themselves. No group of metals is more versatile. Here are electrical, thermal, structural, chemical and finish properties that are unique. Here are metals that can be shaped and joined by almost every known method.

There are over 40 standard alloys of copper. And each has its own set of specifications, its own combination of properties. Finding the one that best matches *your* specifications is the problem. And the answers to that problem keep changing. Copper industry research into new alloys and new forming and preforming methods gives designers a latitude today that challenges both their imagination and their ability to keep posted. Today we must assume that some copper alloy *can* do the job.

Here are just ten of the more important design requirements that point to the selection of a copper alloy:

1.

Electrical Conductivity. The various types of commercially pure copper have long been the most economic conductors. Now, copper-chromium and copper-cadmium alloys have improved mechanical properties along with high conductivity. And silver-bearing coppers with as good conductivity as commercially pure copper have a higher softening temperature for certain applications involving high temperatures.

2.

Thermal Conductivity. Since many of the low-zinc brasses, as well as copper itself, offer outstanding heat transfer rates, selection usually depends on the other properties desired — corrosion resistance, hot strength, ductility, etc.

3.

Corrosion Resistance. Every corrosion problem is different — and there's a copper alloy to meet most: for chemical applications, heat exchangers, processing equipment, refrigeration apparatus, etc.

4.

Strength. The high-zinc brasses, nickel silvers, beryllium copper, the silicon bronzes and the phosphor bronzes can be processed to provide tensile strengths of the order of 140,000 psi for hard-drawn wire.

Copper Metals

5.

Ductility. The ductility of most copper alloys permits forming them into a wide variety of shapes and sizes, by spinning, stamping, deep-drawing, etc. For example, the coppers, most brasses and nickel silvers are ideal for cold forming.

6.

Malleability. Pure copper and many of its alloys have excellent malleability for forging, cold heading, coining, embossing, extruding, knurling, swaging, etc.

7.

Machinability. Free-Cutting Brass, tellurium copper, some of the bronzes and the leaded brasses are readily machinable at high speeds and feeds.

8.

Joining Qualities. Copper and most copper alloys can be easily soldered — or, for even stronger joints, brazed with either silver alloys or copper phosphorus alloy. The non-leaded brasses, phosphor bronzes, silicon bronzes and cupro-nickels as well as deoxidized copper also lend themselves readily to welding by a number of processes.

9.

Surface Qualities. The nickel silvers and low-zinc brasses are widely used in ornamental applications because of their ease of plating and finishing as well as their cold-working properties. New fine-grain brasses offer an ideal surface structure for high finish.

10.

Casting Facility. There are eight basic categories of casting alloys, ranging from the hard, but very strong, manganese bronzes to the free-machining leaded bronzes.

The combination of properties that you need for the best product and the optimum manufacturing cost can probably be found among the copper metals. The copper industry will help you find it. The Copper & Brass Research Association, 420 Lexington Avenue, New York 17, New York, will welcome your inquiry.

There's a new frontier in...

COPPER
BRASS
BRONZE

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1908: "Madam Curie's announcement that she has been unable to obtain experimental verification of Sir William Ramsay's discovery of the transmutation of copper to sodium, potassium and lithium naturally makes one wonder if the late Lord Kelvin was not justified in doubting the accuracy of Sir William's investigation. On the other hand, Ramsay is so careful a chemist that he is not likely to draw rash conclusions. Madam Curie carefully purified her materials. So did Ramsay. Yet we have contradictory results. We must wait now for a third verification or refutation before we can be quite sure."

"A successful test of wireless telephony was recently conducted between the British cruiser *Furious* and the schoolship *Vernon*. Both vessels were steaming at full speed, separated by a distance of 50 nautical miles. The De Forest system was used. The inventor operated the transmitter on the *Furious*, while Mrs. De Forest received the messages on the *Vernon*. The test consisted largely in repeating stock quotations and it is stated that, out of 154 figures, there were only two mistakes."

"Since winning the $1,000 prize offered by the Aviation Committee of the Aero Club of France for the longest flight up to October 1, by his flight of 48.1 kilometers (30 miles), Mr. Wilbur Wright has successfully met the conditions of his contract for the sale of the Wrights's French patents for $100,000. The conditions made by M. Weiller's syndicate required him to make two 50-kilometer flights, carrying a passenger, within a week's time. These flights Mr. Wright accomplished on October 3 and 6. The first, with Franz Reichel of the Paris *Figaro* as passenger, was completed by moonlight. Among those who have flown with Mr. Wright are M. Leon Bollé, who weighs 238 pounds; Mrs. Hart O. Berg, the first woman to fly in a Wright aeroplane; Michalo Pulo, an 11-year-old boy; and Major Baden-Powell of England. Another passenger, George B. Dickin, Paris correspondent of the New York *Herald*, reports that in starting the sudden rush forward was much like the sudden drop on a water toboggan, or roller coaster, but once the machine was soaring he felt perfectly secure, and found the swift motion through the air much more pleasurable than riding in an automobile, as it was unaccompanied by any shock or jar, though the noise of the unmuffled motor beside him was almost deafening."

"Upon the new observations of Prof. Hale, made at Mount Wilson, Calif., on the double lines in sunspot spectra, Prof. Zeeman bases a theory that sunspots are strong magnetic fields. The source of light in a magnetic field emits two rays circularly polarized in opposite directions and parallel to the lines of magnetic force, according to Prof. Zeeman's experiments. The sunspot lines photographed by Prof. Hale are identical in character with these lines. To produce the actual phenomenon observed would require a current of about 5,000 amperes. The theory throws a great light upon meteorological and terrestrial magnetic phenomena, affording, as it does, some reason for the perturbations observed in the electric and magnetic equilibrium of our earth and its atmosphere."

"Less than three months ago Count Zeppelin's fourth airship was destroyed, yet so quickly and generously did the entire German nation come to his aid—$750,000 was raised—that he has already built the *Zeppelin V*, which made its initial flight above Friedrichshaven on the 23d instant. The press reports indicate that a successful flight was accomplished. The new airship carried 10 passengers and maneuvered for three and one half hours. It rose to a height of 600 feet and attained a speed of 29½ miles an hour."

SCIENTIFIC AMERICAN

OCTOBER, 1858: "On the second of June last, an Italian astronomer named Donati discovered a comet approaching slowly toward the sun, in a northwesterly direction, and increasing in brightness—as all comets do—as it draws nearer old Sol. Like a streaming torch of silvery light, extending 15 millions of miles in length through the heavens, it hangs evening after evening gracefully over

1 in 35,000,000

How the telephone switching system sorts numbers in seconds

When you dial out of town, the telephone switching system performs an amazing feat. It sorts out the one other number in 35 million you want, and connects you to it in seconds. The other telephone may be thousands of miles away.

Bell Laboratories engineers endowed this great switching network with almost superhuman capabilities. As you dial, the machine listens, remembers, figures out the best route, makes connections, alerts, reports, even corrects itself. If it detects trouble on the way, it files a report, then chooses other circuits and goes on to complete your call. All you are aware of is the end product—the completed call.

Yet at Bell Telephone Laboratories, switching engineers see the present system as only a beginning. Ahead they see—and are developing—new systems vastly more flexible and capable than today's. Nowhere in telephone technology is the challenge greater. Nowhere are dreams coming true faster.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

These Bell Telephone System directories list some of the 35,000,000 telephones now linked by the Direct Distance Dialing system developed at Bell Laboratories. In seconds, this unique machine sorts out and connects you with precisely the number you want.

the northwest sky. Its head resembles a ring with a bright nucleus in the middle, or an illuminated globe with its intense flame in the center. The diameter of this ring, as measured by Prof. Mitchell of Cincinnati, is 18,000 miles. It has been approaching the path of our planet, with the apparent intention of giving us a friendly brush, and on the date of this number of the Scientific American, it will have attained to its maximum brilliancy."

"No signals have been transmitted through the Atlantic Cable for some time, and it is asserted that there is a leak in it about two hundred miles west of Ireland."

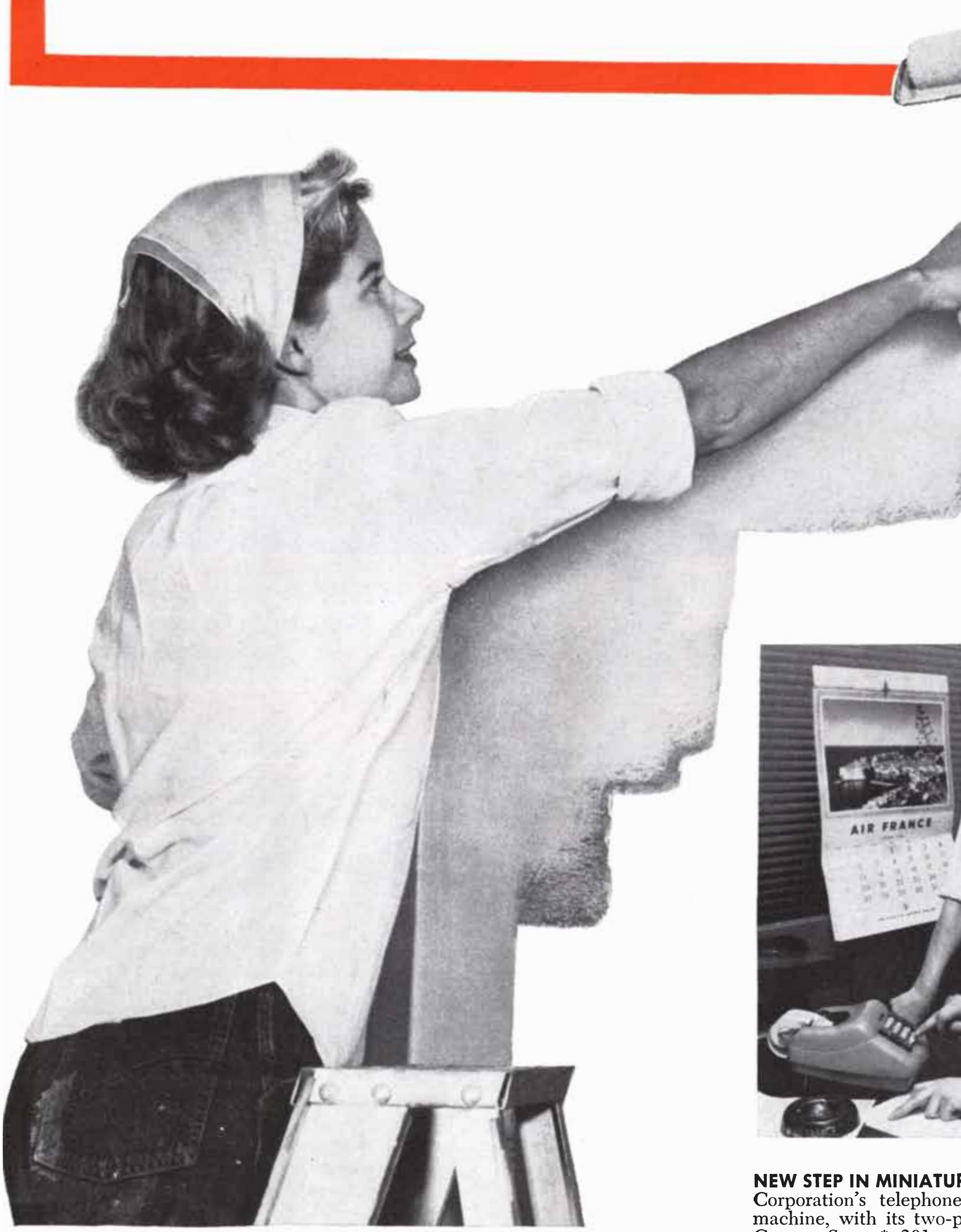
"Recent intelligence has been received from Dr. Livingston's expedition up the River Zambesi in Africa. They are now going up that river slowly, and have discovered a peculiar kind of cotton growing, but it is not to be compared to even the middling quality of South Carolina cotton."

"Overland regular mail communication has been established between St. Louis and San Francisco. The first mail arrived on the 9th inst. in twenty-three days from the shores of Pacific, and it was the occasion of general rejoicing in St. Louis."

"Although we possess inexhaustible stores of the best iron ores for making all kinds of steel, very little of this useful metal is manufactured in our country in comparison with the amount imported from abroad. We import annually about 13,000 tuns of steel, valued at $2,300,000, and the best qualities come from England. We learn from the recently published work of B. F. French on the American iron manufacture that about 6,000 tuns of steel are produced annually in Pennsylvania, but it is of such an inferior quality as not to interfere with the trade in English steel."

"On almost any pleasant day a portly man with flowing hair, white cravat, and broad-brimmed Kossuth hat, may be seen on Broadway, dashing along behind a splendid pair of fancy horses, fit for the stud of an emperor, and with all the ease and indifference of a millionaire. That man is Elias Howe, Jr., once the poor and humble inventor, who in 1849 obtained a patent for the first practically useful sewing machine. We rejoice in the good fortune of our old friend, and can only say to him that he is entitled to all that he has received."

Life on the Chemical Newsfront



NEW SURFACTANT IMPROVES EMULSION PAINTS. AEROSOL® TR *surface active agent* has a very high oil solubility and is particularly effective for oil-in-water emulsions. In emulsion polymerization, it offers an unusually wide working range of concentration from 0.05% to 1.0%, and produces small emulsion particles in a very narrow particle size range of 2 to 3 microns. At an optimum concentration of 0.1% to 0.5%, the emulsion formed is stable and of low viscosity. AEROSOL TR produces high rub resistance and storage stability in paint formulation, and provides excellent water resistance in the dried film. **(Industrial Chemicals Division)**

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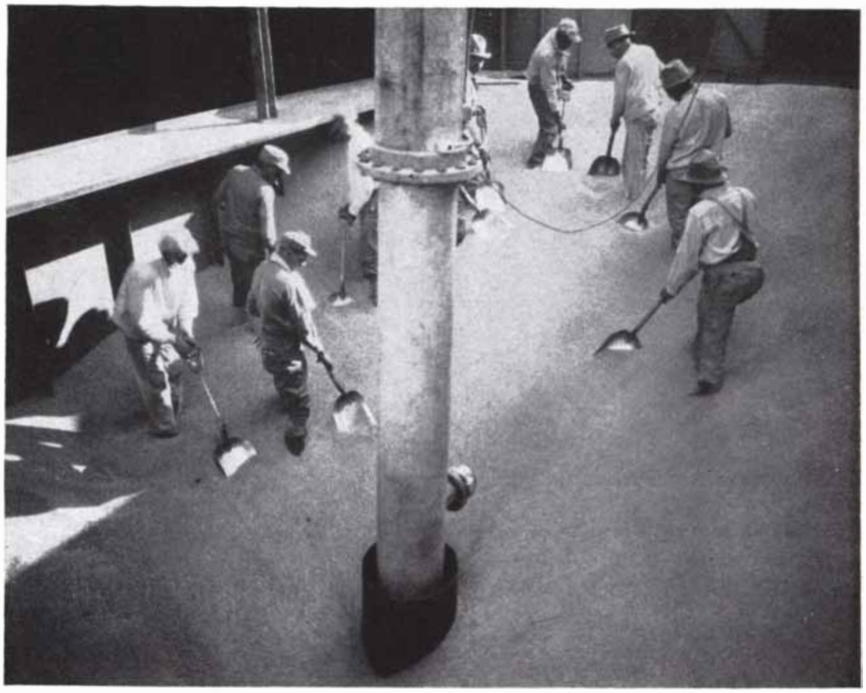
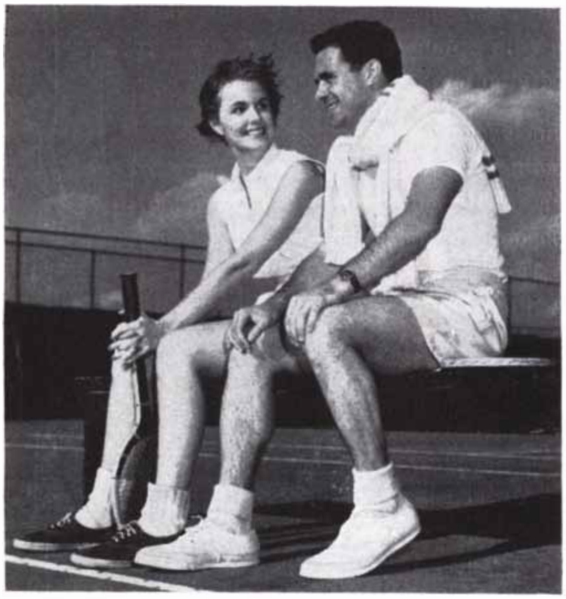


GRAIN GOING INTO STORAGE this year can now be protected against insects by Cyanamid's broad-spectrum insecticide, *malathion*, recently cleared by the United States Food and Drug Administration for direct application to grain after extensive research and almost two years of commercial use in Canada. Malathion has proved highly effective in providing continuous protection over long periods against major pests which infest storage bins. The small amount needed makes it economical to use and also presents no residue problems. Malathion can be applied directly to grain in both sprays and dusts, and used as clean-up sprays in and around both commercial elevators and farm storages. (Agricultural Division)



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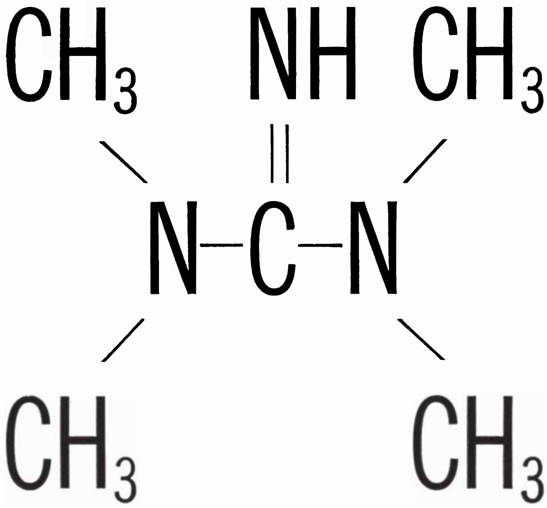

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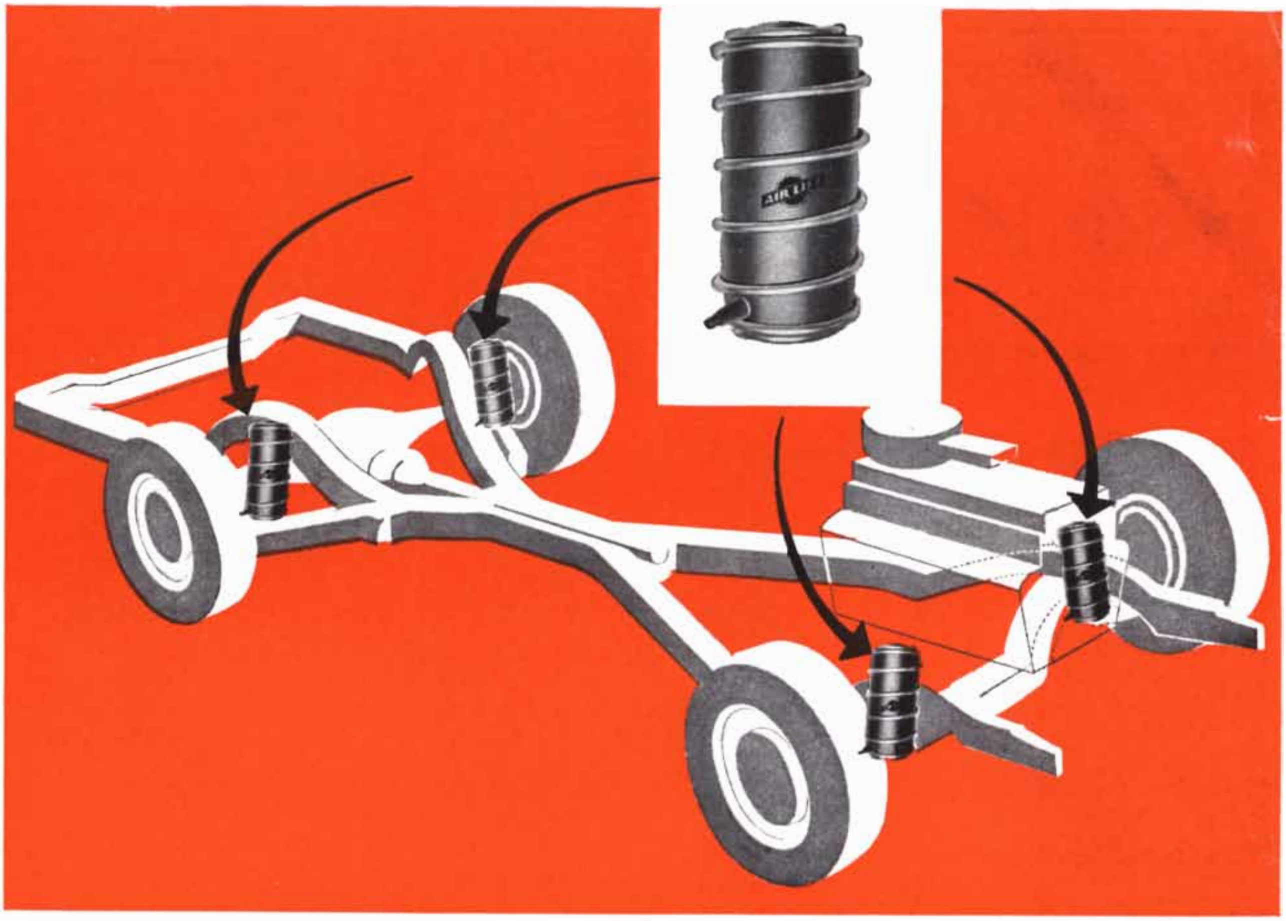
THE AUTHORS

LYMAN SPITZER, JR., ("The Stellarator") is director of Project Matterhorn, a large-scale investigation at Princeton University into the possibilities of fusion power. He is largely responsible for launching the project: in 1951, unaware that the Atomic Energy Commission was already conducting fusion research at the Los Alamos Scientific Laboratory, he approached the Commission with proposals which led to the setting up of a second research center. A native of Toledo, Ohio, Spitzer has studied at Yale, Harvard and Princeton universities and at the University of Cambridge. He has been a member of the Princeton faculty since 1947; in 1952 he was appointed Charles A. Young Professor of Astronomy, succeeding the eminent astronomer Henry Norris Russell. In addition to his duties as director of Project Matterhorn, Spitzer heads the Princeton department of astronomy and is director of the University observatory. Most of his work has been in theoretical astrophysics, though he did sonar research for the Navy during World War II. He became interested in fusion power early in 1951, after reading about the alleged Argentine success in the field. "Shortly after the Argentine story broke," he writes, "I went to Aspen, Colorado, for a ski trip. In the relaxed atmosphere there, and especially while riding the chair lift, I gave some thought to the problem of how a controlled thermonuclear reactor might be built. Many of the essential ideas of the stellarator stemmed from my thinking during that week, and during the weeks in Princeton immediately following. I don't know quite what this story proves, but perhaps it is an argument for more frequent vacations."

DOUGLAS MARSLAND ("Cells at High Pressure") was born in Brooklyn in 1899, and has been a member of the New York University faculty since 1924. Most of his teaching is in the field of general biology, a subject on which he has written a textbook. This, he says, "has kept my interests from becoming narrow." His researches on cell physiology frequently involve work with marine organisms; a study of bioluminescence with Dugald E. S. Brown (now at the University of Michigan) and Frank H. Johnson of Princeton University won the Newcomb-Cleveland Prize of the American Association for the Advancement of Science in 1941. His interest in the ocean was awakened in 1919, when he spent a year as a radio operator on a tramp steamer. Nowadays he spends several months of each year at marine laboratories, mainly the Marine Biological Laboratory in Woods Hole, Mass. He has also worked at the Naples Zoological Station, the Bermuda Biological Station and the Lerner Laboratory in Bimini, British West Indies. He became interested in cellular physiology while doing graduate work at N.Y.U. under Robert Chambers, a pioneer in the field.

LUDWIG F. BIERMANN and RHEA LÜST ("The Tails of Comets") are colleagues at the Max Planck Institute for Astrophysics, which has recently moved from Göttingen to Munich; Biermann is director of the Institute. Born in 1907 in Hamm, Westphalia, he received his Ph.D. from the University of Göttingen in 1932 and spent the next two years as an exchange scholar at the University of Edinburgh. Returning to Germany, he taught at several universities between 1934 and 1947. In the latter year he was made head of the astrophysics section of the Max Planck Institute for Physics, a position he held until 1957, when his section was reorganized as the Institute for Astrophysics. In addition to his work at the Institute, he heads the German program for research into controlled thermonuclear reactions. He is married and has three children. Mrs. Lüst was born in Hannover in 1921. She studied astronomy, mathematics and physics at the University of Göttingen, where she received her Ph.D. in 1953 for an investigation of the atmospheres of variable stars. She remained at Göttingen until 1956, working on problems of the solar atmosphere. She then joined the Max Planck Institute. In 1953 she married Reimar Lüst, an astrophysicist also associated with the Institute.

PAUL THIEME ("The Indo-European Language") is a leader in the field of anthropological linguistics. In addition to his work on reconstructing the language of the original Indo-European people, he has attempted to reconstruct their religion and folklore. He is also the author of works on indigenous Indian linguistics. Born in Berlin in 1905, he took his Ph.D. at the University of Göttingen in 1928. From 1932 to 1935 he had the opportunity to pursue an interest in India at first hand as a lecturer in German and French at Allahabad University. From 1936 to 1946 he taught



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Akron • Boston • Charlotte • Chicago • Detroit • Los Angeles • New Orleans • Tulsa at the University of Breslau, and from 1946 to 1953 at the University of Halle in East Germany. In the spring of 1953 he left Halle to accept a chair at the University of Frankfurt in West Germany. Since 1954 he has been Edward E. Salisbury Professor of Sanskrit and Comparative Philology at Yale University. Yale, he says, provides "a wonderful atmosphere for quiet work, such as I did not have in Germany since 1935 due to political interference."

MARCUS SINGER ("The Regeneration of Body Parts") is professor of zoology at Cornell University. Born in Pittsburgh in 1914, he took his Ph.D. at Harvard University in 1942, and for the next nine years taught anatomy (mainly neuroanatomy) at the Harvard Medical School. In 1951 he moved to Cornell, where he teaches human anatomy and comparative neuroanatomy. In addition to his researches on regeneration, he has published articles on protein chemistry, cell chemistry and neuroanatomy, and is co-author of a book on the human brain. He has recently been elected a Fellow of the American Academy of Arts and Sciences.

JOSEPH V. BRADY ("Ulcers in 'Executive' Monkeys") is head of the department of experimental psychology in the Neuropsychiatry Division of the Walter Reed Army Institute of Research, Washington, D.C. Born in Brooklyn in 1922, he received his B.S. from Fordham University in 1943. While still an undergraduate, Brady had joined the R.O.T.C.; in 1945 he was sent overseas and commanded an infantry platoon in Europe. He remained in the Army after the war, and spent two years in Germany as Chief Clinical Psychologist in the European Command. The Army then sent him to the University of Chicago, where his interest soon shifted from clinical to experimental psychology. He received his Ph.D in 1951; his thesis concerned emotional behavior in rats. Now a major in the Army's Medical Department, Brady presently works on the experimental analysis of behavior, with special reference to its physical concomitants.

F. F. NORD and WALTER J. SCHUBERT ("Lignin") are members of the faculty at Fordham University. Nord is professor of organic chemistry and enzymology; Schubert is associate professor of organic chemistry and biochemistry, and heads the chemistry department of the University's College of Pharmacy. Nord took his D.Sc. at the

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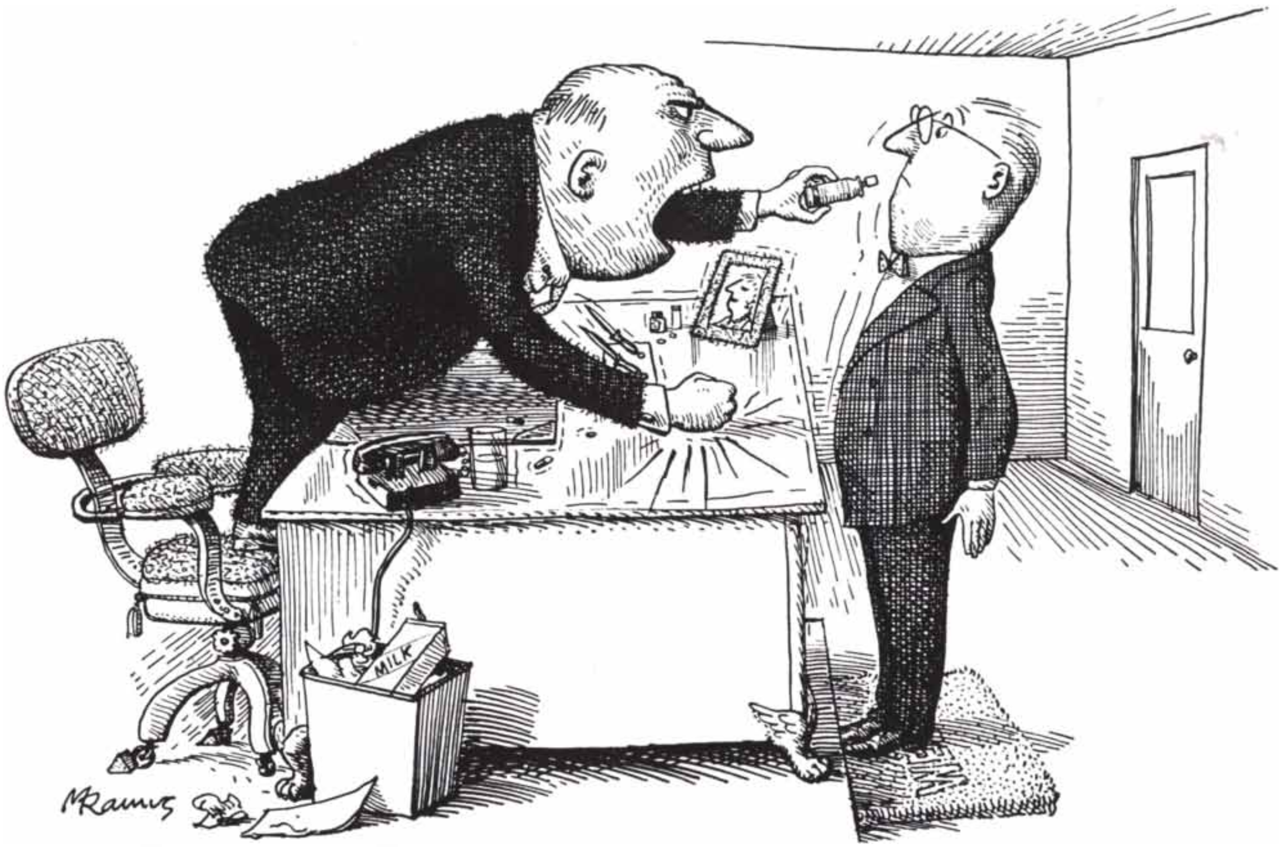
Technische Hochschule in Karlsruhe in 1914. From 1914 until 1920 he was assistant professor at the Kaiser Wilhelm Institute for Biochemistry in Berlin-Dahlem; his activities there were interrupted by a period of service as an officer in the German air force. He first visited the U. S. from 1925 to 1927, when he worked as a Rockefeller Foundation Fellow at the Mayo Clinic and at the University of Minnesota. On his way back to Germany he lectured in Japan and India. He taught at the University of Berlin until 1938, when he was invited to come to Fordham. His researches have spanned more than half a dozen important areas in organic chemistry, including fermentation, catalysis, proteins and polymers. He is an editor of *Advances in Enzymology* and editor-in-chief of *The Archives of Biochemistry and Biophysics.* Schubert was born in Brooklyn in 1925, and received his Ph.D. from Fordham in 1950. While there he helped to initiate some of the studies of wood chemistry which have continued up to the present. After teaching for a year at John Carroll University in Cleveland, Ohio, and for two years at St. John's University in Brooklyn, he returned to Fordham as a Procter and Gamble Research Fellow and once more turned his attention to wood chemistry.

EDWARD S. DEEVEY, JR., ("Bogs") is professor of biology and director of the Geochronometric Laboratory at Yale University. Though his researches have centered on paleoecology, he notes that "I seem to be a general ecologist for teaching purposes." A National Science Foundation award for research in the dating of lake sediments enabled him to spend several months recently boring into lake bottoms in the Auvergne and the Jura Mountains. Born in Albany, N.Y., in 1914, he developed an early interest in nature studies which won him 41 Boy Scout merit badges and the Boy Scout Nature Prize in 1928. His major relaxation is scientific field trips; when forced to stay home he enjoys reading and pre-Beethoven chamber music. He has published a number of articles in SCIENTIFIC AMERICAN, the most recent of which was "The Human Crop" (April, 1956).

ERNEST NAGEL, who reviews J. F. Scott's *A History of Mathematics* in this issue, is John Dewey Professor of Philosophy at Columbia University. An authority on symbolic logic, Nagel is author of *Sovereign Reason* and (with the late Morris R. Cohen) of *An Introduction to Logic and Scientific Method.*



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The Stellarator

Described at last month's Geneva conference, this experimental device for fusion power research employs a twisted magnetic field to contain an ionized gas and electric fields to heat it

by Lyman Spitzer, Jr.

At the first International Conference on the Peaceful Uses of Atomic Energy in Geneva three years ago, representatives of 72 nations gathered to compare their efforts to extract economical power from the energy liberated by nuclear fission. As the Conference opened, however, fission reactions momentarily lost the center of the stage to an even more exciting prospect. The president of the Conference, Homi J. Bhabha, predicted that within 20 years man would be deriving useful power from the thermonuclear reactions. He revealed that Indian workers were already engaged in active development of this possibility. Since these reactions, involving the fusion of nuclei of the heavy isotopes of hydrogen, may look to the oceans as a source of fuel, such a technological breakthrough would guarantee mankind a practically inexhaustible supply of energy.

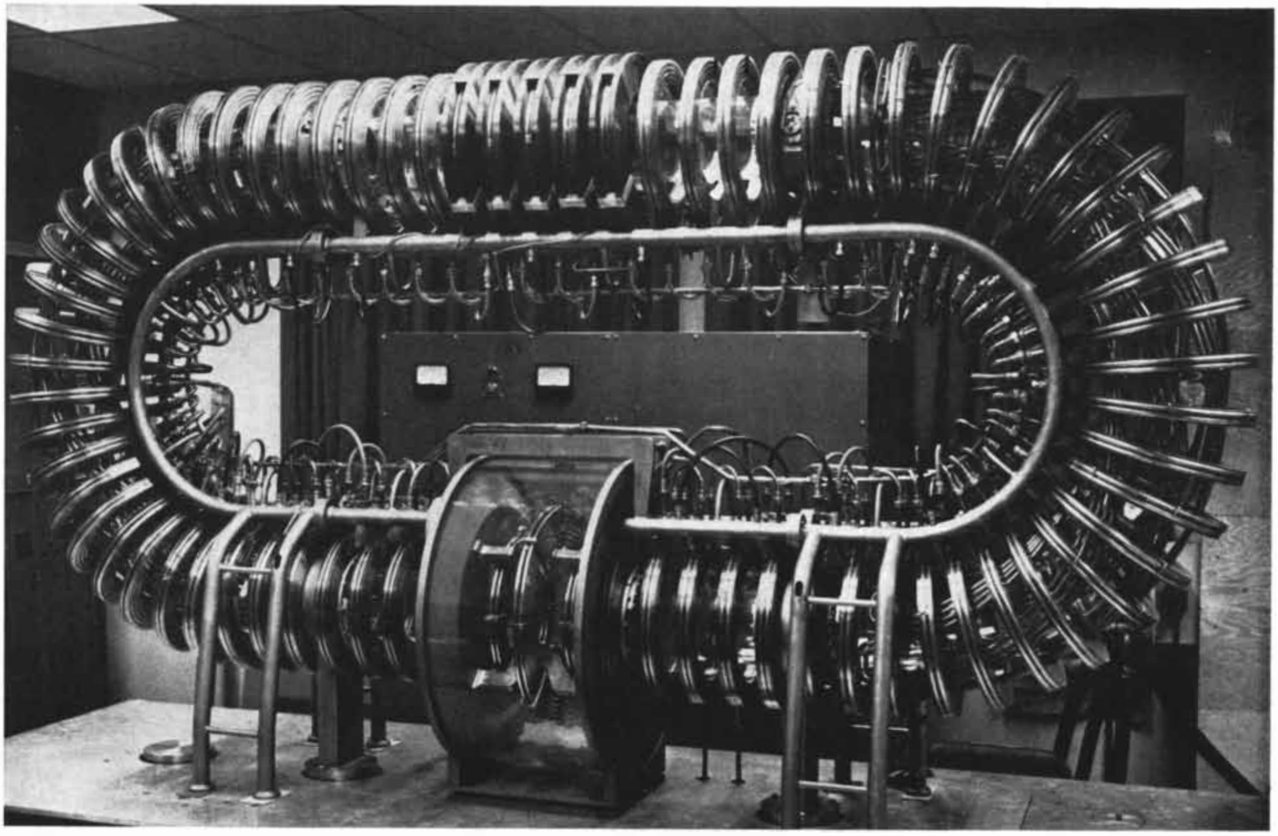
Last month, at the second Geneva conference on atomic power, the fusion reactions were at the center of the stage to stay. The knotty and often profound questions encountered in the research engaged a substantial portion of the formal and informal discussions. The elaborate experimental gear exhibited by the United Kingdom, the U. S. and the U.S.S.R. testified to the huge scale of the programs the major nuclear powers have been conducting, until recently in secret. Amid the hopeful accounts of progress, no one could yet claim conclusive evidence for the attainment of a controlled thermonuclear reaction. On the other hand, no one reported the discovery of any insurmountable obstacle.

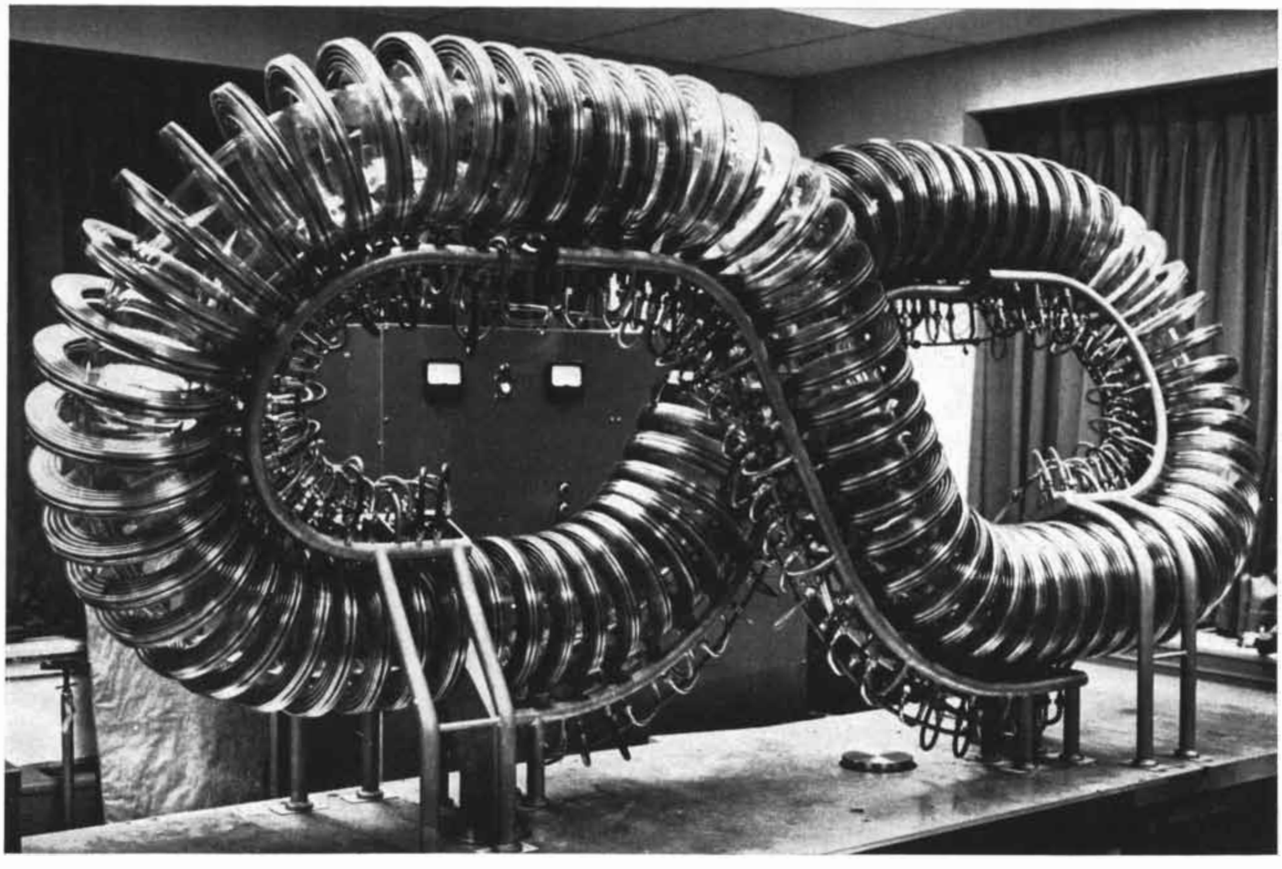
Among the several approaches of the U. S. program publicly disclosed in detail for the first time at Geneva is the "stellarator," the subject of this article. It is the work of Project Matterhorn at Princeton University and embodies some of the things we have learned from theoretical and experimental investigations conducted since 1951.

For us, as for others in the field, the work is defined by the dual objective of igniting and containing a thermonuclear reaction. When two nuclei of heavy hydrogen collide at high energies, they interact, forming a new nucleus and liberating either a proton or a neutron of high energy. To obtain a useful power yield from this reaction, a gas of deuterium (hydrogen of mass 2) or of mixed deuterium and tritium (hydrogen of mass 3) must be brought to an enormously high temperature—about 100 million degrees absolute (degrees centigrade above absolute zero). The problem then is to contain or confine the gas within a limited region away from contact with any solid material. If the ultra-hot hydrogen strikes anything which is solid and, of necessity, relatively cool, the temperature of the gas will drop sharply, and the solid material will tend to evaporate.

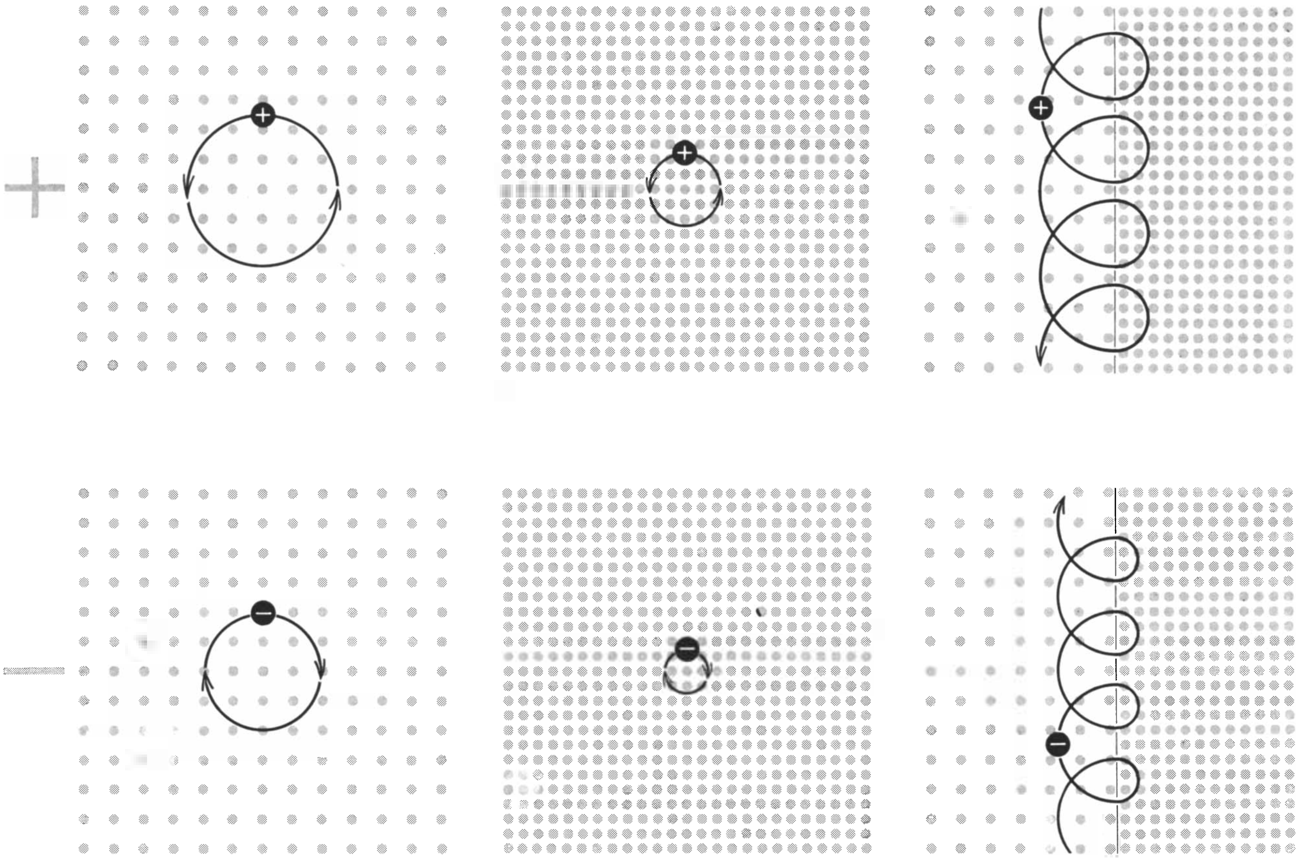
Magnetic forces seem to offer the only way to contain a thermonuclear reaction. One effort in the search for a "magnetic bottle" has been devoted to the so-called "pinch effect." Here the flow of a heavy electrical current through the hot gas generates a strong magnetic field which at once contains the gas and brings it up to high temperature by compressing, that is, pinching, it [see "Fusion Power," by Richard F. Post; SCIENTIFIC AMERICAN, December, 1957]. The Matterhorn project is trying a somewhat different tack. In the stellarator we are undertaking to contain the gas in a magnetic field produced independently of the electric current that heats the gas up through the first million degrees. We hope to reach ultrahigh temperatures via an effect called "magnetic pumping," induced by a second externally generated, rapidly pulsating magnetic field. Whether the stellarator will achieve a controlled thermonuclear reaction we do not yet know. At each step in its development we have had to solve unexpected problems, and each time have learned something new about the weird and wonderful properties of a hot gas in a magnetic field. Many more such problems await us.

The stellarator produces its containing magnetic field by the perfectly straightforward method of passing a strong electric current through a solenoidal coil [*see diagram at top left on page 31*]. In the familiar example of a straight, cylindrical coil, such as that employed in simple relays, the magnetic field parallels the coil axis and has the same strength everywhere both along its





STELLARATOR TUBES, photographed at Project Matterhorn at Princeton University, have twisted magnetic fields designed to prevent the contained gas from striking the vessel walls. In the arrangement at top the twisting is produced by means of the set of helical coils which can be seen between the sections of the main field coil. Figure-eight shape at bottom also produces twist.



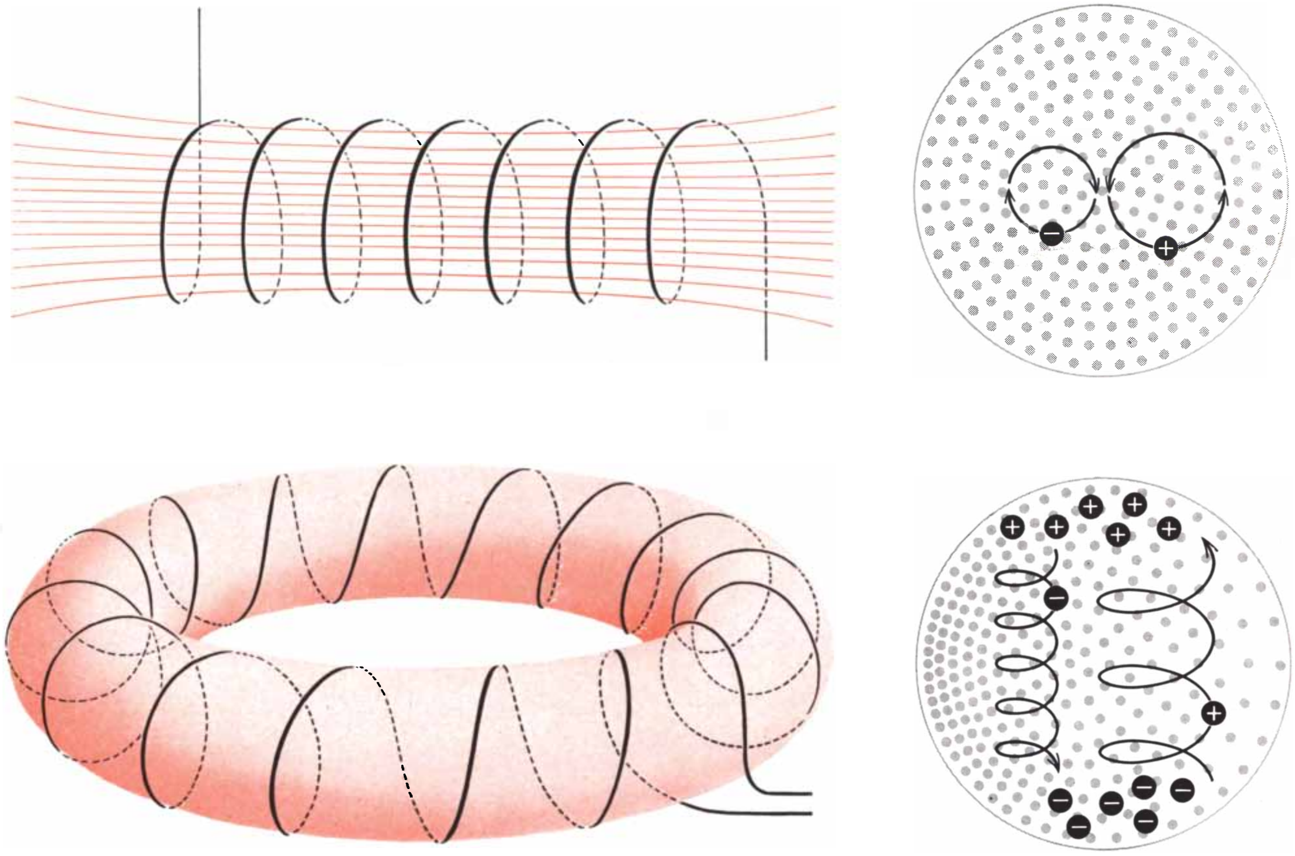
PATHS OF CHARGED PARTICLES in magnetic fields are shown schematically. Small dots represent cross sections of lines of force. In a weak, uniform field (*left*) a positive particle such as a deuteron ion (*top*) describes a circle in one direction; a negative particle such as an electron (*bottom*), a circle in the opposite direction. (Diameter of deuteron's path is actually 60 times as large as electron's.) In strong field (*second from left*) the circles are smaller. In an imaginary field changing abruptly from weak to strong (*right*), paths are spirals in opposite directions, made up of semicircles from the large and small circular paths.

length and through its cross section. The "lines of magnetic force," the imaginary lines following the direction of the field, are straight well inside the coil. If we place a hot deuterium gas in a tube inside such a field, it will respond to the magnetic force because its atoms are ionized, *i.e.*, stripped of their electrons. The electrically charged particles (positively charged nuclei and free electrons) moving across the magnetic field experience a deflecting force, and proceed to gyrate in circles about the lines of magnetic force. Since the motion of the particles along the lines of force is unaffected by the field, the path of each particle is a helix. Thus contained in the magnetic field, the gas will not touch the walls of the tube. We have here, in fact, an ideal bottle for a fusion reactor, were it not for the ends of the coil, where the lines of force must emerge and where the gas in consequence must come in contact with solid matter.

The simplest way to get rid of the ends of a long coil is to bend the coil in a circle, joining the two ends together to form a closed but endless tube. In such a toroidal, or doughnut-shaped, coil [*see diagram at bottom left on opposite page*] the lines of force become circles. Unfortunately this circular coil has a fatal defect which keeps it from qualifying as a satisfactory magnetic bottle. As a result of curvature, the strength of the magnetic field is greater near the inside wall of the tube than it is near the outside. This inhomogeneity of the field alters the helical path of the charged particles. Near the inside wall the relatively stronger field curves the path of a particle more sharply than near the outside. The result is that the charged particles drift across the field, the positively charged nuclei collecting at the top of the tube and the electrons at the bottom [*see diagram at bottom right on opposite page*].

This drift is bad enough by itself, but its indirect effect is catastrophic. The resultant separation of electric charges produces a large electric field, which disrupts the particle paths completely, throwing the entire gas into the wall. If the electric charges could only leak back across the lines of force, this disaster could be averted, but in a fully ionized gas this is not possible. It is a remarkable fact that a steady electric field imposed across a magnetic field produces no current at all in a fully ionized gas, but drives the gas particles in a direction at right angles to both the electric and magnetic fields. A steady electric field imposed along the magnetic field will easily produce an electric current parallel to the lines of force. But this does not help matters in the case of the simple torus, since the lines of force do not connect the regions of opposite electric charge.

It happens that there is a simple remedy for this catastrophic drift of charged particles across the toroidal magnetic field. By one means or another we can twist the magnetic field around



MAGNETIC CONTAINMENT of charged particles can be accomplished with a uniform field like that inside a long, straight tube wound with a helical coil carrying electric current (*top left*). Particles will travel through the tube in helical paths made up of circular motions around lines of force (*top right*) and motion along the lines. If the ends are closed by bending the tube into a doughnut (*bottom left*), the field is no longer uniform, being stronger on the inner part of the doughnut (*bottom right*). The result is that positive and negative particles separate, spiraling to top and bottom as in the right-hand diagrams on the opposite page.

its circular axis (called the "magnetic axis"), giving the lines of force a helical form like the strands of a rope. In this configuration a single line of magnetic force, if followed indefinitely on successive turns around the torus and successive twists around the magnetic axis, will trace out an entire surface, called a "magnetic surface." Lines of force near the magnetic axis will produce magnetic surfaces which are nested inside the surfaces produced by the lines of force farther out. This family of nested magnetic surfaces constitutes the magnetic bottle proposed for confining an ultrahot gas in a stellarator.

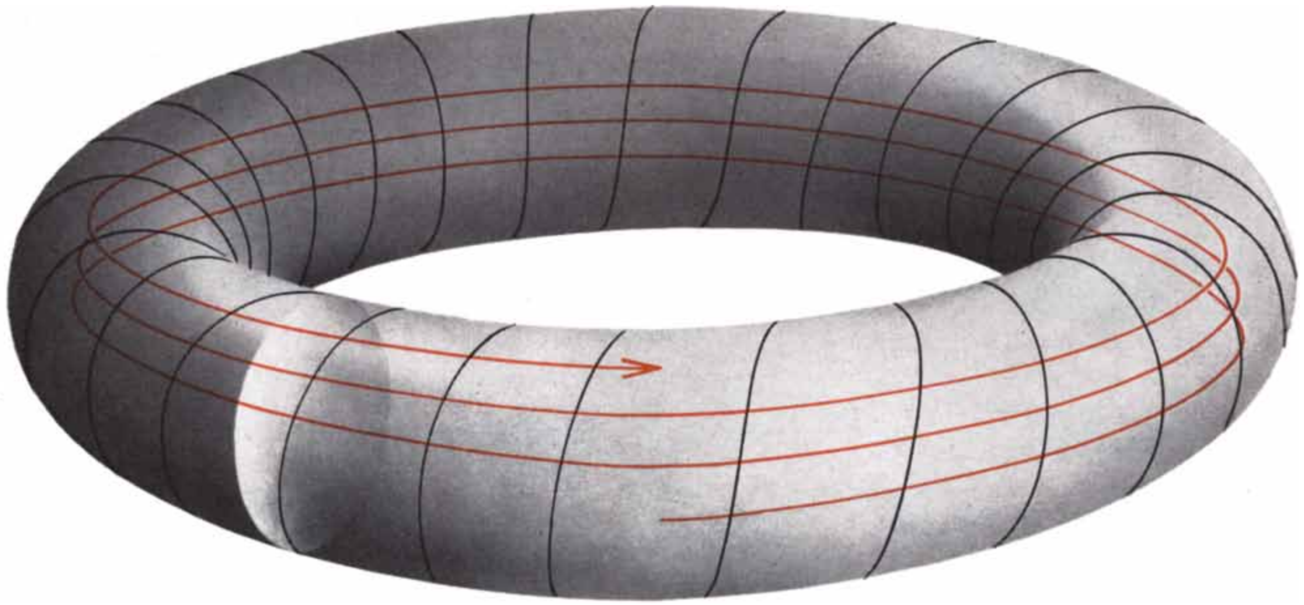
In this twisted toroidal field the effect of particle drift is much reduced. Most particles are moving rapidly along lines of force, and so are rotating about the magnetic axis as they follow the twist in the lines. When the upward-drifting particles are above the magnetic axis, they of course tend to move farther from the axis; when they are below, however, the same upward drift compensates for this by moving them back toward the axis. As a result their average distance from the magnetic axis does not change. Oppositely charged particles still show some tendency to drift apart, with an accompanying separation of charges. But now the charges can leak back along the lines of force, since a single line, if followed for a distance, leads from the top of the tube to the bottom. Any differences in electric charge along a line of force are thus eliminated, and a steady confinement of the ionized gas now becomes possible.

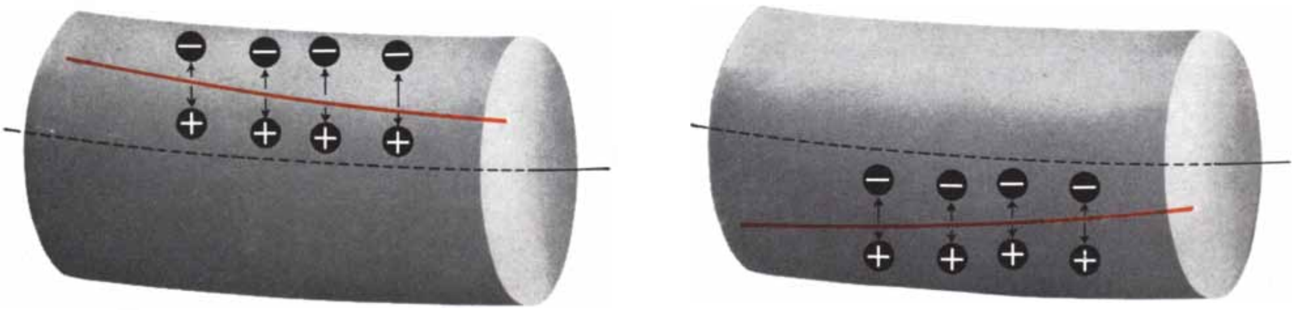
The necessary twist can be imposed on the toroidal field in a number of ways. Passing an electric current along the lines of magnetic force in a torus will do it, but such a current cannot be maintained in a steady state, and would require pulsing every few seconds. Since it is desirable to operate a fusion reactor continuously, without pulsing, some other method of twisting the lines of force is preferable. It turns out that merely bending the simple torus into a figure eight will produce an appreciable twist in the lines of force; most of the experimental work at Project Matterhorn has been carried out with figure-eight-shaped magnetic fields. We are now developing a more promising method in which the toroidal field is twisted by interaction with an additional transverse magnetic field. This transverse field is generated by a set of helical windings in which the current flows in opposite directions in adjacent groups of wires. In the twisting of the field thereby induced, the angle of twist increases as the square of the distance from the magnetic axis; this difference in twist angle between the outer and inner magnetic surfaces helps to stabilize the gas.

At this point we may consider the magnetic bottle of the stellarator more or less ready to contain the hot gas, and we may turn to the question of heating the gas to high temperatures. The stellarator accomplishes the preliminary phase of heating simply enough by inducing a strong electrical current in the gas. With an iron transformer core threading the toroidal tube and a primary winding wrapped around the iron, we have a conventional transformer, the gas providing the secondary circuit. When a voltage is applied to the primary winding, an electric current flows through the gas along the magnetic surfaces. The power dissipated by the resistance of the gas goes into ionizing and heating the gas, as well as into producing some ultraviolet and visible radiation. This is called "ohmic heating," because it is the ohmic resistance of the gas that generates the heat on passage of the current. Unlike the pinch-effect current, the ohmic heating current produces no contraction or compression of the ionized gas; the strong magnetic field of the stellarator holds the gas firmly in place and constant in volume.

Experience with some half-dozen small "Model B" stellarators, with tubes of two to four inches in diameter and 10 to 20 feet in axial length, has established extensive data on ohmic heating. These devices utilized magnetic confining fields of 20,000 to 40,000 gauss. Since the power required at the peak of the field is in the neighborhood of 50,000 kilowatts, the power bill has restricted operations to pulses lasting about .02 second. Within these intervals we have been able to develop ohmic heating discharges of a few thousandths of a second duration. Temperatures of 100,000 to a million degrees observed in these experiments sustain the expectation that ohmic heating is an effective way to ionize the gas in a stellarator and heat it to high temperatures.

In the early days of the program we hoped that the gas would remain steady and motionless during ohmic heating, and that the heating would thus proceed smoothly to its conclusion. Experiments have shown us that this hope was about as well founded as the hope that water flowing rapidly through a large pipe would flow smoothly in straight lines. In truth, of course, water under these conditions becomes turbulent, with eddies moving back and forth across the stream. In the same way the ionized gas develops violent activity during the ohmic heating process. Electric and magnetic forces introduce complications which make the activity quite different from ordinary turbulence. Because of the long-range electrical forces between electrons and the bare nuclei, particles considerable distances from each other can cooperate in large-scale activity. This "cooperative activity" in a heated gas produces many effects. Not all are disruptive; for example, the production of radio-noise bursts similar to those observed from the sun does not appear to affect the performance of a ther-



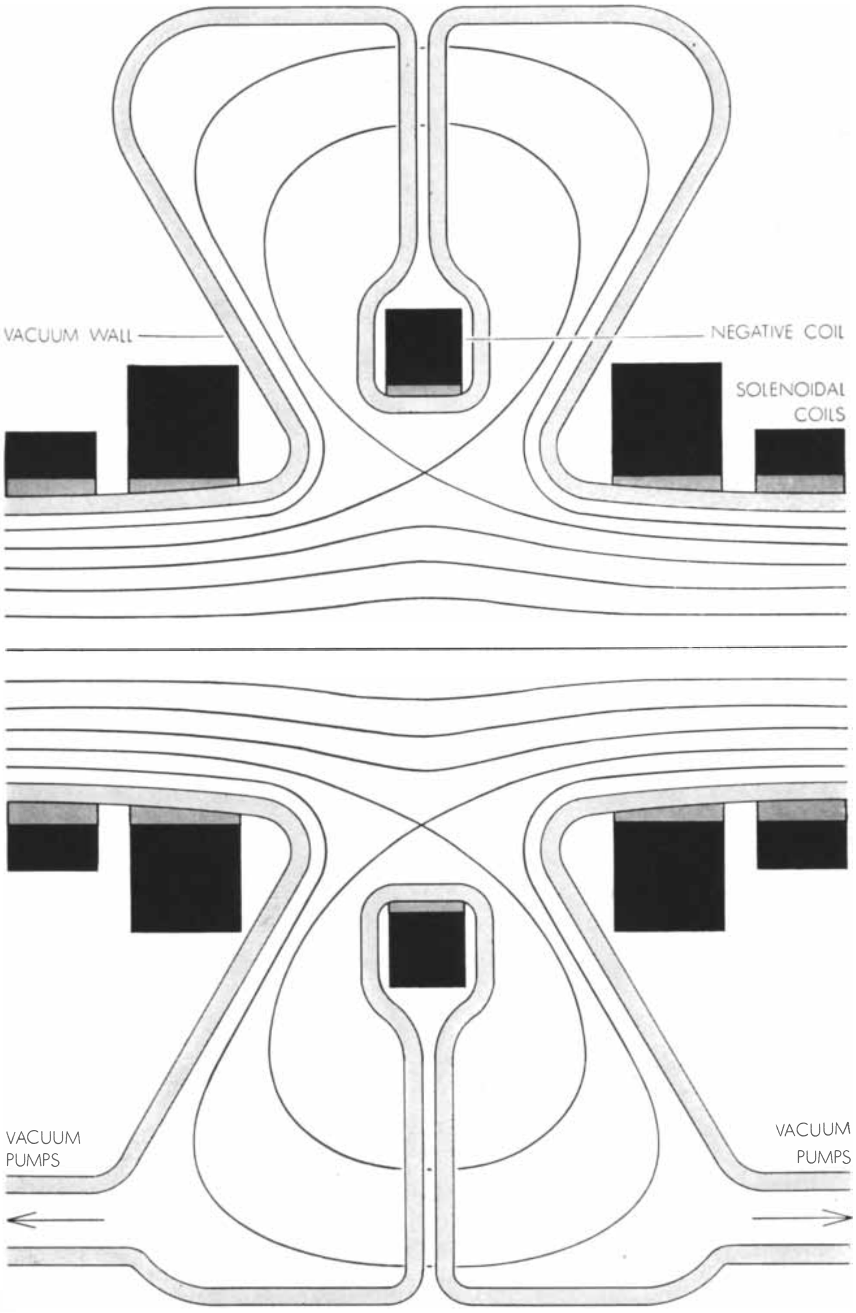


TWISTED MAGNETIC FIELD counteracts tendency of charges to separate. Top diagram shows a part of one line of force, which, if drawn for its whole length, generates a ring-shaped surface. Each line is above axis in some sections of tube (*bottom left*) and below it in others (*right*). Thus both plus and minus charges move away from center line at some points and toward it at others.

monuclear reactor. Other effects may have very serious consequences. Some types of cooperative activity move the individual particles across the lines of force, impairing confinement by the magnetic field and dashing some of the hot gas into the wall. In activity of the so-called "hydromagnetic" (or "magneto-hydrodynamic") type the lines of magnetic force themselves become violently distorted, also dashing ionized gas into the wall. The tendency to such hydromagnetic disturbance should be much reduced in stellarators in which the magnetic field is twisted by transverse helical fields. Theory indicates that the lines of force cannot move about so readily when the angle of twist increases sharply with distance from the magnetic axis.

"Runaway" electrons seem to be responsible for another troublesome variety of cooperative activity. One characteristic of an ionized gas is that the probability of a collision between an electron and another particle falls off rapidly as the particle velocity increases. Thus an electron accelerated to a sufficiently high velocity will engage in practically no collisions and will continue to be accelerated by the field. Such electrons are said to have run away; they can no longer be confined and they strike the wall, producing intense X-rays. When a large number of the electrons runs away, the gas develops strong fleeting electrical fields and the current drops more or less abruptly.

Incidentally, observations on runaway electrons provide an excellent demonstration of the effectiveness of the stellarator magnetic bottle. Under some conditions energetic electrons will travel around the stellarator long after the ohmic heating pulse is over, finally striking the wall only when the magnetic field falls off. During this time they travel several thousand miles, going around the stellarator tube about a million times.



DIVERTOR helps prevent gas particles from striking walls of tube. Magnetic lines near the walls are bent out into side chamber surrounding tube at one point. Particles traveling along these lines are swept into the chamber and pumped out of the system. This diagram is a cross section of the divertor; the black blocks are coils that bend the lines.

The most serious type of cooperative activity is not really understood at all. On occasion, with the gas showing no strong evidence of unsteadiness, the ions and electrons gradually disappear from the discharge, presumably striking the wall. This disappearance of the gas, called "pump-out," represents a serious leak in the magnetic bottle. When ohmic heating terminates, the leak seems to stop, as is evidenced by the long persistence of runaway electrons. A program of investigation to determine the cause of this leak is now under way.

A leak might not be serious if a particle striking the wall simply buried itself there. At least the gas remaining in the bottle would stay hot. Unfortunately an ion striking the wall tends to knock off atoms of various elements. These find their way into the heated gas and cool it, partly because they are themselves so cool to begin with and partly because they radiate energy at such a rapid rate. A controlled thermonuclear reactor is possible in principle only because hydrogen at high temperatures radiates so little energy, and can therefore be kept very hot. Atoms of the heavier elements do not possess this convenient property, and because of their higher nuclear charge radiate energy at a much greater rate. Thus any appreciable amount of oxygen or iron in the discharge makes it very difficult, if not impossible, to maintain thermonuclear temperatures.

Two methods give promise of reducing the influx of impurities from the wall. The chief impurities observed are carbon, oxygen and nitrogen, which are adsorbed on the steel walls of the stellarator tube, and which stream from the walls during the discharge as a result of wall bombardment. To reduce the amount of these gases present, the stellarator tubes are now baked at 450 degrees C. for some 12 hours while the vacuum pumps are operating. This has reduced the influx of impurities during ohmic heating to about a hundredth of its value in unbaked tubes. Baking the vessel has the auxiliary advantage of reducing the initial vacuum (before the discharge gas is introduced) down to 4×10^{-13} atmospheres, about a ten-thousandth of that obtained with more usual techniques. To reduce further the impurities produced during operation, the next generation of stellarators will mostly be equipped with what we call divertors. At the divertor the outer shell of magnetic lines of force is bent away from the axis of the field [*see illustration on preceding page*]. Any charged particles moving along these lines of force, and hence tending to diffuse toward the wall, are drawn into the separate chamber of the divertor before they strike the wall. Impurities produced in the divertor are scavenged by the vacuum pumps. Use of a divertor on an unbaked system has reduced the impurity level to about a fifth of its previous value. In a larger, baked machine use of the divertor may bring the impurities down to a negligible value.

Quite apart from problems of cooperative activity, experience shows that ohmic heating becomes less and less effective as the gas temperature rises above a million degrees. The resistance of the ionized gas decreases sharply as the temperature rises. Since the power dissipated by an electric current depends upon the resistance, the power dissipation drops proportionately. Some other method must be found for heating the gas above a million degrees.

At Project Matterhorn we propose to heat the gas up to ignition temperature by "magnetic pumping," a rapid pulsation of the containing magnetic field along a short section of the stellarator. This pulsation is produced by an oscillating current in a special coil surrounding the heating section, inside the coils which produce the steady magnetic field [*see illustration at bottom of opposite page*]. As the strength of the field increases during the pulsation, the lines of force move closer together, and the charged particles, following the lines of force, also move together. The gas is thereby compressed; with compression, it is heated. The details of this process are complicated, but the net effect on the gas temperature is the same as the heating of an ordinary gas by compression. Hence we may look on the moving lines of magnetic force as a piston which compresses and expands the ionized gas.

Although the gas is heated by compression, it is also cooled by expansion. It is not immediately obvious, therefore, why there should be any net heating. In fact, in order to achieve heating it is necessary to tune the frequency of pulsation close to one of the natural periods of the gas—the time between collisions, or the time it takes a charged particle to pass through the heating section, or the time it takes a particle to gyrate in a circle under the influence of the confining field. Thanks to a type of resonance, the amount of heat fed into the gas during compression will then considerably exceed the heat taken out during expansion. Detailed theoretical studies, still unchecked by experiment, indicate that magnetic pumping should be capable of heating a gas to thermonuclear temperatures. The rate of heating by this technique, however, is not very rapid, and so far the loss of energy by pump-out and the radiation of energy by impurities have prevented the achievement of ultrahigh temperatures.

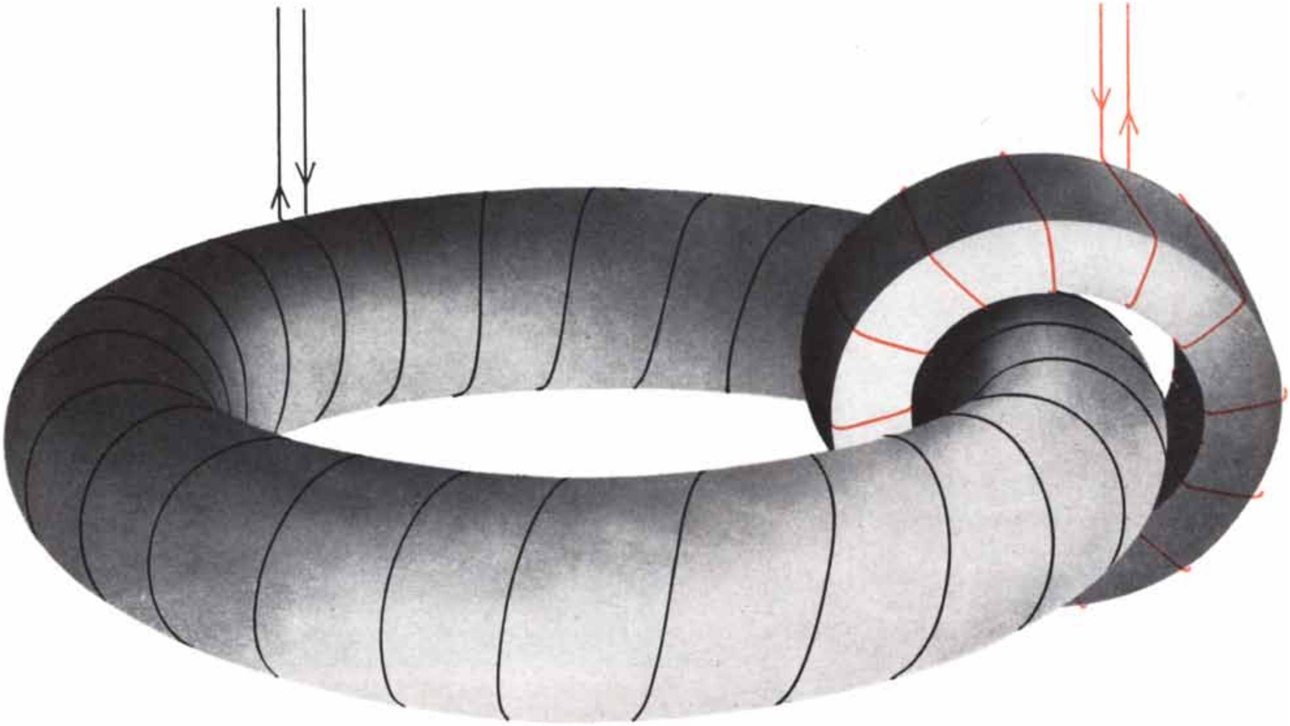
A much larger experimental device, the "Model C" research stellarator now under construction, should aid greatly in the investigation of these problems. This device will have a vacuum tube in the shape of a racetrack; the tube will be some eight inches in diameter and 40 feet in axial length, and will utilize a confining field of 50,000 gauss, twisted by means of helical windings. The tube diameter is some four times larger than in most of the present "B" models, and the correspondingly decreased ratio of surface to volume should reduce the effect of pump-out and of the impurities streaming into the discharge. Finally, powerful magnetic pumping apparatus will be available for attempts to obtain ultrahigh temperatures. The engineering facilities required for this installation are substantial, with a peak direct-current power level of 150,000 kilowatts, obtained with motor-generator sets, and a radio-frequency power level of about the same order.

If continuing research does lead to a power-producing reactor, what would such a device look like? The main answer to this question is that a stellarator must be a very large unit to produce more power than is consumed in maintaining the magnetic field needed for confinement. As a stellarator is increased in size, keeping the magnetic-field strength and all other properties constant, the power required for the magnetic field increases only as the linear dimension. On the other hand, the thermonuclear power produced increases with the volume of the gas, or as the cube of the linear dimension. The break-even point, at which the power put into the magnetic field equals the thermonuclear power generated, occurs with a rather large machine—one with a tube diameter of several feet and an axial length of several hundred feet. The total power produced by such a machine is in the million-kilowatt range.

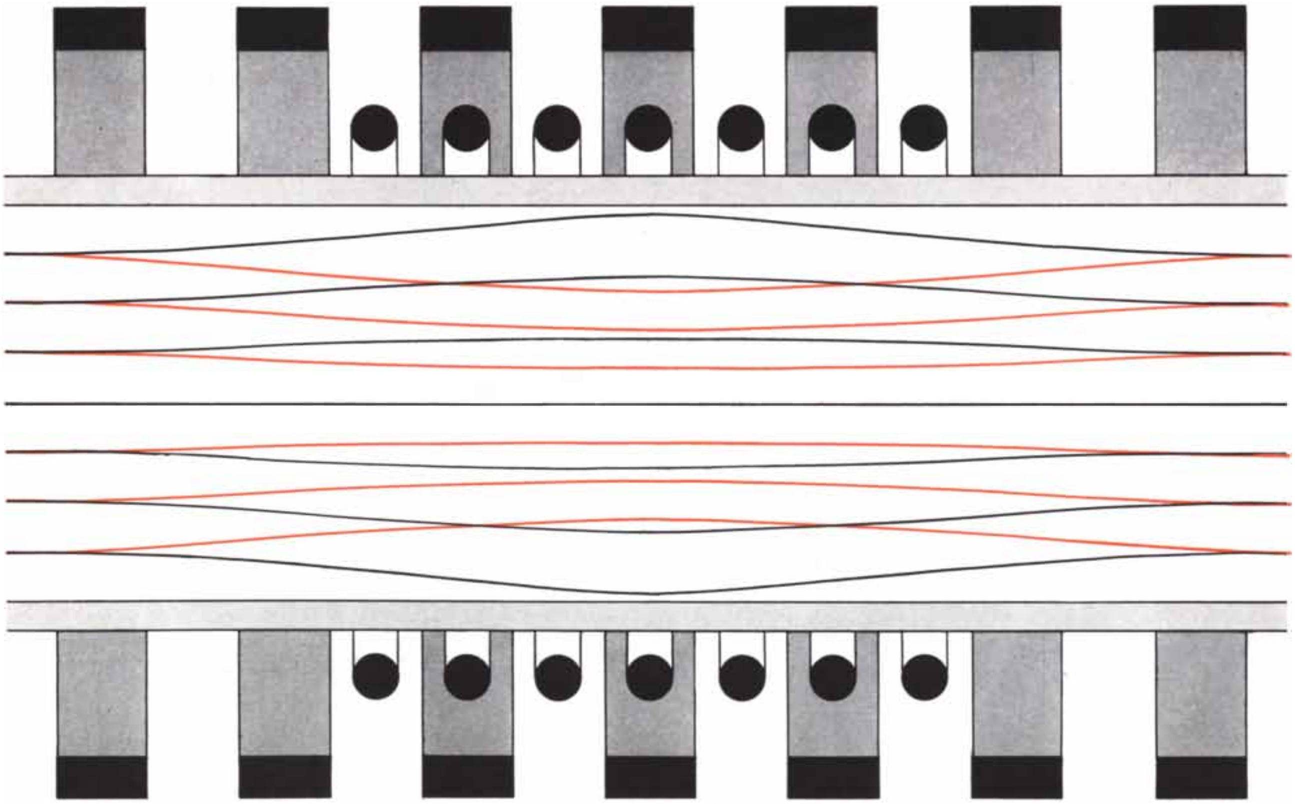
The first power-producing stellarators would be fueled with a mixture of deuterium and tritium, since tritium fuses with deuterium about a hundred times more rapidly than deuterons fuse with each other. To take the power out the reaction tube would be wrapped with a blanket through which water would be circulated in pipes. The hydrogen in the water would take up the energy of the neutrons in elastic collisions, and the water, acting as a coolant, would carry the heat out of the stellarator to external turbogenerators. To replenish the supply of tritium the blanket would be loaded with lithium; one of the isotopes of this element absorbs neutrons readily, and the ensuing nuclear disintegration yields tritium and an alpha particle (nucleus of the helium atom). Surrounding the blanket would be enormous coils in which electric currents would produce the steady magnetic field that is required to confine the ionized gas.

Once the gas is heated, such a device would operate continuously. Fresh supplies of deuterium and tritium would be injected in a fast jet, while the reaction products (mostly helium) and impurities would be withdrawn at the divertor, where very large pumps would be located. Ohmic heating and magnetic pumping equipment would be needed only for starting the stellarator after occasional shutdowns.

A full-scale stellarator would be comparable in size and power output to a large hydroelectric plant, such as Hoover Dam. Whether such an installation will ever be economically feasible, or even possible, is still uncertain. If it works, however, it will provide millions of kilowatts with a negligible fuel cost.



TRANSFORMER ACTION heats gas in stellarator to a temperature of about one million degrees. Current through primary coil around iron core at right induces a secondary current through the gas in the tube. As in an ordinary metallic conductor, the resistance to the flow of current produces heat. As gas gets hotter its resistance drops until further heating becomes impossible.



MAGNETIC PUMPING will be used to heat gas to temperature necessary for fusion reaction. Pumping arrangement, shown in cross section, consists of an auxiliary coil (*black circles*) carrying an oscillating current. This current alternately expands and compresses the lines of force set up by the main coil (*black blocks*). Diagram shows compressed field in color and expanded in black.

CELLS AT HIGH PRESSURE

Temperature and pressure are basic factors in physical and chemical processes, but it is only recently that biologists have considered the role of pressure in the physical and chemical processes of life

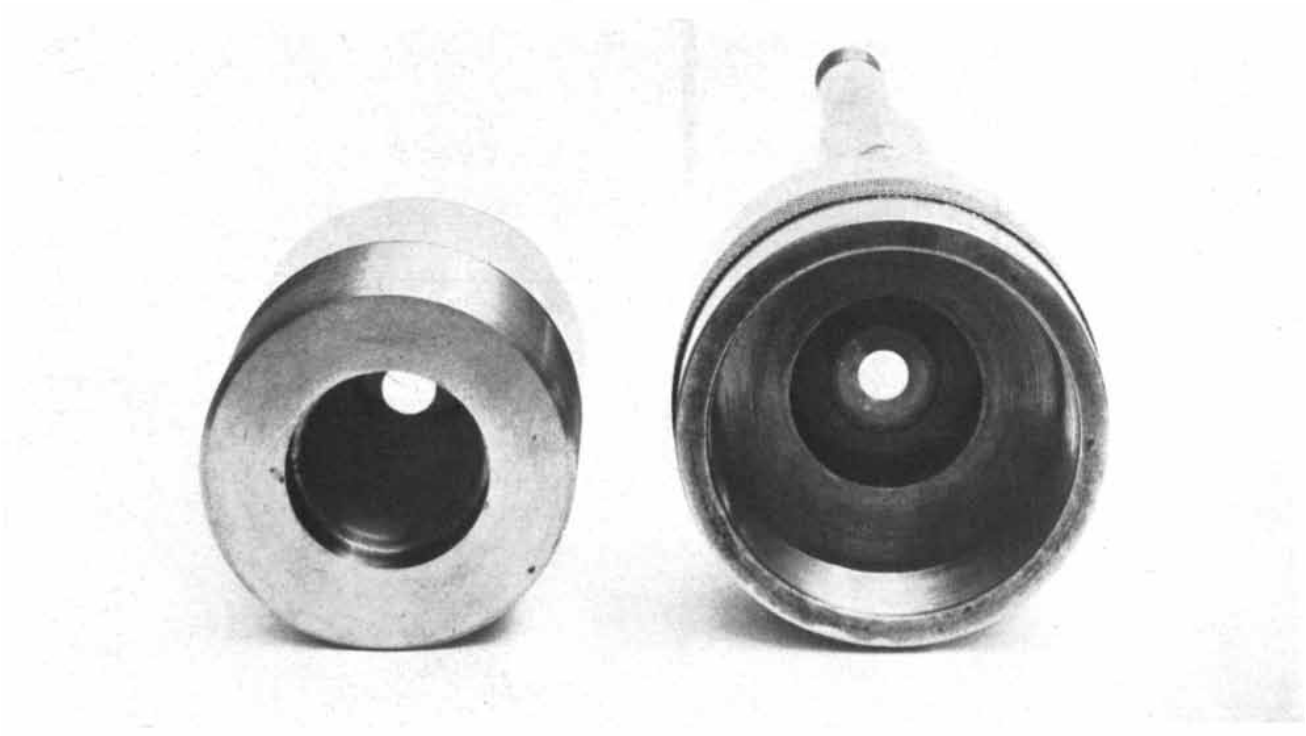
by Douglas Marsland

Everyone knows that living things are profoundly influenced by temperature. In winter plants stop growing and cold-blooded creatures such as frogs and snakes are dormant. As the body temperature of any animal falls, its metabolism slows and eventually stops.

It is not generally recognized that pressure also plays a decisive role in metabolism. In every living cell there are many metabolic reactions which are sensitive to pressure. Until recently the pressure factor was largely ignored in physiological research; now pressure studies are beginning to yield evidence which is helping to solve classic problems. Pressure has become a new tool of physiology.

Man and other air-dwelling creatures are not required to tolerate large changes of pressure because our atmosphere is gaseous and relatively light. At sea level the pressure of the atmosphere averages slightly less than 15 pounds per square inch, and its variations never exceed more than about one pound per square inch. Even if an animal were transported from the highest mountain to the deepest cave, the change in the pressure of its environment would be quite small. The indirect effects of this small change would be important, because it would drastically alter the penetration of oxygen and other atmospheric gases into the protoplasm and body fluids. But the direct effects of the change on the vital processes would be almost negligible.

Water-dwelling organisms, on the other hand, are surrounded by a heavy liquid medium, and in the sea the pressure variations may be tremendous. The cumulative weight of water of course increases rapidly with depth—the pressure mounts roughly at the rate of one pound for every two feet of descent. At a depth of 1½ miles, where a wide variety of species are known to live, the pressure is more than 5,000 pounds per square inch, which is equivalent to the



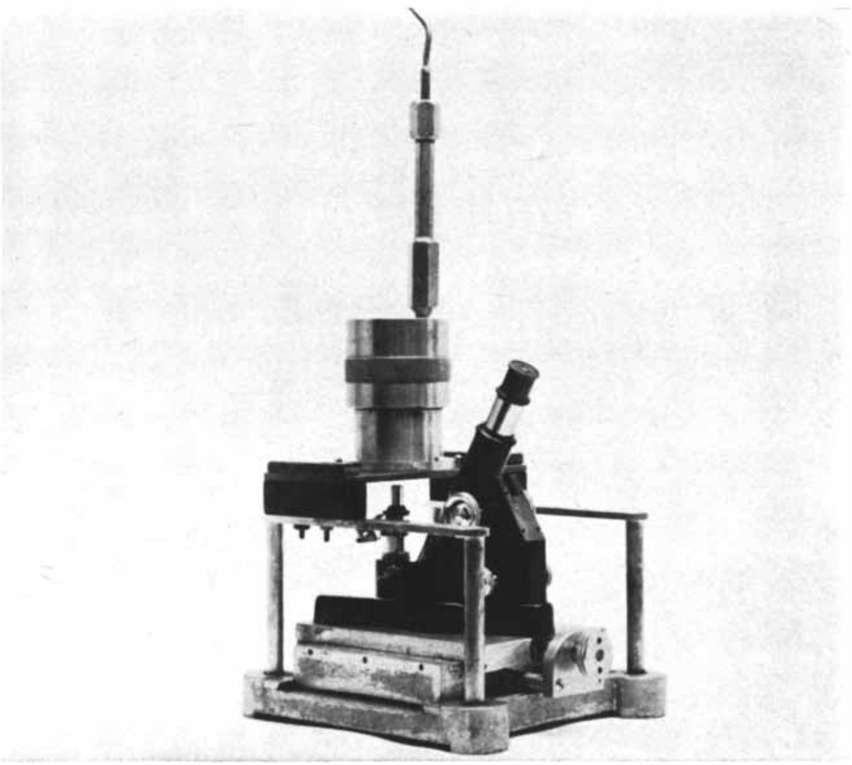
PRESSURE CHAMBER developed in Marsland's laboratory makes it possible to study living cells at pressures up to 15,000 pounds per square inch. In this photograph the two halves of the chamber are unscrewed. The glass window in each half is a quarter-inch thick.

pressure of some 350 atmospheres. Such pressure drastically changes the vital activities of an organism. True deep-sea forms cannot survive very long at surface pressure; conversely, surface forms soon die when subjected to deep-sea conditions. Exactly how does pressure affect the fundamental life processes of various organisms? The question is significant if only because most ancient forms of life were oceanic, and pressure must have played an important part in guiding the evolutionary destiny of many species.

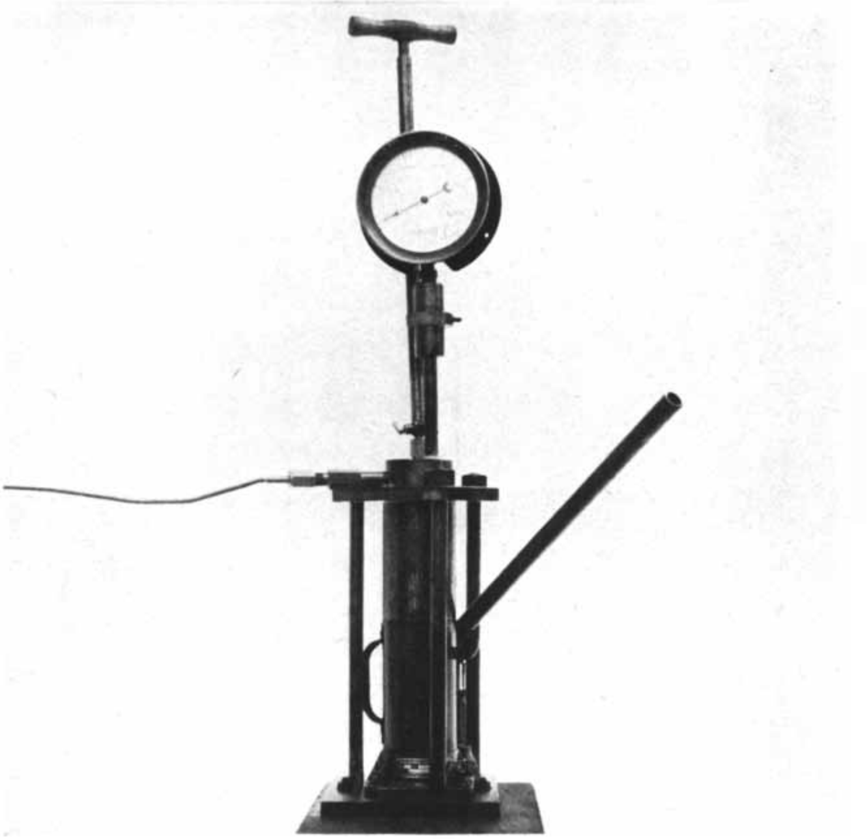
An obvious way to study the effects of pressure on living cells is to subject them to pressure in the laboratory. The development of apparatus to make such studies under controlled conditions began some 75 years ago. Paul Regnard of France became intensely interested in the findings of the French *Talisman* oceanographic expedition, which had succeeded in dredging up quite a variety of organisms from depths of more than seven miles. Here the pressure exceeds 1,000 atmospheres. Regnard undertook an extensive series of pressure studies, on which he reported regularly to the French Academy of Sciences from 1884 to 1888.

The early pressure investigators were handicapped by the fact that the living material could not be examined closely while it was inside the thick-walled pressure chamber. Most of the effects of pressure upon living processes are remarkably transient; the effects rapidly reverse themselves as soon as the pressure is released. Thus many of the early workers reported that pressure had no effect at all. By the time they had removed their cells from the pressure chamber, all evidence of change had disappeared.

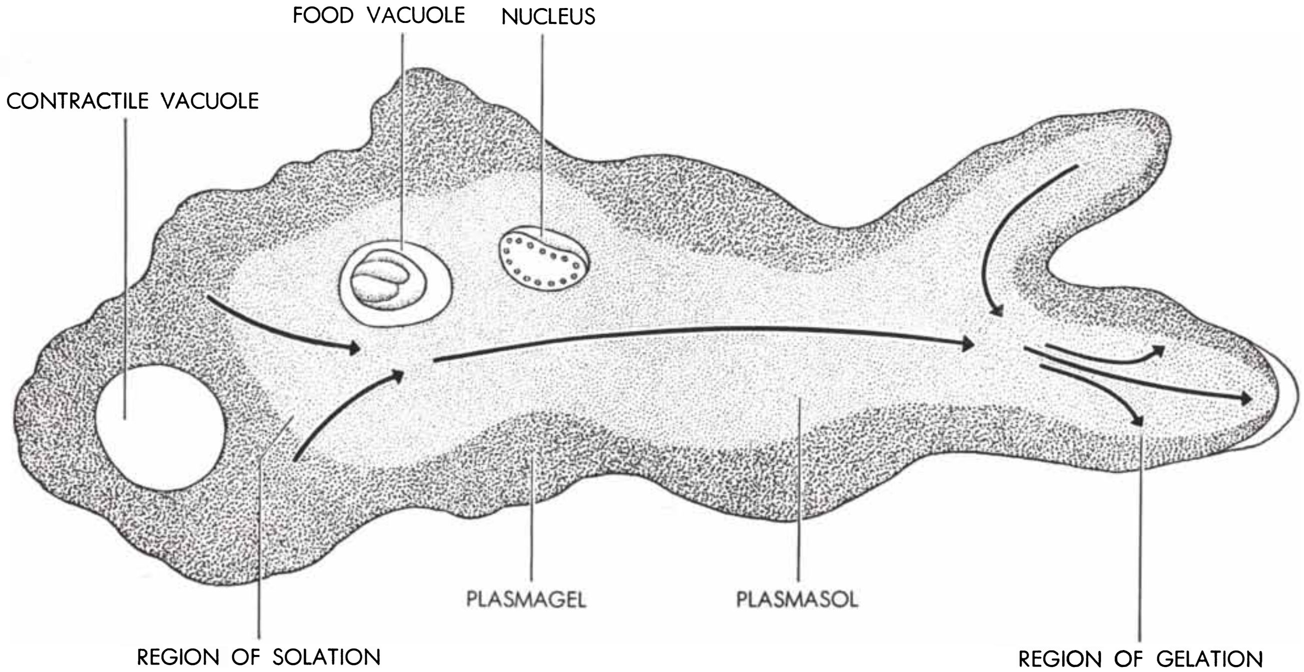
The modern epoch of pressure research awaited the development of windowed pressure chambers and other devices which make it possible to study living material continuously while the pressure is maintained. Among the more useful devices have been: (1) a microscope pressure chamber (developed in our laboratory at New York University), which makes it possible to observe pressurized cells at a magnification of 600 diameters; (2) a muscle-nerve pressure chamber (developed by McKeen Cattell, Dayton J. Edwards and Dugald E. S. Brown at the Cornell University Medical College), which permits measurement of the force of contraction in pressurized muscle and of the intensity of electrical discharges in pressurized nerve preparations; and (3) a pressure



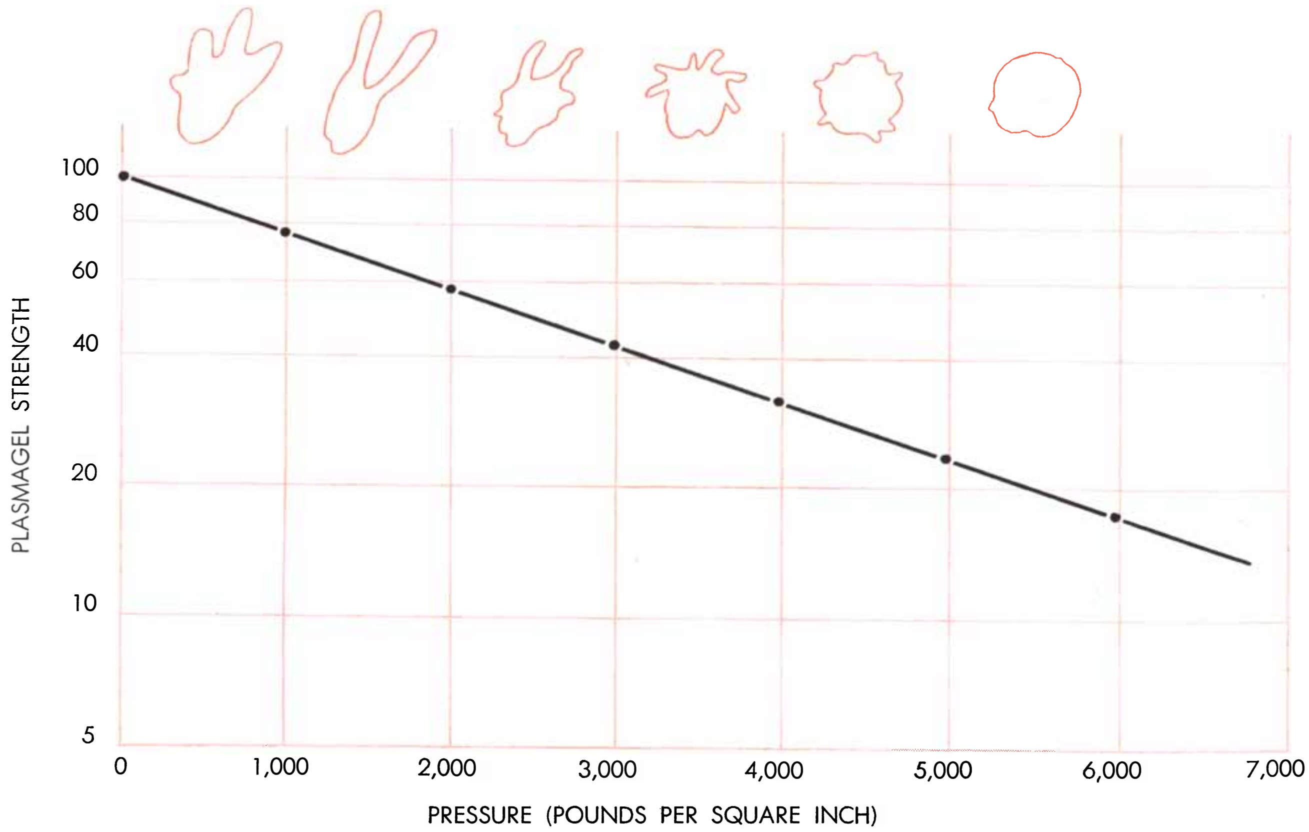
CHAMBER IS MOUNTED with a special microscope so that cells within it can be examined at magnifications up to 600 diameters. Pressure is transmitted to chamber through tube at top.



PRESSURE IS APPLIED by means of a modified hydraulic truck jack. Each full stroke of the handle at right raises the pressure in the chamber by 1,000 pounds per square inch.



MOTION OF AN AMOEBA is outlined in this simplified drawing. As the amoeba moves toward the right, protoplasm in the sol state (*plasmasol*) streams toward the tip of its pseudopod ("false foot"). At the sides of the pseudopod (*region of gelation*) plasmasol enters the gel state (*plasmagel*). At the other end of the amoeba (*region of solation*), plasmagel enters the sol state.



APPLICATION OF PRESSURE decreases the strength of the amoeba's plasmagel layer. The outline drawings at top show how with increasing pressure the shape of the amoeba changes until, at about 6,000 pounds per square inch, it is round and motionless.

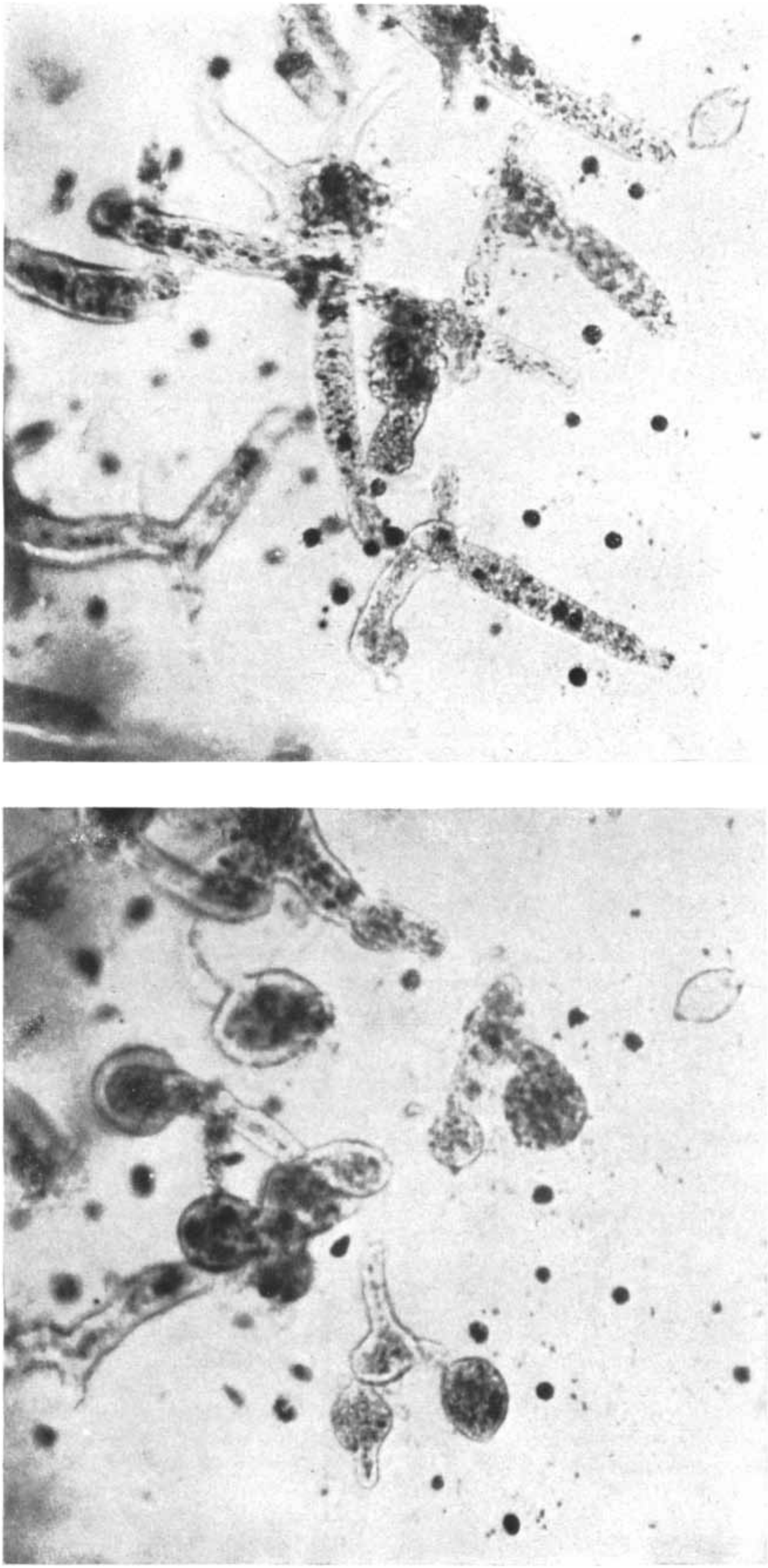
centrifuge (devised by Brown at New York University), which enables the investigator to spin cells at high speeds and at pressures up to 1,000 atmospheres.

One very simple but informative experiment is to see what happens when a single cell is subjected to high pressure. Take, for example, the fertilized egg cell of the sea urchin. Place the cell in the microscope pressure chamber, which is filled with sea water, and quickly build up the pressure by pumping the handle of a modified hydraulic jack. With each full stroke the pressure goes up some 1,000 pounds per square inch (68 atmospheres). Stop, say, at 6,000 pounds per square inch. When one looks into the microscope, one sees that the cell has not perceptibly changed! To be sure, it has stopped developing, and it will never divide into a two-celled embryo unless the pressure is released in reasonable time. But the cell remains perfectly spherical, and its decrease in size is so small that the change can be detected only with refined measuring instruments.

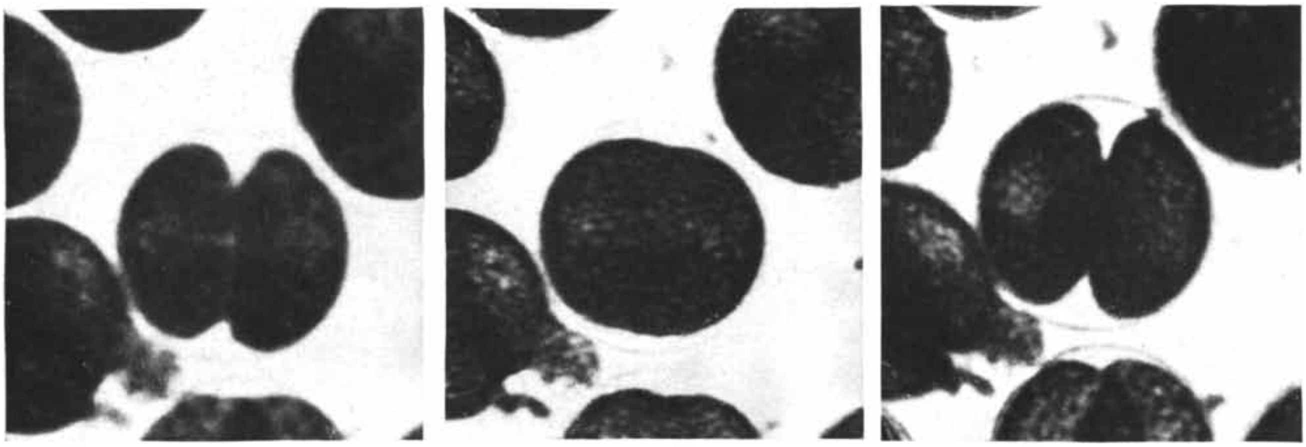
The experiment illustrates two familiar but basic characteristics of hydrostatic pressure. The first is that in a hydrostatic system—which is of course what we manipulate in such experiments—the pressure is equal in all directions. Thus the pressure does not change the shape of the cell. Moreover, the protoplasm of the cell itself is essentially liquid, so the pressure inside the cell is the same as that outside. If a cell is compressed between two *solid* surfaces, it is easily flattened and can be ruptured by very little pressure (less than one atmosphere).

The second characteristic of hydrostatic pressure is that the compressibility of most liquids is exceedingly small. When pure water is subjected to a pressure of 1,000 atmospheres (about 15,000 pounds per square inch), its volume decreases less than 3 per cent; sea water and protoplasm are even more resistant to pressure. It is no wonder that we can see no difference in the size of a cell when we compress it. But the small decrease in volume has large effects upon the interplay of physical and chemical reactions in the cell.

We know from physics and chemistry that pressure tends to oppose any type of reaction which leads to an increase in the volume of the reacting substances. Conversely, pressure favors reactions which decrease the volume of the system. Take boiling water, for example.



AMOEBAS INSIDE THE PRESSURE CHAMBER are photographed at atmospheric pressure (*top*) and two seconds after 6,000 pounds per square inch had been applied (*bottom*).



DIVIDING EGG CELL of the sea urchin was photographed in the pressure chamber five seconds after a pressure of 7,000 pounds per square inch had been applied (*left*), four minutes after the pressure had been applied (*middle*) and four minutes after the pressure had been released (*right*). In the first picture the cell had begun to pinch in two. In the second the pinching process has been reversed and the cell is almost round again. In the third picture the pinching process has resumed and the cell has nearly divided.

Vaporized water takes up far more space than an equivalent amount of liquid water. The boiling reaction must therefore perform work upon the environment; if the pressure of the environment is increased, the work is also increased. Thus pressure opposes boiling and favors condensation.

The effect of temperature is exactly the opposite. Heat provides the energy by which the reaction can perform work upon the environment. To sum up the effects of pressure and temperature: pressure tends to shift the equilibrium of any reversible reaction in the direction of lesser volume, and temperature tends to shift it in the other direction.

One significant reversible reaction in the cell is the sol-gel reaction, which seesaws back and forth more or less continuously. Parts of the protoplasm may have a sol structure in which their consistency resembles that of water; then these same parts will quickly switch to a gel structure resembling strongly set gelatin. Physiologists have long observed these repetitive protoplasmic changes, but the functional significance of the changes remained rather obscure until high-pressure techniques provided a new approach to this old problem.

Sol-gel reactions within the cell proved to be exceedingly sensitive to both temperature and pressure. It was more surprising to discover that the behavior of the protoplasmic gel was quite different from that of ordinary gelatin. Gelatin is made weaker by an increase of temperature and stronger by an increase of pressure. For a protoplasmic gel the opposite is true: it is made stronger by an increase of temperature and weaker by an increase of pressure. In fact, if enough pressure is applied, all the protoplasm in the cell has almost the consistency of water.

It has become increasingly clear that gelation is the mechanism by which the cell generates mechanical energy. Protoplasm in the gel state has the power of contraction, and this contractility enables the cell to change shape and to move. In contracting, however, the protoplasm reverts to the sol condition, so that a continuous regeneration of gel structure is necessary if movement is to continue. Moreover, if gelation is prevented, or if existing gels are converted into sols by high pressure or other influences, protoplasmic contractility is lost and the cell becomes immobile.

These general conclusions have emerged from a long series of pressure-temperature experiments on a wide variety of living things. Here, however, we will give the reader just a few examples. These will deal primarily with the mechanical activities of single cells, especially cell division and the movement of the amoeba.

Amoeboid movement (which can also be observed in other animal cells) is perhaps the most primitive form of locomotion. Such movement is not restricted to the locomotion of lowly forms; it is also displayed by many cells in the human body. White blood cells often leave the capillaries and wander in amoeboid fashion through spaces in the tissues in search of infectious bacteria. Many connective-tissue cells also migrate through the tissue spaces. Moreover, in the embryo, before the tissues assume their adult form, many cells employ amoeboid movement as they migrate to their ultimate stations.

Amoeboid movement has a peculiar fascination when it is observed in an active amoeba under the microscope. As the finger-like pseudopodium (the "false foot") of the amoeba advances, one sees the cytoplasm (the protoplasm between the cell nucleus and the cell wall) flowing steadily through a central channel in the cell. But one also sees that the surface layer of cytoplasm, which lies just inside the outer membrane of the cell, does not participate in the streaming. This layer of cytoplasm maintains a fixed position. It forms a tubular wall around the flowing cytoplasm, and seems to guide the streaming through a definite channel extending toward the tip of the advancing pseudopodium. Thus it is clear from direct observation that the cytoplasm of the amoeba is differentiated into two parts: the plasmasol, a fluid central part which flows while the amoeba is moving; and the plasmagel, a firmly gelated surface layer which surrounds the plasmasol.

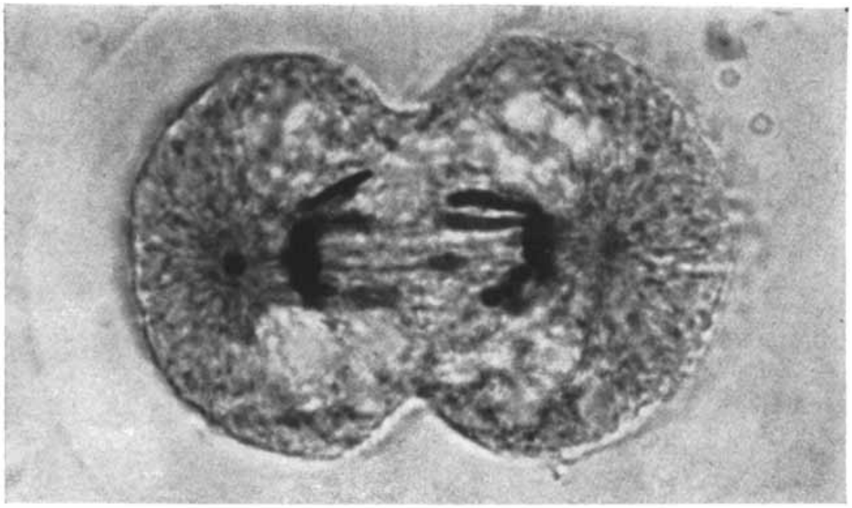
Even before 1900 it was suspected that cyclic sol-gel changes might be involved in amoeboid movement. It seemed clear from direct observation that new plasmagel keeps forming and adding itself to the wall of an advancing pseudopodium. It was also apparent that old gel, at the dragging hind end of the amoeba, keeps transforming itself into new sol, which joins the forward-moving stream. Indeed, it was postulated quite early that the motive force which causes streaming originates with a forceful contraction of the plasmagel layer. Before the pressure studies, however, this "contractile hypothesis" was not supported by experimental evidence.

If we observe an actively moving amoeba in the pressure chamber and suddenly raise the pressure to 7,000 pounds per square inch, the effect is quick and dramatic. The pseudopodia collapse and the cell becomes a motionless sphere. The pressure has apparently liquefied the plasmagel system; the protoplasm now behaves like any small droplet of liquid.

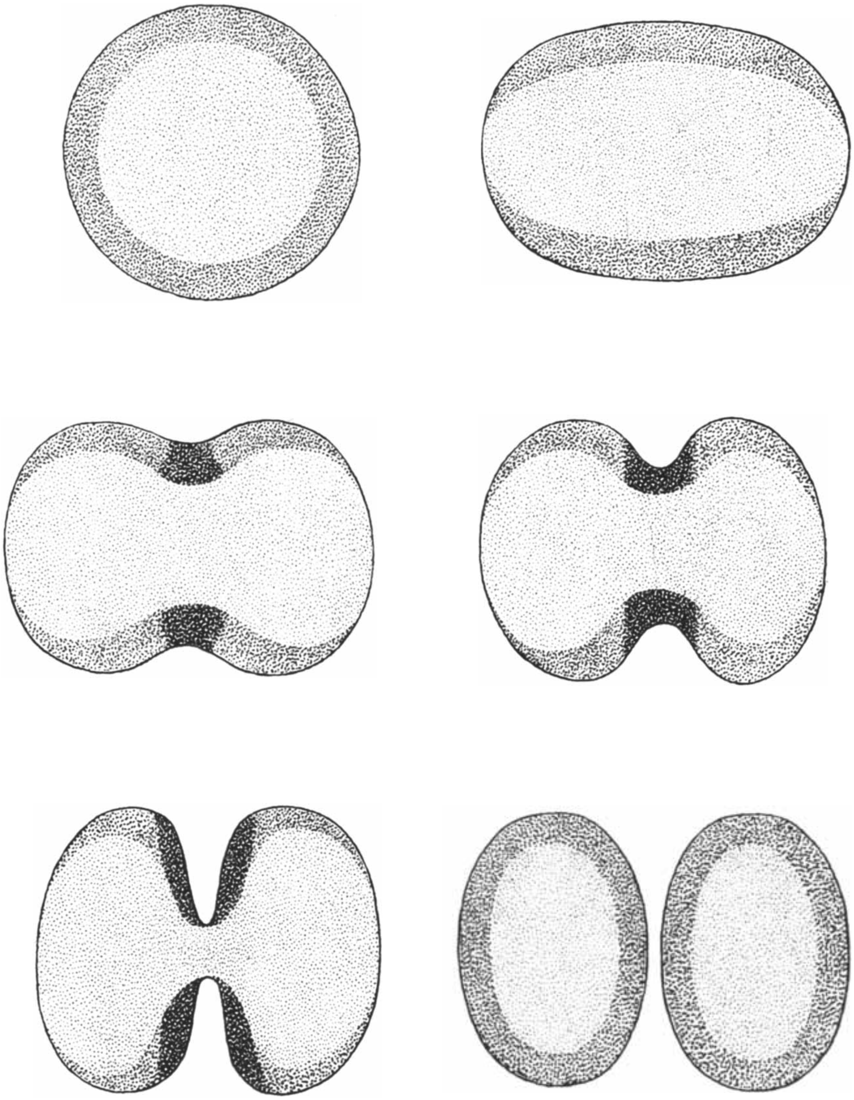
So long as the pressure is maintained, no sign of movement or streaming can be detected in the rounded amoeba. Gradually the nucleus, food vacuoles and other relatively heavy bodies in the protoplasm begin to sink into the lower half of the cell. As soon as the pressure is released, however, activity resumes. Within about two minutes a new plasmagel layer forms and begins to contract violently. This causes a vigorous bubbling at the cell surface. Three or four minutes later normal pseudopodia begin to appear, and soon the amoeba resumes its locomotion.

The effect of various pressures on the plasmagel system can be precisely measured with the pressure centrifuge. One compartment of the centrifuge contains cells at high pressure; a second compartment contains a control group of cells at atmospheric pressure. Thus both pressurized and nonpressurized cells can be subjected to the same centrifugal force (up to 50,000 times the force of gravity). When the cells are spun, the relatively heavy bodies such as the food vacuoles tend to move outward through the cytoplasm. The rate at which these structures move in the pressurized cells can then be compared with their rate of movement in the nonpressurized cells. Obviously the more liquid the cytoplasm of the pressurized cells, the faster the heavy structures will move. In this way it was determined that the increase of pressure progressively reduces the viscosity of the cytoplasm of the amoeba. At 6,000 pounds per square inch all signs of pseudopodia and movement have vanished. By similar measurements it was shown that, up to a point, the increase of temperature strengthens the plasmagel system. As the temperature is raised, the pressure necessary to liquefy the plasmagel must be increased.

Where does the cell obtain the energy to build up its plasmagel system? The evidence strongly suggests that the cell obtains this energy from its high-energy phosphate reserves, partic-

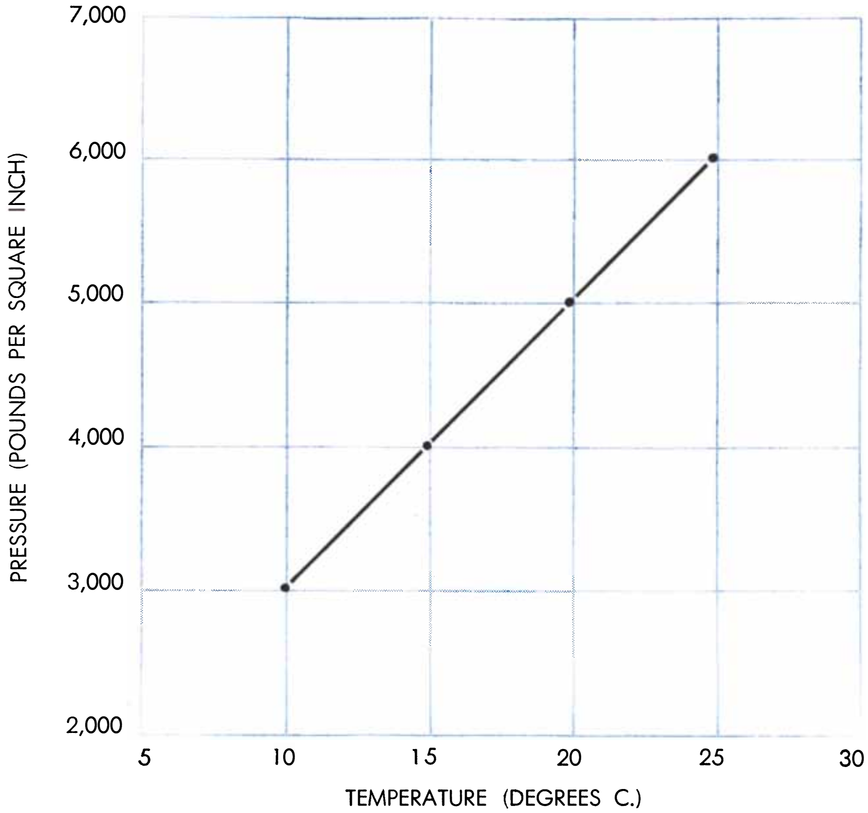


DIVISION OF AN EGG CELL is shown in greater detail. The chromosomes (*stained finger-like bodies*) have been pulled apart by the spindle and the cell has begun to pinch in two.

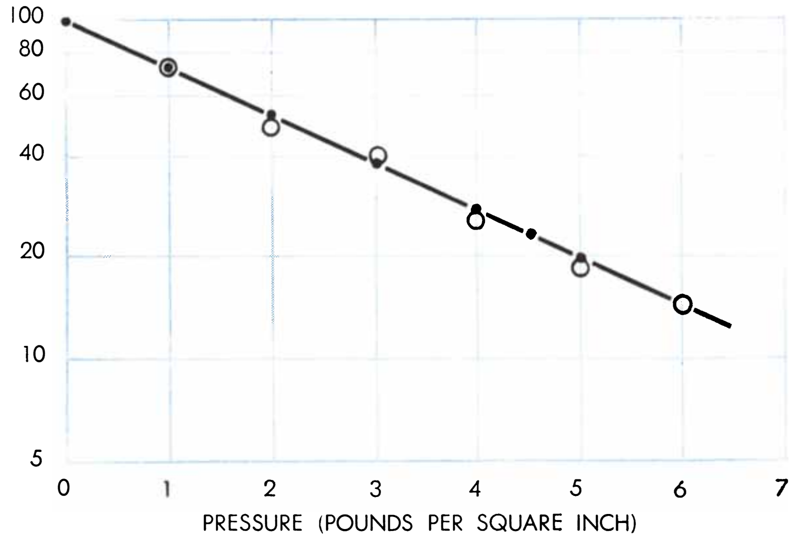


PLASMAGEL CONTRACTION THEORY is illustrated in sequential diagrams. The lighter stippling is the plasmasol; the darker, the plasmagel. In the third, fourth and fifth diagrams the contracting part of the plasmagel (*darkest stippling*) is localized in "cleavage furrow."

ularly adenosine triphosphate (ATP). It has been found, at any rate, that various cells have a stronger gel structure and are better able to perform mechanical work when they are provided with additional quantities of this energy-rich compound. Conversely, the gel structure and work performance are definitely weakened when the phosphate metabolism is inhibited by certain drugs. To this evidence must be added an extremely interesting finding of four workers at the California Institute of Technology: Paul O. P. T'so, Luther Eggman, Jerome R. Vinograd and James Bonner. This group recently succeeded in extracting from the slime mold Pelomyxa (a giant amoeboid form) a protein called myxomyosin which contracts in the presence of ATP. It seems quite certain that myxomyosin is the chief component of the contractile gel system, at least in this large amoeboid organism.



INCREASE OF TEMPERATURE counteracts the effect of pressure on the amoeba. This graph shows that at 10 degrees it takes 3,000 pounds per square inch to stop the motion of the amoeba, and that at 25 degrees it takes 6,000 pounds per square inch to stop the motion.



INCREASE OF PRESSURE slows and eventually stops the pinching process in the sea-urchin egg. The dots in this graph show the rate of progress of the cleavage furrow; the circles, the strength of the plasmasol. The vertical coordinate is marked off in arbitrary units.

Precisely how protoplasmic gels contract and perform work is still unknown. One of the simplest suggestions is that protein molecules, which are the most essential constituents of the gel structure, can forcefully fold and unfold. Individual molecules acting in this way could not perform any useful work for the cell as a whole. But if the extended molecules are linked in a larger structure, they can perform work by contracting in concert.

The unfolding of molecules and the formation of linkages between them apparently involve the absorption of energy and a slight increase in molecular volume. It is for this reason that the formation of a protoplasmic gel structure is opposed by higher pressure and favored by higher temperature. The energy which goes into the building of a gel structure can be returned in the form of mechanical work when the gel contracts and reverts to a sol.

What do the pressure experiments reveal about cell division, the process by which one cell gives rise to two daughter cells? The cell physiologist customarily studies cell division with egg cells, which are relatively large and can be obtained in abundance from lower animals such as the sea urchin. When these cells are placed in a vessel, and sperm cells are added to them, they begin a long series of divisions. Usually the first division occurs within an hour, and the succeeding divisions follow more rapidly. But given the exact temperature and time of insemination, the experimenter knows precisely when each of the successive divisions is destined to occur.

The division of the egg begins with the division of its nucleus. This involves the appearance and splitting of the chromosomes and the formation of a "spindle" which separates the two sets of daughter chromosomes. The division of the cytoplasm, which follows the division of the nucleus, is more direct. The cell merely pinches itself into two cells by means of a constriction, or "cleavage furrow," which cuts deeper and deeper into the egg toward the center of the spindle.

Pressure studies strongly indicate that

SPECIAL CENTRIFUGE HEAD is used to compare the effects of spinning cells at atmospheric pressure and at high pressure. The cells which are to be subjected to high pressure are placed in the chamber at left in this "exploded" view. The pressure is applied through the vertical fitting, which also joins the head to the centrifuge. After the pressure has been applied, the pressure chamber is sealed off by the needle valve next to the right. The cells at atmospheric pressure are placed in the chamber at far right.

the work performed by the dividing cell—in separating the daughter sets of chromosomes and cutting itself in two—is achieved by means of contractile gel structures. Daniel C. Pease, then working at Princeton University, showed that the spindle is a gel structure which is dissolved at a pressure of 6,000 pounds per square inch, and that slightly lower pressures are adequate to keep the chromosomes from moving toward the ends of the spindle. Apparently the fibers which extend from the ends of the spindle to the chromosomes are contractile gel structures which serve to drag the daughter chromosomes apart. But here we will concentrate on our own experiments dealing with the furrow which cuts through the cytoplasm.

If we place a batch of fertilized eggs in the pressure chamber, we can watch them as their first division proceeds. Then, very late in the process, when the chromosomes are widely separated and when the cleavage furrow has cut almost through the cell, let us suddenly apply a fairly high pressure (6,000 to 7,000 pounds per square inch). The furrowing stops immediately and begins to retreat. Gradually the cell loses its hourglass shape, even though its two daughter cells had almost separated. Within about three minutes the cell, which now has two nuclei, has become a single sphere again.

If the pressure is released as soon as the cell is a sphere, the furrowing will start again and the cytoplasm will divide normally. But it is possible to stop the furrowing a second time by re-applying the pressure. In fact, one can reverse the cytoplasmic division three or four times in succession.

If furrowing is held back for 13 to 15 minutes, the cell displays no further tendency to cleave until it is time for the second division to occur. By now each of the two nuclei within the single mass of cytoplasm has begun to divide again. When the cytoplasm divides, a double furrow appears and the cell cuts itself directly into four daughter cells.

Experiments with the pressure centrifuge have shown that the egg cell, like the amoeba, has near its surface a layer of gel which undergoes large and repetitive changes. This plasmagel layer is very weak in the unfertilized egg, but within 10 minutes after insemination it becomes more than 20 times stronger.

The mechanism by which the animal cell divides its cytoplasm is still the subject of debate. There is nonetheless strong evidence for the relatively simple view that the mechanism involves a contraction of the plasmagel layer. According to this hypothesis, cleavage results from a progressively developing contraction of the plasmagel in the furrow region [*see bottom illustration on page 41*]. The process seems to involve a series of sol-gel reactions: new gel steadily mobilizes along the sides of the deepening furrow; old gel at the bottom of the furrow, having spent its contractile force, reverts to a sol. This clears the way for the furrow to finish the work of splitting the cell.

The evidence that tends to substantiate the hypothesis can be outlined as follows. First, furrowing stops whenever the plasmagel strength, as measured in the pressure centrifuge, drops to a certain critical level. Second, the strength of the furrowing reaction, as judged by how quickly the furrow cuts through the cell, is determined by the strength of the plasmagel. Third, increasing the temperature proportionately strengthens the plasmagel and the furrowing reaction, so that higher and higher pressures are required to convert the plasmagel into a sol and block the cleavage. Fourth, egg cells provided with an augmented supply of ATP have a proportionately stronger plasmagel structure and furrowing reaction. Fifth, drugs that inhibit the liberation of energy from ATP reduce the strength of the gel and of the furrowing reaction. Thus both the dividing animal cell and the moving amoeba lead us to the same conclusion: The sol-gel system provides a mechanism which transforms the energy generated by metabolism into mechanical work.

As I have indicated, cell division and amoeboid movement are only examples of the biological processes which have been examined by means of high pressure. High-pressure studies have become a vigorous school of research, initiated in the modern period by Dayton Edwards and McKeen Cattell of the U. S., M. Fontaine of France and U. Ebbecke of Germany. Among the basic processes investigated at high pressure are: bioluminescence, or the production of "cold light" by living things (Dugald Brown, Frank H. Johnson and the author); muscle metabolism and muscle contraction (Brown, Edwards and Cattell); the transmission of nerve impulses (Harry Grundfest); the streaming of protoplasm in plant cells (the author); the mechanism of color change in fish (the author); the effects of the cell nucleus on cell metabolism (Henry I. Hirshfield, Arthur M. Zimmerman and the author); the metabolic control of rhythmic processes such as heartbeat (John A. Kitching and Joseph V. Landau); and the mechanism of enzyme activity (Johnson, Henry Eyring and Milton J. Polissar).

Indeed, pressure has begun to take its place with temperature as a fundamental factor governing physiological processes. Physicists and chemists have always recognized the importance of pressure, as indicated by the basic thermodynamic equation: $PV=nRT$ (pressure times volume equals the Avogadro number times the gas constant times temperature). Physiologists are now following suit.

The Tails of Comets

It has long been assumed that the gases of a comet tail are pushed away from the comet by the pressure of light from the sun. It now appears that many tails are caused by a wind of charged particles

by Ludwig F. Biermann and Rhea Lüst

The planets move across the sky with stately regularity, but new comets appear and disappear unpredictably. It is no wonder that comets have traditionally been surrounded by an atmosphere of mystery. The mystery has been enhanced by their luminous tails, which earlier peoples took as omens of war and pestilence. Even today comets and their tails have not been fully explained, but the labors of astronomers have clarified many of their puzzling features.

In 1951 Fred L. Whipple of the Harvard College Observatory surveyed for the readers of this magazine our knowledge of comets at that time [see "Comets," by Fred L. Whipple; SCIENTIFIC AMERICAN, July, 1951]. The present article will be primarily concerned with recent studies of the tails of comets. At the beginning, however, it may be well to review what we know of comets in general.

It appears that all comets are members of the solar system; none are interlopers from outer space. According to a theory developed by the Dutch astronomers Jan H. Oort and J. J. van Woerkom, there is an enormous number of comets—probably 100 billion. They form a vast cloud at a distance of 50,000 to 100,000 astronomical units from the sun—almost as far as the nearest stars. (One astronomical unit is the mean distance between the sun and the earth.) A comet in the cloud moves around the sun in a huge orbit, one circuit of which takes millions of years. Occasionally, however, the gravitational attraction of a passing star may disturb the orbit of a comet so that the comet comes closer to the sun. Then the pull of the larger planets, notably Jupiter and Saturn, may further distort the orbit so that the comet makes a complete turn around the sun in as little as a few years. Sometimes the orbit may be changed to an open hyperbola, and the comet escapes from the solar system entirely.

The comet itself is normally a conglomeration of solids. Held together by their mutual gravitational attraction, they form a nucleus perhaps a mile to 50 miles in diameter. According to Whipple's picture, the nucleus consists mainly of ices of water (H_2O), methane (CH_4) and ammonia (NH_3). Interspersed among these frozen compounds of the lighter elements are molecules and particles of heavier elements. When the comet is far away from the sun, its ices are kept in a "deep freeze"; when it approaches the sun, they begin to vaporize. The escaping gases surround the nucleus with an envelope (called the head or coma) from 10,000 to more than 100,000 miles in diameter. They may ultimately form the comet's tail, which in some cases extends 100 million miles.

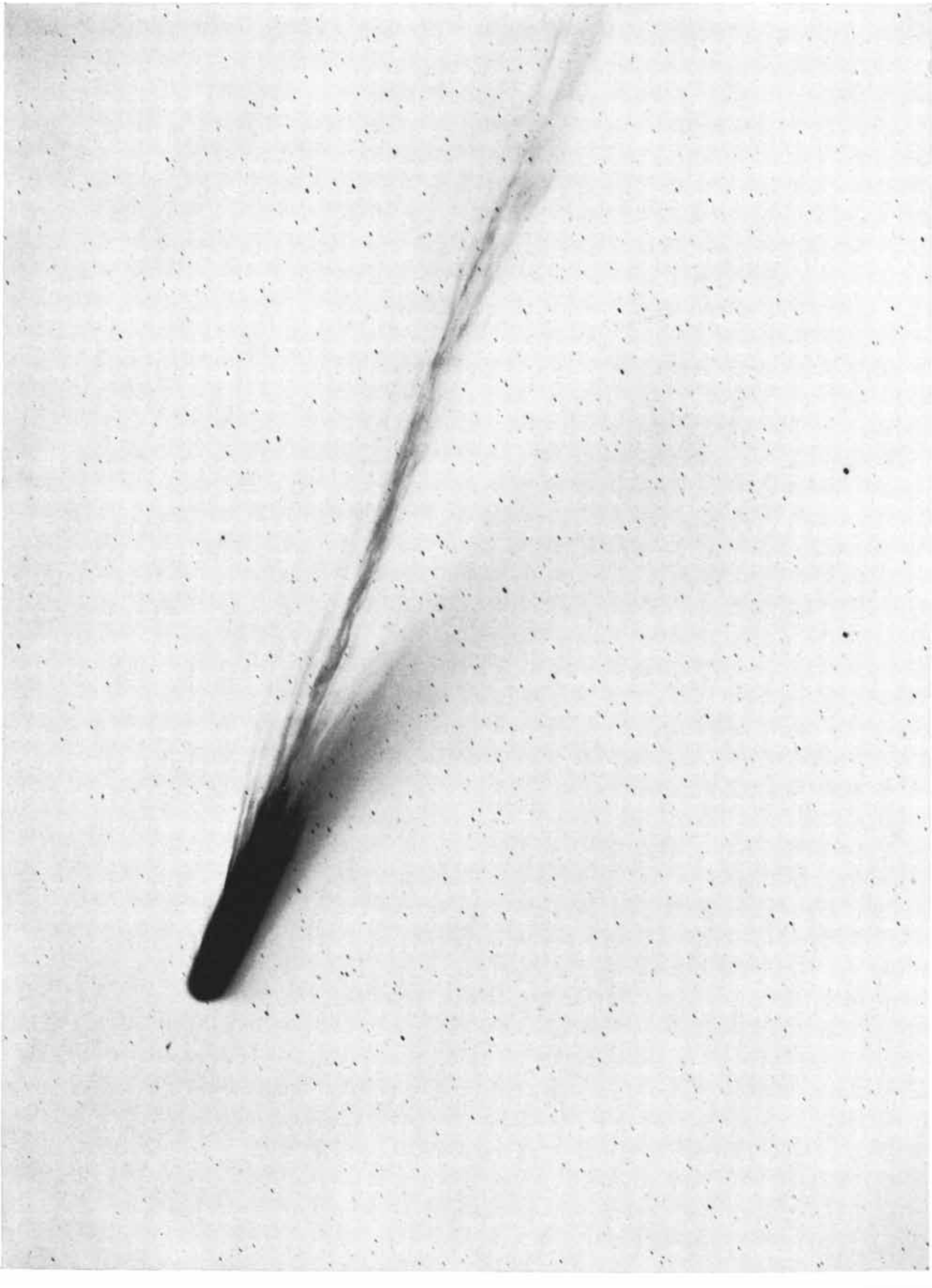
Often the comet does not develop a tail at all. Whether or not the tail forms depends mainly on how close the comet comes to the sun; obviously more material will evaporate from the comet when it is near the sun than when it is farther away. But the formation of a tail also depends on two other factors: the properties of the individual comet (*e.g.*, its chemical composition) and the changing activity of the sun.

Comet tails vary greatly in appearance from comet to comet, and the tail of an individual comet may change from time to time. The tails have been classified into three main groups. Tails of Type I are long and straight; within them there are often threadlike streamers, knots and other structures. Spectra of such tails indicate that they consist mainly of ionized molecules of carbon monoxide (CO^+), nitrogen (N_2^+), carbon dioxide (CO_2^+) and the hydrocarbon radical CH^+. Of these molecules those of ionized carbon monoxide appear to be by far the most abundant. Tails of Type II and Type III are more or less curved; most of them are shorter than tails of Type I. They are fuzzy and have little or no internal structure. Their spectra show no lines of ionized molecules; they are probably composed largely of gases which are not ionized and of dust. Often both kinds of tail—the straight and the curved—appear simultaneously in one comet [*see photographs on next two pages*].

What forces act on comets to produce the varied patterns of their tails? All comet tails point predominantly away from the sun, so it would seem reasonable to look for the origin of these forces in the sun itself. Of course the sun exerts a strong gravitational pull on all the matter in a comet. But there must also be a repulsive force which pushes the matter in the tails away from the sun.

In order to get a clearer picture of how the repulsive force operates, astronomers have measured the acceleration of matter in comet tails. This is done by noting on a photographic plate the position of an individual structure in a tail, and then observing on plates made at successive intervals how far the structure has moved. It turns out that the acceleration varies with the kind of tail. The acceleration of matter in a tail of Type I requires a repulsive force of the order of 200 times (occasionally up to 2,000 times) greater than the attractive force of the sun's gravitation. The acceleration in a tail of Type II requires a force equal to or perhaps twice as strong as the sun's gravitation; the acceleration

COMET MRKOS was photographed on August 23, 1957, with the 48-inch Schmidt telescope on Palomar Mountain. In this negative print the light areas are dark, and *vice versa.* Such prints are used by astronomers to increase contrast and accentuate faint objects.



SAME COMET was photographed with the 48-inch Schmidt telescope two days later, when the structure of its tail had changed considerably. The long, thin streamers comprise a tail of Type I. The faint, curved dark area to right of this tail is a tail of Type II.

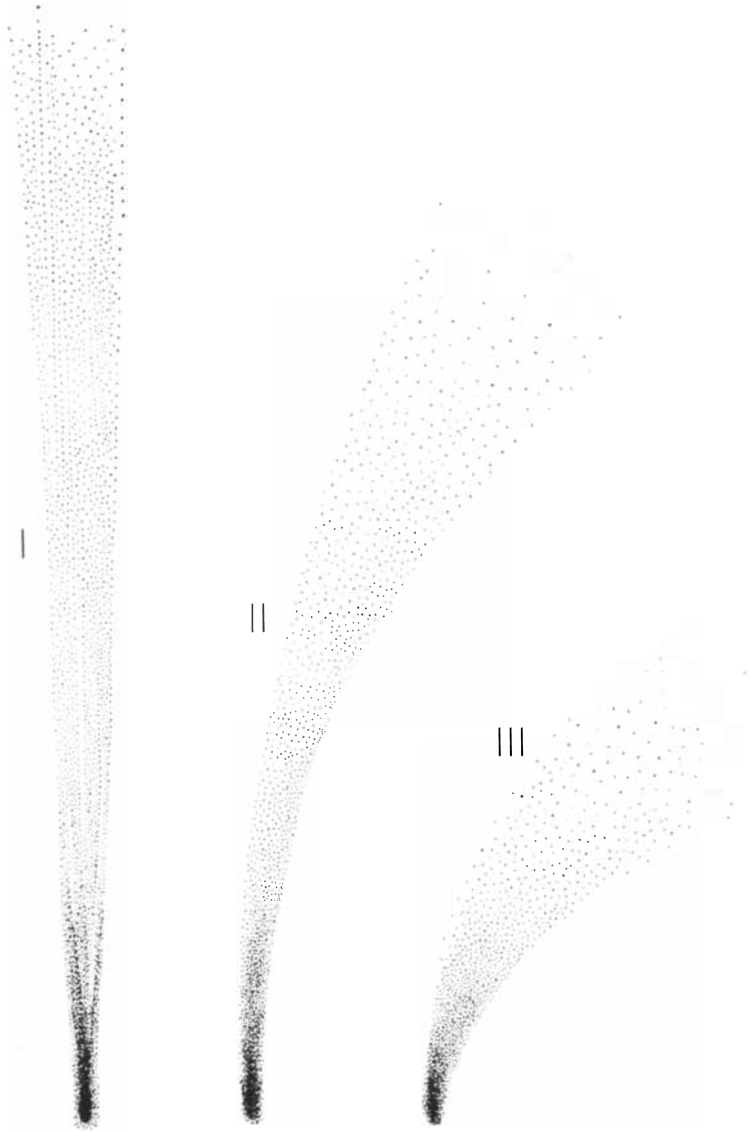
in a tail of Type III, a force even smaller than the sun's gravitation.

Now astronomers have long assumed that the repulsive force was the pressure of light from the sun. Theoretical studies have indicated, however, that the force exerted by light on molecules or dust particles in the tail of a comet would be at most a few times greater than the gravitational force of the sun. Thus light pressure may account for the tails of Type II and Type III, but not for those of Type I. To explain the large accelerations of matter in the spectacular tails of Type I another force is needed.

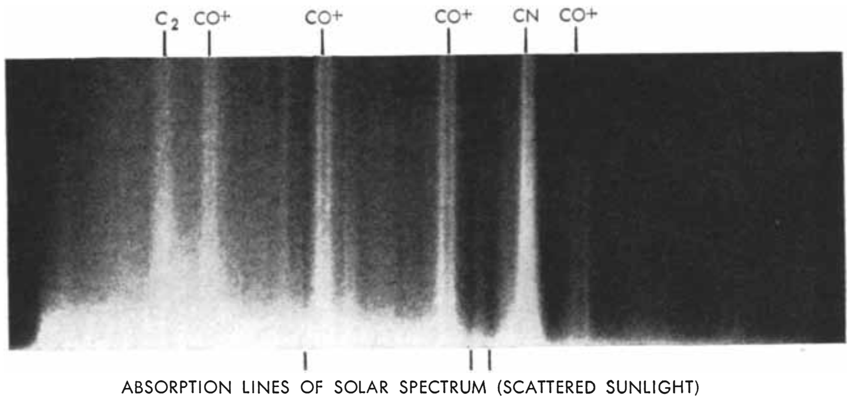
Is it perhaps the ultraviolet radiation of the sun, as distinct from the sun's visible light? Sunspots are associated with an increase in the sun's ultraviolet radiation, and the German astrophysicist Max Beyer found indications that they are also associated with an increase in the brightness of the heads of comets. It is possible that this energetic radiation enhances the photochemical reactions which give rise to the molecules and ions of the tails. But a closer examination shows that ultraviolet radiation is even less able than visible light to account for the large accelerations of Type I tails.

What about the particles of matter which are ejected by the sun? In recent years much has been learned about this corpuscular radiation [see "Corpuscles from the Sun," by Walter Orr Roberts; SCIENTIFIC AMERICAN, February, 1955]. We know that it consists of electrons and positive ions in equal numbers—what the physicist calls a "plasma." These oppositely charged particles must surely interact with the positive ions of the long Type I tails. Can they account for the acceleration of matter in these tails?

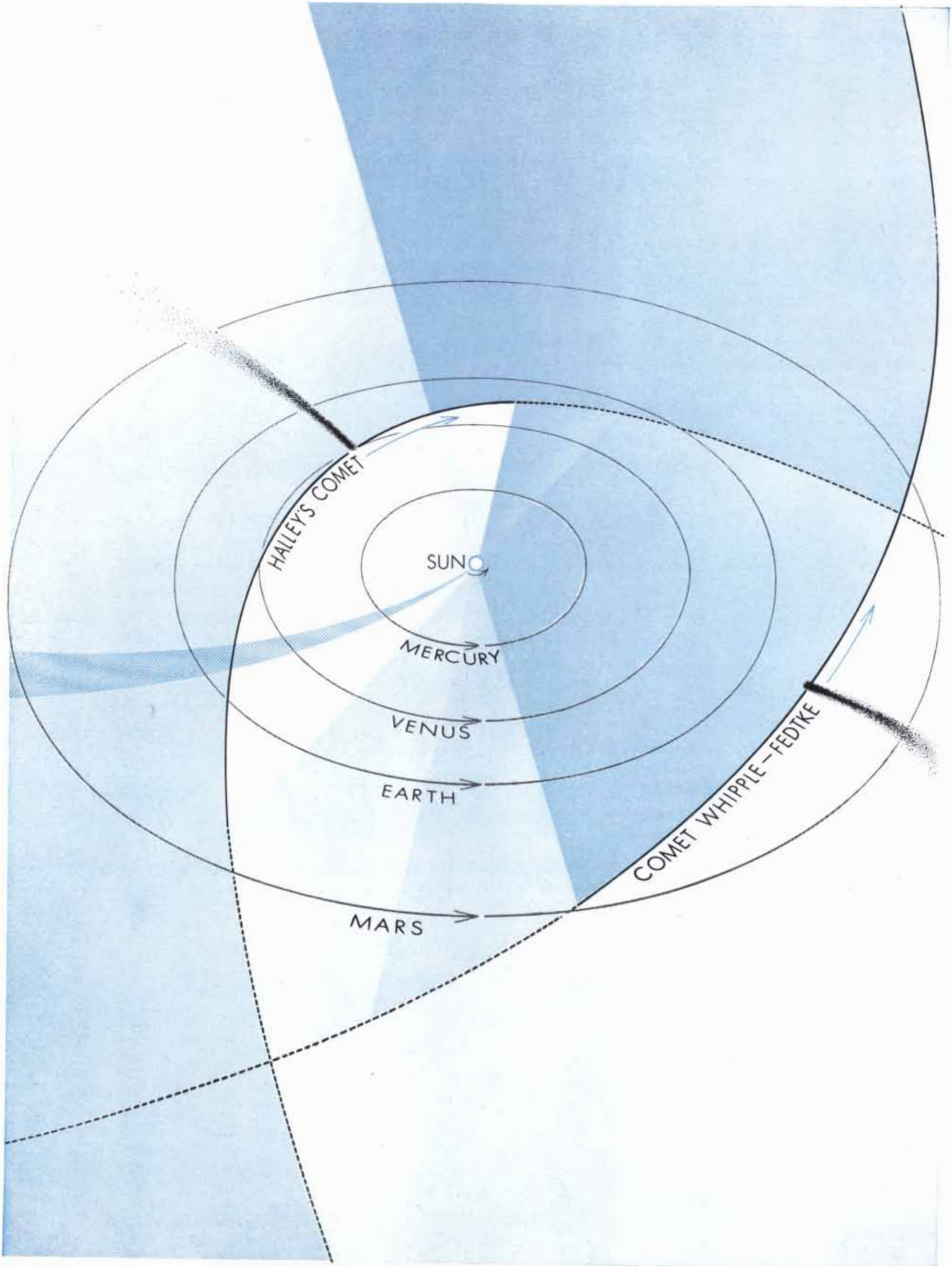
The corpuscular radiation of the sun originates in the vicinity of a group of sunspots, but often it persists much longer than the spots. Sometimes, however, a brilliant eruption in the lower atmosphere of the sun gives rise to an unusually strong blast of corpuscles. When the corpuscles reach the earth, they cause a "storm" in the earth's magnetic field. By correlating the time of the eruption with the beginning of the magnetic storm, we can calculate the velocity of the corpuscles: they move at speeds up to 1,000 miles per second. The German astrophysicist Albrecht Unsöld and the British geophysicist Sydney Chapman have estimated the density of the corpuscles in these powerful streams: in violent magnetic storms it goes as



THREE TYPES OF COMET TAIL are depicted in these schematic drawings. Type I tails are long and straight; Type II tails are curved; Type III tails are also curved but shorter.



SPECTRUM OF COMET MRKOS was made on August 28, 1957, by George H. Herbig of the Lick Observatory. The bright horizontal area at the bottom of the photograph is the spectrum of the nucleus of the comet. The vertical streaks are bright and dark lines in the spectrum of the comet's tail. The bright lines reveal the presence in tail of carbon (C_2), positively charged ions of carbon monoxide (CO^+) and the radical of carbon and nitrogen CN.



ORBITS OF TWO COMETS are depicted with respect to the orbits of the four inner planets. The planets move in the plane of the ecliptic. The sun also turns on its axis approximately in this plane. The orbits of the comets are inclined to the plane of the ecliptic. The curved hatched area represents a stream of particles emitted by the sun. The tails of the comets are depicted schematically.

high as 100,000 corpuscles per cubic centimeter.

Sometimes storms in the magnetic field of the earth occur at intervals of 27 days. Since it takes 27 days for the sun (as it is seen from the earth) to make one turn on its axis, it is assumed that these recurrent storms are caused by long-lasting streams of corpuscular radiation. If there is a relationship between corpuscular radiation and comet tails of Type I, periodic changes should also occur in the tails.

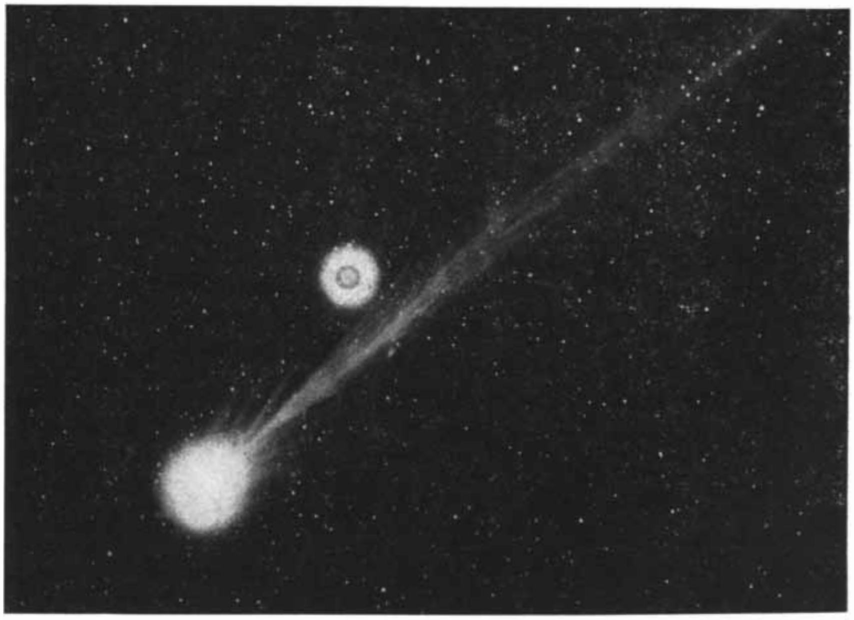
The changes will not come at intervals of 27 days, because the sun's period of rotation as seen from a comet will differ from the period of rotation as seen from the earth. Actually the sun turns on its axis once every 25 days with respect to the stars. To us the period of rotation appears to be longer because the earth moves along its orbit in the direction of the sun's rotation. The length of the period as seen from a comet similarly depends on the comet's motion with respect to the sun. Further complicating the situation is the fact that comets usually do not move in the plane of the ecliptic—the plane in which the planets move along their orbits, and which approximately coincides with the plane of the sun's rotation.

Consider the following two examples. We regard a comet as moving in the direction of the sun's rotation and the planets' orbital motion. Viewed in this way, Comet Whipple-Fedtke (discovered in 1942) moves in an orbit which is inclined to the plane of the ecliptic by an angle of 20 degrees. From the comet, as from the earth, the sun's period of rotation is longer than the true period. Viewed in the same way, Halley's Comet (last seen in 1910) moves in an orbit which is inclined at an angle of 162 degrees. Thus for all practical purposes Halley's Comet moves in a direction opposite the direction of the sun's rotation, and is inclined at an angle of only 18 degrees. From the comet the period of the sun's rotation is several days *shorter* than the true period.

The acceleration of matter in the Type I tail of Comet Whipple-Fedtke was measured at various times; the largest accelerations were observed on March 3, 1943, and on March 29 of the same year. Photographs made on these dates also show unusual features in the tail. The dates coincide with the period of rotation of the sun as seen from the comet: 26½ days.

On April 22, 1910, the acceleration of matter in the Type I tail of Halley's Comet was 240 times greater than the acceleration of matter falling toward the

HALLEY'S COMET was photographed on May 6, 1910, from a station of the Lick Observatory in Santiago, Chile. The short streaks which appear in the background were made by the images of stars, which remained stationary while the telescope followed the comet.



COMET WHIPPLE-FEDTKE was photographed in 1942 from the Sonneberg Observatory in Germany. The large spot above the tail of the comet is the image of a bright star.

sun; between June 5 and June 9 it was of the order of 1,000 times greater. During all other observations the acceleration was considerably smaller. The interval between April 22 and June 7 corresponds exactly to two turns of the sun as seen from the comet. The intermediate date in May fell in an interval when the comet was so close to the sun that it could not be satisfactorily observed.

If corpuscular streams caused these cometary events, we would expect to find that the events were correlated with magnetic storms on the earth. Both comets were near the plane of the ecliptic, and the same corpuscular streams which hit them should also have played over the earth. On March 29, 1943, when large accelerations were observed in the tail of Comet Whipple-Fedtke, there was indeed a major magnetic storm; presumably the stream first hit the earth and some hours later the comet. The data of 1910 are not so clear-cut, because of a generally higher level of solar activity at that time, but there does appear to be a statistical correlation between the accelerations in Halley's Comet and magnetic disturbances on the earth.

This evidence (and some we have not discussed here) would seem to show that the sun's corpuscular radiation does have an effect on the tails of comets. But exactly how does it exert this effect?

The simplest mechanism would be ordinary friction. Here one would have three gaseous fluids moving through one another: the solar ions (mostly nuclei of hydrogen), the cometary ions (mostly molecules with one electron removed) and the free electrons of both the solar plasma and the cometary plasma. Calculations have shown that, if the temperature of the electrons is 10,000 degrees absolute (10,000 degrees centigrade above absolute zero), a solar plasma of 100 billion corpuscles per square centimeter per second would give the cometary ions a frictional acceleration of one meter per second per second.

The coupling of the solar corpuscles and the cometary ions may be enhanced by magnetic fields carried along with the corpuscles. There is evidence for such fields in the long, thin streamers of Type I tails. These streamers are sometimes as much as 500,000 miles long and only 500 miles wide. Even if one assumes that the temperature of the ions in a streamer is as low as 300 degrees absolute, their random thermal motions should make the streamer much wider. It is possible that the charged cometary molecules are held in narrow bundles by the magnetic field of a corpuscular stream. Curious helical structures in tails of Type I also suggest the presence of a magnetic field. We are presently studying photographs of Comet Mrkos, which came into view last year, to gain some insight into these relationships.

COMET AREND-ROLAND was photographed on April 27, 1957, with the 48-inch Schmidt telescope on Palomar Mountain. The projection to the left of the comet is not material projected toward the sun but is cometary debris in the plane of the comet's orbit.

Kodak reports on:

the boys who do their arithmetic in advance . . . 1,000,000 program chairmen and how to help them . . . why 5,000 $5 bills were stuffed into our till

A fast film with a quiet name

Dearly as a hunting-and-fishing editor loves to describe some high Andean stream which only a major general has ever had occasion to whip, so the photographic press dotes on miracles in making pictures with a parsimony of radiant energy that few occasions demand. We would no more discourage this than we would the game of bridge.

The fastest film that can be obtained by walking up to a film counter without previous notice and plunking down the money is labeled *Kodak Royal-X Pan Film*. It comes either as roll film or sheet film. It is grainy. The average photo-hobbyist needs it about as badly as he needs a fishing trip to the Andes, except that a roll of the 120 size lists for only 75¢.

On the other hand, take a fellow whose hobby is bridge but whose job is to record the path of a piece of metal hurtling through the twilight a thousand miles above him. Or take his classmate who needs to analyze the first microsecond of a thermonuclear explosion. These boys are not apt to mail in their negatives to us with a letter asking how come they turned out so dark. They have been in close touch with us before going out to their stations. In their behalf we have very carefully considered all the data on the *Royal-X Pan* emulsion and concluded that for the present putting it on 16mm, 35mm, or 70mm film would not be a good idea. Furthermore, the arithmetic indicates that the most sensitive regular-production films in these widths, *Kodak Tri-X Film* and *Kodak Linagraph Pan Film*, might not be quite sensitive enough.

No, this is not leading up to some new "Quadruple Grand Ducal Whoosh!-X Film." In these cases of speed-above-all what we often recommend bears the quieter name, Kodak Spectroscopic Film, Type I-D(2). *It is one of 111 special emulsions we make for astrophysicists and the like. By some tests it is faster than* Royal-X Pan, *but we are not prepared to prove this. By advance arrangement through Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N.Y., as little as 100 feet of it in 35mm perforated form can be furnished for $10, or two 100-foot 16mm rolls for $6.60 apiece (list).*

A talisman from New Haven

We manufacture 16mm motion picture projectors and film. The projectors are sold by audio-visual dealers, to be found in many cities. The film is purchased by motion picture producers, who place suitable images on it, so that there shall be some further purpose served by running it through the projectors sold by the audio-visual dealers. Our intentions are direct and praiseworthy. We want large numbers of persons to visit the audio-visual dealers, to discuss with them such matters as the advantage of a 25-watt amplifier over a 15-watt amplifier, and to conclude each such visit with a substantial order for each of the four current models of *Kodak Pageant Sound Projectors*. We also want a large increase in the number of new 16mm films produced. At latest count, only 77 new films were being professionally produced in the United States each day.

Finding ourselves in mid-20th century, we have to proceed toward these simple objectives by sophisticated routes. We use more than mere words for persuasion. We employ graphic communication. From the Yale News Bureau, we acquire a photograph of their serene campus.

We assure the Bureau that no endorsement of us or our works is to be implied. The photograph serves only as a visual symbol of scientific objectivity.

Next we establish why we picture Yale instead of some other equally serene haven of objectivity. Yale was the site of two important conferences at which learned psychologists and successful communicators met and scrutinized the obstacles to wider and wiser use of films, slides, sound filmstrips, etc., in conveying information, skills, or attitudes from one group of heads to another.* A second Yale angle is that two of its professors of psychology have prepared a scholarly evaluation of scientific principles for maximum learning from motion pictures and other audio-visual media. In the native patois of their discipline they say that movies are fine for teaching and suggest lines of research on how to improve them even further than they have already been improved by all the research they cite.

Their views and those of the conferees are given in a book entitled "Graphic Communication—and the Crisis in Education," obtainable from the Department of Audio-Visual Instruction of the National Education Association, 1201 16th Street, N.W., Washington 6, D.C. We suggest the hard-cover edition at $2. It makes just the right noise when slapped down at the opposite end of the table from any finance committee member who insists on something scientific that he can take home in his briefcase.

*The obstacles haven't been too bad, mind you. The nation's schools manage to keep 171,000 16mm projectors busy, while the churches and their affiliates operate another 90,000. Business firms own almost as many as the schools. Over 3500 companies and trade associations currently sponsor one or more of their own 16mm movies. Eager to get them are the program chairmen of the estimated 1,000,000 groups in the U.S.A. that have 50 or more members and meet regularly. That's a lot of P.-T.A.

The stickum of last resort

For *Eastman 910 Adhesive*, of which the active ingredient is methyl-2-cyanoacrylate, we now have a slogan —"the adhesive to try if no other will do."

We are just being sensible. Its price by the ounce is $10; special pound price, $75. It *does* make possible some distinctly advantageous new assembly techniques in a large number of industries. So we gather from the correspondence incidental to the 5,000 orders filled during the past year. It bonds virtually everything (except silicones and polyolefins, else how could we deliver it?).

The biggest plus is the speed at which enormous bond strength is developed within minutes after application of this thin, clear liquid to one of the adherents. Within hours the tensile strength of its bond to steel is in the thousands of pounds per square inch. In the case of glass, rubber, or wood, bonds are stronger than the material itself. There is virtually no shrinkage on setting. No heating, no great squeezing, no evaporation is required. The bond, however, should not be depended on for too many weeks at temperatures above 175°F, particularly in the presence of much moisture. That's the minus.

In case Eastman 910 Adhesive *sounds more interesting now than it did when we practically swamped our boat by offering samples at $5 an ounce, write to Eastman Chemical Products, Inc., Department E 910A, Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).*

Prices stated are subject to change without notice.

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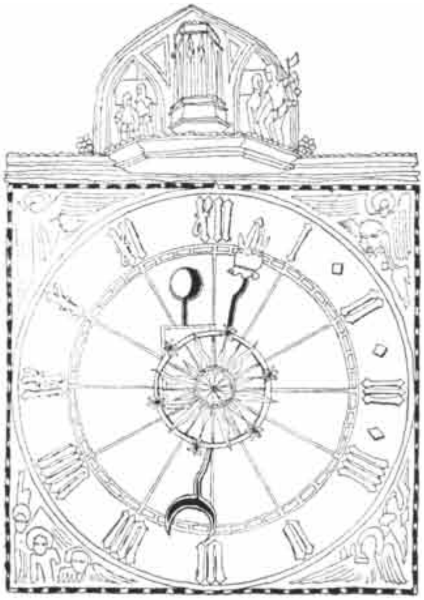


Aid to Education

Just before it adjourned Congress enacted a law allotting about $900 million to aid education over the next four years.

A total of $295 million was made available for loans of up to $1,000 per year to gifted undergraduates. The money will be repayable at 3 per cent interest over 10 years. But those who teach in public schools for five years after graduation will be forgiven half their debt. Students with unusual ability in science, mathematics or foreign languages are preferred candidates for the loans, which may go to as many as 100,000 new undergraduates each year.

Three-year graduate fellowships starting at $2,000 per year and increasing to $2,400 will be granted to 5,500 Ph.D. candidates in the next four years. Each fellow will also receive an annual allowance of $400 for each dependent, and the institution he attends will be paid up to $2,500 to cover the cost of his training. Fellowships and loans beginning in the last year covered by the act will continue until the recipients have completed their courses.

Other major provisions of the act include: $280 million for grants to states and loans to private schools to buy equipment; $15 million a year to finance counseling and testing programs; $15 million a year for the improvement of vocational education; and $18 million over four years for research on educational radio, films and television.

In passing this legislation Congress failed to act on a number of other proposals that had been made during the past year. It made no provision for school construction; granted no scholarships for undergraduates; made available no funds for current recruiting of teachers or for raising teachers' salaries.

Scientific Diplomacy

Leading scientists for the first time held an international diplomatic conference when the scientific representatives of eight nations met in Geneva to decide how to patrol the world for nuclear explosions. As diplomatic meetings go, this one went smoothly. For eight weeks in July and August the scientists discussed methods of detecting explosions from afar. In the end they agreed on recommendations to guide the statesmen convening in Geneva in September to draw up an international ban on the testing of nuclear weapons.

For the first month the scientists reviewed and evaluated possible ways of detecting nuclear explosions. They decided that a detection network should rely on four types of instruments:

1. Sensitive pressure-gauges to pick up shock waves in the air.
2. Seismographs to register ground waves generated by explosions under or near the surface of the earth.
3. Air-sampling devices to collect and analyze radioactive debris.
4. Photocells and radio receivers to pick up electromagnetic radiation.

There was then some disagreement as to how dense the detection network ought to be. The U. S. representatives, James B. Fisk of Bell Telephone Laboratories and Robert F. Bacher of the California Institute of Technology, wanted the stations to be more closely spaced than the Soviet delegates thought necessary. After about three weeks of discussion Yevgeny K. Federov, head of the Soviet delegation, yielded on this point.

The detection network finally recommended should, in the scientists' opinion, disclose a major nuclear detonation set off anywhere on earth. Very small explosions (equivalent to less than 1,000 tons of TNT) might escape notice, particularly if they took place deep underground or high in the atmosphere. The scientists envisioned a world-wide network of 180 stations: 37 in Asia, 24 in North America, 16 in South America, 16 in Africa, six in Europe, four in Antarctica, 60 on islands and 10 on ships at sea. In areas where earthquakes are rare, the stations would be spaced 1,050 miles apart; elsewhere they would be 620 miles apart. There would probably be 10 or 11 stations in the U. S., and 16 or 17 in the U.S.S.R.

The nations represented at the conference, in addition to the U. S. and the U.S.S.R., were Great Britain, Canada, Czechoslovakia, France, Poland and Rumania.

Astron

A promising new way of generating thermonuclear energy from heavy hydrogen is now being tested at the University of California Radiation Laboratory at Livermore, Calif. The new idea was proposed by Nicholas Christofilos, who described it at an American Physical Society meeting in Vancouver, B.C.

Christofilos is the man who caused a stir among the U. S. physicists when it turned out that he had anticipated them in devising the strong-focusing principle used in high-energy accelerators. At the time he proposed strong focusing he was an obscure electrical engineer in Greece. When he sent a report of his work to the Atomic Energy Commission, physicists failed to recognize its meaning, largely because of his unconventional mathematics. He was given credit for his idea only some years later, after strong focusing had been developed independently by physicists at the Brookhaven National Laboratory. Christofilos is now on the staff at Livermore.

His idea for controlling nuclear fusion is also original. He has developed in theory a machine called "astron," a name which, like "stellarator" [*see page 28*], connotes the thermonuclear reactions of stars. It is a long vacuum-cylinder with a magnetic field parallel to its axis. When electrons with energies of several million electron volts are injected into the cylinder, the magnetic field will make them bounce back and forth in corkscrew-shaped orbits; they will in effect form a lining for the cylinder. The layer of electrons should serve two purposes: it should help contain the heavy hydrogen ions and it should also transmit energy to raise the ions to the temperature required for nuclear fusion.

Christofilos and a group of colleagues

are now building an experimental astron. This first machine will not be powerful enough to fuse hydrogen atoms, but it should provide a test for his theory.

Too Hot to Travel?

Radiation at high altitudes is even stronger than reports from the first U. S. earth satellites had indicated [see "Science and the Citizen," June]. Counters in Explorer IV, launched in July, reveal an intensity of 10 roentgens per hour 1,200 miles above South America. At this rate a space traveler would absorb a whole week's permissible dose in about two minutes, according to Carl E. McIlwain of the State University of Iowa, who helped design the satellites' instruments.

The radiation evidently consists mainly of charged particles, for it varies with the earth's magnetic field at different latitudes. It varies also with altitude, doubling every 60 miles up to at least the 1,350-mile outer limit of the Explorer IV orbit. Whether the intensity continues to increase rapidly at still greater altitudes is a question that may be settled by one of the first "moon-probing" rockets. The radiation is extremely penetrating. One Geiger counter shielded with a 1/16th-inch layer of lead recorded 60 per cent as many impacts as an unshielded counter. It is not yet possible to deduce the nature of the particles. But if they are electrons, they must have energies of about six million electron volts. If they are protons, their energies must range around 40 million electron volts.

Explorers I and III were unable to measure the radiation; it was so intense that it swamped the counters in these earlier satellites. When they planned the instrumentation for Explorer IV, McIlwain and his co-workers purposely made the counters less sensitive by decreasing the size of the counter windows that admit radiation. Even though they made the effective area of the windows only 1/75th as large, the counters in Explorer IV have still recorded up to 5,000 impacts per second.

Splitting the Gene

A hereditary trait may be determined by as little as a tenth of a molecule of deoxyribonucleic acid, the genetic substance commonly called DNA. In a paper presented to the Tenth International Congress of Genetics at Montreal, Leonard S. Lerman of the University of Colorado Medical Center reported changing certain hereditary characteristics of pneumococci with fragments of DNA.

A pneumococcus has about 500 molecules of DNA in its own genetic apparatus, and it is capable of exchanging about 100 of these with another strain. Lerman started with normal pneumococci and incorporated into them some DNA from a strain that was resistant to streptomycin. The foreign DNA made his original strain also resistant to the drug. Even when he first partially deactivated the foreign DNA with enzymes, it was able to confer resistance to streptomycin. Lerman estimated that the enzyme treatment had destroyed all but a tenth to a fifth of the DNA molecule. His experiments indicate that of the 20,000 nucleotide building blocks in a single DNA molecule, only about 3,000 are needed to determine a single genetic characteristic.

Power from Plutonium

The first substantial non-military application of plutonium in the U. S. has been made by the Atomic Energy Commission. The Materials Testing Reactor at Arco, Idaho, has been loaded with plutonium fuel and operated at a level of 30,000 kilowatts. Since 1952 this reactor had run on uranium enriched with fissionable U-235.

Although plutonium has heretofore been reserved for weapons, it is potentially a better fuel than uranium. Plutonium fissions more readily than uranium and burns more completely before the fuel elements have to be reprocessed to remove fission products. The reactor had to be modified slightly so that it could burn plutonium. Uranium is fissioned by slow neutrons and requires a moderator, such as graphite or heavy water, to slow fast neutrons. Plutonium, on the other hand, is fissioned by fast, unmoderated neutrons.

After completing tests with plutonium, the AEC plans to load the reactor with U-233, the artificial uranium isotope derived from thorium.

Is Bigger Better?

The corn will grow scarcely higher than an elephant's knee this year on 1,000 acres of Illinois farmland. Plant breeders there are closely watching the first extensive field tests of eight dwarf varieties of corn.

In comparison with U. S. No. 13, a common hybrid corn, the dwarf varieties are doing well, reports E. R. Leng,

a plant geneticist at the University of Illinois. Even high winds that have flattened up to 80 per cent of average-sized corn plants have in no case broken more than 10 per cent of the dwarf stalks. The yields of dwarf corn are good: 96 bushels per acre. Although this is 10 per cent lower than a yield of ordinary corn, dwarf corn is much easier to harvest by machinery. And in some locations the yield of dwarf varieties was higher than that of normal corn, Leng writes in the magazine *Crops and Soils.*

Commercial seed firms are interested, and next year there will be enough seed for 10,000 acres of dwarf corn.

Antarctic Antibiotic

It is a strange fact that the wildlife of the Antarctic is free from bacterial infection. After some on-the-spot detective work, John McNeill Sieburth of the Virginia Polytechnic Institute thinks he has found the explanation.

On an International Geophysical Year polar expedition last winter, Sieburth started by studying the gentoo penguin. Every bird he examined was germfree. Next he turned to a species of shrimp, the gentoo penguin's only food. The shrimp, too, contained no bacteria. Finally he investigated the phytoplankton, the microscopic plants on which the shrimp feed. The phytoplankton were not only germfree; they were also actively antibiotic.

Since these phytoplankton are abundant in the Antarctic seas, and since they are the foundation of the food cycle throughout the area, the antibiotic they contain may be able to protect every Antarctic animal from bacteria. Sieburth brought back samples of the tiny plants, and he and his coworkers are presently attempting to isolate the antibiotic in pure form.

The Perfect Metal

Physically perfect crystals of silicon larger than a man's finger have been grown by a new process invented by William C. Dash, a General Electric Research Laboratory physicist. The extraordinary feature of these crystals is that they contain no dislocations, that is, no rows of atoms that are out of line with the rest of the crystal lattice.

Crystals ordinarily contain a great many dislocations, for a speck of dust, an odd-sized foreign atom, or even a slight jar can cause a dislocation when a crystal is forming. The most nearly perfect crystals up to now have been "whiskers" deposited on cold surfaces by hot vapors. Such whiskers, usually much thinner than a human hair, have a single dislocation running up the middle. Metallic whiskers are uncommonly strong, presumably because they are so nearly perfect. Iron whiskers, for example, have tensile strengths up to almost two million pounds per square inch—five times the strength of the best piano-wire steel and about 60 times the strength of commercial iron.

The new silicon crystals also appear to be exceptionally strong. It is difficult, however, to measure their strength, because anything used to grip the crystals scars them and introduces dislocations. To take practical advantage of the strength of dislocation-free metals, it will be necessary to coat them so that their surfaces will be protected from scratches.

Dash's process can probably be adapted to a variety of metals. He starts with a tiny, dislocation-free crystal which he dips into a pool of molten silicon that is held atop a silicon pedestal by an electromagnetic field. Then, as he slowly withdraws the seed in the direction of a main crystal axis, the molten silicon grows into a big crystal.

Drug Fission

Reserpine acts like two entirely different drugs. It tranquilizes, and it also lowers blood pressure. Chemists at Ciba Pharmaceutical Products have now separated the two functions of the drug by making two derivatives, one a tranquilizer and the other an agent that lowers blood pressure. They reported their work at the 134th national meeting of the American Chemical Society, held in Chicago.

The new hypotensive agent, methyl carbethoxysyringoyl reserpate, is as strong as reserpine in this respect but has only a twentieth of reserpine's potency as a tranquilizer. The other new drug, methyl 3-dimethylaminobenzoyl reserpate, is about a fourth as effective a tranquilizer as reserpine, and has a fortieth of the hypotensive activity.

The chemists who made the report were R. A. Lucas, M. E. Kuehne, Miss M. J. Ceglowski, R. L. Dziemian and H. B. MacPhillamy.

Stimulation by Germs

Animals must be exposed to germs from an early age in order to build up a mechanism for combatting specific diseases, according to experiments reported by two Swedish workers. Writing in *The Journal of Experimental Medicine,*

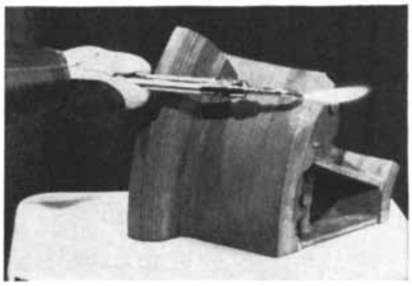
THE FACTS ABOUT MAGNESIUM AND FIRE

There are many misunderstandings about the lightest structural metal...Here are some facts everyone in manufacturing should know.

MAGNESIUM is being used today in many varied applications. Some of these uses involve normal operating temperatures while others involve elevated temperatures ranging from 500° to 700°F. and above. Such items as ladders, luggage, hand trucks, aircraft wheels and skins are all used at temperatures where ignition is improbable. Supersonic jets and missiles, however, rely on magnesium alloys for dependable performance at the elevated temperatures previously mentioned.

Yet some designers, engineers and production men hesitate to work with magnesium because they have heard that it "burns." What are the facts about this highly useful metal?

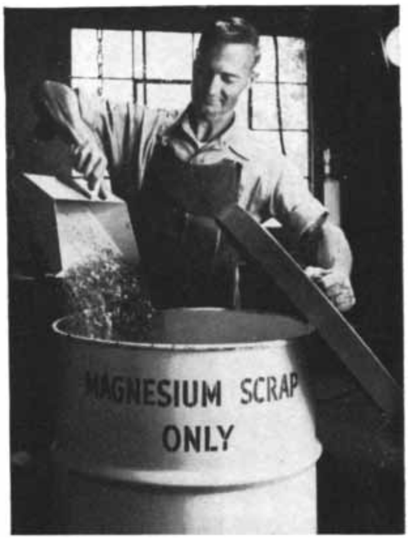
The National Fire Protection Association discusses the combustibility of magnesium as follows: "The ease of ignition of magnesium depends to a large extent upon the size and shape of the material as well as the size or intensity of the source of ignition. In the form of ribbon, shavings, or chips with thin feather-like edges, or grinding dust, a spark or the flame of a match may be sufficient to start the material burning. Heavier pieces such as ingots and thick wall castings are difficult to ignite because heat is conducted rapidly away from the source of ignition. If the entire piece of metal can be raised to the ignition temperature (about 1200°F. for pure magnesium and many of the alloys) self-sustained burning will occur."*



AN ACETYLENE TORCH fails to sustain ignition of this magnesium casting, even after prolonged contact. Heat is conducted rapidly away from the point of application.

Hundreds of foundries and metal-working fabricators work with magnesium every day. Because these firms know how to handle the metal, the incidence of fires attributed to magnesium is very small.

It is important that proper machine shop practices and rules of good housekeeping be followed. Correctly ground tools will decrease tool pressure and friction on the work, preventing temperatures high enough to reach the



GOOD HOUSEKEEPING, proper machine shop practices keep risk of fire to a minimum.

ignition point of the chips and turnings. A shower of hot sparks from the grinding of a steel tool bit could ignite dust left from the previous grinding of a magnesium part, but magnesium will not ignite spontaneously.

Once ignited, a fire in magnesium can be extinguished effectively by sprinkling on a layer of a graphite base powder such as G-1. Various other proprietary powders are also available. Water, or any of the liquid, gas, or foam type extinguishers should not be used. They tend to react with the burning metal and accelerate the fire. With the correct basic knowledge and proper attention to safety precautions, anyone can handle magnesium in the shop with negligible risk.

DIRECT CONTACT with an open flame will not ignite magnesium alloy in this application. Magnesium griddles for cooking have been in use for many years.

* *Source: Chapter One* (N.F.P.A.), *Bulletin No. 48,* STANDARDS FOR MAGNESIUM. *This bulletin available on request without cost or obligation.*

FOR FURTHER DETAILS on safe handling of magnesium, contact your nearest Dow Sales Office or write to THE DOW CHEMICAL COMPANY, Midland, Michigan, Department MA1482AA.

YOU CAN DEPEND ON DOW

Bengt E. Gustafsson of the University of Lund and Carl-Bertil Laurell of the Malmö General Hospital tell how they raised five generations of rats in germ-free surroundings. After the first generation, all the animals were markedly deficient in gamma globulin, the blood-protein fraction in which antibodies are found.

Human infants acquire an initial supply of gamma globulin from their mothers and produce none for the first few months [see "Agammaglobulinemia," by David Gitlin and Charles A. Janeway; Scientific American, July, 1957]. The gamma globulin level of an infant's blood declines for the first two or three months, then starts to rise. Gustafsson and Laurell conclude from their experiments that the rise is stimulated by germs in the air, the mouth and the intestinal tract. The rats that had never been exposed to germs produced only a third as much gamma globulin as rats raised on the same diet but in a normally unhygienic environment.

Submarine Mining

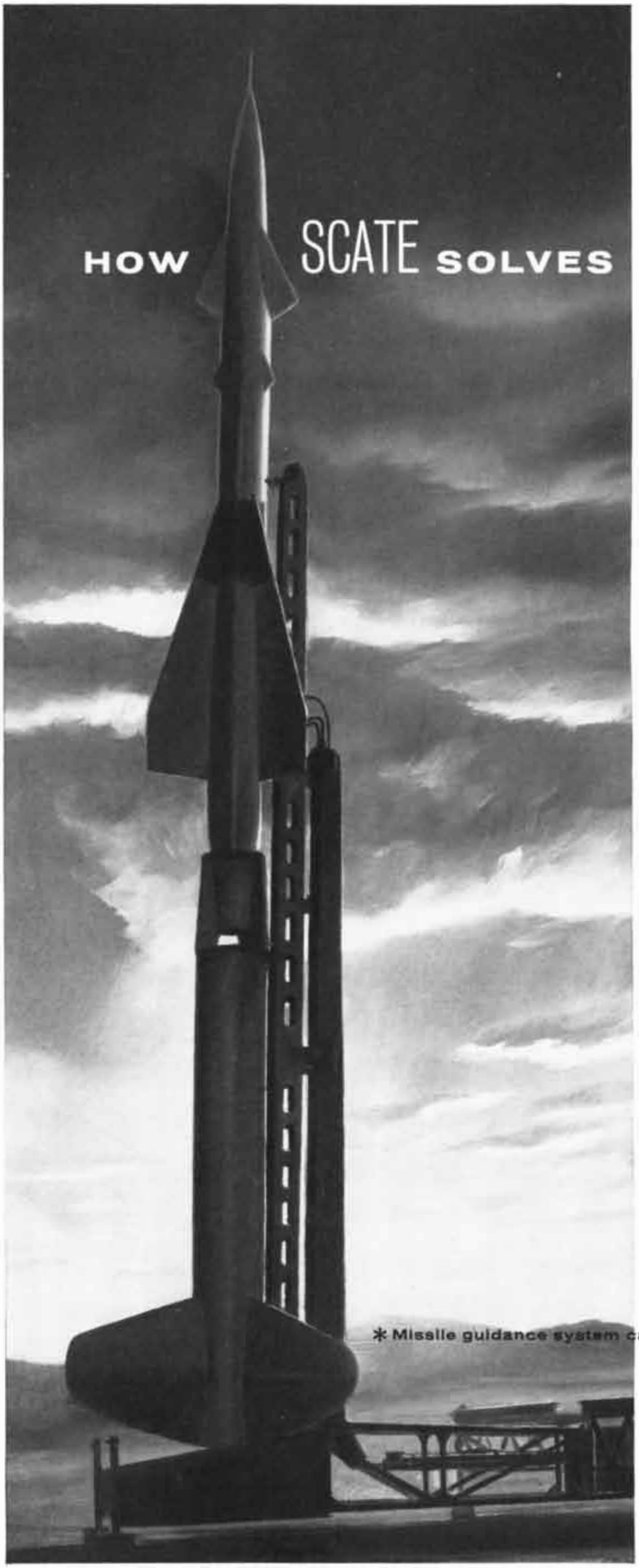
A virtually inexhaustible supply of manganese, more concentrated than any found on dry land, could now be dredged from the bottom of the sea, state Herbert E. Hawkes and John Mero of the University of California. The manganese is in the form of "nodules," round stones usually about the size of a man's fist, which are scattered over an estimated 40 million square miles of ocean floor. In some places nodules cover up to 50 per cent of the bottom. They generally contain 25 per cent manganese, 15 per cent iron, and also considerable copper, nickel and cobalt. Hawkes and Mero calculate that a square mile of sea bottom might yield $1.5 million worth of metal.

No one has explained how nodules were formed. Apparently they grew gradually through some process of deposition: in the center of each nodule is a bit of foreign matter, such as a chunk of volcanic glass, a piece of pumice or a shark tooth.

Mining equipment presents no problems. Early this year an expedition from the Scripps Institution of Oceanography dredged up plenty of nodules from the shallow coastal waters off the Tuamotu Islands in the South Pacific. There are dredges that operate like a vacuum cleaner and can raise boulders a foot in diameter from a depth of 1,000 feet. Hawkes and Mero are now trying to devise an economical process for separating the various metals in the nodules.


USAF


the telephone in color!
CELANESE FORTICEL PLASTIC HELPS



HOW SCATE SOLVES 2 BASIC PROBLEMS in testing electronic systems

Many complex electronic systems—missile guidance is a good example—may require testing that takes days by conventional methods. Yet the end function of such a system may last only a few minutes—**even seconds.**

Other systems, though less complex, must be tested in such large numbers that adequate personnel are frequently unavailable to perform tests by conventional means.

The SCATE system of automatic test equipment can solve **both** problems. It provides **self-checking** automatic testing which is **fast, flexible** and **foolproof.**

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*** Missile guidance system can be tested automatically by the SCATE system.**

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The Indo-European Language

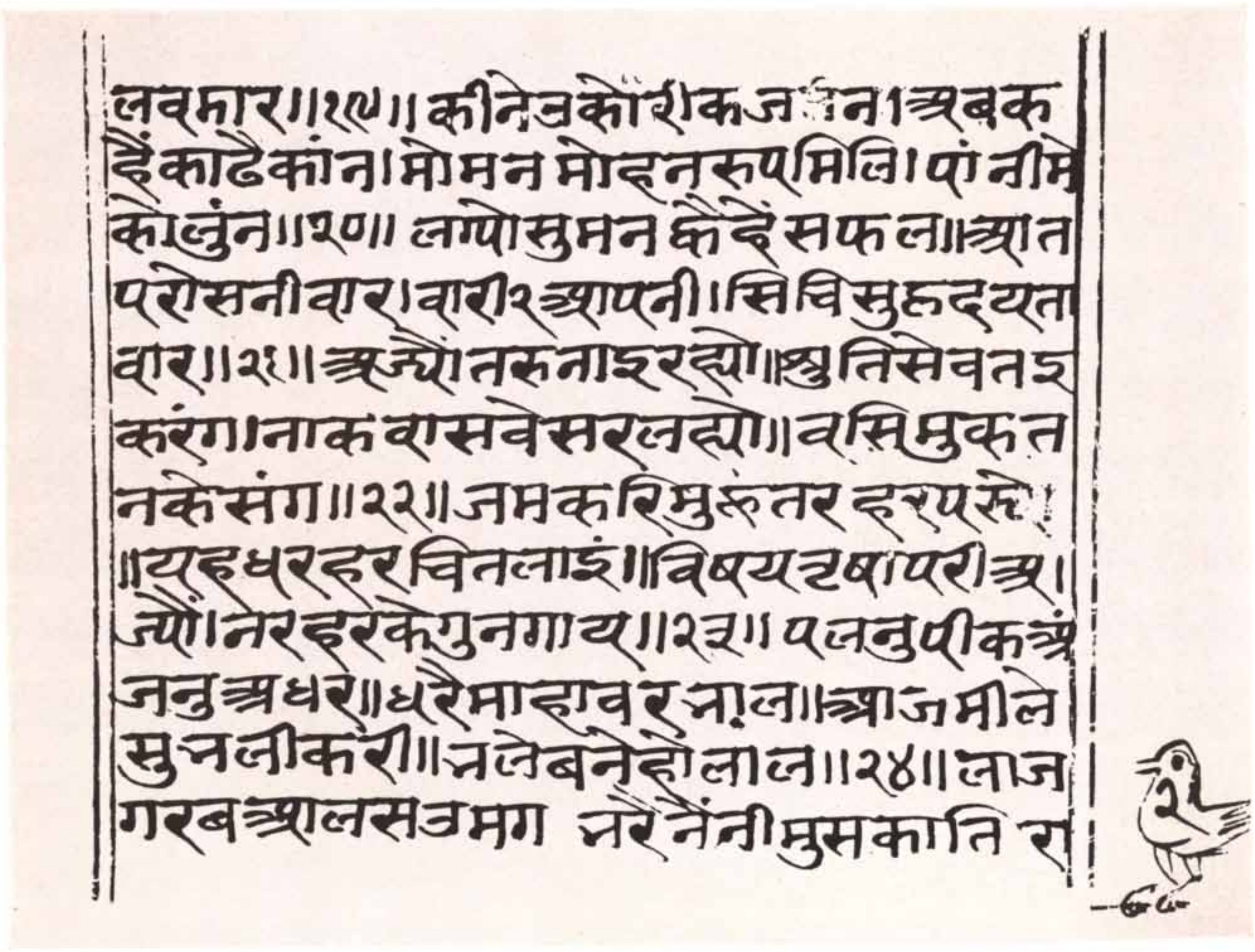
The descendants of this forgotten tongue include English, Sanskrit and Greek. By comparing its "daughter languages" with one another, linguists have learned how it sounded and even where it originated

by Paul Thieme

Every educated person knows that French and Spanish are "related" languages. The obvious similarity of these tongues is explained by their common descent from Latin; indeed, we could say that French and Spanish are two dialects of "modern Latin," forms of the ancestral language that have grown mutually unintelligible through long separation. Latin has simply developed somewhat differently in these two fragments of the old Western Roman Empire. Today these dialects are called Romance languages.

The other great family of European languages is of course the Germanic. It includes English, Dutch, German and the Scandinavian tongues, all descended from an ancient language—unfortunately unrecorded—called Teutonic.

Romance languages and Teutonic,



SANSKRIT, the classical language of India, is one of the oldest members of the Indo-European family. Its discovery by Western scholars led to the first research in historical linguistics. Shown here is an Indian religious text written in Sanskrit script in the 17th century. Sanskrit hymns, handed down orally since second millennium B.C., are better preserved than most Roman writings.

plus Greek—these were once the center of our linguistic universe. During the past 200 years, however, linguistics has been undergoing a kind of prolonged Copernican revolution. Now the familiar European tongues have been relegated to minor places in a vaster system of languages which unites Europe and Asia. Known collectively as the Indo-European languages, this superfamily is far and away the most extensive linguistic constellation in the world. It is also the most thoroughly explored: while other language families have remained largely unknown, the Indo-European family has monopolized the attention of linguists since the 18th century. The modern discipline of linguistics is itself a product of Indo-European studies. As a result of these intensive labors we have come to know a great deal about both the genealogy and the interrelationships of this rich linguistic community.

If we look at the family as a whole, several questions spring to mind. Where did these languages come from? Every family traces its descent from a common ancestor: what was our ancestral language? What did it sound like? What manner of men spoke it? How did they come to migrate over the face of the earth, spreading their tongue across the Eurasian land mass?

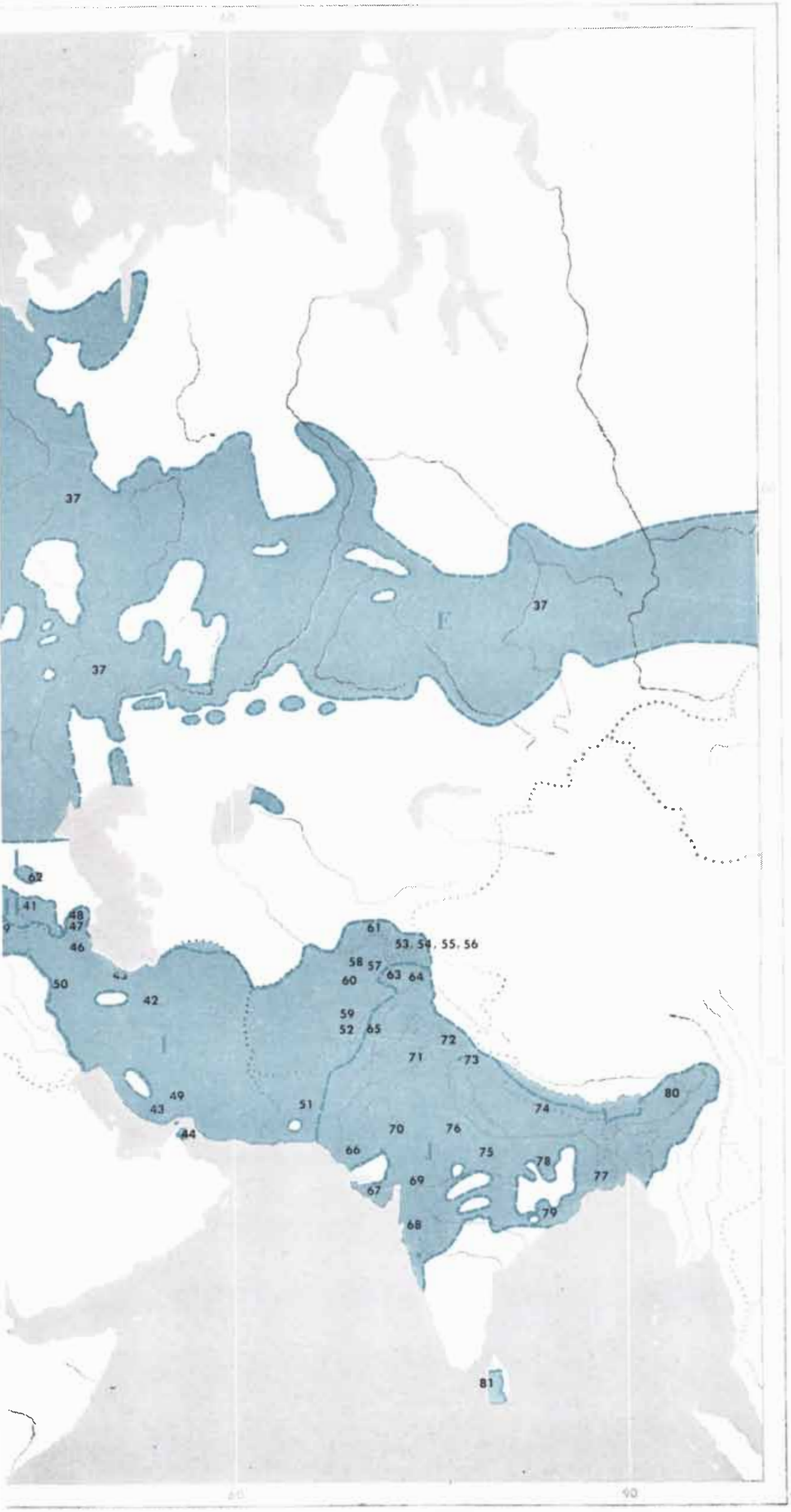
Linguistics can now provide definite —if incomplete—answers to some of these questions. We have reconstructed in substantial part the grammar and sound-system of the Indo-European language, as we call this ultimate forebear of the modern Indo-European family. Although much of the original vocabulary has perished, enough of it survives in later languages so that we can contrive a short dictionary. From the language, in turn, we can puzzle out some characteristics of Indo-European culture. We can even locate the Indo-European homeland.

We can never hope to reconstruct the Indo-European language in complete detail. The task would be immeasurably easier if the Indo-Europeans had only left written records. But the Indo-Europeans, unlike their Egyptian and Mesopotamian contemporaries, were illiterate. Their language was not simply forgotten, to be relearned by archaeologists of another day. It vanished without a trace, except for the many hints that we can glean and piece together from its surviving daughter languages.

The Discovery of the Language

The first clue to the existence of an Indo-European family was uncovered

INDO-EUROPEAN LANGUAGES are spoken today throughout the area shown in color on this map. The faint dotted lines are national boundaries. The broken lines in color indi-



A. TEUTONIC

1 ENGLISH
2 FLEMISH
3 DUTCH
4 LOW GERMAN
5 FRISIAN
6 HIGH GERMAN
7 DANISH
8 SWEDISH
9 NORWEGIAN
10 ICELANDIC

B. ROMANCE

11 FRENCH
12 FRANCO-PROVENÇAL
13 PROVENÇAL
14 CATALAN
15 SPANISH
16 PORTUGUESE
17 GALICIAN
18 ITALIAN
19 SARDINIAN
20 RHAETO-ROMANIC
21 ROMANIAN

C. CELTIC

22 GAELIC
23 WELSH
24 BRETON

D. BALTIC

25 LETTISH
26 LITHUANIAN

E. SLAVONIC

27 BULGARIAN
28 MACEDONIAN
29 SERBO-CROATIAN
30 SLOVENIAN
31 CZECH
32 SLOVAK
33 POLISH
34 WENDISH
35 KASUBIAN
36 UKRAINIAN
37 GREAT RUSSIAN
38 WHITE RUSSIAN

F. ALBANIAN

39 ALBANIAN

G. GREEK

40 GREEK

H. ARMENIAN

41 ARMENIAN

I. IRANIAN

42 PERSIAN
43 LŪRĪ
44 KUMZĀRĪ
45 MĀZANDARĀNĪ
46 GHĪLAKĪ
47 TALISHI
48 TAT
49 KURDISH
50 GURĀNĪ
51 BALUCHI
52 PASHTO
53 ŠUGNI
54 YĀZGULĀMI
55 IŠKĀŠIMĪ
56 SANGLĒČĪ
57 YIDGHĀ
58 WAXĪ
59 ŌRMURĪ
60 PARĀČĪ
61 YAGNABI
62 OSSETIC

J. INDIC

63 KAFIRI
64 DARD
65 LAHNDA
66 SINDHI
67 GUJARATI
68 MARATHI
69 BHILI
70 RAJASTHANI
71 PANJABI
72 EASTERN PAHARI
73 WESTERN PAHARI
74 NEPALI
75 HINDI
76 HINDUSTANI
77 BENGALI
78 BIHARI
79 ORIYA
80 ASSAMESE
81 SINGHALESE

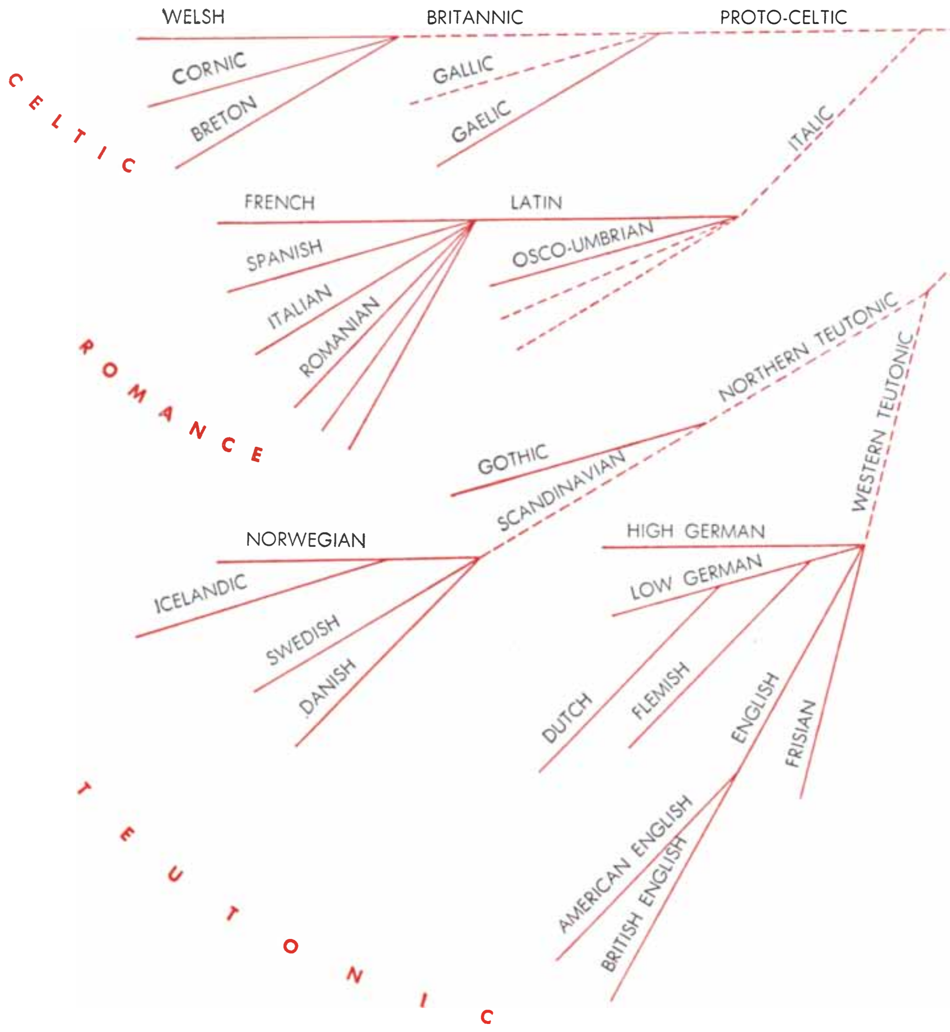
cate boundaries between the 10 groups of Indo-European languages. The language groups (*lettered A to J*) and the languages (*numbered 1 to 81*) may be identified by referring to the legend. Latin, Sanskrit and other extinct Indo-European languages are not shown.

with the opening of trade with India. In 1585, a little less than a century after Vasco da Gama first rounded the Cape of Good Hope, an Italian merchant named Filippo Sassetti made a startling discovery in India. He found that Hindu scholars were able to speak and write an ancient language, at least as venerable as Latin and Greek. Sassetti wrote a letter home about this language, which he called *Sanscruta* (Sanskrit). It bore certain resemblances, he said, to his native Italian. For example, the word for "God" (*deva*) resembled the Italian *Dio*; the word for "snake" (*sarpa*), the Italian *serpe*; the numbers "seven," "eight" and "nine" (*sapta*, *ashta* and *nava*), the Italian *sette*, *otto* and *nove*.

What did these resemblances prove? Sassetti may have imagined that Sanskrit was closely related to the "original language" spoken by Adam and Eve; perhaps that is why he chose "God" and "snake" as examples. Later it was thought that Sanskrit might be the ancestor of the European languages, including Greek and Latin. Finally it became clear that Sanskrit was simply a sister of the European tongues. The relationship received its first scientific statement in the "Indo-European hypothesis" of Sir William Jones, a jurist and orientalist in the employ of the East India Company. Addressing the Bengal Asiatic Society in 1786, Sir William pointed out that Sanskrit, in relation to Greek and Latin, "bears a stronger affinity, both in the roots of verbs and in the forms of grammar, than could possibly have been produced by accident: so strong, indeed, that no philologer could examine them all three without believing them to have sprung from some common source, which, perhaps, no longer exists; there is similar reason, though not quite so forcible, for supposing that both the Gothick and the Celtick, though blended with a very different idiom, had the same origin with the Sanskrit."

Sir William's now-famous opinion founded modern linguistics. A crucial word in the sentence quoted is "roots." Jones and his successors could not have done their work without a command of Sanskrit, then the oldest-known Indo-European language. But they also could not have done it without a knowledge of traditional Sanskrit grammar. Jones, like every linguist since, was inspired by the great Sanskrit grammarian Panini, who sometime before 500 B.C. devised a remarkably accurate and systematic technique of word analysis. Instead of grouping related forms in conjugations and declensions—as European and U. S. school-grammar does to this day—Panini's grammar analyzed the forms into their functional units: the roots, suffixes and endings.

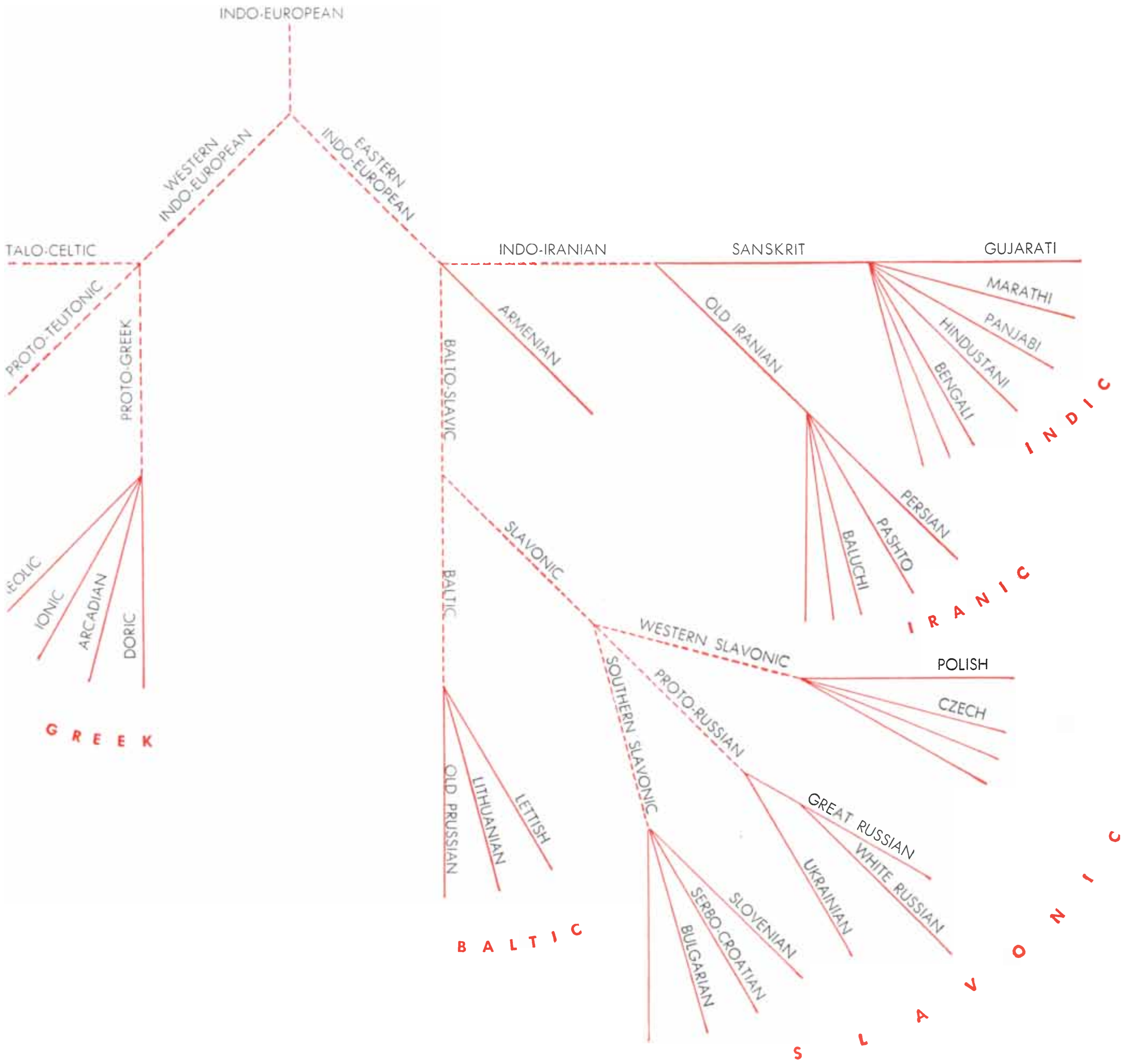
Comparative grammar, in the strict sense, was founded by a young German named Franz Bopp. In 1816 Bopp published a book on the inflection of verbs in a group of Indo-European languages: Sanskrit, Persian, Greek, Latin and the Teutonic tongues. Essentially Bopp's book was no more than the application to a broader group of languages of Panini's technique for the analysis of Sanskrit verbs. But Bopp's motive was a historical one. By gathering cognate forms from a number of Indo-European languages he hoped to be able to infer some of the characteristics of the lost language



FAMILY TREE traces the descent of the modern Indo-European languages. English (*bottom of right-hand page*) stems from the Teutonic branch of Western Indo-European. Broken

—the "common source" mentioned by Jones—which was the parent of them all.

In the course of time Bopp's method has been systematically developed and refined. The "affinities" which Jones saw between certain words in related languages have come to be called "correspondences," defined by precise formulas. The "Indo-European hypothesis" has been proved beyond doubt. And many more groups of languages have been found to belong to the Indo-European family: Slavonic, Baltic, the old Italic dialects, Albanian, Armenian, Hittite and Tocharian. The "family tree" of these languages has been worked out in some detail [*see illustration on these two pages*]. It should be borne in mind, however, that when it is applied to languages a family-tree diagram is no more than a convenient graphic device. Languages do not branch off from one another at a distinct point in time; they separate gradually, by the slow accumulation of innovations. Moreover, we cannot be sure of every detail in their relationship. The affinities of the Celtic and Italic languages, or of the Baltic and Slavonic, may or may not point to a period when each of these pairs formed a



lines indicate dead languages which have left no written remains. Albanian is not shown because its lineage is not known. Tocharian and Hittite have been omitted for the same reason. Although they were spoken in Asia, they appear to belong to the Western branch.

common language, already distinguished from the Indo-European. Some Indo-European languages cannot be placed on the family tree because their lineage is not known. Among these are Tocharian and Hittite. These extinct languages (both rediscovered in the 20th century) were spoken in Asia but descend from the western branch of the family.

Reconstruction

Let us see how a linguist can glean information about the original Indo-European language by comparing its daughter tongues with one another. Take the following series of "corresponding" words: *pra* (Sanskrit), *pro* (Old Slavonic), *pro* (Greek), *pro* (Latin), *fra* (Gothic), all meaning "forward"; *pitā* (Sanskrit), *patēr* (Greek), *pater* (Latin), *fadar* (Gothic), all meaning "father." Clearly these words sprang from two words in the original Indo-European language. Now what can we say about the initial sounds the words must have had in the parent tongue? It must have been "p," as it is in the majority of the languages cited. Only in Gothic does it appear as "f," and the odds are overwhelmingly in favor of its having changed from "p" to "f" in this language, rather than from "f" to "p" in all the others. Thus we know one fact about the original Indo-European language: it had an initial "p" sound. This sound remains "p" in most of the daughter languages. Only in Gothic (and other Teutonic tongues) did it become "f."

Now let us take a harder example: *dasa* (Sanskrit), *deshimt* (Lithuanian), *deseti* (Old Slavonic), *deka* (Greek), *dekem* (Latin), *tehun* (Gothic), all meaning "ten"; *satam* (Sanskrit), *shimtas* (Lithuanian), *suto* (Old Slavonic), *he-katon* (Greek), *kentum* (Latin), *hunda-* (Gothic), all meaning "hundred." (The spelling of some of these forms has been altered for purposes of exposition. The hyphen after the Gothic *hunda-* and certain other words in this article indicates that they are not complete words.)

Certainly the "s," "sh," "k" and "h" sounds in these words are related to one another. Which is the original? We decide that "k" changed into the other sounds rather than *vice versa.* Phoneticians tell us that "hard" sounds like "k" often mutate into "soft" sounds like "sh." For example, the Latin word *carus* ("dear") turned into the French word *cher*; but the reverse change has not occurred.

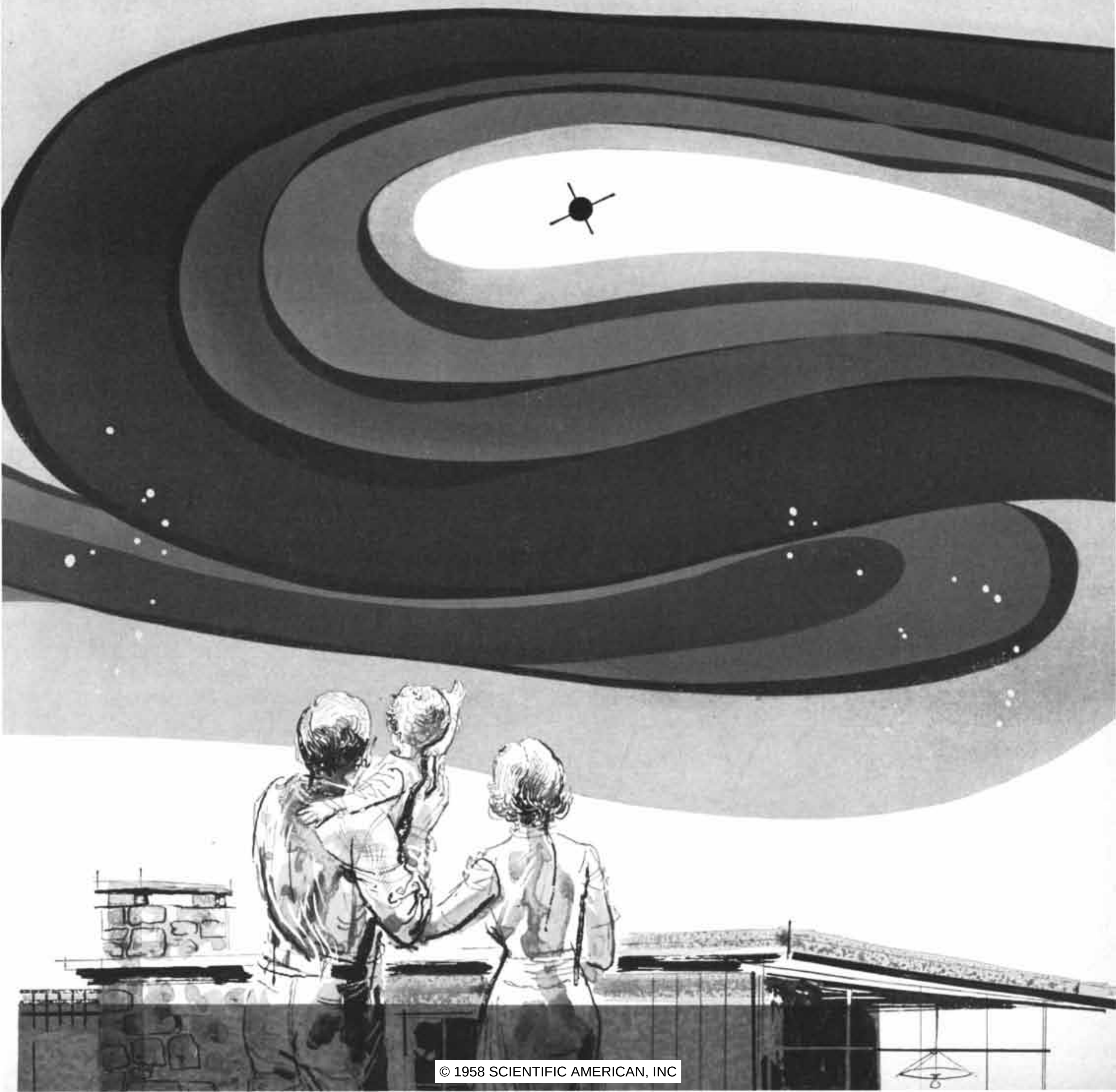
Reconstruction would be much easier sailing but for two all-too-common events in the history of language: "convergence" and "divergence." In Sanskrit the three old Indo-European vowels "e," "o" and "a" have converged to become "a" (as in "ah"). In the Germanic languages the Indo-European vowel "e" has diverged to become "e" (as in "bet") next to certain sounds and "i" (as in "it") next to others.

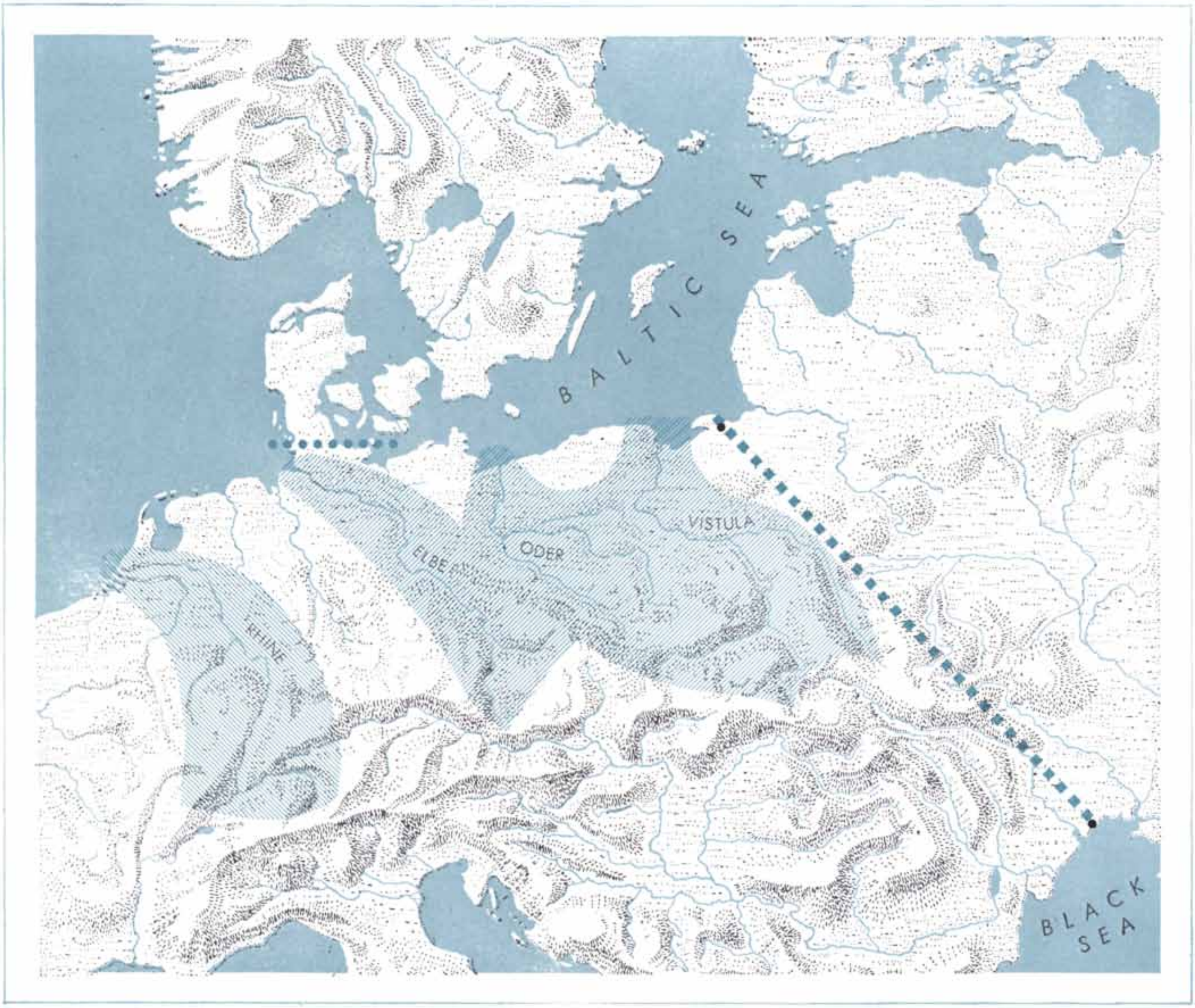
Like most procedures in modern science, linguistic reconstructions require a certain technical skill. This is emphatically not a game for amateurs. Every step is most intricate. Some people may even wonder whether there is any point to the labors of historical linguists—especially in view of the fact that the reconstructions can never be checked by immediate observation. There is no absolute certainty in the reconstruction of a lost language. The procedure is admittedly probabilistic. It can only be tested by the coherence of its results.

But the results in the reconstruction of ancestral Indo-European are heartening. By regular procedures such as those I have illustrated, we have reconstructed a sound system for Indo-European that has the simplicity and symmetry of sound systems in observable languages. We have discovered the same symmetry in our reconstructions of roots, suffixes, endings and whole words. Perhaps even more important, the Indo-European words we have reconstructed give a convincing picture of ancient Indo-European customs and geography!

The Indo-European Culture

Consider the words for "mother," "husband," "wife," "son," "daughter," "brother," "sister," "grandson," "son-in-law," "daughter-in-law," all of which we can reconstruct in Indo-European. As a group they prove that the speakers lived in families founded on marriage—which is no more than we might expect! But we obtain more specific terms too: "father-in-law," "mother-in-law," "brother-in-law," "sister-in-law." Exact correspondences in the speech usage of the oldest daughter languages which have been preserved lead to the conclusion that these expressions were used exclusively with reference to the "in-laws" of the bride, and not to those of the groom. There are no other words that would designate a husband's "father-in-law," and so on. The inference is unavoidable that the family system of the old Indo-Europeans was of a patriarchal character; that is, that the wife married into her husband's family, while the husband did not acquire an official relationship to his wife's family as he does where a





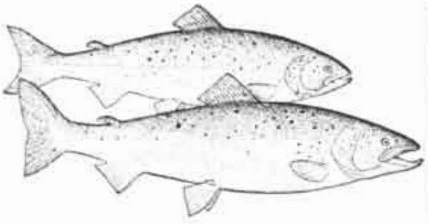
INDO-EUROPEAN HOMELAND is shown by the author to have been located within the area of this map. Since the Indo-Europeans had a word for "beech," they must have lived within the beech-bearing area of Europe; the eastern boundary of this area is indicated by the heavy broken line at right. Linguists have also reconstructed an Indo-European word for "turtle"; in ancient times turtles did not live north of the heavy dotted line at upper left. These two words roughly define the original Indo-European area.

matriarchal family system exists. Our positive witnesses (the accumulation of designations for the relations a woman acquires by marriage) and our negative witnesses (the complete absence of designations for the relations a man might be said to acquire by marriage) are trustworthy circumstantial evidence of this.

The Indo-Europeans had a decimal number system that reveals traces of older counting systems. The numbers up to "four" are inflected like adjectives. They form a group by themselves, which points to an archaic method of counting by applying the thumb to the remaining four fingers in succession. Another group, evidently later arrivals in the history of Indo-European, goes up to "ten" (the Indo-European *dekmt-*). "Ten" is related to "hundred": *kmtom*, a word which came from the still earlier *dkmtom*, or "aggregate of tens." In addition to these four-finger and ten-finger counting systems there was a method of counting by twelves, presumably stemming from the application of the thumb to the twelve joints of the other four fingers. It is well known that the Teutonic languages originally distinguished a "small hundred" (100) from a "big hundred" (120). The latter is a "hundred" that results from a combination of counting by tens (the decimal system) and counting by twelves (the duodecimal system). Traces of duodecimal counting can also be found in other Indo-European languages.

Reconstruction yields an almost complete Indo-European inventory of body parts, among them some that presuppose the skilled butchering of animals. The Indo-European word for "lungs" originally meant "swimmer." We can imagine a prehistoric butcher watching the lungs float to the surface as he put the entrails of an animal into water. There is no reference in the word to the biological function of the lungs, which was presumably unknown. The heart, on the other hand, appears to have been named after the beat of the living organ.

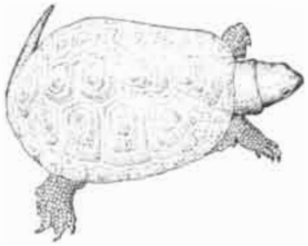
So far as tools and weapons are concerned, we are not quite so lavishly served. We obtain single expressions for such things as "arrow," "ax," "ship,"



BALTIC SALMON

RHINE SALMON

LIMIT OF BEECH



NORTHERN LIMIT OF TURTLE

The area is better located by the word for "salmon"; salmon are found in rivers flowing into Baltic and North seas but not in those into Black Sea or Mediterranean.

"boat," but no semantic system. This poverty is due partly to an original lack of certain concepts, and partly to the change of usage in the daughter languages. It is evident that new terms were coined as new implements were invented. We do find words for "gold" and perhaps for "silver," as well as for "ore." Unfortunately we cannot decide whether "ore" was used only with reference to copper or to both copper and bronze. It is significant that we cannot reconstruct a word for "iron," which was a later discovery. In any case we need not picture the people who spoke Indo-European as being very primitive. They possessed at least one contrivance that requires efficient tools: the wagon or cart. Two Indo-European words for "wheel" and words for "axle," "hub" and "yoke" are cumulative evidence of this.

The Indo-European Homeland

Especially interesting are the names of animals and plants, for these contain the clue to the ancient Indo-European homeland. It is evident that our reconstructed language was spoken in a territory that cannot have been large. A language as unified as the one we obtain by our reconstruction suggests a compact speech community. In prehistoric times, when communication over long distances was limited, such a community could have existed only within comparatively small boundaries.

These boundaries need not have been quite so narrow if the people who spoke Indo-European had been nomads. Nomads may cover a large territory and yet maintain the unity of their language, since their roamings repeatedly bring them in contact with others who speak their tongue. The Indo-Europeans, however, were small-scale farmers and husbandmen rather than nomads. They raised pigs, which kept them from traveling, and they had words for "barley," "stored grains," "sowing," "plowing," "grinding," "settlement" and "pasture" (*agros*), on which domesticated animals were "driven" (*ag*).

We cannot reconstruct old Indo-European words for "palm," "olive," "cypress," "vine," "laurel." On the strength of this negative evidence we can safely eliminate Asia and the Mediterranean countries as possible starting points of the Indo-European migrations. We can, however, reconstruct the following tree names: "birch," "beech," "aspen," "oak," "yew," "willow," "spruce," "alder," "ash." The evidence is not equally conclusive for each tree name; my arrangement follows the decreasing certainty. Yet in each case at least a possibility can be established, as it cannot in the case of tree names such as "cypress," "palm" and "olive."

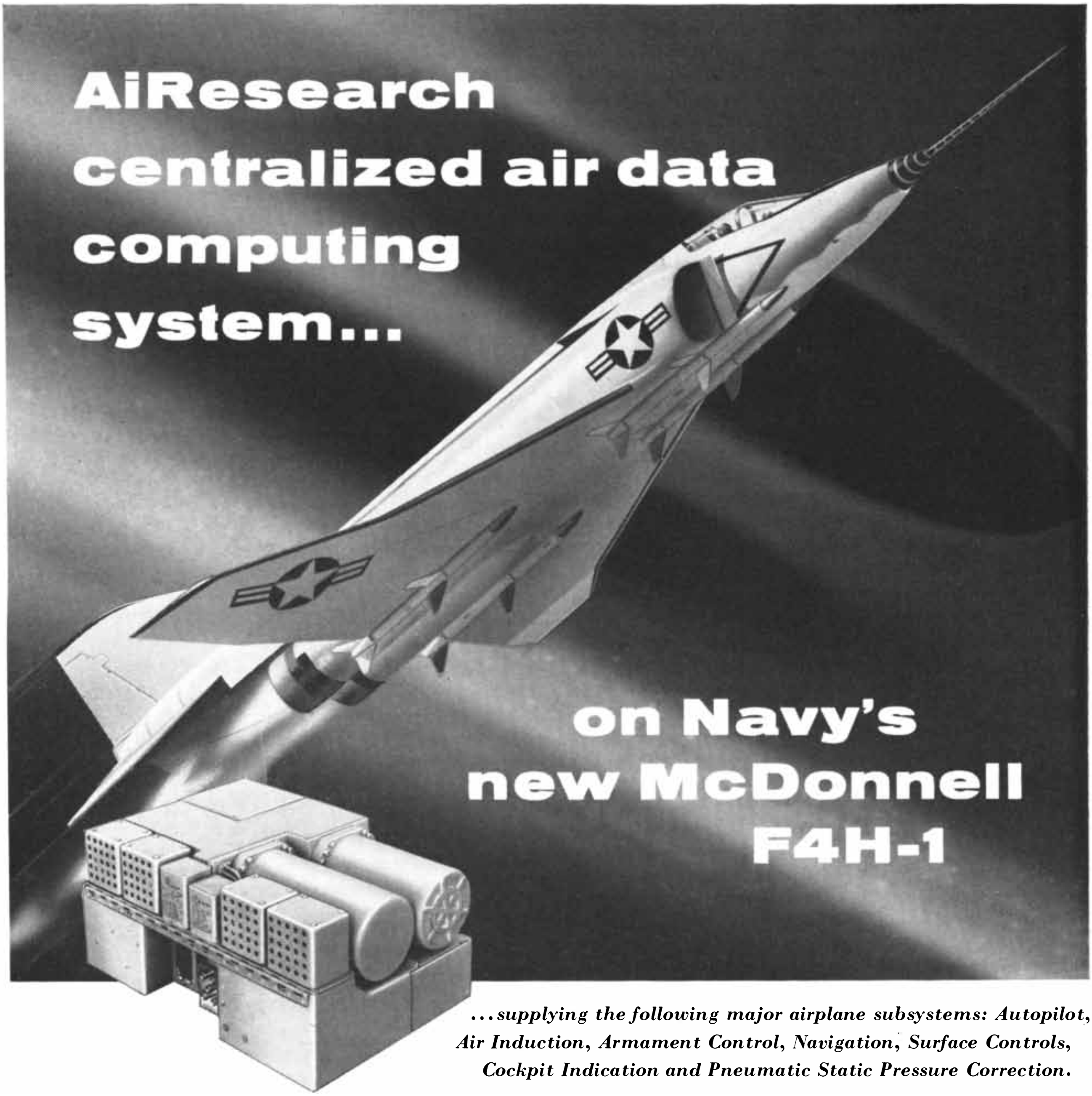
Of the tree names the most important for our purposes is "beech." Since the beech does not grow east of a line that runs roughly from Königsberg (now Kaliningrad) on the Baltic Sea to Odessa on the northwestern shore of the Black Sea, we must conclude that the Indo-Europeans lived in Europe rather than in Asia. Scandinavia can be ruled out because we know that the beech was imported there rather late. A likely district would be the northern part of Middle Europe, say the territory between the Vistula and Elbe rivers. It is here that even now the densest accumulation of Indo-European languages is found—languages belonging to the eastern group (Baltic and Slavonic) side by side with one of the western group (German).

That the Indo-Europeans came from this region is indicated by the animal names we can reconstruct, all of them characteristic of the region. We do not find words for "tiger," "elephant," "camel," "lion" or "leopard." We can, however, compile a bestiary that includes "wolf," "bear," "lynx," "eagle," "falcon," "owl," "crane," "thrush," "goose," "duck," "turtle," "salmon," "otter," "beaver," "fly," "hornet," "wasp," "bee" (inferred from words for "honey"), "louse" and "flea." We also find words for domesticated animals: "dog," "cattle," "sheep," "pig," "goat" and perhaps "horse." Some of these words are particularly significant. The turtle, like the beech, did not occur north of Germany in prehistoric times.

The Importance of the Salmon

It is the Indo-European word for "salmon" that most strongly supports the argument. Of all the regions where trees and animals familiar to the Indo-Europeans live, and the regions from which the Indo-Europeans could possibly have started the migrations that spread their tongue from Ireland to India, it is only along the rivers that flow into the Baltic and North seas that this particular fish could have been known. Coming from the South Atlantic, the salmon ascends these rivers in huge shoals to spawn in their upper reaches. The fish are easy to catch, and lovely to watch as they leap over obstacles in streams. Without the fat-rich food provided by the domesticated pig and the salmon, a people living in this rather cold region could hardly have grown so strong and numerous that their migration became both a necessity and a success.

The Indo-European word for "salmon" (*laks-*) survives in the original sense where the fish still occurs: Russia, the Baltic countries, Scandinavia and Germany (it is the familiar "lox" of Jewish delicatessens). In the Celtic tongues another word has replaced it; the Celts, migrating to the West, encountered the Rhine salmon, which they honored with a new name because it is even more delectable than the Baltic variety. The Italic languages, Greek and the southern Slavonic tongues, spoken where there are no salmon, soon lost the word. In some other languages it is preserved, but with altered meaning: in Ossetic, an Iranian language spoken in the Caucasus, the word means a large kind of



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Systems, Packages and Components for: AIRCRAFT, MISSILE, ELECTRONIC, NUCLEAR AND INDUSTRIAL APPLICATIONS trout, and the Tocharian-speaking people of eastern Turkestan used it for fish in general.

Several Sanskrit words echo the importance of the salmon in Indo-European history. One, *laksha*, means "a great amount" or "100,000," in which sense it has entered Hindustani and British English with the expression "a lakh of rupees." The assumption that the Sanskrit *laksha* descends from the Indo-European *laks-* of course requires an additional hypothesis: that a word meaning "salmon" or "salmon-shoal" continued to be used in the sense of "a great amount" long after the Indo-European immigrants to India had forgotten the fish itself. There are many analogies for a development of this kind. All over the world the names of things that are notable for their quantity or density tend to designate large numbers. Thus in Iranian "beehive" is used for 10,000; in Egyptian "tadpole" (which appears in great numbers after the flood of the Nile) is used for 100,000; in Chinese "ant," for 10,000; in Semitic languages "cattle," for 100; in Sanskrit and Egyptian "lotus" (which covers lakes and swamps), for "large number." Several words in Sanskrit for "sea" also refer to large numbers. In this connection we may recall the words in *Hamlet:* ". . . to take arms against a sea of troubles, and by opposing end them."

A second Sanskrit word that I believe is a descendant of the Indo-European *laks-* is *lākshā*, which the dictionary defines as "the dark-red resinous incrustation produced on certain trees by the puncture of an insect (*Coccus lacca*) and used as a scarlet dye." This is the word from which come the English "lac" and "lacquer." *Lākshā*, in my opinion, was originally an adjective derived from the Indo-European *laks-;* meaning "of or like a salmon." A characteristic feature of the salmon is the red color of its flesh. "Salmonlike" could easily develop into "red," and this adjective could be used to designate "the red (substance)," *i.e.*, "lac."

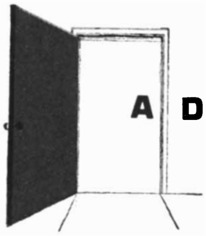
There is even a third possible offshoot: the Sanskrit *laksha* meaning "gambling stake" or "prize." This may be derived from a word that meant "salmon-catch." The apparent boldness of this conjecture may be vindicated on two counts. First, we have another Indo-European gambling word that originally was an animal name. Exact correspondences of Greek, Latin and Sanskrit show that the Indo-Europeans knew a kind of gambling with dice, in which the most unlucky throw was called the "dog." Second, in Sanskrit the gambling stake can be designated by another word, a plural noun (*vijas*) whose primary meaning was "the leapers." The possibility that this is another old word for "salmon," which was later used in the same restricted sense as *laksha*, is rather obvious.

By a lucky accident, then, Sanskrit, spoken by people who cannot have preserved any knowledge of the salmon itself, retains traces of Indo-European words for "salmon." Taken together, these words present a singularly clear picture of the salmon's outstanding traits. It is the fish that appears in big shoals (the Sanskrit *laksha*, meaning "100,000"); that overcomes obstacles by leaping (the Sanskrit *vijas*, meaning "leapers," and later "stake"); that has red flesh (*lākshā*, meaning "lac"); that is caught as a prized food (*vijas* and *laksha*, meaning "stake" or "prize").

The Age of the Language

If we establish the home of our reconstructed language as lying between the Vistula and the Elbe, we may venture to speculate as to the time when it was spoken. According to archaeological evidence, the domesticated horse and goat did not appear there much before 3000 B.C. The other domesticated animals for which we have linguistic evidence are archaeologically demonstrable in an earlier period. Indo-European, I conjecture, was spoken on the Baltic coast of Germany late in the fourth millennium B.C. Since our oldest documents of Indo-European daughter languages (in Asia Minor and India) date from the second millennium B.C., the end of the fourth millennium would be a likely time anyhow. A thousand or 1,500 years are a time sufficiently long for the development of the changes that distinguish our oldest Sanskrit speech form from what we reconstruct as Indo-European.

Here is an old Lithuanian proverb which a Protestant minister translated into Latin in 1625 to show the similarity of Lithuanian to Latin. The proverb means "God gave the teeth; God will also give bread." In Lithuanian it reads: *Dievas dawe dantis; Dievas duos ir duonos*. The Latin version is *Deus dedit dentes; Deus dabit et panem*. Translated into an old form of Sanskrit, it would be *Devas adadāt datas; Devas dāt* (or *dadāt*) *api dhānās*. How would this same sentence sound in the reconstructed Indo-European language? A defensible guess would be: *Deivos ededōt dntns; Deivos dedōt* (or *dōt*) *dhōnās*.



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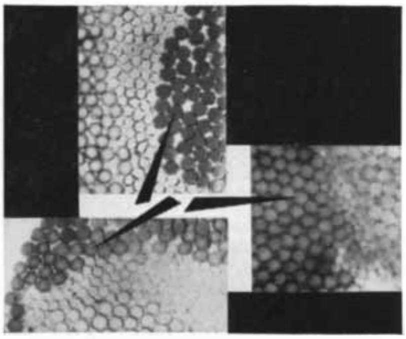

Dyeability. *Dark areas show dye penetrating CAPROLAN carpet staple in contrast to surface-tinting conventional nylon (light areas). Both nylons were dyed together in the same bath.*

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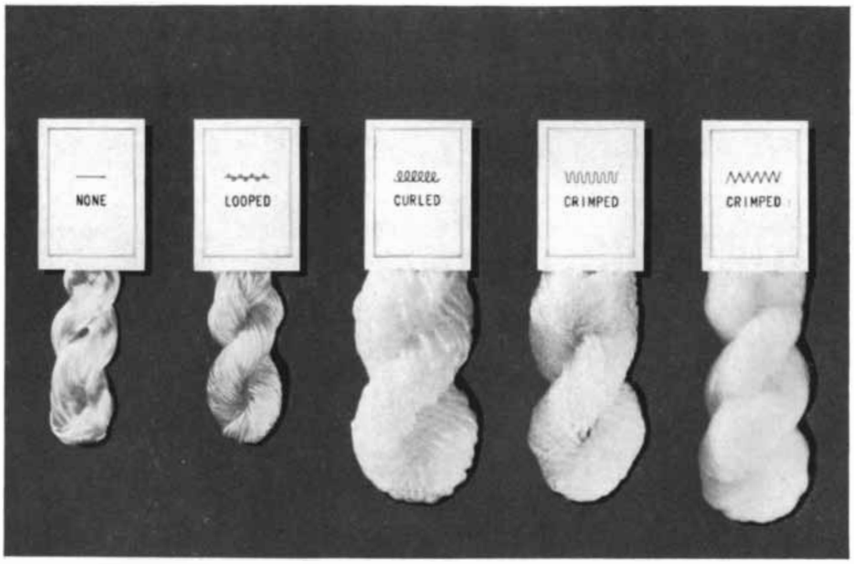

Texturized filament CAPROLAN yarn. *Each skein is 60 yards of the same weight. Note how texturizing processes offer versatility of style and design.*

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Dyeability. This new nylon, being a white white, gives truer colors. It has a marked affinity for virtually every class of dyestuff, and its "deep-dye" characteristic permits dyes to penetrate deep into the fiber itself instead of being merely deposited on the surface.

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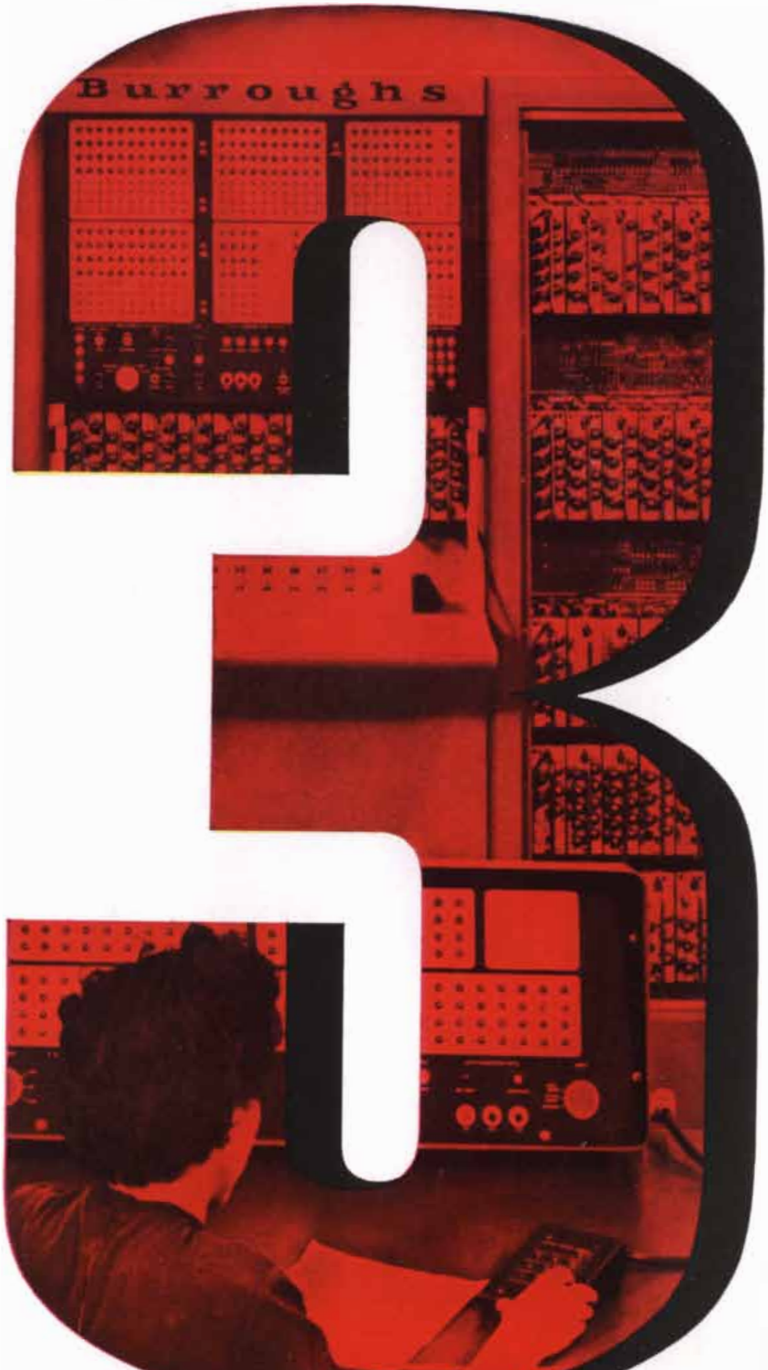

Burroughs

THE REGENERATION OF BODY PARTS

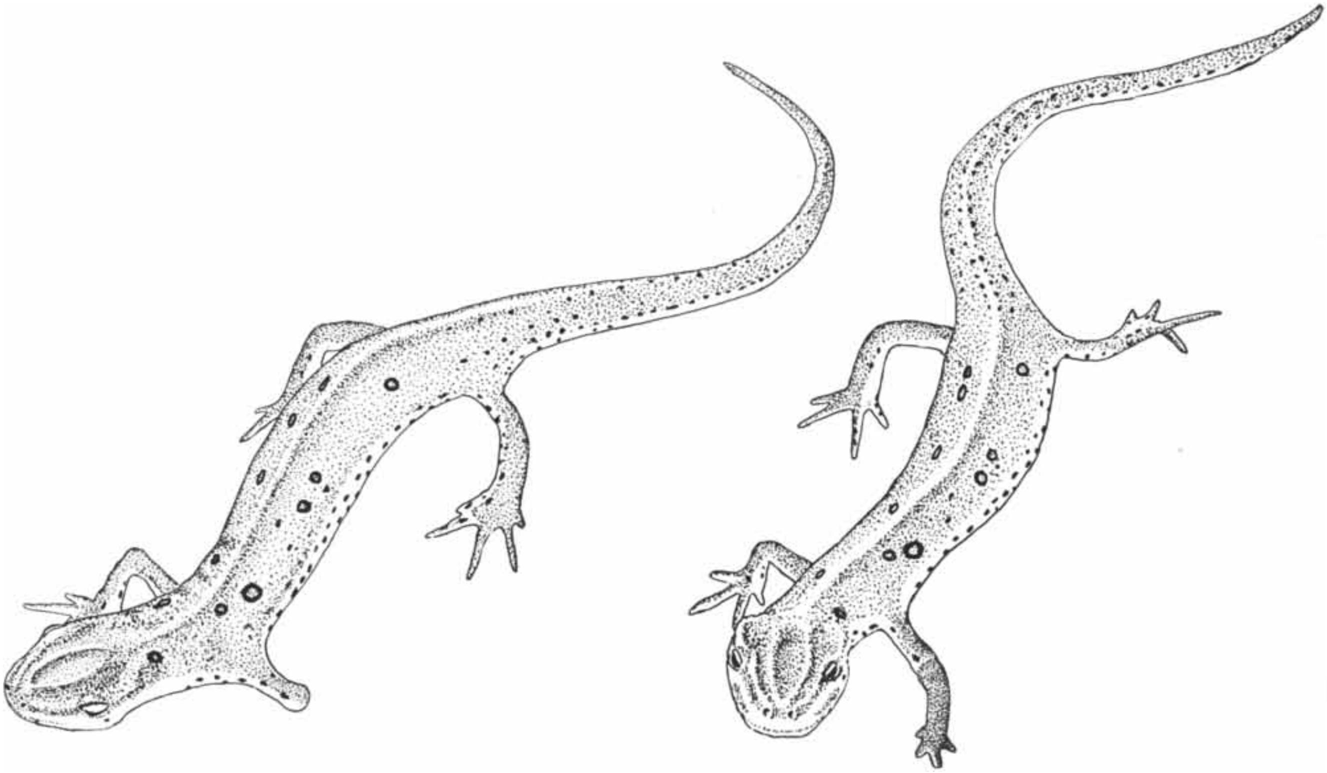
How is it that a salamander can regrow an amputated limb but a higher animal cannot? The question is investigated by means of experiments with the salamander and the frog

by Marcus Singer

Trying to capture a lizard by the tail or a crab by its claw can be a frustrating experience. The tail or the claw snaps off in the hand of the would-be captor, and the prey escapes. The hasty sacrifice is repaired at leisure, for these animals can replace the lost parts by the process of regeneration. Salamanders also can regenerate a missing leg or tail. Some animals, such as frogs, enjoy this advantage only in their younger days, and as adults must make one set of limbs last a lifetime. While other animals, including man, cannot regrow limbs at any stage, they exhibit the faculty of regeneration in less dramatic ways. The replacement of skin, feathers, antlers or fingernails is a kind of regeneration. Indeed, the ability to regenerate is a fundamental property of living matter.

Obviously there is some practical interest in the possibility that human beings might some day be able to regrow tissues and organs which they presently cannot. But apart from such possibilities regeneration holds both theoretical and experimental interest for the biologist, because it demonstrates that developmental processes are not entirely absent in the adult animal. The adult organism "remembers" some of its developmental history and repeats it, albeit in a limited and sometimes devious way. In man, a break in the skin is repaired quite rapidly when the skin around the wound grows over it and thickens. Bone shows remarkable ability to mend a break or other deficiency; so do the connective tissues: tendon, ligament, blood and so on. Muscle also repairs itself after serious injury, and a severed nerve can regrow, if the conditions are favorable, by extending its fibers.

But in spite of the regenerative pow-



ADULT SALAMANDER, enlarged to about two and a half times its natural size, is shown at two stages in regenerating a forelimb. At left, about 10 days after amputation, the wound has healed and the end of the stump is beginning to enlarge. At right, about four or five weeks later, the new limb is well advanced and appears much like a normal forelimb except for its color and size.

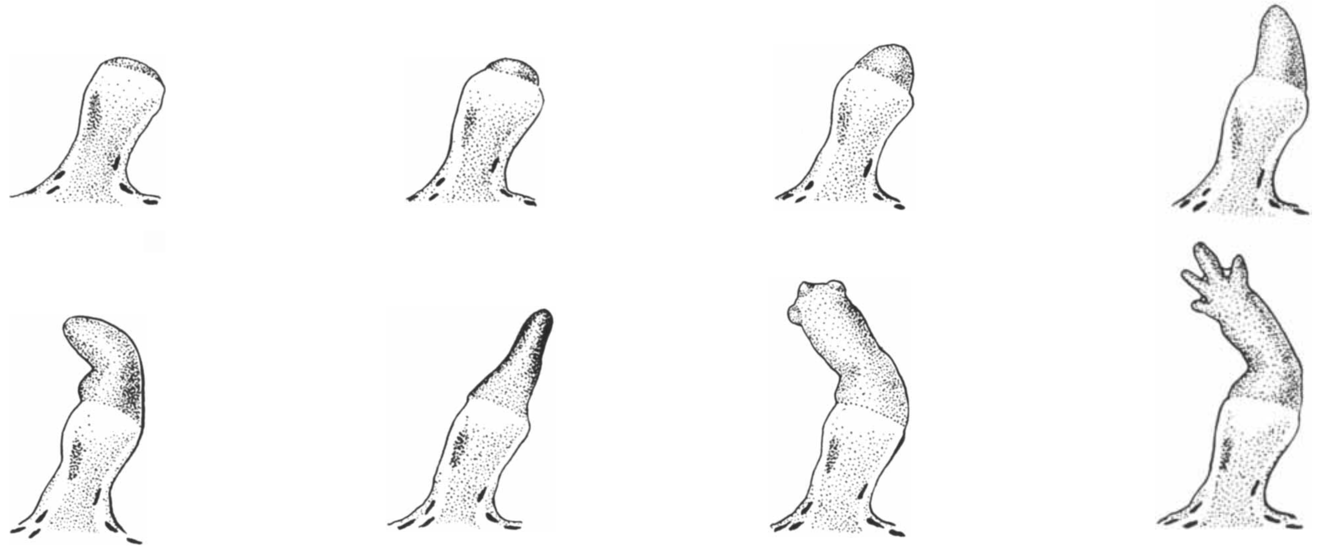
ers of these individual tissues, a human leg will not grow back after it has been amputated. A complex organ, consisting of many tissues, regenerates less easily than a single tissue. In man, only some internal organs such as the liver, the pancreas and the salivary glands have this capacity. Animals much lower on the evolutionary scale are endowed with considerably greater powers to replace lost or injured parts. In some very lowly forms, for example the hydra, the animal can be chopped into a number of pieces, and each piece will regrow the parts it lacks [see "The Indestructible Hydra," by N. J. Berrill; SCIENTIFIC AMERICAN, December, 1957]. So ingrained are the powers of repair in some sponges and hydra-like organisms that when one of these animals is broken up by forcing it through a coarse cloth, its fragments will reassociate in clumps which grow into new individuals. A fish, or an amphibian such as a salamander, can regenerate a tail, limbs, fins and other parts. A lizard regenerates a tail and part of the jaw, but not limbs.

How is it that lower vertebrates are able to regrow a lost extremity or other part, and that higher animals, including man, cannot? Most studies of this question have centered around the frog, which exhibits a gradual decline and loss of regenerative power within its own life cycle. A young tadpole whose tail or limb is removed will grow another completely and easily. An older tadpole, with more fully formed limbs, regenerates a missing leg less perfectly, and soon it cannot regrow its hind limb at all. It is still able to regenerate a forelimb, but as it approaches metamorphosis into a young adult frog, it also loses this ability.

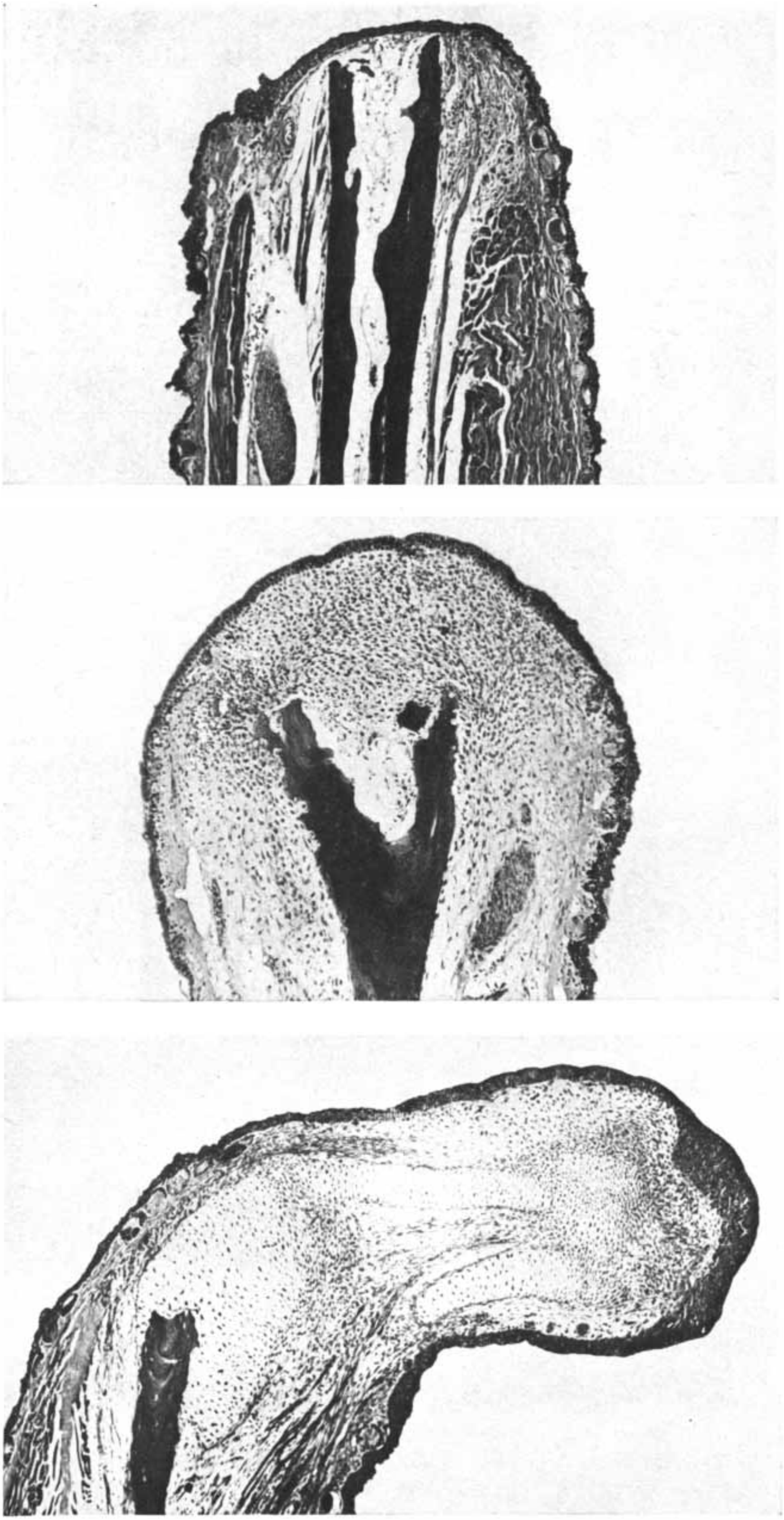
As far back as 1768 Lazzaro Spallanzani, a founder of modern studies in regeneration, posed the problem as follows: "But if these species [frogs] are able to renew their legs when young, why should they not do the same when farther advanced? . . . Are the wonderful reproductions hitherto mentioned [in newts] only to be ascribed to the effect of water, in which these animals were kept? This is contradicted in the instance of the salamander, whose parts were reproduced even on dry ground. But if the above-mentioned animals, either aquatic or amphibian, recover their legs when kept on dry ground, how comes it to pass that other land animals, such as are accounted perfect, and are better known to us, are not endued with the same power? Is it to be hoped that they may acquire them by some useful dispositions? And should the flattering expectation of obtaining this advantage for ourselves be considered entirely as chimerical?"

The hunt for a "useful disposition" began with observations on regeneration of limbs in salamanders. If a salamander's leg is amputated, the wound first heals: skin covers the stump, and beneath the skin scar tissue forms. Within 10 days the scar tissue begins to disappear and the end of the stump enlarges. The tip of the swelling is really a bud containing many rapidly dividing cells which look like the undifferentiated cells of an embryo. These cells spring from the old tissues at the wound surface, but their precise origin is unknown. They may arise from incompletely developed cells held in reserve; from the transformation of muscle, bone or other tissue back to the undifferentiated state; or from a combination of the two processes. Whatever the origin of these cells, the process from this stage on resembles embryonic development. At first the primitive cells multiply rapidly with a certain abandon resembling that of a cancerous growth. But unlike a cancer, which would continue to grow in a disorderly fashion, the regenerated tissue eventually grows at a slower rate and gradually takes the form of a functional organ. About a week after the start of regeneration the bud already looks very much like the limb bud of an embryonic salamander. The bud elongates into a cone, and by the third or fourth week the cone is transformed into the rudiment of an arm with a bend representing the elbow and a flattened area at the end anticipating the formation of a "hand." During the next week or two, little nubs appear on the hand rudiment and grow into fingers. In the meantime the embryo-like cells within change into specialized tissue: muscle, tendon, bone and so forth. The new limb soon begins to move and finally assumes its full function.

Since regeneration apparently involves the return of cells to an embryonic state, one theory holds that the frog loses its regenerative ability because its cells



PROGRESSIVE STAGES in regeneration of a salamander's arm are drawn about six times natural size. The small mound of tissue at the end of the stump 10 days after amputation (*first drawing*) enlarges rapidly to form a cone. Front and side views of a later stage (*fifth and sixth*) show the formation of the elbow and hand as the cone bends in the middle and flattens at the end. Fingers begin to appear four or five weeks after amputation (*seventh*), and about six weeks later reach the size shown in the last drawing.



LONGITUDINAL SECTION of stump a few days after amputation of a salamander's forelimb (*top*) shows bone (*dark areas in center*) and muscle, topped by skin which has healed over the wound surface. Twelve days after amputation (*middle*) a mound of embryo-like cells has formed at the end of the stump. At a later stage, when fingers begin to form (*bottom*), the embryo-like cells are in the process of transformation into muscle and cartilage (later into bone) for the new arm and wrist. End of the old bone marks the amputation line in these photomicrographs, which enlarge the structures approximately 40 diameters.

and tissues become too specialized to return to such a state. But if this were so, how could animals which never regenerate limbs succeed in regenerating individual tissues such as a bit of missing bone or muscle? Moreover, at the time the tadpole loses the ability to regenerate, the tissues of its leg are actually much less specialized than those of a salamander which can regrow a limb. The famous biologist Thomas Hunt Morgan suggested the possibility that in a very complex organ the regeneration of tissues may not be sufficiently synchronized.

Despite the striking similarities between regeneration and embryonic development, the two processes differ greatly. The most notable difference is that the new organ is now developing in close relationship with adult tissues; the embryo grows either apart from the adult or screened from its tissues. The cells of the regenerated tissue actually arise from the cells of adult tissues, and they are covered by adult skin. They are fed by the adult bloodstream, bearing the hormones of the adult and substances which are required for its metabolism. And from the start the new tissue is invaded by fibers which sprout from the amputated ends of adult nerves. Each of the adult tissues must play some part in the development of the new structure, and the thought naturally occurs that some alteration in the activity of one or more tissues could account for the inability to regenerate. A considerable number of all experimental studies of regeneration has been devoted to the role of one or another adult tissue.

Some attempt has been made to implicate hormonal changes in the loss of regenerative capacity. Hormones are among the factors controlling the alterations in body structure which transform the tadpole into a frog. Indeed, recent work by Oscar E. Schotté of Amherst College shows that hormones are of some importance in regeneration. Yet the limb of a young tadpole transplanted to an adult frog is still able to regenerate even though it is supplied with adult blood containing adult hormones; and an adult limb does not recover its regenerative capacity when it is transplanted to a young tadpole whose internal chemistry should favor regrowth.

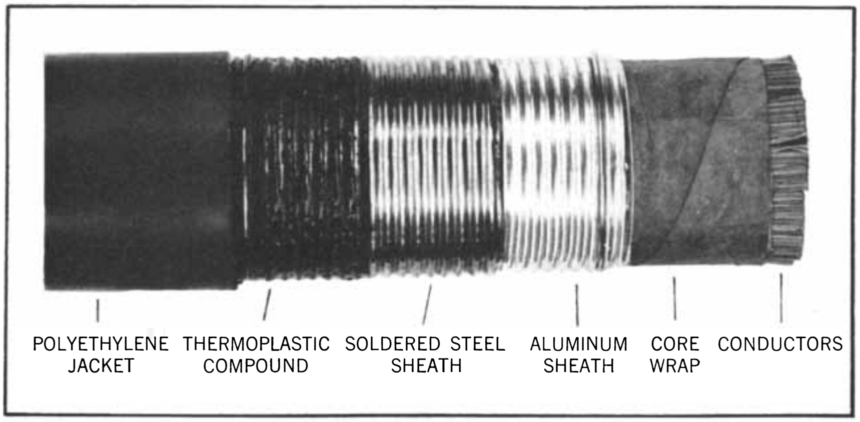
The best clue to a "useful disposition" comes from the role of nerve tissue. If the nerves leading to the stump of the amputated limb of a salamander are cut so that the stump becomes insensitive and paralyzed, the limb does not regenerate. This fact was discovered in 1823

How wall thickness of polyethylene sheath is measured by electrical capacitance

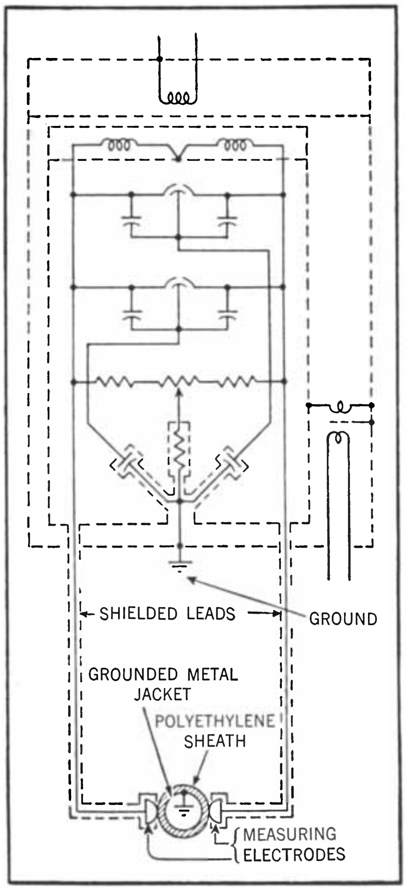
Even though they're no bigger than your arm, telephone cables may contain over 4000 wires and can carry over 2000 conversations at once. Western Electric protects these vital cables by shielding them primarily with aluminum, steel, and extruded sheath of high molecular weight polyethylene.

To assure proper application of each material, highly accurate non-destructive test systems were quickly established for all components but one. Unfortunately, the thickness of the polyethylene sheath could be determined only after it was applied . . . and then only by cutting through it.

But cutting and measuring the sheath a few inches from the ends of a cable, which could be up to a mile long, provided far too small a sample for accuracy. So Western Electric engineers set out to find a way to measure distances from the outer surface to the inner surface without visually locating this inner surface.



This typical telephone exchange cable contains 4242 insulated wires in its core. They are protected by paper, aluminum, steel, thermoplastic compound and, finally, with a polyethylene sheath.



Simplified schematic of measuring circuit, showing special protective shield (broken lines).

They considered several approaches that might allow non-destructive testing on a continuous basis. Two looked promising—X-ray and measurement of electrical capacitance.

Both offered challenging problems—X-ray presented difficulties in protecting personnel and in application . . . and the capacitance method required precision to an order of magnitude beyond any then available. The latter method was ultimately selected because it had better potential for accuracy under production line conditions.

Essentially, the capacitance test determines thickness by establishing an electrical charge between a metal contact against the sheath's outer surface and the inside metal shielding, and measuring differences in voltage or electrical force required to maintain this charge.

In designing equipment that would make this test on the production line, Western Electric engineers faced two problems which could result in great inaccuracy. One was noise or stray electrical impulses; the other, the presence of unwanted stray capacitances. If not solved, these could work harm by obscuring and distorting the truth to be learned from the measurement. Such troubles are ordinarily overcome by the use of protective electrical shielding, so arranged as to intercept unwanted signals and conduct them to a point where their effect is nil. Application of this technique in the present case was accomplished by a specially developed circuit which employs double shielding. An inner shield protects the critical measuring conductors from stray capacitances and connects to a non-critical point; and a grounded shield protects the entire assembly from unwanted random impulses.

This plus other innovations resulted in test equipment that maintains a circuit stability that would be difficult even under good laboratory conditions.

Western Electric is sure of the thickness and quality of the cable's vitally important polyethylene sheath. In addition, as is so often the case with engineering achievements, other equally important advantages were gained. The improved quality control permitted the elimination of a 10% safety margin in jacket thickness, which resulted in a saving of nearly a hundred dollars per mile of cable. It is one more example of how the wide-ranging creative and applied engineering activities of Western Electric are helping the Bell System serve you better and more economically.

Western Electric
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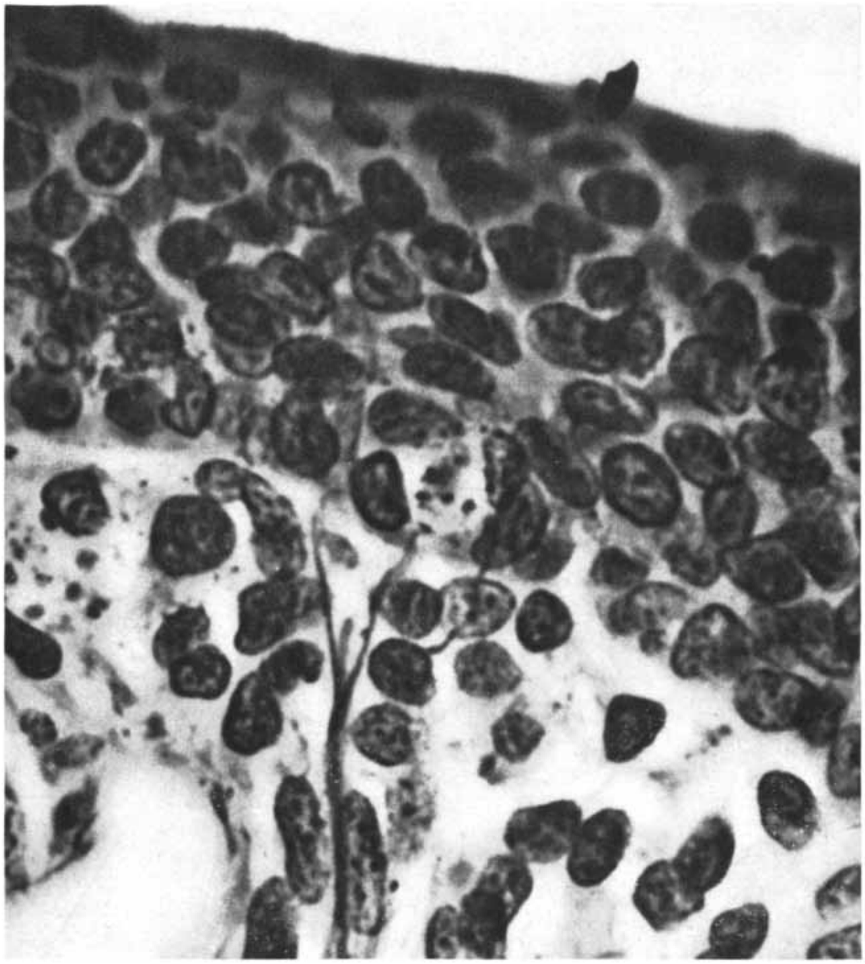


NERVE FIBERS (*dark lines in center and bottom left center*) spread into the thick skin of a regenerating salamander limb. The fibers are stained and enlarged some 800 diameters.

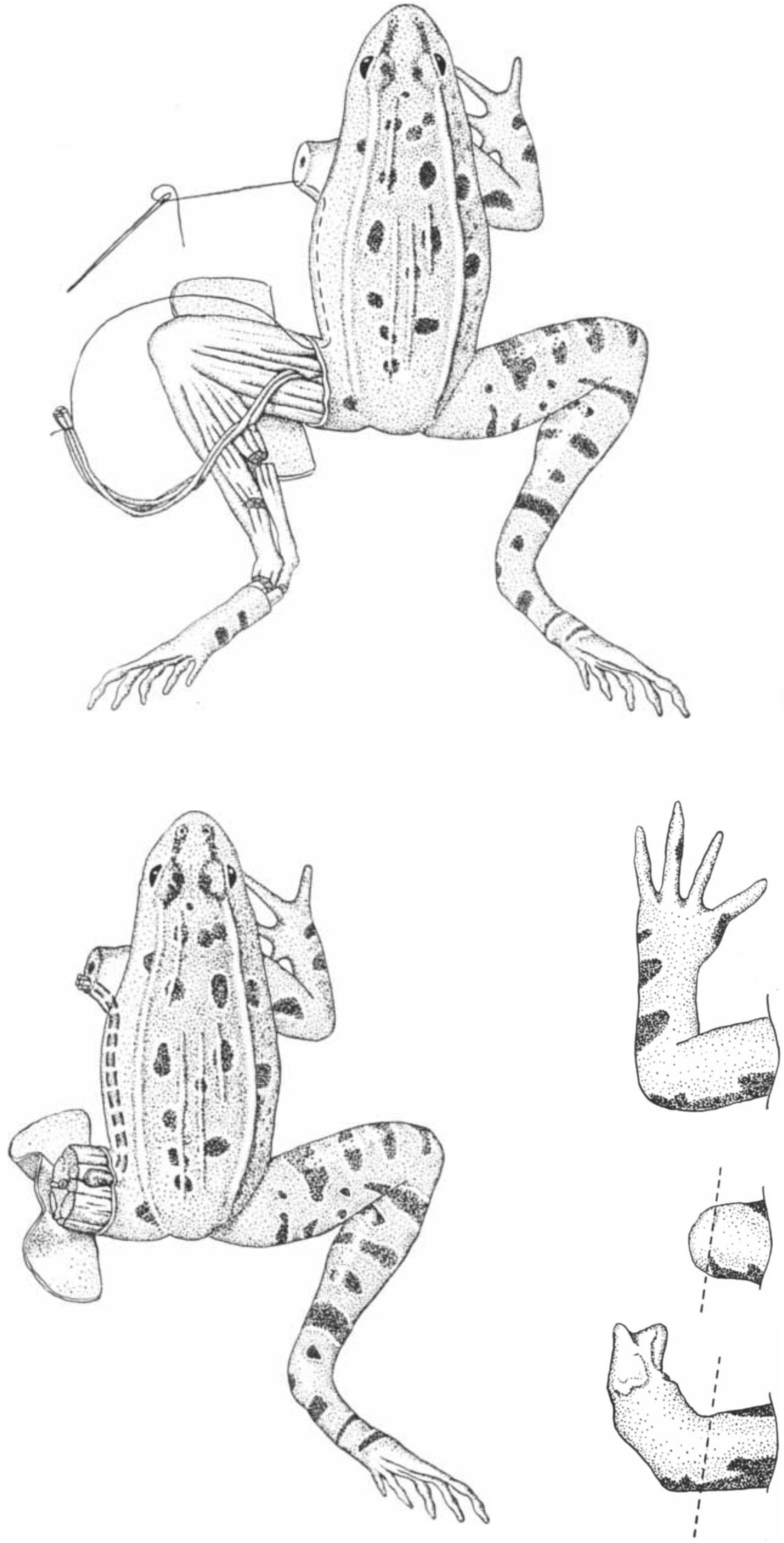
EXTRA FORELIMB, complete with fingers, grew out after the nerve in salamander's arm had been freed and moved from its normal position to a new site on surface of the upper arm. This experiment was performed by C. W. Bodemer, now of the University of Washington.

by an English investigator, Tweedy John Todd, and others have repeatedly affirmed it. In the larval salamander the nerveless stump not only fails to regenerate; it also shrivels and disappears. After a number of days, however, the nerve grows back into the stump, and when it reaches the amputation surface regeneration may resume. If the nerve is cut after regeneration has started, the early growth also wastes away.

The regeneration of the salamander's tail depends upon the nerve supply in the same fashion: the tail will not regrow after the spinal cord is destroyed. The role of the nerve is not unique to regeneration in the salamander. The regeneration of parts in fishes and in lower forms such as the earthworm and crayfish may be inhibited in the same manner. It is a general rule that the regeneration of an external organ requires the presence of nerves at the wound surface. In fact, if one of the major nerves of a salamander's limb is cut and brought to the surface of a fresh wound on the limb, a small supernumerary limb will grow at that site [*see photograph below*].

The function of nerve which we know best is that of conduction. Nerve fibers carry messages from one nerve cell to the next, from the brain and spinal cord by way of nerves to every tissue of the body and back again. All our actions and thoughts depend upon this capacity of nerve cells. It seems proper that this system which is responsible for maintaining the wholeness of bodily function should also serve to repair the mutilated body. However, experiments on the salamander have shown that the nerve's role in regeneration is distinct from that in carrying messages. The growth function, for example, does not require the reflex circuits which are necessary to nerve conduction. Indeed, in the absence of all other innervation, sensory nerve ganglia implanted in regenerated tissue will enable it to continue growing.

How nerve assists regeneration is poorly understood, but most probably the nerve fibers give off substances which promote growth. It is difficult to test this hypothesis, because at the stage when the nerve effect is crucial the volume of the regenerating tissue is very small—about a thousandth of a cubic centimeter. Attempts to influence the nerve or the regenerated tissue chemically by immersing the whole animal in a solution of a drug or by injecting the solution into the body have been unsuccessful. Either the solution was so strong that the whole animal was poisoned by it, or the solution was so diluted and



REGENERATION OF A FROG'S ARM can be induced by supplementing the nerve supply to the stump. At top the nerves of the hind limb are shown after they were dissected free of other tissues and attached to a thread leading under the skin into the arm stump. The drawing at lower left shows the nerve after it has been pulled into position (*broken line*), and the damaged hind limb removed. Drawings at lower right compare a normal arm (*top*) with regenerated arm at an early stage (*middle*) and three months after operation (*bottom*).

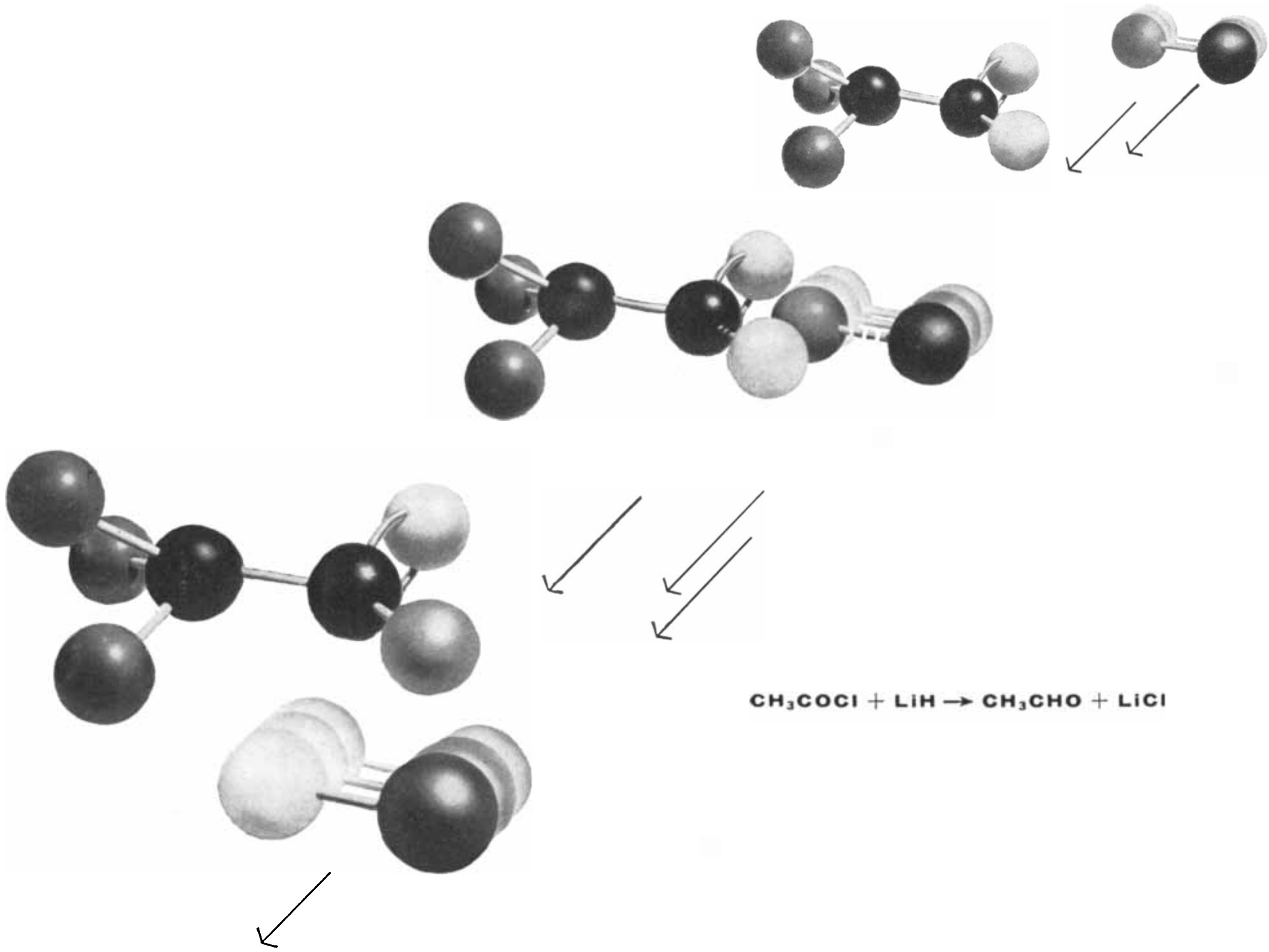
screened by body fluids that it had no effect on the nerve or the growth. It is obviously necessary to apply test substances at the site of nerve influence; namely, within the regenerating organ.

In our laboratory at Cornell University we have recently developed a technique by which we can introduce solutions directly into regenerated tissue in its early critical phases. We implant a fine hollow glass needle in the growth and attach a polyethylene tube through which drug solutions are injected. Solutions can be made to flow in at a rate of a thousandth of a cubic centimeter or less per hour by means of a device which constantly advances the plunger on a small syringe attached to the polyethylene tube [*see the cover of this issue of* SCIENTIFIC AMERICAN]. We have found that chemicals known to paralyze nerves will block growth when infused into the regenerated tissue in this way. We hope that further studies with the technique may eventually reveal the nature of the nerve factor.

The nerve's effectiveness does not depend on the kinds of nerves present, but the number of nerve fibers is important. In the salamander, for instance, the nerves at the surface of an amputation in the upper arm normally contain about 2,500 fibers. If we destroy some of the nerves, and thus reduce the number of fibers to a fourth or a half, regeneration does not occur. A threshold number of nerve fibers act in concert to induce the new growth—the individual fiber is ineffective.

If a nerve threshold also exists in the frog, is it possible that the animal loses its ability to regenerate because its normal nerve supply gradually loses its effectiveness? This could hold if in the course of the tadpole's development the tissues become less responsive to the growth factor of the nerve and require more nerve fibers than are normally available to provoke a response. It could also be true if the nerve fibers in the tadpole's limb do not increase in number in proportion to the volume of other tissues. As a result the relative number of nerve fibers would gradually decrease and might fall below the minimum required for regeneration. Recent work by J. M. Van Stone at Princeton University indicates that the number of nerve fibers in the tadpole does indeed decline with respect to the growth of other tissues, and parallel to the gradual loss of regenerative capacity.

It occurred to us to determine what would happen in the frog if we increased the number of nerve fibers avail-



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Lithium hydride can convert carbon dioxide to free carbon . . . can reduce acetyl chloride to acetaldehyde and lithium chloride (illustrated above) . . . can be used to prepare new hydrides which would otherwise be unobtainable except in small yields and by difficult synthesis . . . functions efficiently in many organic condensation and reduction reactions . . . and can easily be increased in solubility or controlled in reactivity by conversion to mixed hydrides.

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Lithium hydride reacts with alcohols to form lithium alcoholates and hydrogen. This reaction makes possible the convenient preparation of anhydrous lithium alcoholate which is useful as an alcoholysis catalyst.

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Lithium hydride is an ideal source of hydrogen . . . just one pound of lithium hydride will generate as much as 45 cubic feet of hydrogen gas at S.T.P. This gives you more hydrogen per unit of weight than can be secured by using "bottled" gas in steel containers.

. . . as a nuclear shielding material

N_H of lithium hydride is 5.90 compared to 6.68 for water at room temperature. And because of its low dissociation pressure at its melting point (27 mm at 680°C.), lithium hydride can be heated to red heat in a thin-wall container . . . without requiring a pressure shell. It appears to be stable indefinitely at this temperature.

These and many other useful characteristics of lithium hydride may help improve your product or process. For complete technical data, write for Bulletin 102. Address request to Technical Literature Dept., Foote Mineral Co., 454 Eighteen West Chelten Bldg., Phila., 44, Pa.

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The tissues varied in size and structure but were nevertheless recognizable as limbs. The results support the view that the normal nerve supply in the frog is inadequate for regeneration. An increase in the number of nerve fibers, however, is able to satisfy the threshold requirement.

We were not the first to induce regeneration in frogs. L. W. Polezhayev of the U.S.S.R. and then S. Meryl Rose of the University of Illinois had succeeded earlier by means of injuring the amputation wound excessively and repeatedly. Rose immersed the freshly cut stump again and again in a hypertonic salt solution, "rubbing salt into the wound," so to speak. In time a growth, irregular in structure but obviously a limb, appeared at the amputation surface. We repeated Rose's experiments, but when we cut the nerves regeneration did not take place. Since trauma itself cannot cause growth, it may be that excessive injury makes the tissues more responsive to nerve, and then the available nerve supply is sufficient to induce regeneration. The loss of ability to regenerate may thus be attributed to a decline in the responsiveness of the tissue to stimulation by the nerve, as well as a relative deficiency of nerve at the site of amputation.

The evocation of regeneration in the limb of the frog fulfills the hope expressed almost two centuries before by Spallanzani and strengthens the possibility that ways of inducing regrowth in still higher forms may be found. "Should the expectation of obtaining this advantage for ourselves be considered entirely chimerical?" It is probably safe to assume that every organ has the power to regrow lying latent within it, needing only the appropriate "useful dispositions" to bring it out.

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Se++++++ (mg/coulomb)	0.13637
Index of refraction	
(solid) 5890 Angstroms	2.75 – 3.06
Latent heat of fusion (cal/g)	16.4
Latent heat of vaporization (cal/mol)	
Se_2 boiling point 753°C (1387°F)	25,490
Se_6 boiling point 736°C (1357°F)	20,600
Linear coefficient of thermal expansion/°C	37×10^{-6}
Mechanical properties	
Mohs hardness	2.0
Modulus of elasticity, psi	8,400,000
Melting point	
Crystalline (hexagonal)	217°C (423°F)
Amorphous (changes to vitreous)	40°-50°C (104°-122°F)
Nuclear Data	
Stable Isotopes (74, 76, 77, 78, 80, 82)	6
Thermal neutron cross section (2200 m/s)	
Absorption (barns)	11.8±0.4
Scattering (barns)	11±2
Specific heat (cal/g/°C)	
28°C	0.084
Specific volume (cc/g)	
20°C (68°F)	0.207
Surface tension (dynes/cm)	
217°C (422.6°F)	92.5
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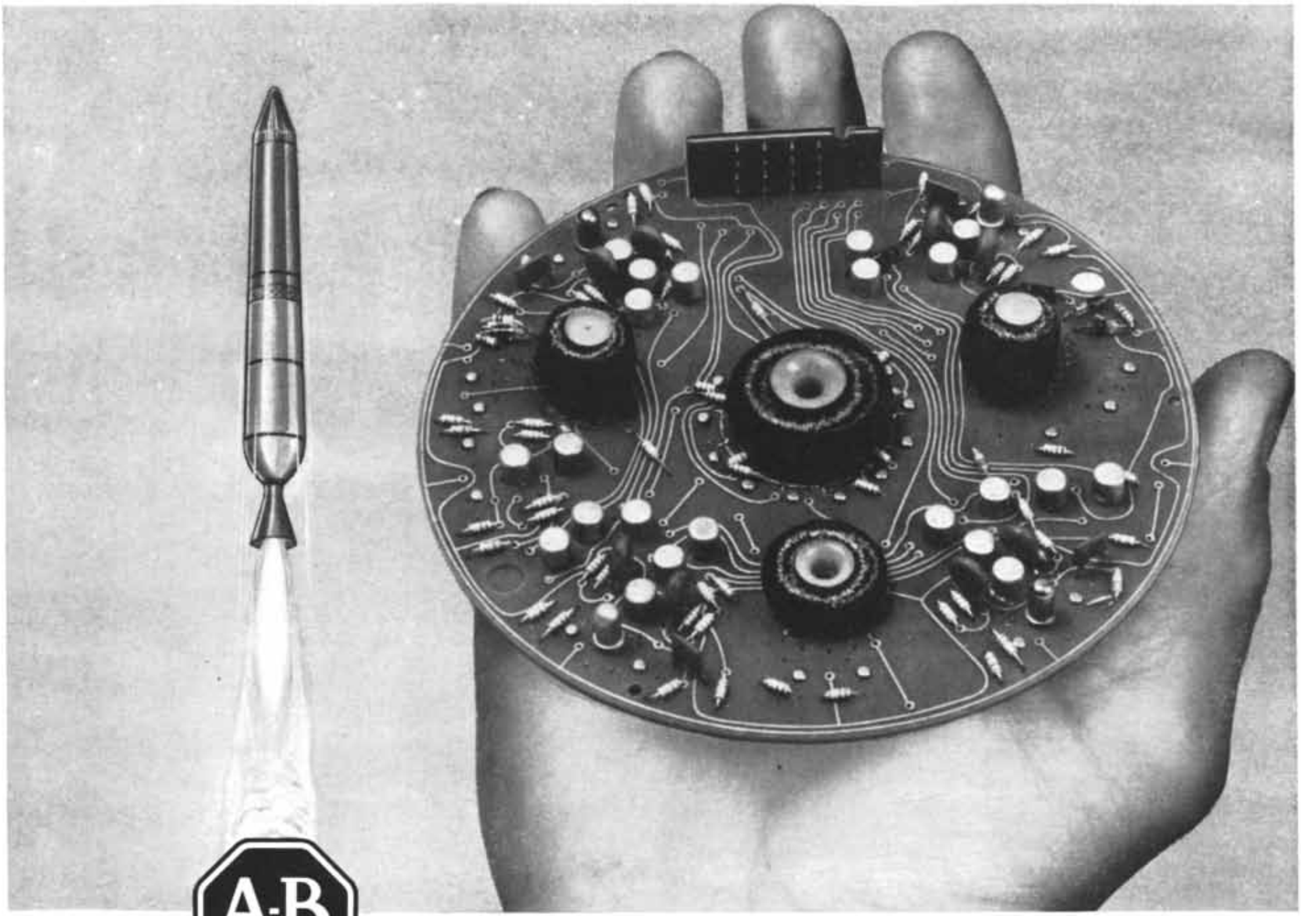

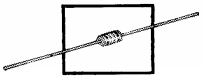

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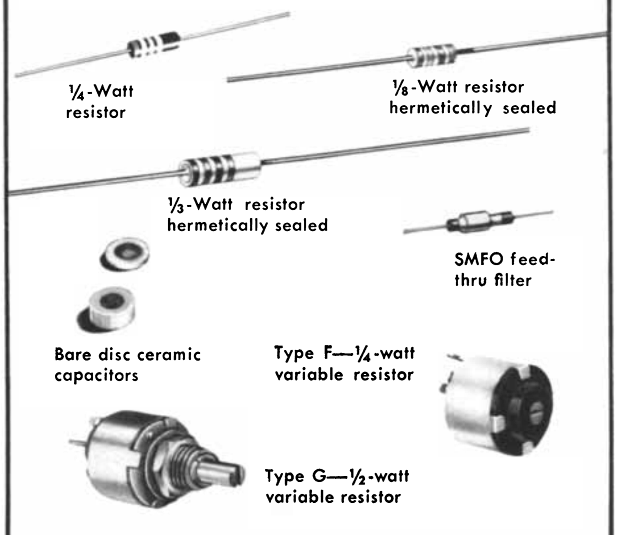

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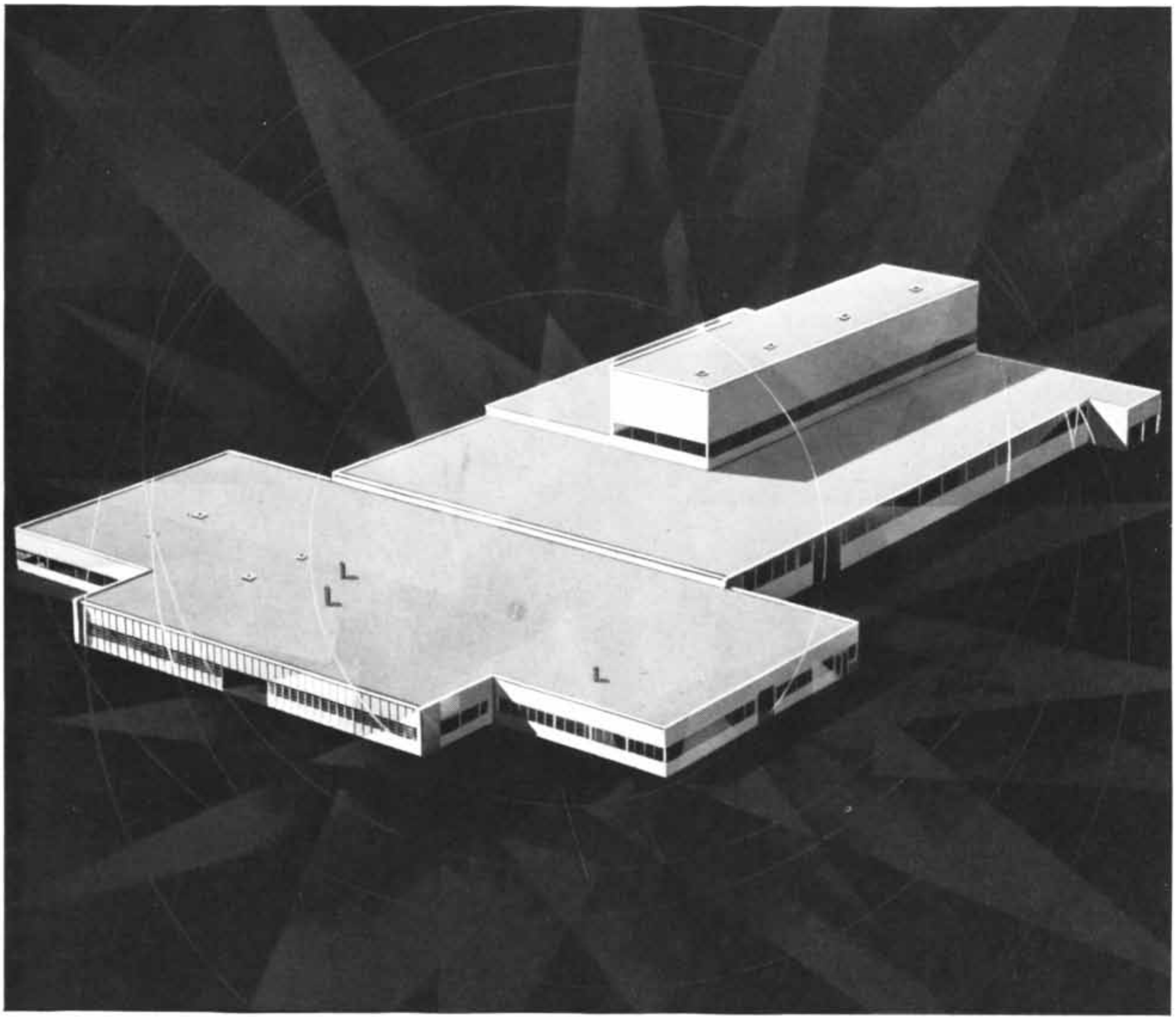

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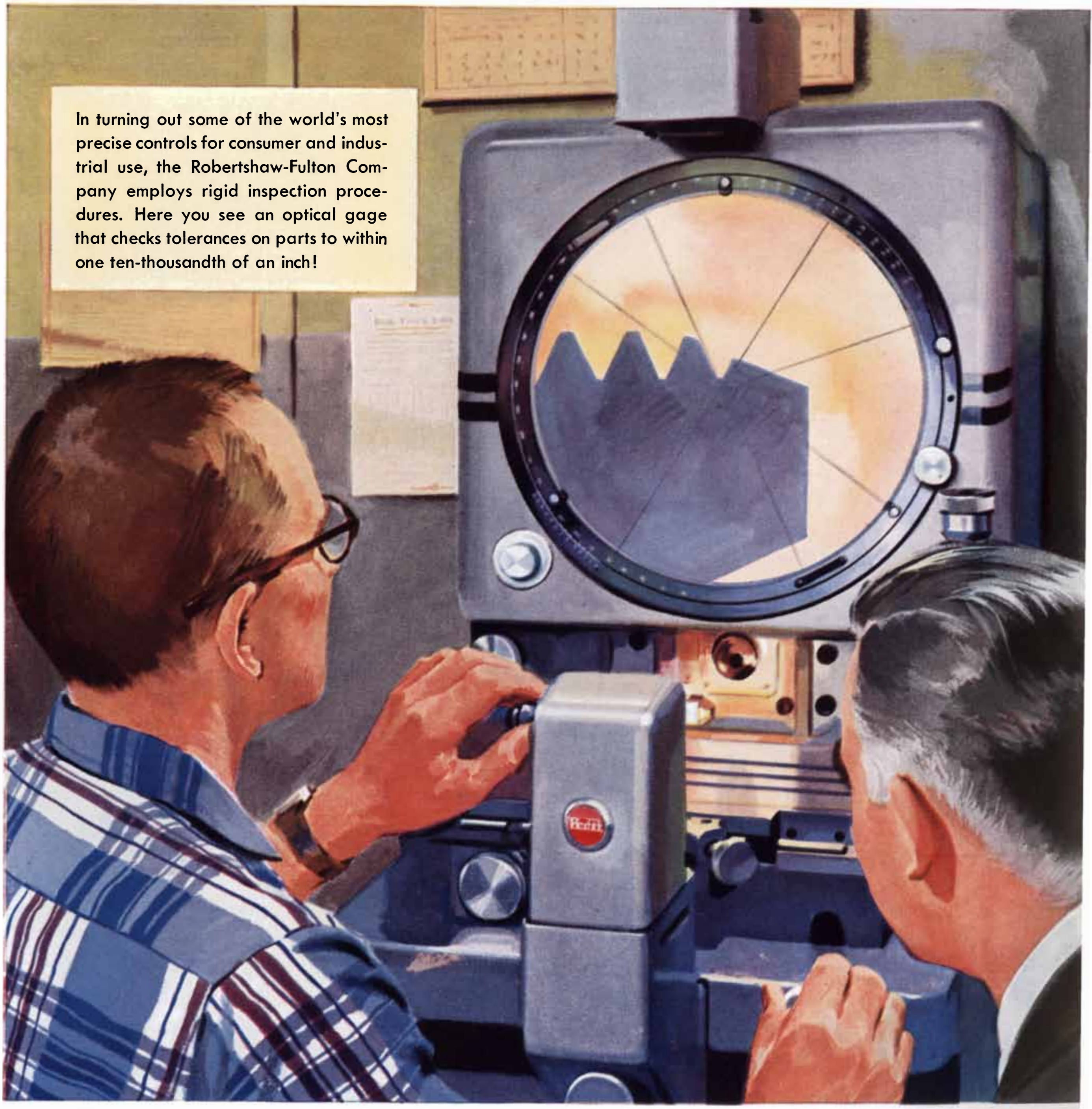

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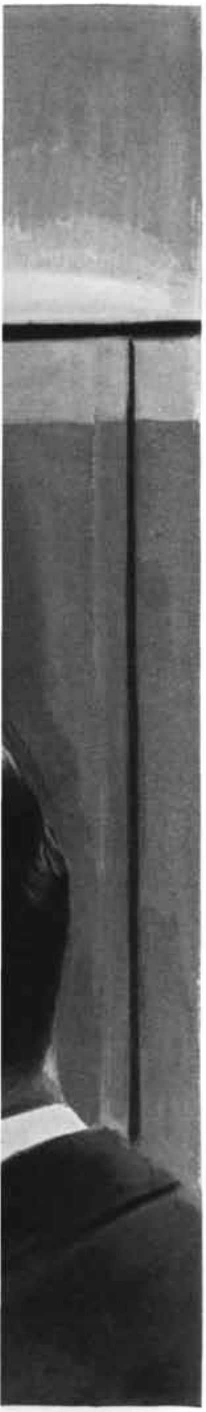

Here's how Robertshaw-Fulton Controls Company and Mobil cut maintenance costs in numerous ways!

"Miracles with metals!" That's the description for the precision controls produced by the Fulton Sylphon Division of Robertshaw-Fulton Controls Company in Knoxville, Tenn. To turn out these finely engineered products takes the utmost coordination between machines and men. Here's where *Mobil Correct Lubrication* comes in.

Mobil engineers and plant maintenance personnel work as a team to solve maintenance problems and keep production at a maximum. For example: Bearing failures on controlled atmosphere furnace caused occasional shutdowns. Mobil engineers and plant supervisors developed a special automatic lubricating system that solved extreme temperature problems. Result: *no more bearing replacements* . . . in a year, *$2,700 saved.*

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Turret lathe heads weren't indexing properly at times, resulting in losses on machined parts. Lathe had to be serviced several times a week. Mobil and plant men pinpointed trouble in soluble oil emulsion. New formulation solved problem . . . saved $2,000 a year in repair costs alone.

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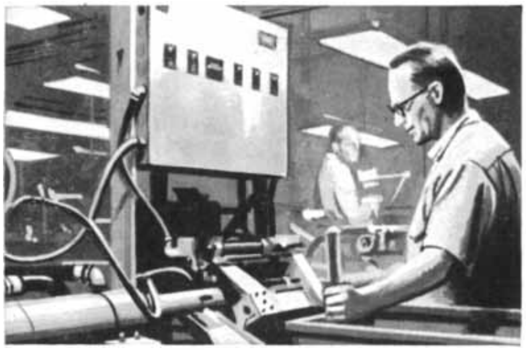

The four-way pilot valves on twenty-six hydraulic Corrugating Machines "froze" after shutdown over weekend . . . had to be disassembled and cleaned each time. Mobil analysis found trouble to be corrosion. Mobil recommendation eliminated trouble . . . saved $2,072 per year.

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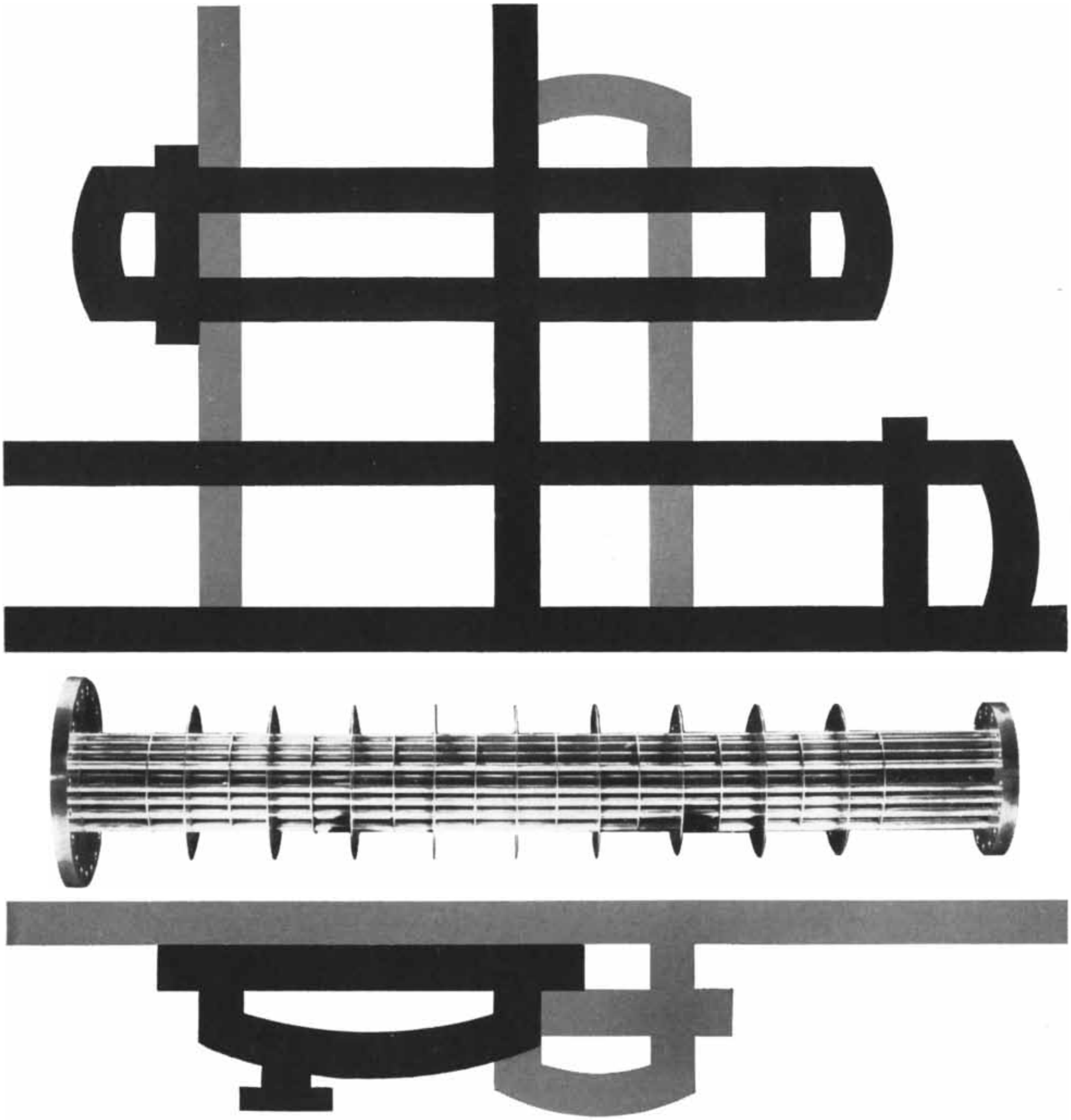


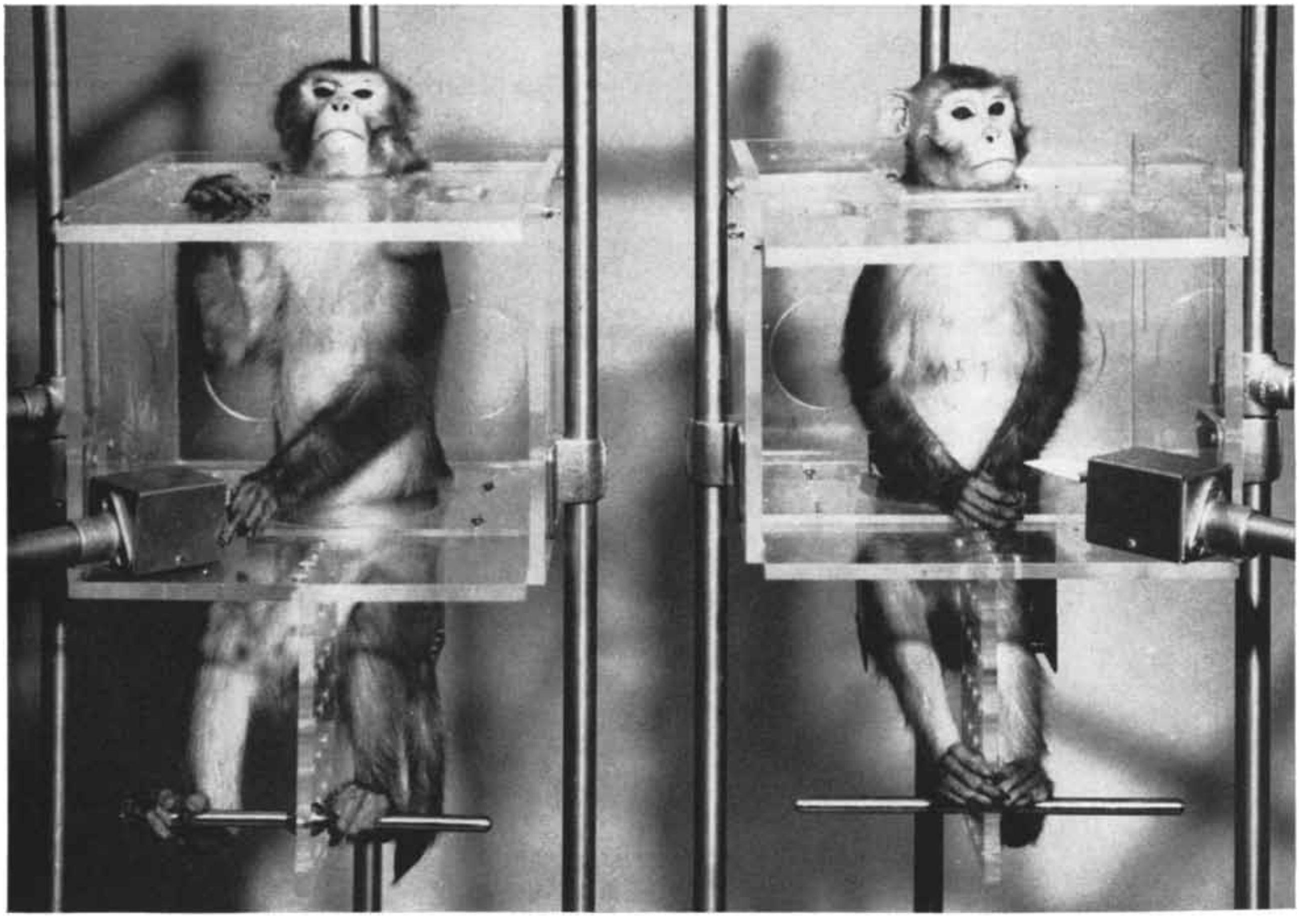
Ulcers in "Executive" Monkeys

In which monkeys subjected to psychological stress in a laboratory apparatus develop gastrointestinal lesions. The technique provides a promising means of studying the causes of psychosomatic diseases

by Joseph V. Brady

Physicians and laymen alike have long recognized that emotional stress can produce bodily disease. Psychic disturbances can induce certain skin and respiratory disorders, can set off attacks of allergic asthma and may even play a part in some forms of heart disease. Of all the body's systems, however, the gastrointestinal tract is perhaps the most vulnerable to emotional stress. The worries, fears, conflicts and anxieties of daily life can produce gastrointestinal disorders ranging from the "nervous stomach," which most of us know at first hand, to the painful and often disabling ulcers which are the traditional occupational disease of business executives.

Emotional stress appears to produce ulcers by increasing the flow of the stomach's acid juices. The connection between emotional disturbance, stomach secretion and ulcers is well documented. A recent study of 2,000 Army draftees, for example, found that those who showed emotional disturbance and excessive gastric secretion during their initial physical examination developed



CONDITIONING EXPERIMENT involves training monkeys in "restraining chairs." Both animals receive brief electric shocks at regular intervals. The "executive" monkey (*left*) has learned to press the lever in its left hand, which prevents shocks to both animals. The control monkey (*right*) has lost interest in its lever, which is a dummy. Only executive monkeys developed ulcers.

ulcers later on under the strains of military life.

But not every kind of emotional stress produces ulcers, and the same kind of stress will do so in one person and not in another. Experimental investigation of the problem is difficult. Animals obviously cannot provide wholly satisfactory experimental models of human mind-body interactions. They can, however, be studied under controlled conditions, and it is through animal experiments that we are finding leads to the cause of ulcers as well as to the effect of emotional stress on the organism in general.

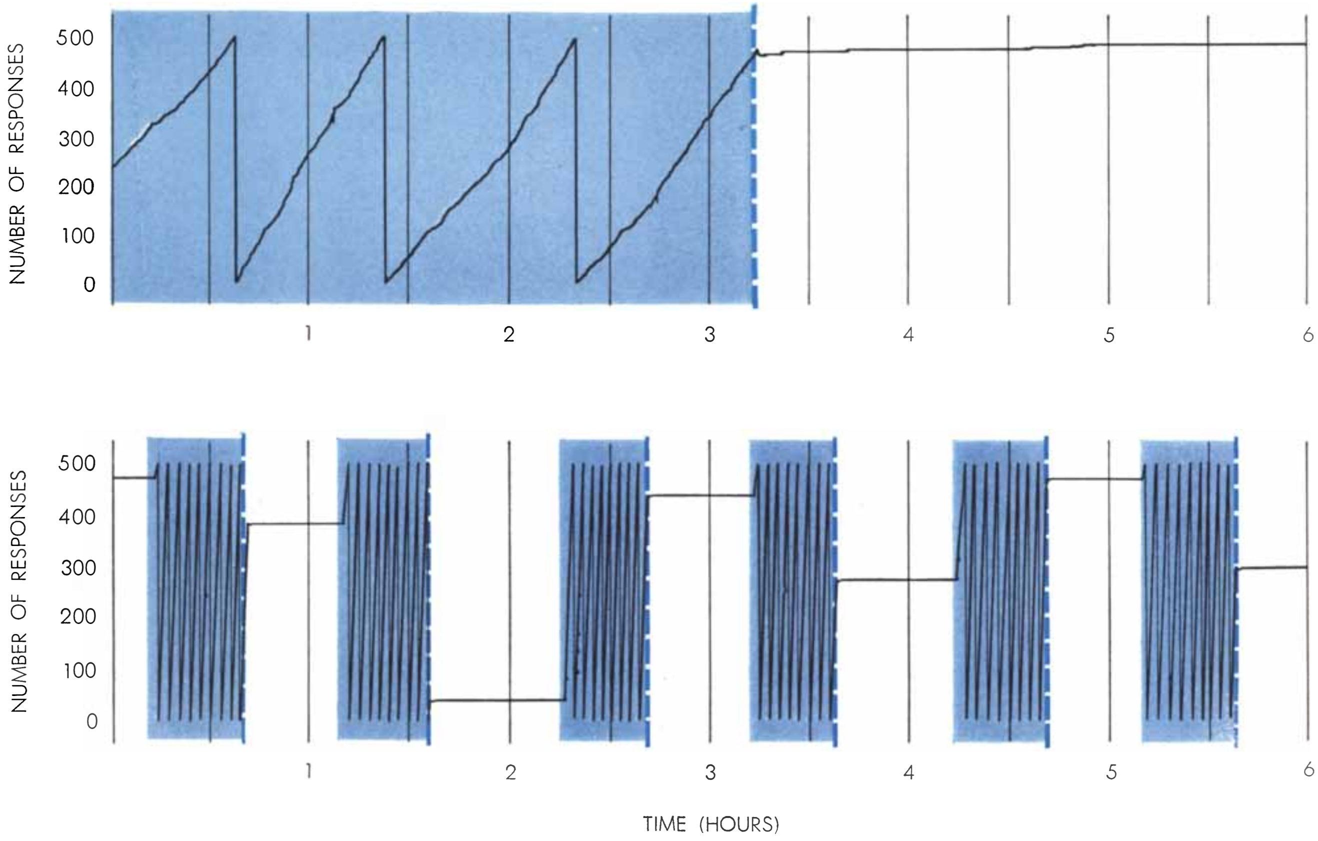
Various investigators have succeeded in inducing ulcers in experimental animals by subjecting them to physical stress. But the role of the emotional processes in such experiments has been uncertain. Experiments on dogs by George F. Mahl of Yale University Medical School indicate that a "fear producing" situation lasting many hours increases the animals' gastric secretions, but these animals do not develop ulcers. William L. Sawrey and John D. Weisz of the University of Colorado produced ulcers in rats by subjecting them to a conflict situation: keeping them in a box where they could obtain food and water only by standing on a grid which gave them a mild electric shock. But this experiment, as Sawrey and Weisz themselves pointed out, did not prove conclusively that emotional stress was the crucial factor in producing the ulcers.

Our studies of ulcers in monkeys at the Walter Reed Army Institute of Research developed somewhat fortuitously. For several years we had been investigating the emotional behavior of these animals. In some of our experiments we had been keeping monkeys in "restraining chairs" (in which they could move their heads and limbs but not their bodies) while we conditioned them in various ways. Since these procedures seemed to impose considerable emotional stress on the animals, we decided that we ought to know something about their physiological reactions. Preliminary investigation showed that stress brought about dramatic alterations in the hormone content of the animals' blood, but a more extensive study of 19 monkeys was brought to a halt when many of them died.

At first we considered this merely a stroke of bad luck, but the post-mortem findings showed that more than bad luck was involved. Many of the dead monkeys had developed ulcers as well as other extensive gastrointestinal damage. Such pathological conditions are normally rare in laboratory animals, and previous experiments with monkeys kept in restraining chairs up to six months convinced us that restraint alone did not produce the ulcers. Evidently the conditioning procedures were to blame.

One of the procedures which showed a high correlation with ulcers involved training the monkey to avoid an electric shock by pressing a lever. The animal received a brief shock on the feet at regular intervals, say, every 20 seconds. It could avoid the shock if it learned to press the lever at least once in every 20-second interval. It does not take a monkey very long to master this problem; within a short time it is pressing the lever far oftener than once in 20 seconds. Only occasionally does it slow down enough to receive a shock as a reminder.

One possibility, of course, was that the monkeys which had developed ulcers under this procedure had done so not because of the psychological stress in-



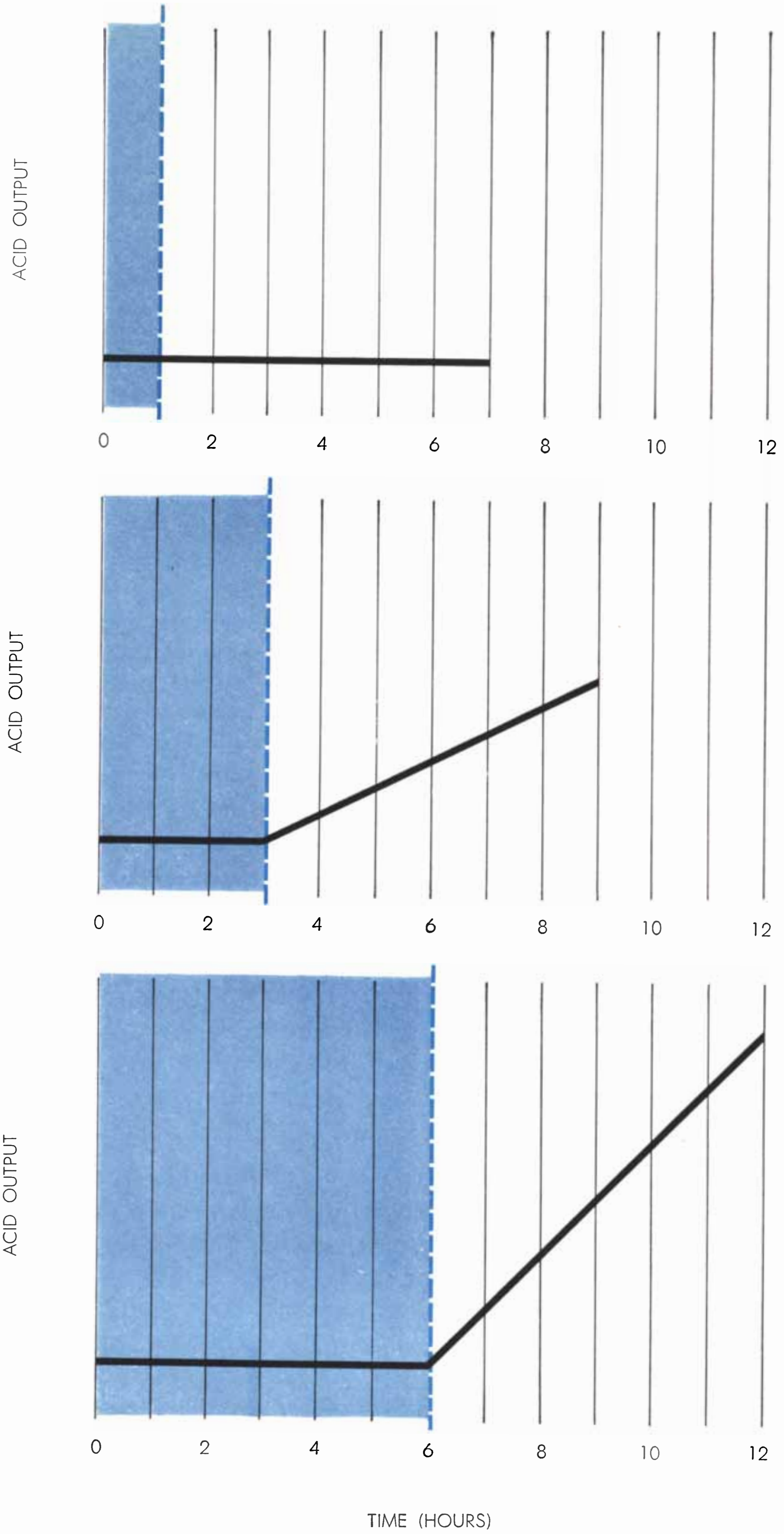
RESPONSES OF MONKEYS were recorded automatically. Slope of the lines shows the rate of lever-pressing (*vertical lines indicate resetting of stylus*). Upper chart shows responses of an executive monkey during the last half of a six-hour avoidance session (*colored area*) and the first half of a six-hour rest period; shocks were programmed every 20 seconds. Monkeys kept on this schedule developed ulcers. Lower chart shows responses during a 30-minutes-on, 30-minutes-off schedule with shocks programmed every two seconds. Monkeys on this schedule failed to develop ulcers, despite more intense activity and presumably greater psychic stress.

volved but rather as a cumulative result of the shocks. To test this possibility we set up a controlled experiment, using two monkeys in "yoked chairs" in which both monkeys received shocks but only one monkey could prevent them. The experimental or "executive" monkey could prevent shocks to himself and his partner by pressing the lever; the control monkey's lever was a dummy. Thus both animals were subjected to the same physical stress (*i.e.*, both received the same number of shocks at the same time), but only the "executive" monkey was under the psychological stress of having to press the lever.

We placed the monkeys on a continuous schedule of alternate periods of shock-avoidance and rest, arbitrarily choosing an interval of six hours for each period. As a cue for the executive monkey we provided a red light which was turned on during the avoidance periods and turned off during the "off" hours. The animal soon learned to press its lever at a rate averaging between 15 and 20 times a minute during the avoidance periods, and to stop pressing the lever when the red light was turned off. These responses showed no change throughout the experiment. The control monkey at first pressed the lever sporadically during both the avoidance and rest sessions, but lost interest in the lever within a few days.

After 23 days of a continuous six-hours-on, six-hours-off schedule the executive monkey died during one of the avoidance sessions. Our only advance warning had been the animal's failure to eat on the preceding day. It had lost no weight during the experiment, and it pressed the lever at an unflagging rate through the first two hours of its last avoidance session. Then it suddenly collapsed and had to be sacrificed. An autopsy revealed a large perforation in the wall of the duodenum—the upper part of the small intestine near its junction with the stomach, and a common site of ulcers in man. Microscopic analysis revealed both acute and chronic inflammation around this lesion. The control monkey, sacrificed in good health a few hours later, showed no gastrointestinal abnormalities. A second experiment using precisely the same procedure produced much the same results. This time the executive monkey developed ulcers in both the stomach and the duodenum; the control animal was again unaffected.

In a series of follow-up experiments which is still in progress we have tried to isolate the physiological and



STOMACH ACIDITY of executive monkeys, as shown in these highly simplified charts, did not increase during avoidance sessions (*color*) but rather during the subsequent rest periods. The greatest increase followed a six-hour session; no rise followed a one-hour session.

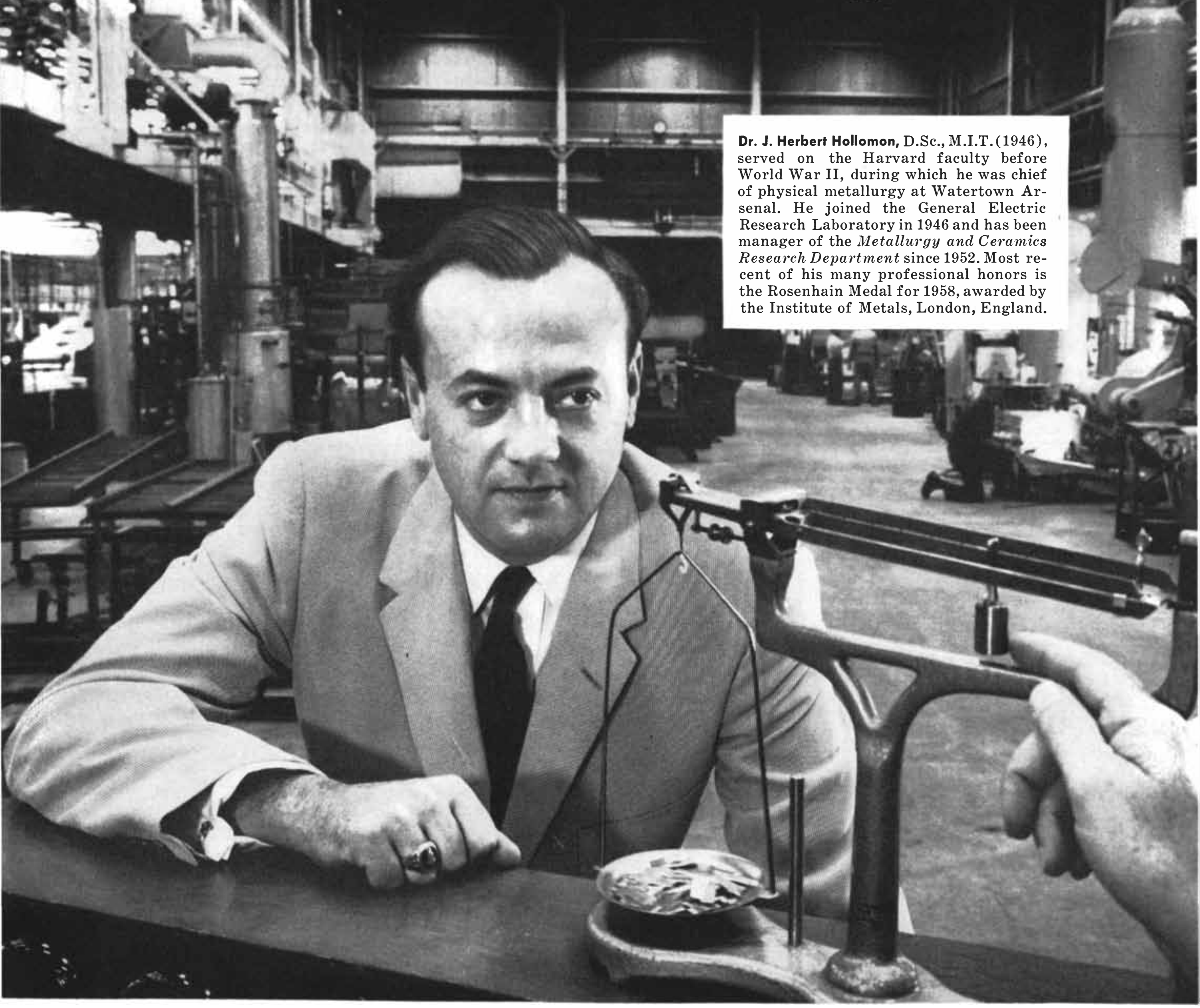
psychological factors which produce the "laboratory ulcers." For example, one of our groups suggested that the "social" interaction between the two monkeys might be important. Certainly the most casual observation showed that considerable "communication" was going on between the two animals, who were seated within easy chattering distance of each other. We therefore studied several pairs of animals isolated from each other in soundproof "telephone booths." Unfortunately isolation failed to protect the executive monkeys, for they continued to develop ulcers.

More recently, however, we have found a factor or group of factors which does seem to be critical in producing ulcers. What we have learned seems to pivot on our chance selection of six hours as the interval for shock-avoidance and for rest in the conditioning procedure. We made this discovery when we sought to improve on the results of our experiments. Though laboratory animals can rarely be made to develop ulcers, we had come upon a procedure that seemed to produce ulcers "to order." The only uncertainty was the length of exposure required. This varied greatly among individual monkeys; some came down with ulcers in 18 days, others took as long as six weeks. If we could develop a technique guaranteed to produce ulcers in, say, 10 days, we could stop the shock-avoidance sessions on the eighth or ninth day, apply various therapeutic measures and study the monkey's response to them.

It seemed reasonable to assume that we might induce ulcers more rapidly and dependably by simply increasing the stress on the animals. We therefore put several monkeys on an 18-hours-on, six-hours-off schedule. After a few weeks one of the animals died, but of tuberculosis, not ulcers. The rest continued to press their levers week after week with no apparent ill effects. Finally, when it began to seem as if we might have to wait for the animals to die of old age, we sacrificed them—and found no gastrointestinal abnormalities whatever!

We put another group on an even more strenuous schedule: 30 minutes on and 30 minutes off, with the shocks programmed for every two seconds rather than every 20. Again one of the animals died, this time of a generalized virus infection unrelated to ulcers. The others, after weeks of frantic lever pressing, showed no gastrointestinal changes.

We had to conclude that the crucial factor was not the degree or even the frequency of stress but was to be sought in the relationship between the length



Dr. J. Herbert Hollomon, D.Sc., M.I.T. (1946), served on the Harvard faculty before World War II, during which he was chief of physical metallurgy at Watertown Arsenal. He joined the General Electric Research Laboratory in 1946 and has been manager of the *Metallurgy and Ceramics Research Department* since 1952. Most recent of his many professional honors is the Rosenhain Medal for 1958, awarded by the Institute of Metals, London, England.

Materials to match ideas

General Electric's Dr. J. Herbert Hollomon cites need for "materials scientists" and "materials engineers"

For centuries, when inventive men came up with unique and useful ideas, there was almost always something available from which a practical device could be made. But recently, man's brain has begun to outrun the available materials. He could design and build faster planes, safer cars, improved missiles—*if* there were better materials.

Dr. J. Herbert Hollomon, one of the leaders of a group of outstanding scientists at the General Electric Research Laboratory, believes the problem can be solved only by taking a much broader view of *materials research and development.*

"From a scientific standpoint," says Dr. Hollomon, "the science that underlies the behavior of metals, ceramics, semiconductors, or polymers is essentially the same. And the design engineer — for whatever product — wants *the best material for the job.* He is not concerned whether the material is metallic, ceramic, plastic, or made of green cheese."

Dr. Hollomon looks to the day when universities will produce topflight materials scientists and materials engineers for important jobs in tomorrow's world. "The closer interaction of physics, electronics, chemistry, metallurgy, and ceramics," he says, "will strengthen the nation's defense, extend the capabilities of American industry, and improve the level of living for people everywhere."

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of the stress period and that of the rest period. The six-hours-on, six-hours-off schedule had produced ulcers (and occasionally other somatic disorders) despite individual differences in monkeys, variations in diet and maintenance routines and gross alterations in preliminary physiological tests. No other schedule we had tried produced ulcers at all.

This unexpected finding suggested that we should investigate what was going on in the monkeys' stomachs during the conditioning procedure. A standard technique for investigating gastric processes in experimental animals makes use of an artificial opening, or fistula, in the animal's abdominal and stomach walls through which the contents of its stomach can be sampled. Such fistulas have played an important role in expanding our knowledge of the gastrointestinal system. In the early 19th century the famous U. S. Army surgeon William Beaumont made the first systematic study of the digestive process with the cooperation of a young Canadian who had a fistula due to an imperfectly healed gunshot wound. More than a century later Stewart G. Wolf, Jr., and Harold G. Wolff at the Cornell University Medical College, with the help of a man who had a similar injury, conducted a pioneer investigation of the relationship between emotional stress and ulcers. They found that situations which produced feelings of anxiety or aggression in their subject stepped up his gastric secretions and engorged his stomach wall with blood. Physiological changes of this sort, they believed, are the precursors of ulcers.

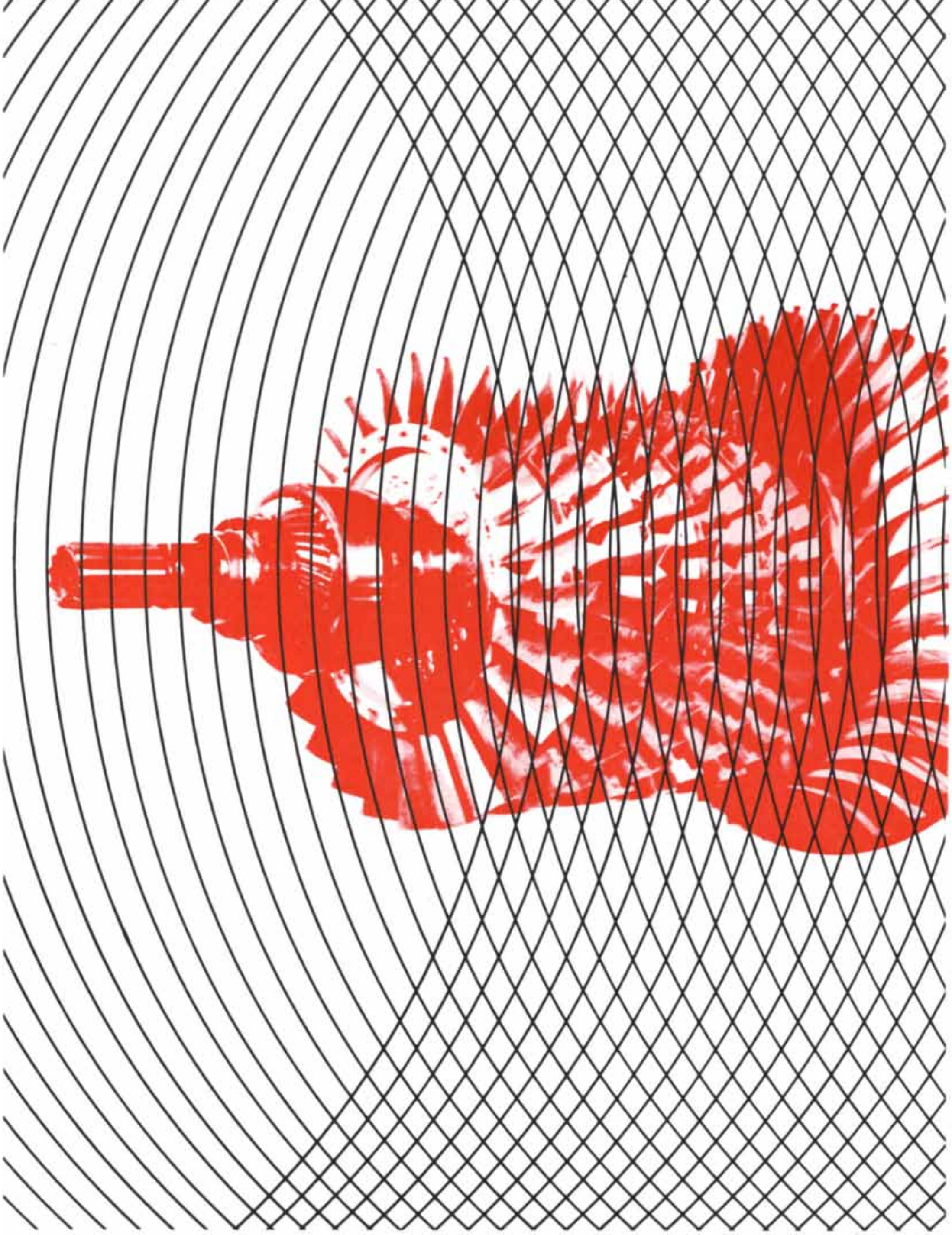
Edwin Polish of our department of neuroendocrinology has been studying the stomach acidity of some of our executive monkeys by means of artificial fistulas. His measurements, though far from complete, seem to provide one possible explanation of the results of our experiments.

The stomach secretions of the executive monkeys do indeed become considerably more acid, but not (as one might expect) during the avoidance periods. When the animals are actually pressing the levers the acidity of their stomachs rises little. The significant increase in acidity begins at the end of the avoidance session and reaches a peak several hours later, while the animal is presumably resting. This finding suggests a close relationship between the formation of ulcers and the cyclic character of the six-hours-on, six-hours-off procedure. Emotional stress, it appears, must be intermittent—turning the animal's system on and off, so to speak—if it is to cause ulcers. Continuous emotional stress seems to permit a stable adjustment (at least for a while) under which ulcers do not develop. It is tempting to consider the analogy of the vacuum tube or light bulb which seems to last much longer under conditions of continuous current than when it is subjected to frequent heating and cooling.

Like most analogies, this one limps badly and has its limitations. For example, our experiments show that periodic stress does not always bring on ulcers, and Polish's findings are consistent with this. His measurements indicate that the greatest increase in acidity occurs after a six-hour avoidance session. After a three-hour session acidity rises, but less sharply; after a one-hour session it does not rise at all [*see illustration on page 98*]. Periodic emotional stress apparently causes ulcers only if its period coincides with that of some natural rhythm of the gastrointestinal system.

Obviously our knowledge of the physiological and psychological processes which produce ulcers is far from complete. Our understanding of even the relatively well-controlled experiments I have described is just beginning to progress beyond the primitive level. We have yet to discover why emotional stress steps up the stomach's acidity later rather than immediately. We are still looking for a method of producing ulcers at will, in days rather than weeks. Eventually we hope to learn to detect an incipient ulcer before the animal collapses, by examining the subject's blood, urine and other secretions, thus making post-mortem examinations unnecessary.

There are many other questions about the effects of emotional stress which we have not yet begun to investigate. Really thorough examination of the experimental animals might well show other types of damage of which we are at present unaware. The two monkeys which died of causes unrelated to ulcers, for example, may have succumbed because their resistance had been lowered in some way by psychological stress. It would be surprising to find physical processes wholly unimpaired in monkeys who have been on a 30-minutes-on, 30-minutes-off schedule for several weeks. The opportunity to bring psychosomatic relationships under experimental scrutiny in the laboratory seems to open broad horizons for research into the causes and alleviation of this poorly understood class of ills.



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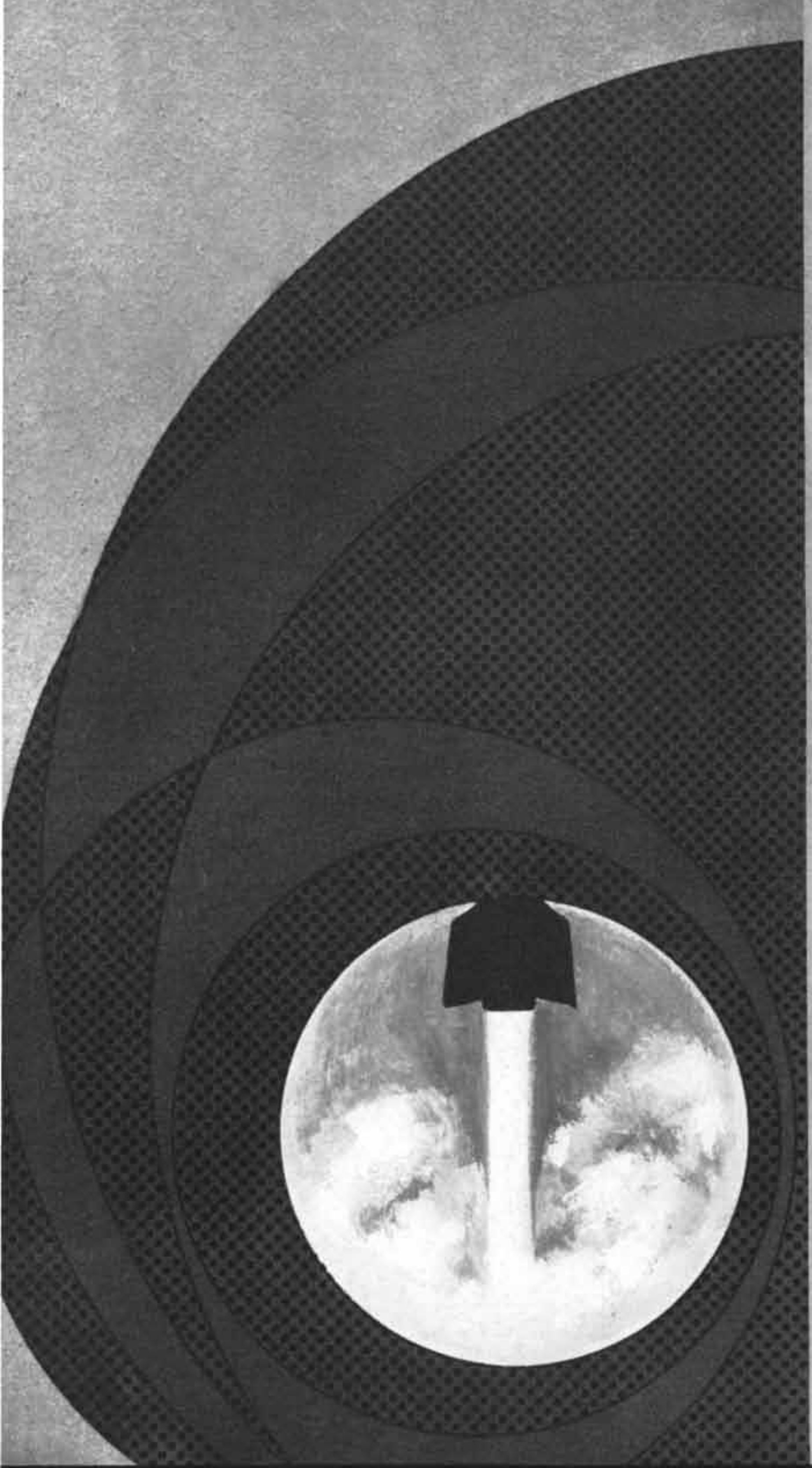

ACOUSTIC NOISE

When huge rocket engines lift a ballistic missile or satellite vehicle into the air, the thundering noise of the engines violently shakes intricate electronic components and the missile structure itself. Acoustic noise is one of the many environments that must be thoroughly explored and understood by the missile designer.

But it is expensive and impractical to conduct acoustic noise tests by operating rocket engines on the ground. Noise—of the same frequencies and amplitudes as rocket engine noise—must be produced in the laboratory.

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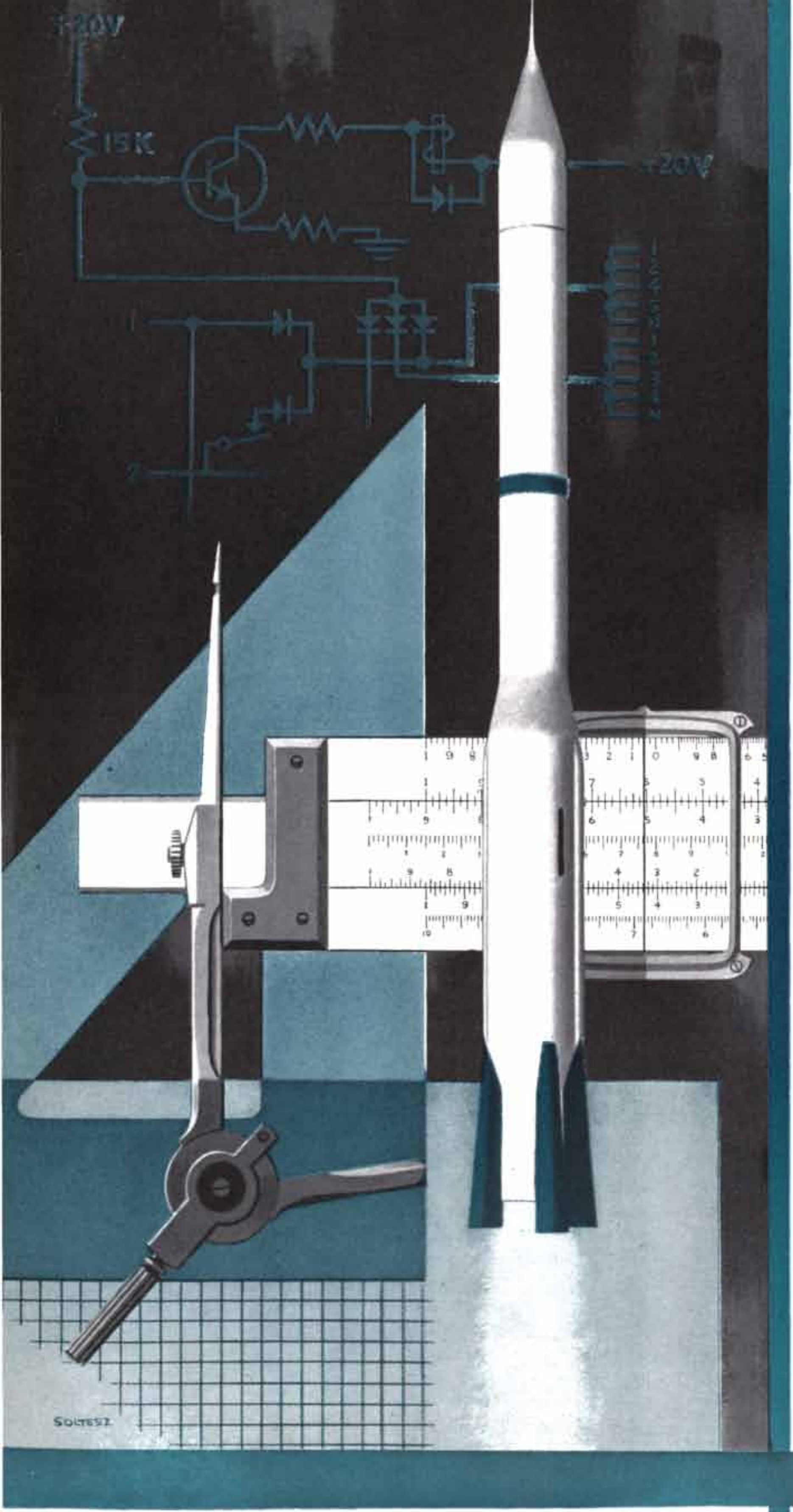

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LIGNIN

This important constituent of wood is slowly yielding to efforts to isolate it and determine its molecular structure. Now almost entirely wasted, it may ultimately become a valuable raw material

by F. F. Nord and Walter J. Schubert

Wood is a structural material unmatched in its strength, elasticity, lightness and beauty. These desirable properties it owes in great measure to the two main substances that make up its peculiar structure. Wood is composed of long, springy fibers of cellulose banded together and stiffened by a durable and highly stable natural plastic called lignin. More than a century ago chemists conceived the ambition of separating cellulose and lignin from each other and exploiting the virtues inherent in each. With cellulose chemists have had some success: in the form of paper, rayon, plastics and explosives it is one of the most important commodities we owe to industrial organic chemistry. Lignin is another story. Its great promise remains locked up in the natural structure of wood; it is a chemical enigma and a major industrial waste.

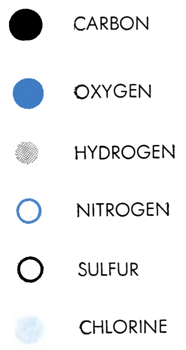
Like cellulose, lignin is a polymer, that is, a giant molecule built up from identical or similar smaller molecular units (monomers) linked together in a long chain. But whereas the structure of cellulose is well known [see "Cellulose," by R. D. Preston; Scientific American, September, 1957], the structure of lignin is only now yielding to study. The little we have learned makes the search seem all the more worthwhile. Lignin, it is clear, belongs to the large and fruitful family of "aromatic" compounds on which the dyestuff and pharmaceutical industries are largely built, and from which come some of the most useful plastics. Technology could realize even more of the rich possibilities of aromatics if the supply were more abundant. For the present they are a byproduct of coke ovens. (The molecular structures found in bituminous coal suggest, in fact, that it consists mainly of fossilized lignin.) Lignin, however, is available in enormous quantities: the U. S. pulpwood industry alone last year processed more than four billion cubic feet of wood containing close to 20 million tons of lignin. It is potentially a source not only of familiar aromatic compounds, but of still unknown substances that may emerge in the future from lignin chemistry. But for today's pulp mills lignin is little more than a nuisance. The great bulk of it is either burned or sluiced into streams, polluting the water and poisoning the fish.

A better understanding of the chemical structure of lignin will someday convert this nuisance into a valuable resource. In the process of investigation we may also solve the problem of how plants manufacture lignin (and other aromatic compounds) and thus come to understand one of the key processes of life.

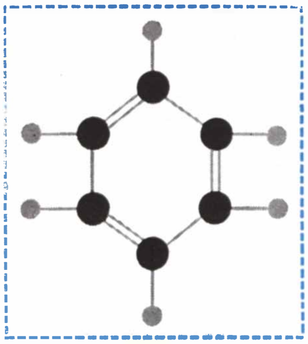
Wood chemistry began with the investigations of Anselme Payen in France during the second quarter of the 19th century. Suspecting that wood consisted not of one substance but of several, he tried to separate them. By treating wood chips first with nitric acid and then with caustic soda he obtained a resistant substance which he called cellulose. The substance which he had removed from the cellulose he called "the incrusting material," shrewdly guessing that it surrounded or impregnated the cellulose. This material, we now know, was an impure form of lignin. The name itself is one of a half-dozen which Payen suggested.

Payen never succeeded in obtaining pure lignin. He had, in fact, come up against what is still the main roadblock to an easy understanding of this substance: the difficulty of isolating it. Later investigators have established that whereas cellulose occurs in some plants (*e.g.*, cotton) in almost pure form, lignin is found only in association with cellulose. Its function in the trees and woody plants which produce it is not only to stiffen the cellulose fibers and bind them together but also to protect them against chemical attack. So effective is this protection that no known solvent can get at the cellulose unless the lignin is first removed by powerful reagents. These destroy the giant lignin molecules and break down their fragments into simpler substances; thus lignin preparations obtained with different reagents have different chemical properties.

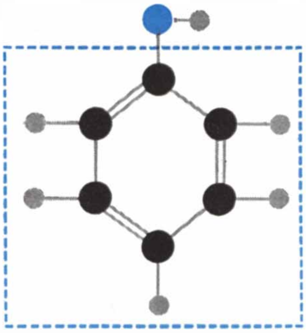
The development during the latter part of the 19th century of the sulfite process for obtaining cellulose from wood made possible the modern pulpwood industry. But this process committed the industry to the destructive removal of the lignin. The boiling of the wood chips with sulfites carries the



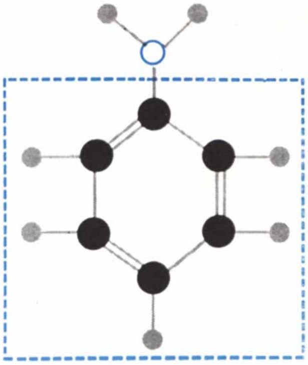
SIMPLE AROMATIC compounds are diagrammed on the opposite page; above is the key to these drawings and those on the four following pages. These compounds and hundreds of other useful substances contain the



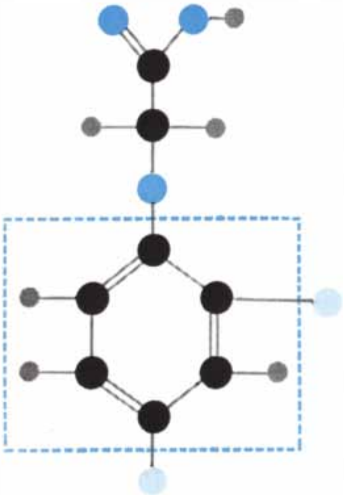
BENZENE



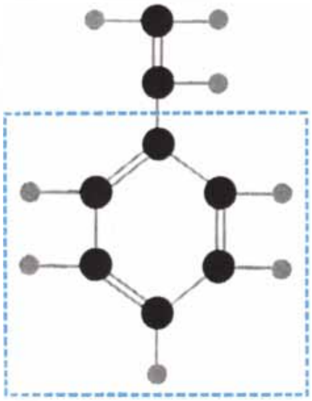
PHENOL



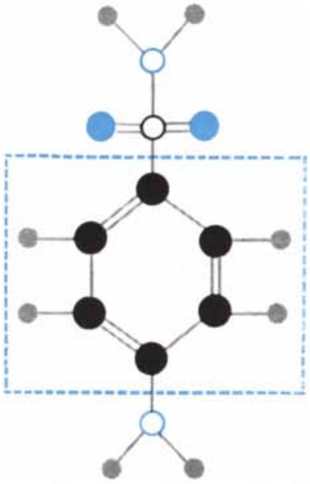
ANILINE



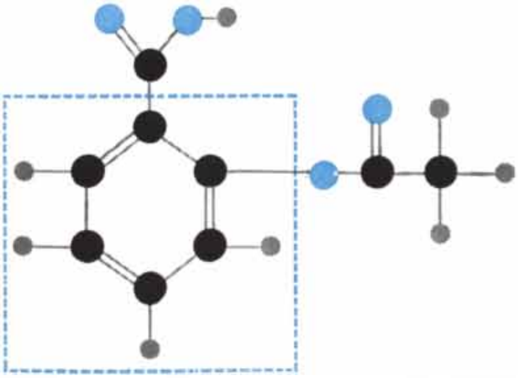
2-4-D



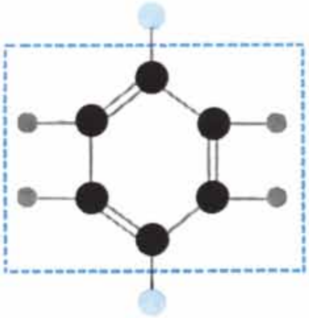
STYRENE



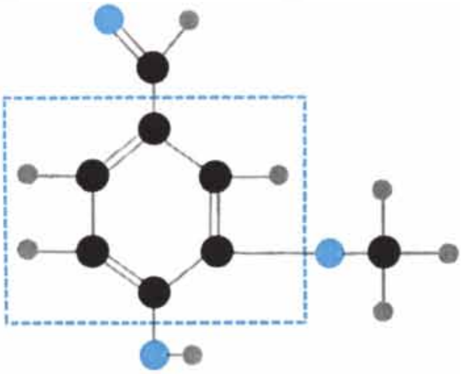
SULFANILAMIDE



ASPIRIN

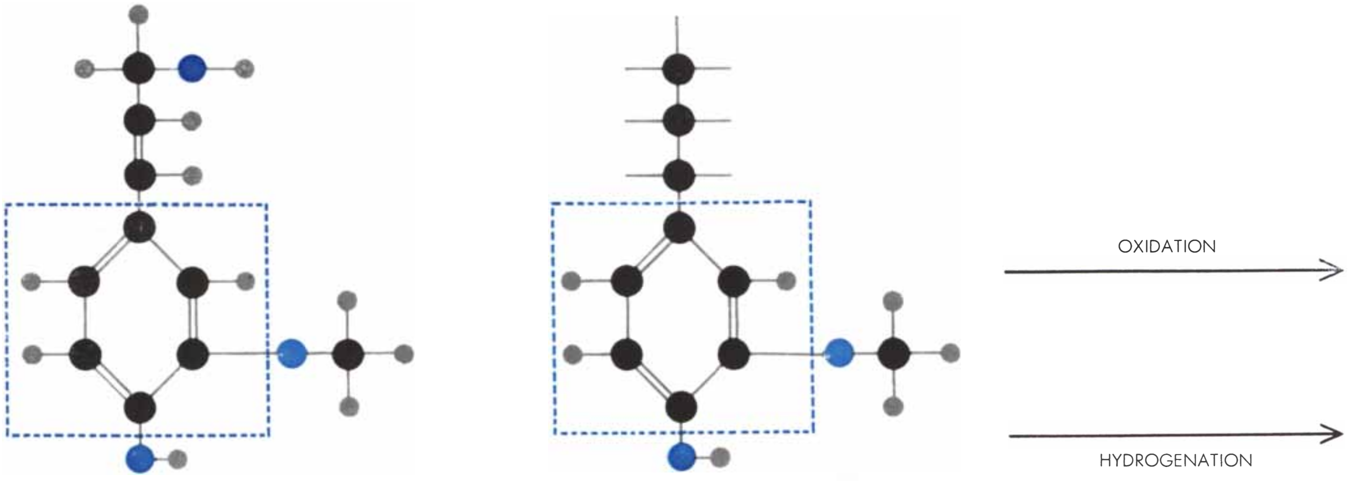


PARADICHLOROBENZENE



VANILLIN

hexagonal "benzene ring" (*within colored rectangles*) also found in lignin; eventually they may be obtained from lignin. The chief present source of aromatic compounds is coal tar, whose primary derivatives include the basic chemical raw materials benzene and phenol. Benzene is also used as a solvent; phenol ("carbolic acid"), as a disinfectant. Both phenol and styrene can be polymerized into plastics. Aniline is used to make dyes and other chemicals. Paradichlorobenzene is an insecticide; 2,4-D is a plant-growth regulator and weed killer. Vanillin, an artificial flavoring agent, is related to lignin and can be obtained from it as well as from coal tar.



STRUCTURE OF LIGNIN MONOMER *(center)* **is still not completely known. Its similarity to coniferyl alcohol** *(left)*, **noted more than 50 years ago, is confirmed by the fact that it can be oxidized to vanillin** *(upper right)* **and hydrogenated to compounds of the cyclohexylpropyl type** *(lower right)* **in which the "unsaturated" benzene ring changes into a "saturated" cyclohexane ring.**

lignin off in water-soluble lignosulfonate compounds. As the pulp industry grew, wood chemists began seeking ways to utilize the noxious waste liquors which were its main byproduct.

Around 1890 Peter Klason, often called the father of lignin chemistry, obtained the first clue to the structure of lignin by his investigation of coniferyl alcohol. This aromatic compound is a derivative of coniferin, a substance found in the growing tissue of coniferous trees. Its structure [*see illustration above*] is based on the hexagonal benzene ring that characterizes all aromatic substances; a chain of three carbon atoms occupies one corner of the ring, a hydroxyl group (–OH) occupies the opposite corner, and a methoxyl group ($-OCH_3$) is attached to a corner alongside the hydroxyl. Klason observed that when he treated coniferyl alcohol with sulfites he obtained compounds very similar to the lignosulfonates. He concluded that lignin must be a polymer whose building block was a compound resembling coniferyl alcohol.

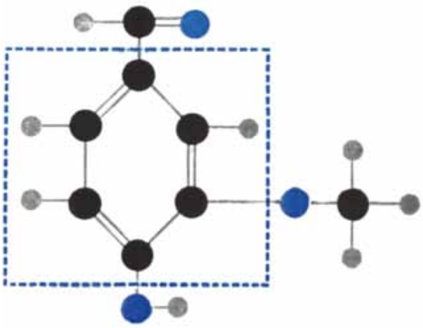
Subsequent researches have confirmed Klason's deduction. Lignin can be oxidized to vanillin, a flavoring agent whose molecule contains the benzene ring with the hydroxyl and the methoxyl groups in the positions which Klason had suggested for lignin. (Synthetic vanilla flavoring, incidentally, is one of the few useful products now made from lignin.) When lignin is hydrogenated, on the other hand, the chain of three carbon atoms mentioned earlier appears in the resulting compound attached to a ring which, unlike the benzene ring, is "saturated" with hydrogen.

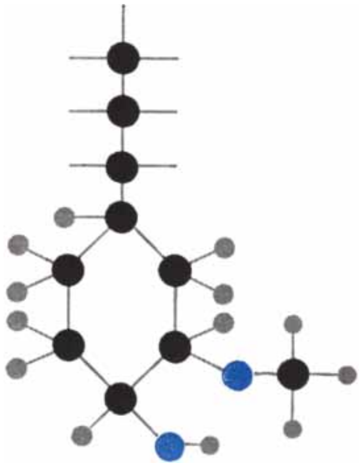
The problem of isolating pure lignin remained unsolved until 1939, when Friedrich E. Brauns, then at the Institute of Paper Chemistry in Appleton, Wis., reported that he had extracted pure "native lignin" from pulverized spruce wood with alcohol at room temperature. This substance was a dry, tan powder, unlike previous lignin preparations, which were dark brown and frequently gummy. But Brauns had managed to extract only 3 per cent of the wood's lignin content. This suggested that perhaps his native lignin was not really lignin but some closely related substance which happened to be soluble in alcohol.

The only way to dispel the doubt was to find some method of getting at the 97 per cent of the lignin which remained inaccessible. Some years ago it occurred to us that nature herself had devised a most effective method for separating lignin from cellulose, namely, the fungi which cause wood to decay. One group of these organisms, the "brown rot" fungi, feeds on cellulose but leaves the lignin alone. (Another, the "white rot" fungi, feeds on lignin, leaving the cellulose more or less intact.) Perhaps the brown rot fungi could help to solve the problem of isolating lignin in its original state! Perhaps we could also learn from them some of the precise enzyme chemistry by which they promote all sorts of delicate chemical reactions, only a few of which we can duplicate in the laboratory.

We ground and sterilized batches of Scots pine and fir wood, inoculated them with several species of brown rot fungi, and left them to rot. Periodic analyses showed the proportion of cellulose diminishing, and that of lignin increasing. Moreover, the lignin was becoming more and more accessible, for the percentage we were able to extract with alcohol rose steadily as the months went by. In one case, after 15 months we were able to extract more than 25 per cent of the lignin content, as compared to Brauns's 3 per cent. Had we been willing to let the fungi continue their slow work for several years we could doubtless have extracted all the lignin. But we were impatient to examine this enzymically liberated lignin and compare it with the native lignin which Brauns had described.

An exhaustive series of tests–involving solubility, color reactions with various reagents, the analysis of elemental composition, ultraviolet and infrared absorption spectra–showed no significant differences between the two types of lignin. As a check, we repeated the experiments, this time using wood from

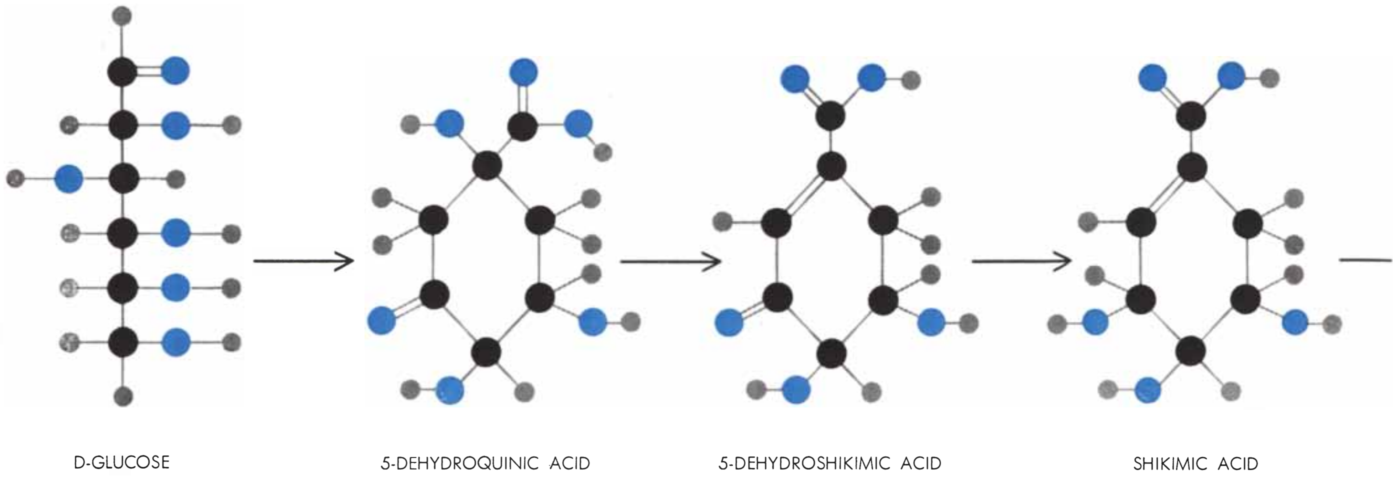




which all the "native lignin" had previously been extracted by Brauns's method. The results were the same. We put hardwoods (including oak, birch and maple) and bagasse (the woody residue of sugar cane from which the juice has been pressed) through the same process and obtained further confirmation of the identity of "native" and enzymically liberated lignin.

These experiments revealed a new and interesting fact: Lignin varies from one species to another, showing small but consistent differences in the proportions of carbon, hydrogen and oxygen which it contains. As one might expect, lignins from closely related plant species are more alike than those from more divergent types. Softwood lignins form one group, hardwood lignins another, and lignins from woody annual plants (such as sugar cane) a third.

Studies of the breakdown products of these different lignins reveal the cause of their diversity. Each is built up, it seems, from monomers of slightly different types in different combinations. The lignin monomer that yields vanillin has precisely the structure which Klason suggested; of the other two known types,

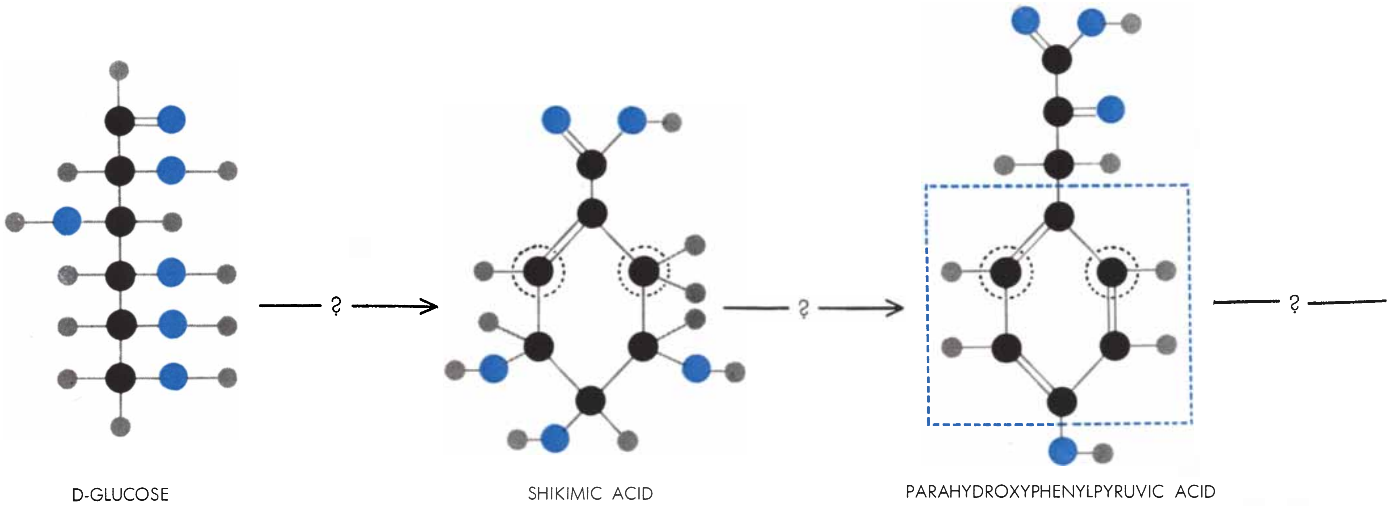


SYNTHESIS OF AROMATIC COMPOUNDS by bacteria occurs in a series of steps, some of which are shown here. The linear molecule of glucose (the fundamental product of photosynthesis) is first converted to a cyclic compound and then, through several inter-

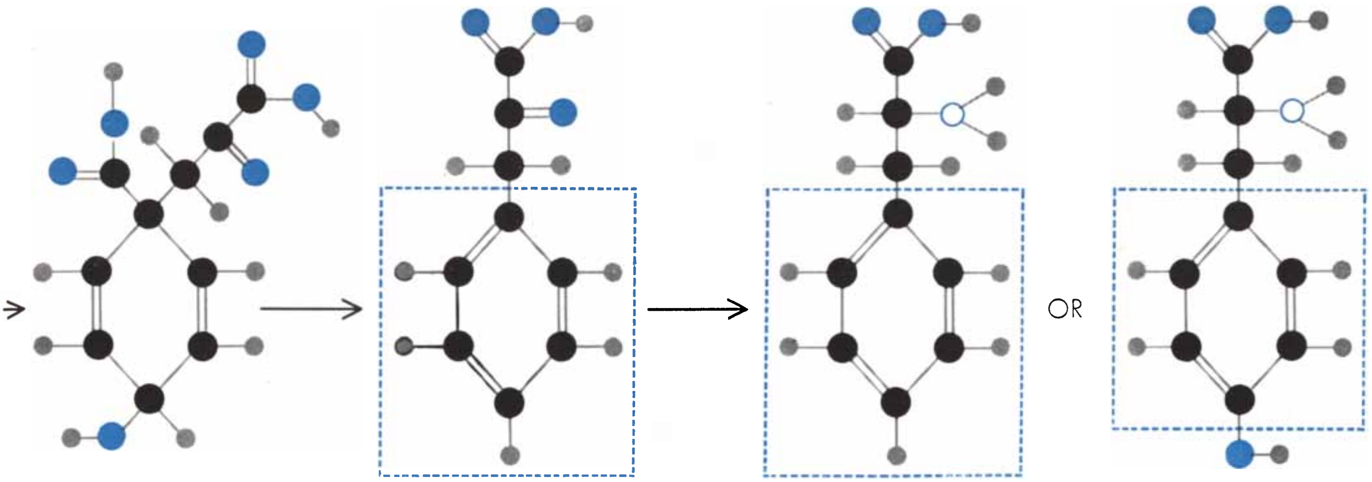
one lacks the methoxyl group and the other has two methoxyl groups. The vanillyl monomer ocurs in all the lignins we have studied, along with smaller amounts of one (or both) of the other two. The differences between lignins, then, are due to their construction from somewhat different monomers in varying proportions.

Properly speaking, the term lignin refers not to a single compound but to a group of closely related compounds. In this respect lignin may be likened to the polysaccharide family, the members of which are made up of chains of simple sugar monomers and include such diverse substances as starch and cellulose. The lignins are more complex than the polysaccharides, which are generally composed of a single type of monomer. They are much less complex, however, than the proteins, which are chains of many different amino acids; for example, insulin, one of the simplest proteins, contains 17 of the 20-odd amino acids.

So far we know very little about how the monomers of lignin are linked together to form lignin polymers. By way of illustrating the difficulties involved, let us consider the simpler case of the polymerization of glucose. Two molecules of glucose can join together (with the loss of a molecule of water) to form cellobiose, a substance which we may call the secondary building block of cellulose. If, however, one of these two identical glucose molecules is first turned through 180 degrees, the two form not cellobiose but maltose, the secondary building unit of starch. Thus the same monomer can give rise to two distinct substances. The monomers of lignin, however, are of two or three different types, and there is reason to believe that the secondary building blocks of lignin contain at least four monomers. Clearly



SYNTHESIS OF LIGNIN MONOMERS by plants resembles the bacterial synthesis shown at top of these two pages, but many more steps remain to be worked out. Broken circles show the atoms of radioactive carbon which trace the conversion of intermediate



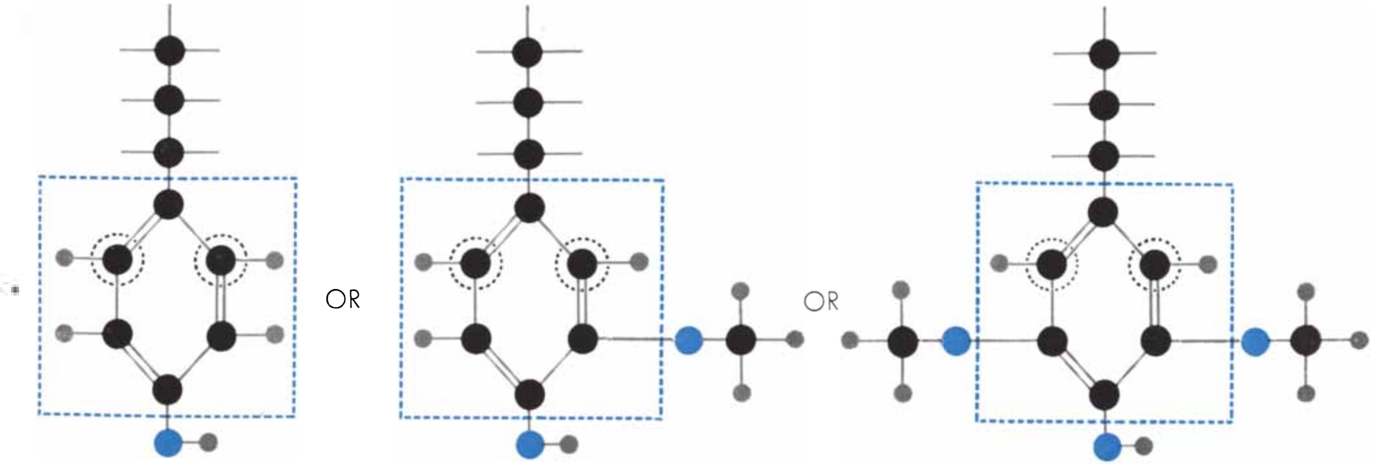
PREPHENIC ACID   PHENYLPYRUVIC ACID   PHENYLALANINE   TYROSINE

mediate substances, into the aromatic compound phenylpyruvic acid. This substance is thought to be the precursor of the aromatic amino acids phenylalanine and tyrosine, two of the 20-odd molecular units which make up the long-chain molecules of proteins.

the polymers of lignin may assume many different forms, corresponding to the lignins of different species.

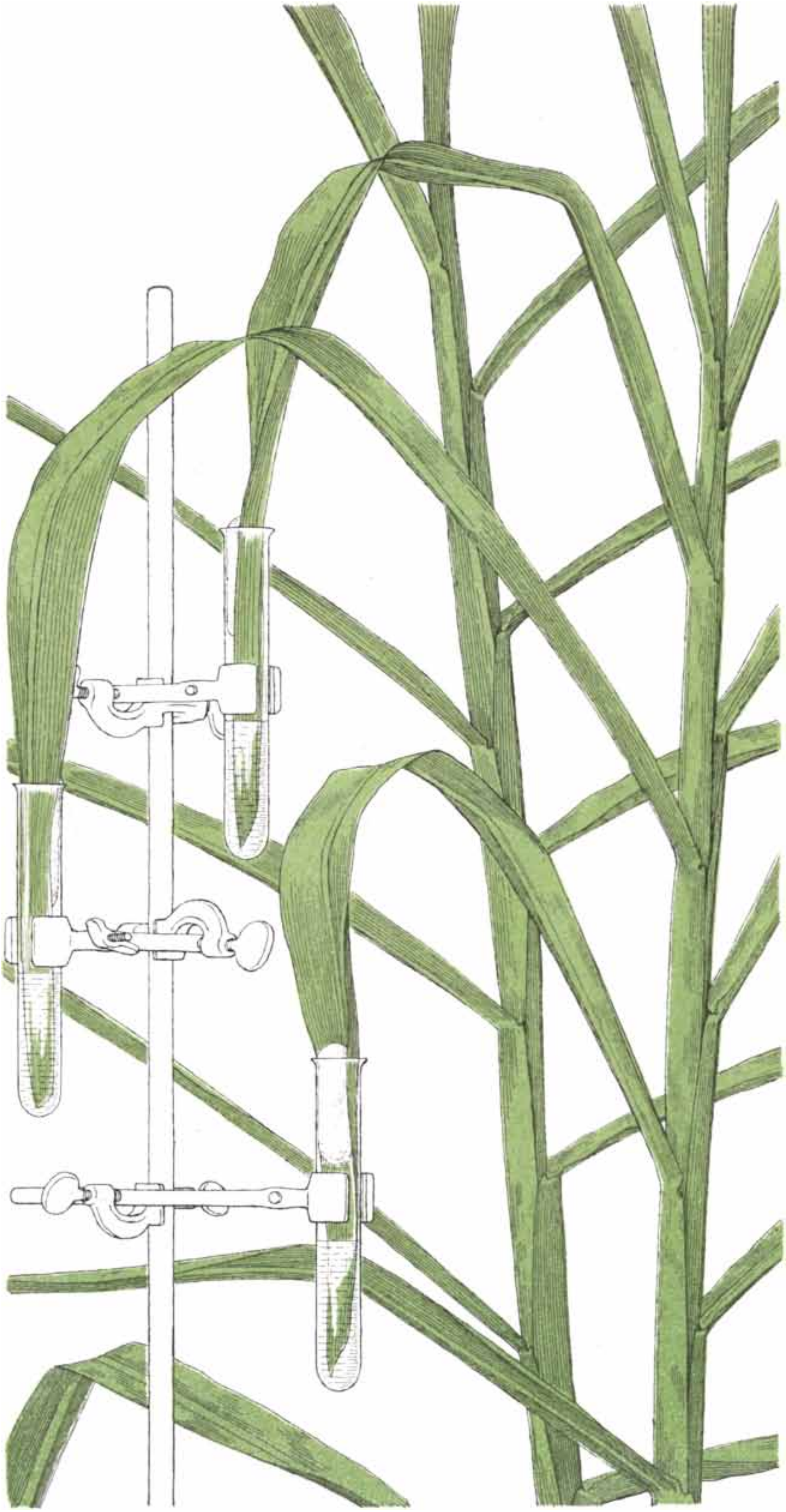
The properties of a polymer, moreover, may derive not only from the structure of its monomers and secondary building blocks but also from the way these secondary blocks are joined together to make the polymer. Starch (to return to our polysaccharide example) actually consists of two different structural species: amylose, in which the maltose groups are joined together in straight chains like those of cellulose; and amylopectin, in which they form branching chains. An even more complex branching structure is involved in glycogen, a carbohydrate which serves as an energy reserve in the liver and muscles of animals. At present we are not sure whether the secondary building blocks of lignin are linked together in straight chains, branching chains or in some other way to form the giant molecules of lignin. An answer to this question could explain lignin's remarkable stiffening and protective qualities.

Biochemists have long speculated on how plants produce lignin. The over-all nature of the process is clear enough. A growing plant first builds the framework of its structure out of cellulose. In woody plants, however, the spaces between the cellulose fibers are later filled in with lignin, or perhaps some of the cellulose is converted into lignin. But how do plants synthesize the aromatic benzene ring around which lignin is built? The first products of photosynthesis are chains of carbon atoms—the glucose monomers. These may be looped into rings by processes which are reasonably well understood. But we do not know the next steps in the process that converts these "cyclic" compounds to aromatics. Laboratory processes that accomplish this are difficult and inefficient. Plants, however, synthesize aromatics



LIGNIN MONOMER   LIGNIN MONOMER   LIGNIN MONOMER

compounds into lignin with no rearrangement of the six "ring" carbon atoms. The vanillyl type of lignin monomer (*second from right*) seems to occur in all kinds of lignin; the other two types are found in varying quantities in lignins from different plant species.



SUGAR-CANE PLANTS were used to work out the synthesis of lignin shown on the preceding two pages. Fed on labeled intermediate compounds, they produced radioactive lignin.

(principally lignin) by the ton as part of their normal metabolism.

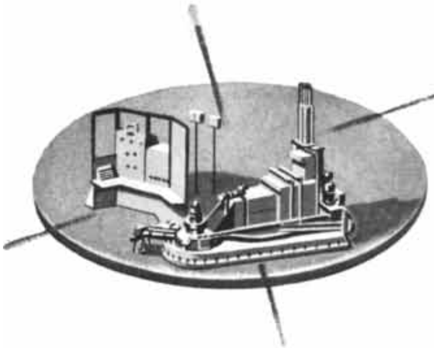
The first real clue to how plants synthesize lignin arose from studies of the proteins. Several of the amino-acid protein monomers contain benzene rings. Investigators recently turned up two mutant strains of bacteria which can synthesize two of these aromatic amino acids (phenylalanine and tyrosine) from glucose. Bernard D. Davis, now at Harvard University, traced some steps of the synthesis [*see illustration at top of preceding two pages*]. The organisms first convert the linear molecule of glucose into a cyclic (but not aromatic) compound and then, via several transformations, into the aromatic compound phenylpyruvic acid. This substance seems to be the immediate precursor of the amino acids.

Now these amino acids resemble the lignin monomers in having a chain of three carbon atoms attached to a benzene ring. It seemed likely to us that the process by which plants synthesize lignin might resemble the bacterial synthesis of the aromatic amino acids. Accordingly we labeled some samples of shikimic acid (an intermediate compound in the bacterial synthesis) with the radioactive isotope carbon 14. Shikimic acid is not aromatic, but it does contain a ring of six carbon atoms; we labeled two of them.

We force-fed the labeled acid via the leaves to sugar-cane plants. After several days of this feeding we cut down the plants, extracted the lignin and converted it into vanillin. Not only did we find the vanillin radioactive, but we also determined that the labeled carbon atoms occupied precisely the two positions in the vanillin molecule that correspond to the positions labeled in the shikimic acid. Clearly the sugar cane had converted the nonaromatic ring of shikimic acid into the aromatic ring of lignin.

By similar experiments we were able to identify another compound involved in the lignin synthesis—parahydroxyphenylpyruvic acid. This formidably named aromatic substance may be the immediate precursor of the lignin monomers. At any rate, it is closer to them than is the nonaromatic shikimic acid. The other steps in the synthesis remain to be mapped out.

A final answer to the question of how plants make lignin will not be given until we know the complete structure of lignin. We can obtain the original, pure lignin polymer, and we know that it consists of two or more different monomers,



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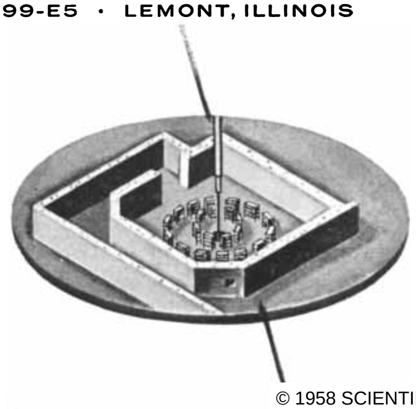

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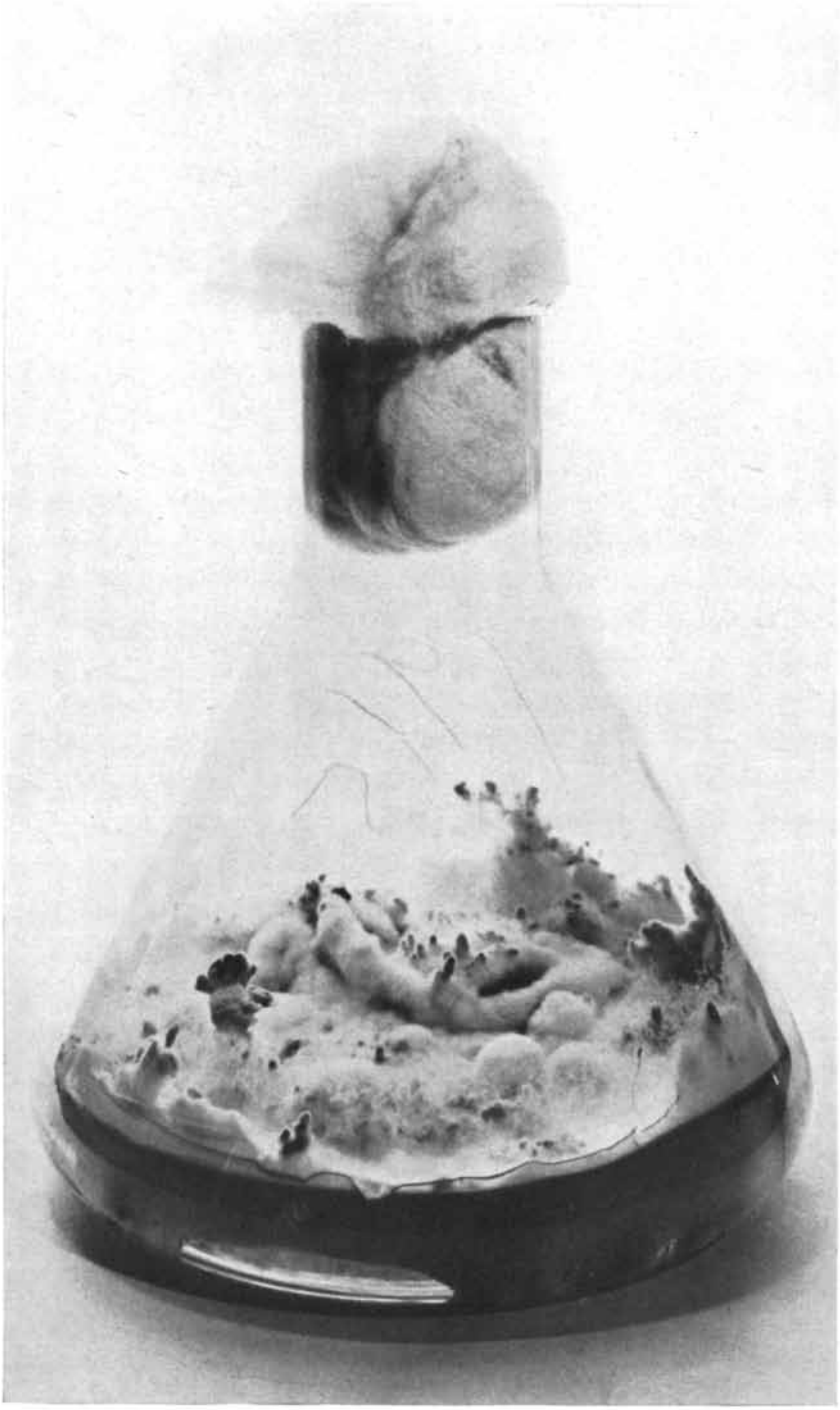
but we still do not know the precise structure of these monomers. So tightly are they bound together in the lignin molecule that we cannot tear them apart without damaging them. But here too enzymes may succeed where more violent chemical methods fail. Some microorganism may be able to break lignin into its component monomers as delicately and precisely as the brown rot fungi can separate it from cellulose. The discovery of an enzyme which can depolymerize lignin would bring us still closer to unlocking the final secret of this mysterious and potentially valuable substance.



"BROWN ROT" FUNGI, a culture of which is shown here, can eat away the cellulose and related substances in wood, leaving pure "enzymically liberated" lignin. The giant molecules of lignin and cellulose are so tangled in wood that commercial methods for separating them depend on breaking up lignin molecules and converting them into simpler compounds.

BOG near Bethany, Conn., is represented by the large dark patch in this aerial photograph. The area, once a lake, now has only one pool of open water (*tiny dark spot near center of bog*). Evergreen trees such as spruce and cedar grow around periphery of the bog.

BOGS

When a lake is filled with silt and organic debris, it gives way to a unique system of living things and their remains. These wet spots on the land may have a significant effect on world climate

by Edward S. Deevey, Jr.

Matthew Arnold could never have expressed his feeling for Dover Beach with such words as: "The heath is calm tonight,/ The swamp is full, the moon lies fair/ Upon the peat." For the poetic geographer a bog is Gothic when it is not downright menacing, a "ghoul-haunted woodland" or a trysting place for witches. Myths of bogland are very old, and may be based on a well-founded dread of savage woodsmen; Western civilization, originating near the Mediterranean shores, has fought the forest and its denizens at every step, and has successively driven the Goth, the Pict, the Caledonian and the Seminole into dank morasses of oblivion. Today the connection between Picts and pixies, bogs and bogeys is generally forgotten. By odd coincidence, however, the bog itself offers a historical record of changing landscape and climate that leads back into those murky mists of memory. Close study suggests also that the boglands of the Northern Hemisphere may be cast to play an ominous role in changes of the earth's climate that are yet to come.

The true bog must be distinguished from the reedy marsh. Marshes form near salt water and contain mainly grasses; few trees other than mangroves can stand much salt around their roots. Bogs are found in the drier interiors of continents as well as near the ocean, but they require some rainfall—deserts have few bogs. If the rainfall is great enough and the summers are cool enough for trees to grow on the uplands of a region, bogs may be expected in the lowlands. Bogs in rainy areas may be more sodden than a tropical rain forest, but the rain water they soak up contains few salts and other nutrients. Only plants that partake sparingly of nutrients, like the shrubs and perennials of arctic barrens and cold steppes, can survive in a bog.

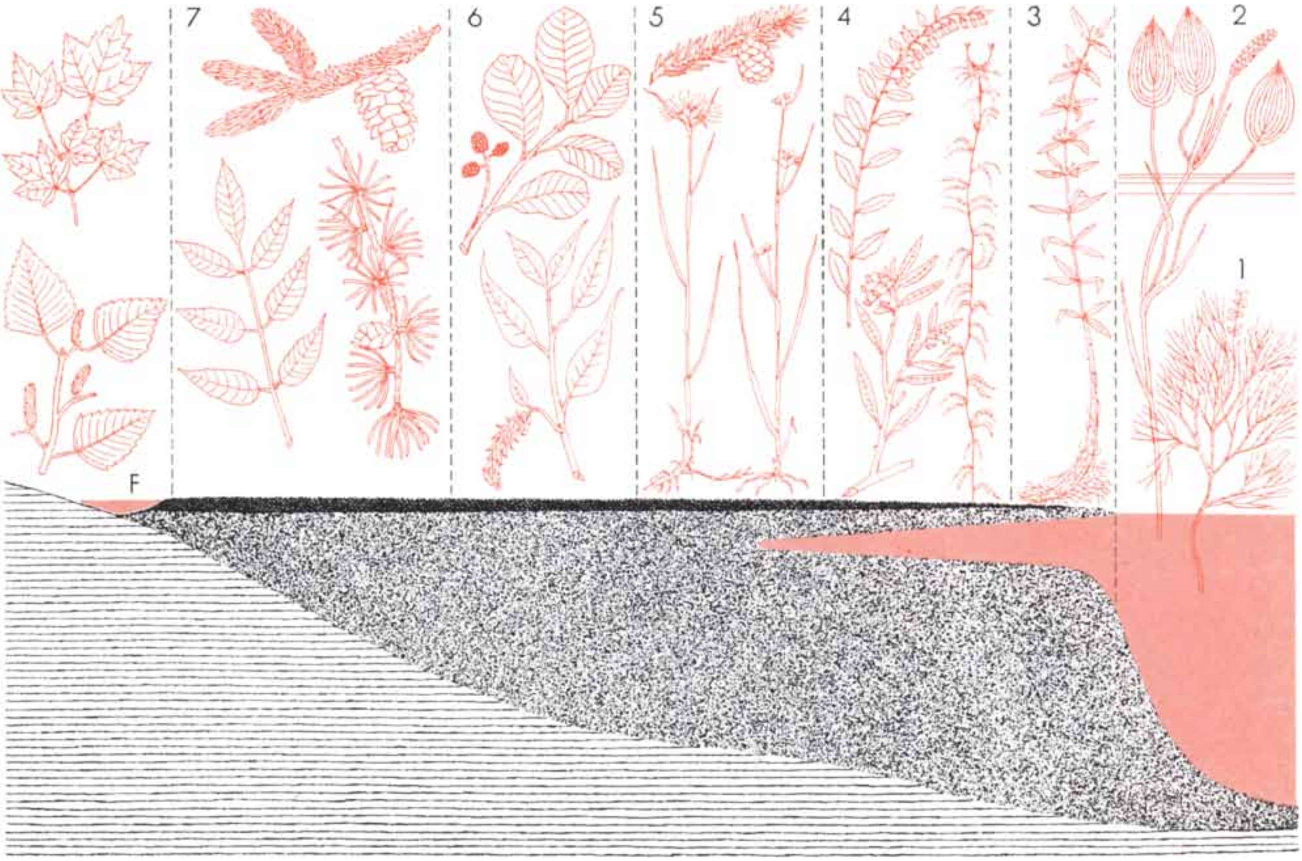
Upland and lowland are relative terms, and refer to the flow of water through the ground. Whenever a barrier lies athwart the flow, water is interrupted in its steady descent to the sea and may rise above the surface of the ground behind the dam. So lowlands can occur near the tops of hills. A lake of clear water formed in this way will not last long. An entering stream dumps silt into the lake, and plants growing along the water's edge add their debris. More organic material may be deposited by runoff from land above the lake, especially from swampy flats. Eventually the lake is obliterated and the mud becomes

PLANT ZONES are clearly visible in this photograph of a bog outside Bemidji, Minn. The kinds of plants found in such zones are shown in detail in the illustration on next page.

firm enough to support shrubs and then trees. Pools left in the center of the lake may be bridged by plants like the sedge or swamp loosestrife. With their aid other plants form a floating mat on which trees can grow while the water below is yet unfilled. Most bogs are probably made in this way.

The raised bog (the German *Hochmoor*) does not have to start in a lake but can form in any wet meadow. It depends on the presence of sphagnum, commonly known as peat moss. When dry, this remarkable substance resembles a sponge in its ability to take up great quantities of water by capillary action. It holds more water than absorbent cotton and so is useful as a plant mulch or even as a surgical dressing. The accumulation of dead sphagnum in a meadow forms a layer of half-decayed material, or peat, which draws ground water upward, thus permitting still more of the moss to grow on top. Where sphagnum grows in large masses, it actually raises the water table. When thoroughly wet, however, peat is as impervious to more water as dry rock. Rainwater then cannot percolate downward and runs off horizontally. The extra water eventually reaches the edge of the dome-shaped mass of sphagnum, where the peat is thinner. Thus watered at its margins, the bog grows upward and outward, and can even grow uphill. Plants other than sphagnum grow on the surface, and their remains are added to the peat. So long as the bog is growing, this debris, being water-soaked, accumulates almost unchanged. Eventually the bog reaches a size at which evaporation from the surface balances the rainfall and upward flow of ground water, and growth on the bog halts. Plant debris on the surface then decays about as fast as it accumulates, and little or no new peat forms. Material below the outer skin of the bog does not decay because oxygen cannot reach it, and plant remains—even corpses of men—do not decompose for centuries. Heather or other shrubs of the same family may grow on the stabilized surface, but few trees are to be seen. A growth of forest on a raised bog probably implies a recent change toward a drier climate.

All bogs are stores of peat with sluggish circulation. The water at the surface is poor in salts and bases, partly because much of it is rain water, and partly also because the peat absorbs dissolved matter like a chemist's Amberlite resin. In most boggy districts there is a third reason: The local rock is usually granite, which contributes almost no minerals to the ground water flowing through it. The result is that bog plants are starved for lime, phosphorus and nitrogen. The deeper the peat, the more this is true. In consequence bogs are enclaves of subarctic life; they abound in plants like black spruce, cotton grass and Labrador tea. The bogs of Cape Cod support cranberries; those of New Jersey, blueberries. Both these plants are heaths of northern lands. Even subarctic animals like the bog lemming and the olive-



ECOLOGICAL ZONES mark the conversion of a lake to a bog, both in space and in time. Pondweed (1) grows in deeper water; pondweeds with floating leaves (2), in shallows. Loosestrife (3) invades the water by means of a creeping stem and gradually forms a floating mat which permits the spread of leatherleaf, bog rosemary and sphagnum (4, *left to right*). Where the fill is drier (5) black spruce, cottongrass and sedge prosper; they are followed by tall shrubs such as smooth alder and shining willow (6, *top and bottom*). At the edge of the bog is a forest of red spruce, mountain ash or larch (7). A shallow ditch or "fossa" of water (F) marks the original shoreline, and separates the bog forest from dry-land trees such as red maple (*top*) and white birch (*bottom*).

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58	CeO_2. CERIC OXIDE	215 216	99.8 99.9	0.2 (largely La + Pr + Nd). 0.1 (largely La + Pr + Nd).
59	Pr_6O_{11}. PRASEODYMIUM OXIDE	726 729.9	99 99.9	1 La + Nd + smaller amounts of Ce and Sm. 0.1 Ce + Nd.
60	Nd_2O_3. NEODYMIUM OXIDE	628 629 629.9	95 99 99.9	1-4 Pr, 1-4 Sm, 0.5-1 others. 0.1-0.4 Pr + 0.1-0.4 Sm + 0.5 others. 0.1 (largely Pr + Sm).
62	Sm_2O_3. SAMARIUM OXIDE	822 823	99 99.9	0.2-0.7 Gd, 0.2-0.6 Eu, and smaller amounts of others. 0.1 (largely Nd + Gd + Eu).
63	Eu_2O_3. EUROPIUM OXIDE	1012 1011	98-99 99.8	1-2 Sm + smaller amounts of Nd + Gd + others. 0.2 (largely Sm + Gd + Nd).
64	Gd_2O_3. GADOLINIUM OXIDE	928.9 929.9	99 99.9	1 Sm + Eu + trace Tb. 0.1 Sm + Eu + trace Tb.
65	Tb_4O_7. TERBIUM OXIDE	1803 1805	99 99.9	1 Gd + Dy + Y. 0.1 Gd + Dy + Y.
66	Dy_2O_3. DYSPROSIUM OXIDE	1703 1705	99 99.9	1 (largely Ho + Y + Tb + small amounts of others). 0.1 Ho + Y + traces of others.
67	Ho_2O_3. HOLMIUM OXIDE	1603 1605	99 99.9	1 (largely Er + Dy + small amounts of others). 0.1 Er + Dy + traces of others.
68	Er_2O_3. ERBIUM OXIDE	1303 1305	99 99.9	1 Ho + Dy + traces Yb and Y. 0.1 Ho + Tm.
69	Tm_2O_3. THULIUM OXIDE	1405 1403	99.9 99	0.1 Er + Yb + trace Lu. 1 Er + Yb + trace Lu
70	Yb_2O_3. YTTERBIUM OXIDE	1201 1202	99 99.9	1 Er + Tm + trace Lu. 0.1 Tm + trace Lu + Er.
71	Lu_2O_3. LUTETIUM OXIDE	1503 1505	99 99.9	1 Yb + Tm + traces of others. 0.1 Yb + Tm + traces of others.
39	Y_2O_3. YTTRIUM OXIDE	1112 1115 1116	99 99.9 99.9+	1 Dy + Gd + traces Tb and others. 0.1 Dy + Gd + traces Tb Approx. 0.05 Dy + Gd.

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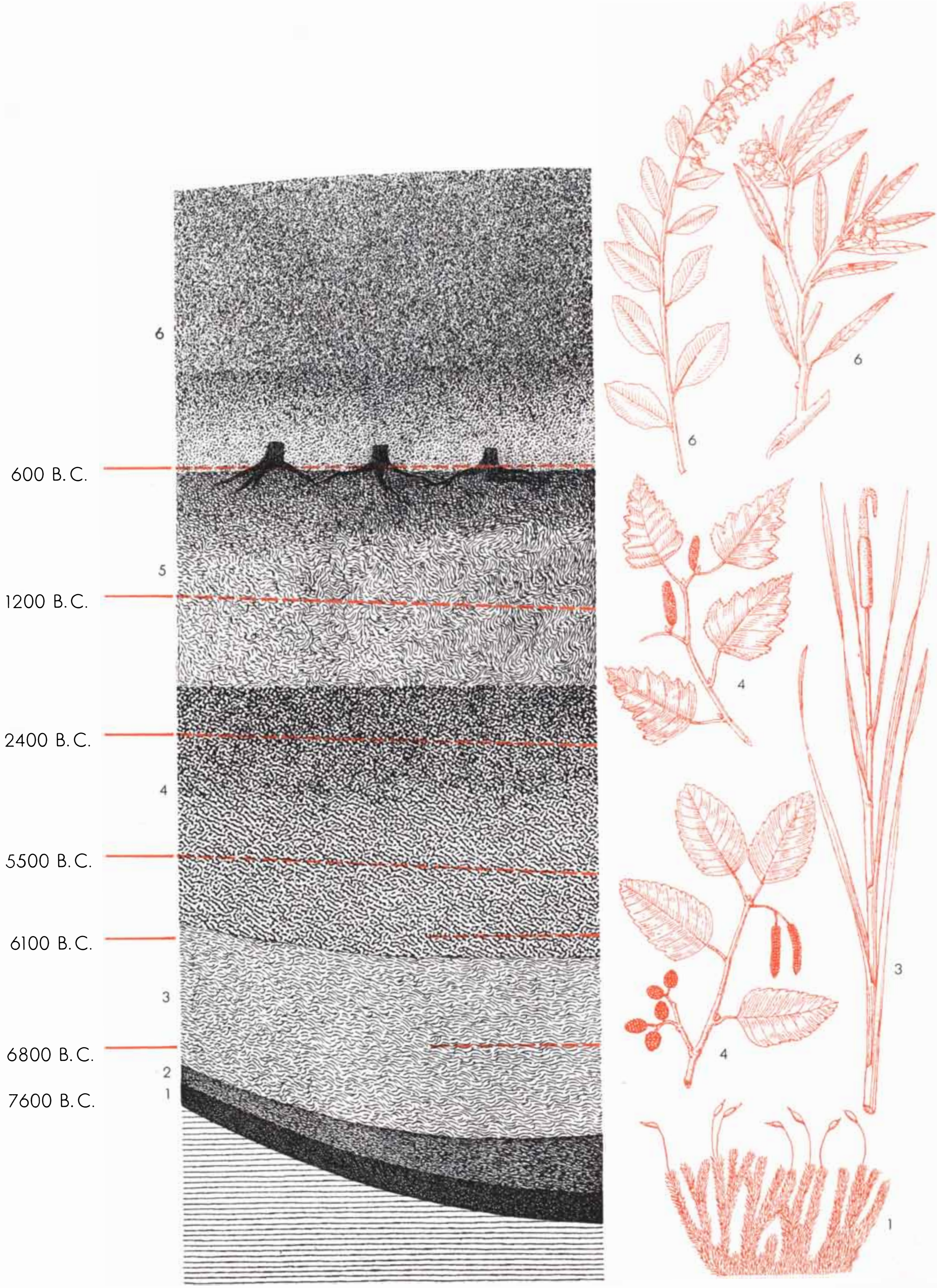
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backed thrush may be found far south of their regular ranges, giving bogs in temperate regions a northern flavor. In a sense they were left behind as the last continental ice sheet retreated northward, taking with it the belts of tundra and taiga (spruce forest) that lay beyond its margin when it covered the present locations of New York and Chicago. Probably no area has been continuously boggy since those days, but any partly closed-in bog in the northern U. S. can be thought of, from a lemming's point of view, as tundra enclosed by taiga.

Amid the plants of the muskeg, however, are others reminiscent of the tropics. Sogginess and nitrogen deficiency are common to rain forests as well as to bogs. So a few of the hardier orchids have ventured northward to meet the Labrador tea. Insectivorous plants, mainly tropical, are also successful in bogs, since their unorthodox behavior solves the problem of nitrogen deficiency; sundews, butterwort and pitcher plants grow in bogs. The pitcher plants, in fact, go north almost to the arctic tree-line, and their rain-filled leaves serve not only as traps for unwary insects but, being enriched in nitrogen and phosphorus, form an aquatic habitat for the larvae of other insects (particularly those of midges, blowflies and mosquitoes) which can withstand the digestive enzymes in the leaves. The pitcher plant mosquito (*Wyeomyia smithii*) has followed its host northward.

Although cool, cloudy summers are essential for the existence of a raised bog, a few hot days will not destroy it, but will merely dry out its surface. A bog can then be crossed dry-shod. In damp or cooler weather it squishes underfoot like the arctic muskeg. A change in temperature or rainfall over a long period of time, however, upsets the stability of a bog. Raised bogs especially are sensitive indicators of climate. If the climate becomes moister or cooler, the bogs renew their growth both upward and outward. In drier or warmer conditions the surface will stabilize, but air will penetrate deeper into the drying peat and the zone of decay will thicken downward. If the drought is long-continued, the peat will be deeply weathered, the decay zone extending even into the older peat, and the bog will dwindle away in the sun like an ice cube.

Sensitive indicators of weather are nowhere hard to find. In tune with the variable march of the seasons, some insects emerge, some birds arrive or depart, some flowers bloom. The term of such an indicator, however, is short. Bogs exist for such long periods and respond to weather so slowly that they integrate weather into climate. Best of all, they also record it. When we cut into a bog for fuel and garden mulch, it resembles a cake of three, four, five or more layers, each marking a change in climate. At each boundary the dark, well-oxidized peat which formed, or rather weathered, when that layer was at the surface is topped by a brighter, fresher (and less combustible) peat representing renewed growth.

The episodes of rejuvenation indicated by the layers in any one bog may not mean anything important. The local water table could rise and fall for many reasons. But when all the bogs for miles around have layers formed at the same time, the implication can only be that the climate has changed repeatedly. Bright-colored layers composed of raw sphagnum peat, rich in the remains of such water plants as cotton grass, record a stage of flooding which lasted for years: the climate was cooler, and rainfall was more effective. Dark-colored, humus-rich peat—poor in recognizable fossils because of oxidation, but sometimes containing the remains of heather, birch, or alder—records a stage of stability or destruction during a run of drier, warmer summers.

This matchless record of past climates needs only a time scale to be read with assurance. The climatic chronology determined by the pollen method—according to ratios of fossilized pollen grains from different plants—is relatively coarse [see "Living Records of the Ice Age," by Edward S. Deevey, Jr.; SCIENTIFIC AMERICAN, May, 1949]. Pollen is plenti-

HISTORY OF A RAISED BOG is recorded in the layers of peat (*left*), dated by pollen and radiocarbon content. This section is taken from left center of the bog diagrammed on next page. The oldest layers contain the remains of forest mosses (1), followed by diatoms (2) that once grew in a nutrient-poor pond. Between 6800 B.C. and 6100 B.C. the pond was dry enough to permit the growth of cattails, cotton grass and sedge (3, *left to right*), and on their remains grew birch (4, *upper*) and alder (4, *lower*). The fifth layer, formed during a moist period, is rich in moss such as *Sphagnum cuspidatum* (5). The tree stumps overlying this layer mark a cold, dry period about 600 B.C. When the climate again grew cooler and moister, bog plants returned; leatherleaf, bog rosemary, butterwort and *Sphagnum rubellum* (6, *left to right*) may be represented in the layer of peat at top of bog.

ful in the peat, but a pollen period is thousands of years long, covering the span of two or three bog layers. Nevertheless one point of equivalence with the pollen chronology became obvious early in the science of bogs. Before 1916, when the pollen method was founded by the great Swedish geologist Lennart von Post, C. A. Weber had noticed that one of the episodes of bog rejuvenation in northern Germany was especially well-marked and widespread. Von Post soon realized that Weber's *Grenzhorizont* coincided with the beginning of his own last pollen period, the "sub-Atlantic climatic deterioration" when northern countries such as Germany and Sweden became cold and rainy. Refinements such as radiocarbon dating confirm von Post's deduction that Europe's climate took a turn for the worse about 600 B.C. The upland vegetation responded to the new conditions slowly—some plants thriving, others dying out—and the pollen count reflects this. But the bogs record a finer embroidery of moisture changes superimposed on the longer swings of temperature.

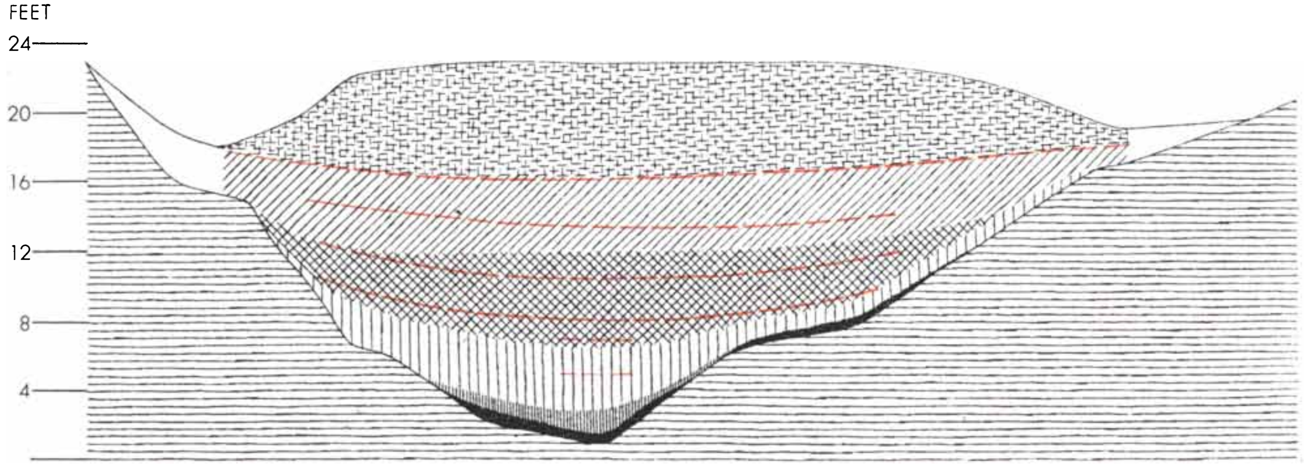
Human history has not been unrelated to these events. The decline of Greece and the rise of Rome clearly correlate with climatic change shortly after 600 B.C. The climate was somewhat better when Rome's power was at its height, but Rome's conquest of Britain was given up, in part for climatic reasons, at the time of another change, about 400 A.D. As Gibbon put it, "The masters of the fairest and most wealthy climates on the globe turned with contempt . . . from the cold and lonely heaths over which the deer of the forest were chased by a troop of naked barbarians." Since that time, or at most since 600 B.C., the extraordinary blanket-bog has crept like a glacier down the slopes of the Irish and Scottish mountains, and down the Pennines in England, overwhelming pine forests and cropland alike. Today the British Isles are very different from the sunny, forested land the Neolithic farmers knew in the third millennium B.C. Already in the Middle Bronze Age (about 1200 B.C.) the bogs were getting out of hand. Wooden tracks were laid over the increasingly squishy countryside, in an effort to keep trade routes open. Such tracks, datable by pollen, by artifacts and by radiocarbon, often turn up when British bogs are dug.

Most of Europe's forests were cut down long ago. Peat is not so good a fuel as wood, but it will burn, and the heat can be used for distilling. Fortified with peat-smoke-flavored alcohol, a man can tolerate the sight of a treeless landscape and can even come to prefer a heath to a forest. The raised bogs have been drained and dug extensively in Ireland, Scotland, Denmark, western Scandinavia, northern Germany, and to a smaller extent in Maine and New Brunswick, where wood is more plentiful. As a fuel resource the peat bogs of the world are not to be despised. George Kazakov, a Russian peat expert now living in this country, computes that there are 223 billion dry tons of peat available on earth, more than half of it in the U.S.S.R.

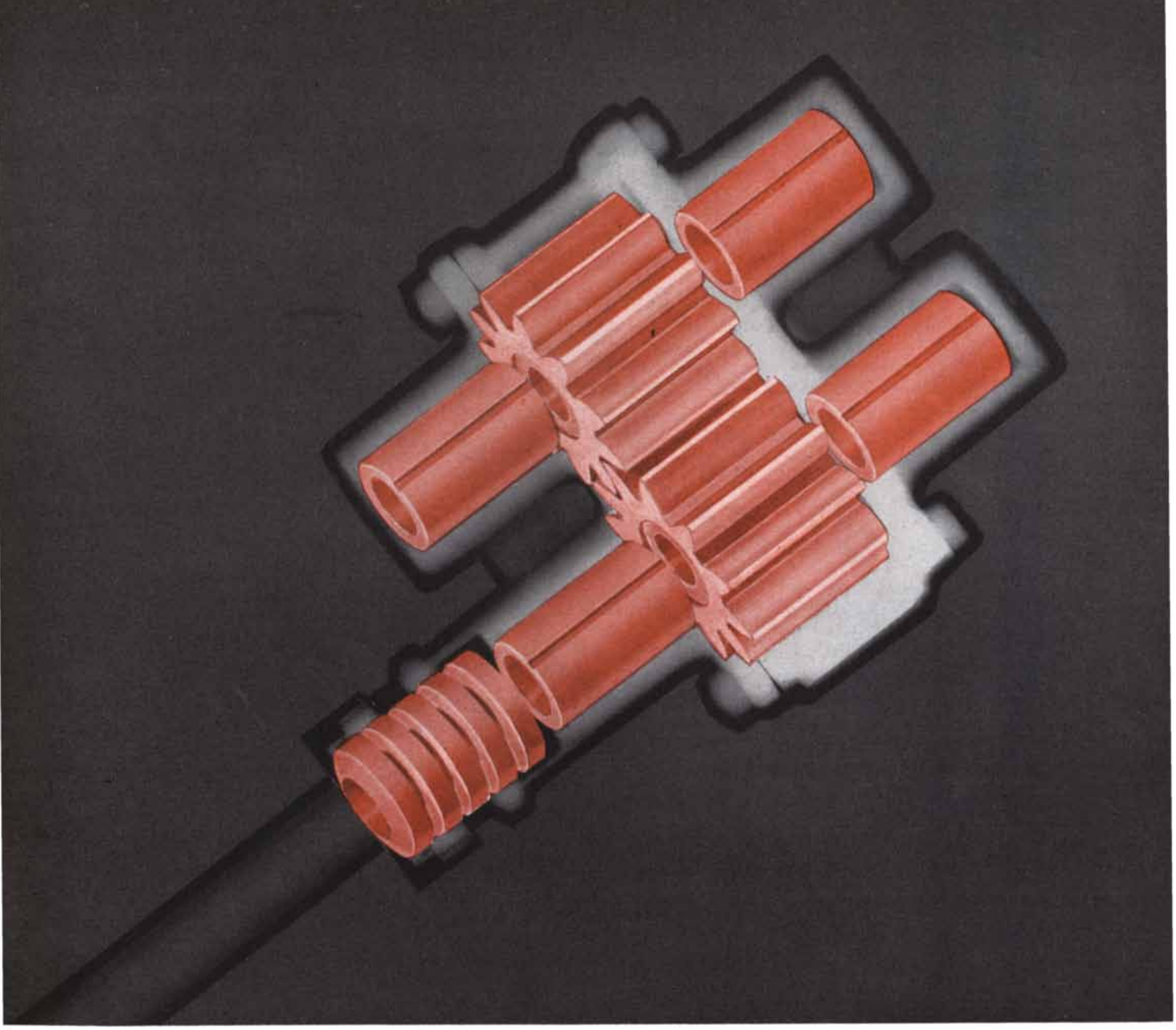
So large a supply of combustible carbohydrate, delicately poised between growth and destruction, can seriously affect the earth's carbon balance. The carbon-dioxide content of air has increased by 11 per cent since about 1870 and apparently is still increasing. Radiocarbon assays by Hans Suess, now of the Scripps Institution of Oceanography, prove that most of the added carbon dioxide is compounded of modern carbon. It is much too young, judging by its high radiocarbon content, to have all come from the burning of fossil fuels by industry. Fossil fuels can account for only a small portion of the increase. The rest of the new carbon dioxide must be modern, and a finger of suspicion points to bogs as the source.

The warming of the world's climate since the last century may well have set a slow fire to the peat, simply by favoring surface oxidation by soil bacteria. If the world's climate should become so warm and dry that all the peat is oxidized, about 366 billion tons of carbon dioxide would be released. This is a sixth of the amount now present in the atmosphere, and the whole reserve of carbon in land plants and animals is only 15 times as much. The estimate does not include the carbon of humus in ordinary soils which would also be oxidized if the climate changed. So it is not impossible that the carbon dioxide added to the earth's atmosphere may have come mainly from peat and humus.

Though the changes of climate and of the amount of carbon dioxide have run parallel, we cannot yet be sure which is cause and which effect. Carbon dioxide added to air causes it to absorb more heat from the sun, and it may be that the climate has become warmer because of the extra 11 per cent of "dephlogisticated air." If so, we may be in for trouble. A doubling in the carbon



SECTION OF A RAISED BOG (the German *Hochmoor*) is diagrammed to show the depth of the various layers. The original ground level is indicated by the horizontally hatched area. The broken lines correspond to the dated levels in the diagram on the preceding two pages, where the layers are described in detail. The clear areas on either side are ditches of water around the bog.



Gears, bearings, packings of new pump are made of TFE-fluorocarbon resin. ("GearChem" pump by ECO Engineering Co., Newark, N. J.)

THE INSIDE STORY: pump for taming savage corrosives

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The robust *gears* of glass-filled TFE-resin cannot seize or spark. *Bearings* of TFE resins make the pump entirely "self-lubricating". Low-friction *packings* use the superb sealing properties of TFE resins to assure a leak-free shaft. The gears show no abrasive wear either on their mating areas or against the stainless-steel casing after long periods of operation.

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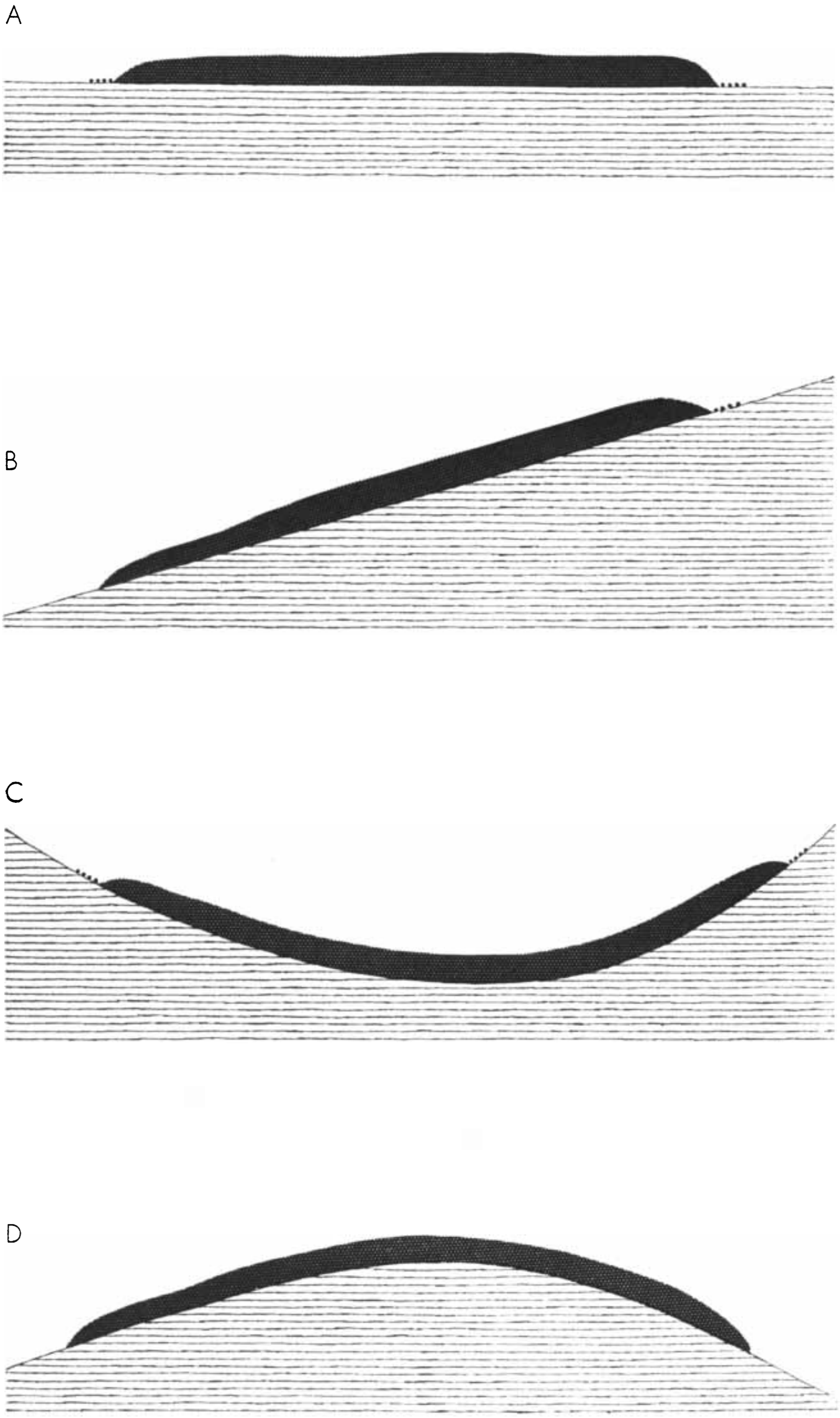
dioxide content of the air would almost certainly warm the climate enough to cause the glaciers to melt. The added water would raise the sea level perhaps by 100 feet, drowning the largest cities of the world. It may be that before such a calamity happens, a new balance will be struck; the carbon dioxide should be dissolved in the oceans, and it is a major mystery why the extra 11 per cent has not been dissolved already. But if the added carbon dioxide does not go into the oceans, New York and London will simply have to move, and the pixies too will need new haunts, for the bogs will be thin air.



CREEPING BOGS rich in sphagnum can spread on flat land (A), uphill (B), in valleys (C) and on hills (D). The rows of dots indicate the ditch of water which bounds most bogs.

WARHEAD

circa 400 A. D.

Centuries ago, the Indians of New Mexico designed and developed warheads like this one.

Today, we at Sandia Corporation do very much the same job—but we call it research and development in the ordnance phases of nuclear weapons for the Atomic Energy Commission.

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MATHEMATICAL GAMES

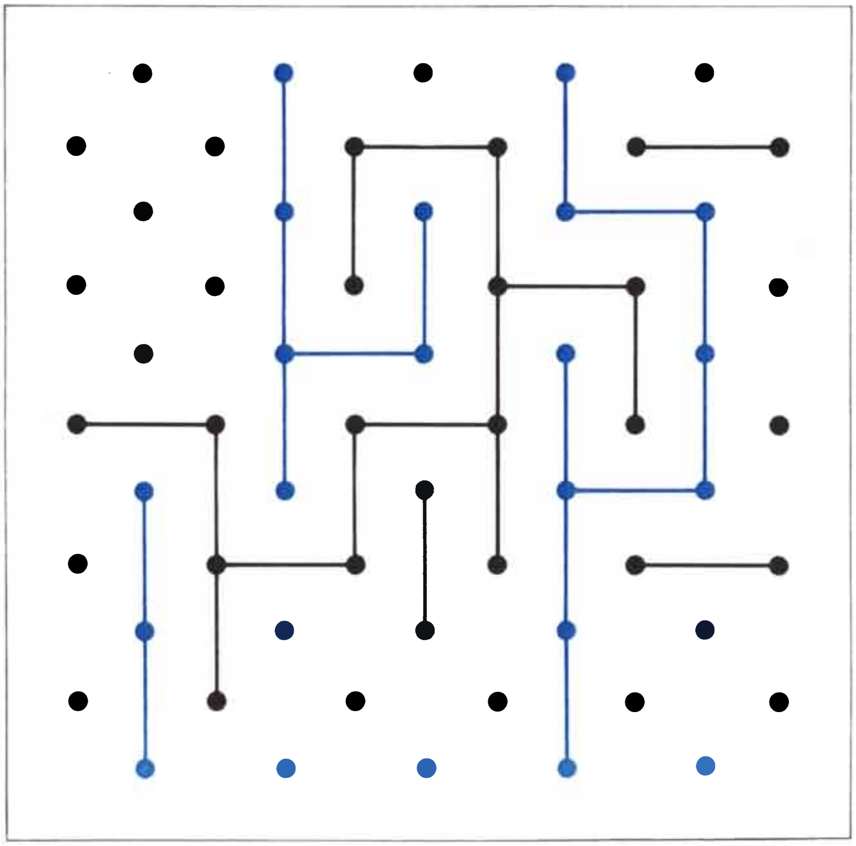
Four mathematical diversions involving concepts of topology

by Martin Gardner

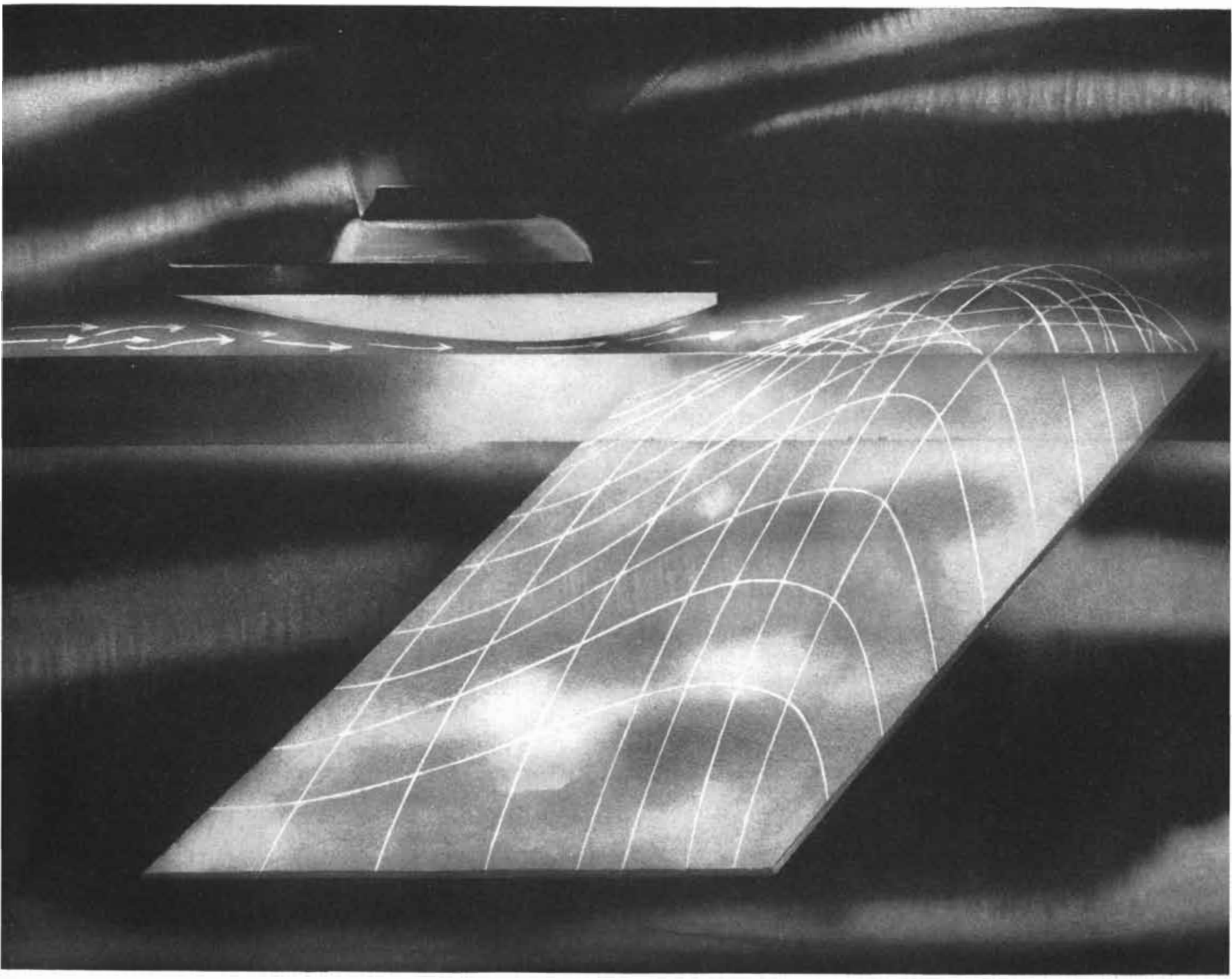
Topologists have been called mathematicians who do not know the difference between a cup of coffee and a doughnut. Because an object shaped like a coffee cup can theoretically be changed into one shaped like a doughnut by a process of continuous deformation, the two objects are topologically identical, and topology can be roughly defined as the study of properties invariant under such deformation. A wide variety of mathematical recreations (including conjuring tricks, puzzles and games) are closely tied to topological analysis. Topologists may consider them trivial, but for the rest of us they remain diverting.

A few years ago Stewart Judah, a Cincinnati magician, originated an unusual parlor trick in which a shoelace is wrapped securely around a pencil and a soda straw. When the ends of the shoelace are pulled, it appears to penetrate the pencil and cut the straw in half. The trick is disclosed here with Judah's permission.

Begin by pressing the soda straw flat and attaching one end of it, by means of a short rubber band, to the end of an unsharpened pencil [*1 in illustration on page 126*]. Bend the straw down and ask someone to hold the pencil with both hands so that the top of the pencil is tilted away from you at a 45-degree



The topological game of Gale



Air Bearing Design—Without Trial And Error

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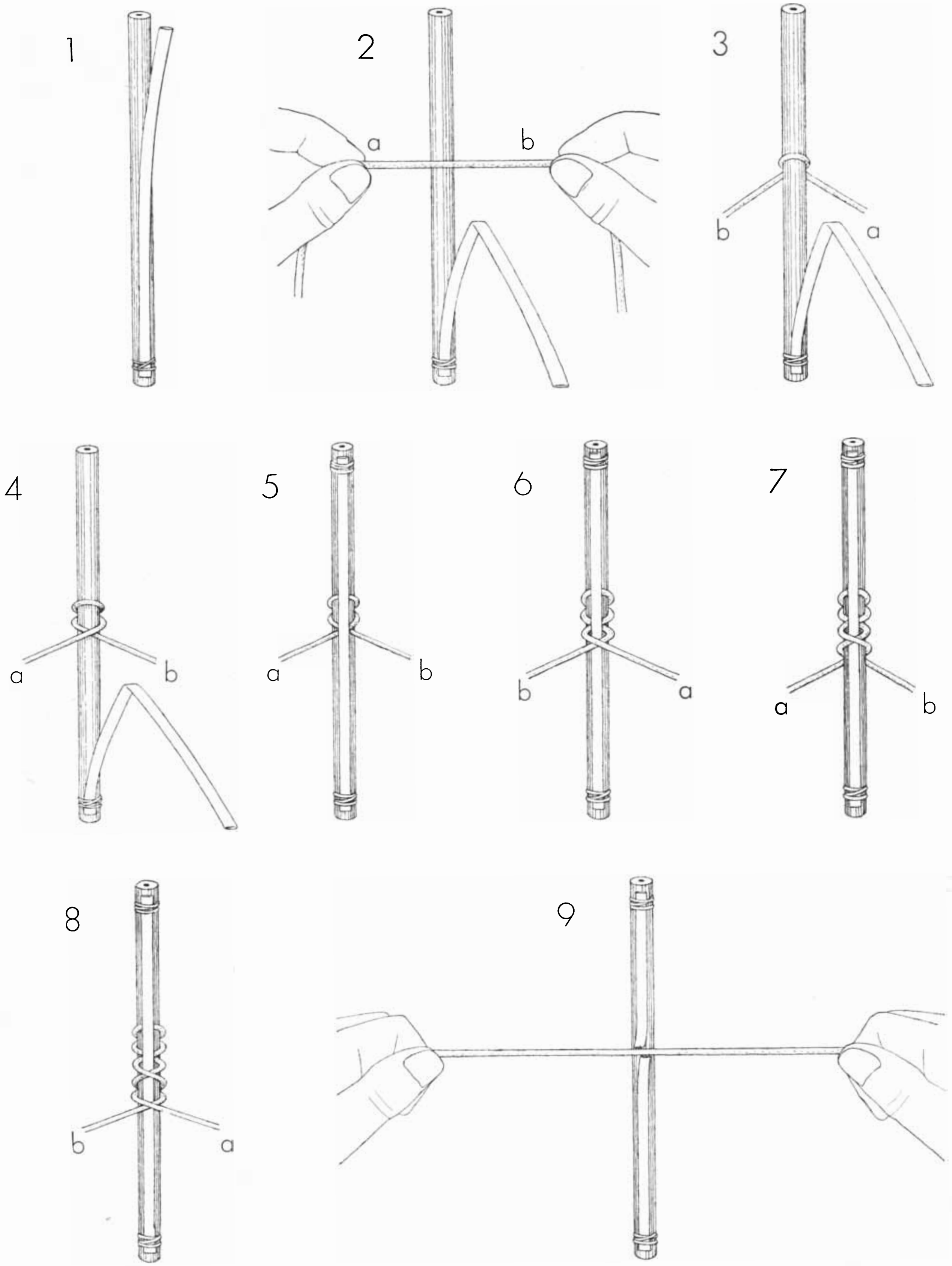


Stewart Judah's penetration trick

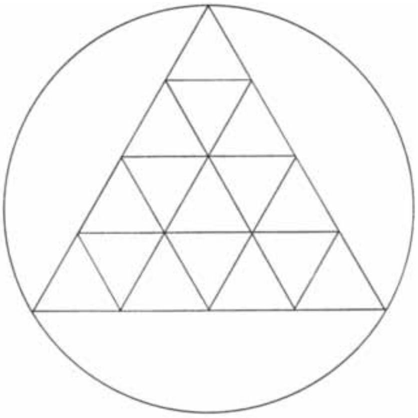
angle. Place the middle of the shoelace over the pencil [2 *in illustration*], then cross the lace behind the pencil [3]. Throughout the winding, whenever a crossing occurs, the same end—say end *a*—must always overlap the other end. Otherwise the trick will not work.

Bring the ends forward, crossing them in front of the pencil [4]. Bend the straw upward so that it lies along the pencil [5] and fasten its top end to the top of the pencil with another small rubber band. Cross the shoelace above the straw [6], remembering that end *b* goes beneath end *a*. Wind the two ends behind the pencil for another crossing [7], then forward for a final crossing in front [8]. In these illustrations the lace is spread out along the pencil to make the winding procedure clear. In practice the windings may be tightly grouped near the middle of the pencil.

Ask the spectator to grip the pencil more firmly while you tighten the lace by tugging outward on its ends. Count three and give the ends a quick, vigorous pull. The last illustration on the opposite page shows the surprising result. The shoelace pulls straight, apparently passing right through the pencil and slicing the straw, which (you explain) was too weak to withstand the mysterious penetration.

A careful analysis of the procedure reveals a simple explanation. Because the ends of the shoelace spiral around the pencil in a pair of mirror-image helices, the closed curve represented by performer and lace is not linked with the closed curve formed by spectator and pencil. The lace cuts the straw that holds the helices in place; then they annihilate each other as neatly as a particle of matter is annihilated by its antiparticle.

Many traditional puzzles are topological. In fact topology had its origin in Leonhard Euler's classic analysis in 1736 of the puzzle of finding a path over the seven bridges at Königsberg without crossing a bridge twice. Euler showed that the puzzle was mathematically identical with the problem of tracing a certain closed network in one continuous line without going over any part of the network twice. Route-tracing problems of this sort are common in puzzle books. Before tackling one of them, first note how many nodes (points that are the ends of line segments) have an even number of lines leading to them, and how many have an odd number. (There will always be an even number of "odd" nodes.) If all the nodes are "even," the network can be traced with a "re-entrant" path beginning anywhere



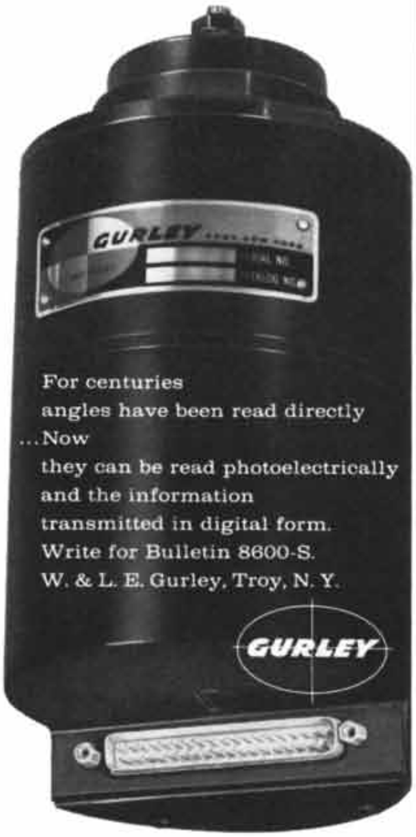
The network-tracing puzzle

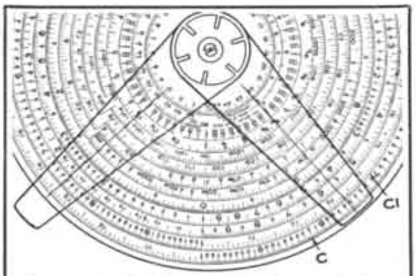
and ending at the same spot. If two points are odd, the network can still be traced, but only if you start at one odd node and end at the other. If the puzzle can be solved at all, it can also be solved with a line that does not cross itself at any point. If there are more than two odd nodes, the puzzle has no solution. Such nodes clearly must be the end points of the line, and every continuous line has either two end points or none.

With these Eulerian rules in mind, puzzles of this type are easily solved. However, by adding additional features such puzzles can often be transformed into first-class problems. Consider, for example, the network shown in the illustration above. All its nodes are even, so we know it can be traced in one reentrant path. In this case, however, we permit any portion of the network to be retraced as often as desired, and you may begin at any point and end at any point. The problem (to be answered next month): What is the minimum number of corner turns required to trace the network in one continuous line? Stopping and reversing direction is of course regarded as a turn.

Mechanical puzzles involving cords and rings often have close links with topological-knot theory. In my opinion the best of such puzzles is the one pictured in the illustration on the opposite page. It is easily made from a piece of heavy cardboard, string and any ring that is too large to pass through the central hole of the panel. The larger the cardboard and the heavier the cord, the easier it will be to manipulate the puzzle. The problem is simply to move the ring from loop *A* to loop *B* without cutting the cord or untying its ends.

This puzzle is pictured in many 19th-century puzzle books, usually in a de-



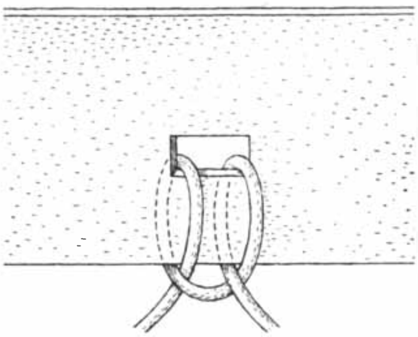


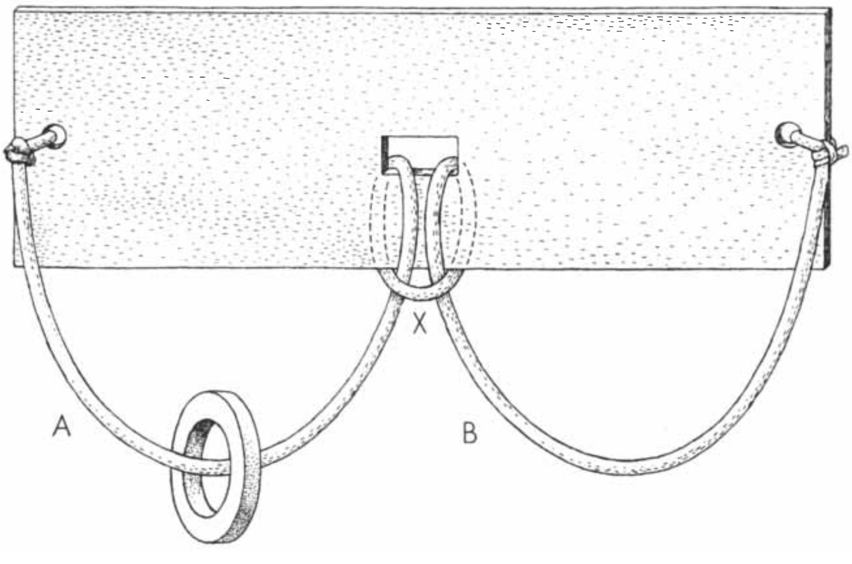
cidedly inferior form. Instead of tying the ends of the cord to the panel, as shown here, each end passes through a hole and is fastened to a bead which prevents the end from coming out of the hole. This permits an inelegant solution in which loop *X* is drawn through the two end holes and passed over the beads. The puzzle can be solved, however, by a neat method in which the ends of the cord play no role whatever. It is interesting to note that the puzzle has no solution if the cord is strung so that loop *X* passes over and under the double cord as shown in the illustration at upper right below. Steps in solving the puzzle will be given next month.

Among the many mathematical games which have interesting topological features are the great Oriental game of Go and the familiar children's game of "dots and squares." The latter game is played on a rectangular array of dots, players alternately drawing a horizontal or vertical line to connect two adjacent dots. Whenever a line completes one or more unit squares, the player initials the square and plays again. After all the lines have been filled in, the player who has taken the most squares is the winner. The game can be quite exciting for skillful players, because it abounds in opportunities for gambits in which squares are sacrificed in return for capturing a larger number later.

David Gale, associate professor of mathematics at Brown University, has devised a delightful dot-connecting game which I shall take the liberty of calling the game of Gale. It seems on the surface to be similar to the topological game of Hex explained in this department for July, 1957. Actually it has a completely different structure. The field is a rectangular array of black dots embedded in a similar rectangular array of colored dots [*see illustration on page 124*]. Player A uses a pencil with a black lead. On his turn he connects two adjacent black dots, either horizontally or vertically. His objective is a continuous line connecting the left and right sides of the field. Player B uses a colored pencil to join two adjacent colored dots. His objective is a line connecting the top and bottom of the field. No line is permitted to cross an opponent's line. Players draw one line only at each turn, and the winner is the first to complete a continuous line between his two sides of the field. The illustration depicts a winning game for the player with the colored pencil.

Last month readers were asked to identify which one of 12 structures could not be built with the seven pieces of a Soma cube. The impossible structure is the skyscraper.





Can the ring be moved to loop B?

THE AMATEUR SCIENTIST

Mostly about some ingenious ways of studying the artificial satellites

Conducted by C. L. Stong

There is something about the flight of an artificial satellite across the night sky that fires the imagination of even a casual observer. Some people who witness the spectacle for the first time come down with a psychological disease known as "space fever," and rush out to order a high-powered telescope. One consequence is that the telescope business is currently booming. Another is that many recently purchased instruments have begun to gather dust. Before the novice acquires a telescope, he should look up an old hand and spend a few hours at the eyepiece of someone else's instrument. He will learn first of all that it is next to impossible to keep a satellite in the field of view unless the telescope is electronically guided. Even when the instrument is equipped with such special controls, it adds nothing to the view of the naked eye. The satellite is brighter, but it is still only a point of light. Unless the novice is prepared to devote much of his time to observation, the purchase of a telescope can be a costly mistake. With the exception of the sun and the moon and some of the planets, celestial objects look about the same with or without a telescope. Even a serious amateur astronomer can occupy himself for years with no equipment at all. Of course *making* a telescope can be fascinating, but that is another matter entirely.

It is possible to determine the approximate height, speed, distance and orbit of an artificial satellite without seeing it—if the satellite broadcasts radio signals. The method, which requires a modified radio receiver, was described in this department last January. The same article told how to make an astrolabe out of three boards to measure the height of satellites visually. Now it turns out that one does not need even this simple equipment.

Within 12 days of the date the first satellite had been launched Jane Shelby, a high-school student in Teaneck, N.J., observed it without instruments, announced its period of orbit with an error of less than three seconds, and accurately computed its velocity, height and orbital inclination. For this accomplishment she was selected as a finalist in the Westinghouse Science Talent Search last year, placed third and received a $5,000 scholarship.

Her method of observing the orbit of a satellite requires the use of a watch with a second hand, a few friends and the ability to consult a table of trigonometric functions. "In 1956," she writes, "I joined one of the Moonwatch teams then being organized all over the world to track the artificial satellites to be launched as part of the International Geophysical Year. My group planned to observe from the roof of the RCA building in New York. But midway in our preparations the U.S.S.R. put Sputnik I on orbit and caught us by surprise. After the first two or three alerts, it was necessary for the group to shift its base of operations to the borough of Queens until more permanent arrangements for the RCA-building site could be made. This was too far away for me to travel in the early-morning hours, so I decided to organize an informal group in my home town of Teaneck.

"The team of eight members was recruited from the Bergen County Astronomical Society. We had no equipment and only two experienced observers. Accordingly the technique of observing had to be simple. One team member was designated as timekeeper and the others as observers. The timekeeper's watch was set beforehand by telephone time signals and checked afterward to determine whether the recorded times should be corrected.

"Each observer was assigned a section of the sky in which to keep naked-eye watch for the satellite. As soon as the object was sighted, all observers followed its motion across the sky. This technique had the advantage of conforming to human nature: most observers, especially novices, watch the satellite as soon as it is spotted anyway. Each individual called out 'fix' at the instant the satellite formed a recognizable configuration with the stars it was passing. The eye is surprisingly accurate in judging such shapes. The timekeeper recorded the time to the nearest second and the name of the observer who made the fix. The observers plotted the position of each fix on a star chart. The coordinates of the plotted positions were

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ALBERT G. INGALLS

Albert G. Ingalls, who had conducted this department of SCIENTIFIC AMERICAN from 1928 to 1955, died on August 13. His age was 70. As editor of the department and of three widely read books on amateur telescope making, and as a tireless personal correspondent, he did more than any other man to stimulate and guide the development of optics as an avocation.

The cause of Ingalls's death was characteristic of his lively spirit. He liked to make long trips on his Italian motor scooter, and last year he was gravely injured in a collision with an automobile. The accident left him almost entirely paralyzed, and he never recovered. The Editors of this magazine, and all amateur telescope makers, have lost a good friend.

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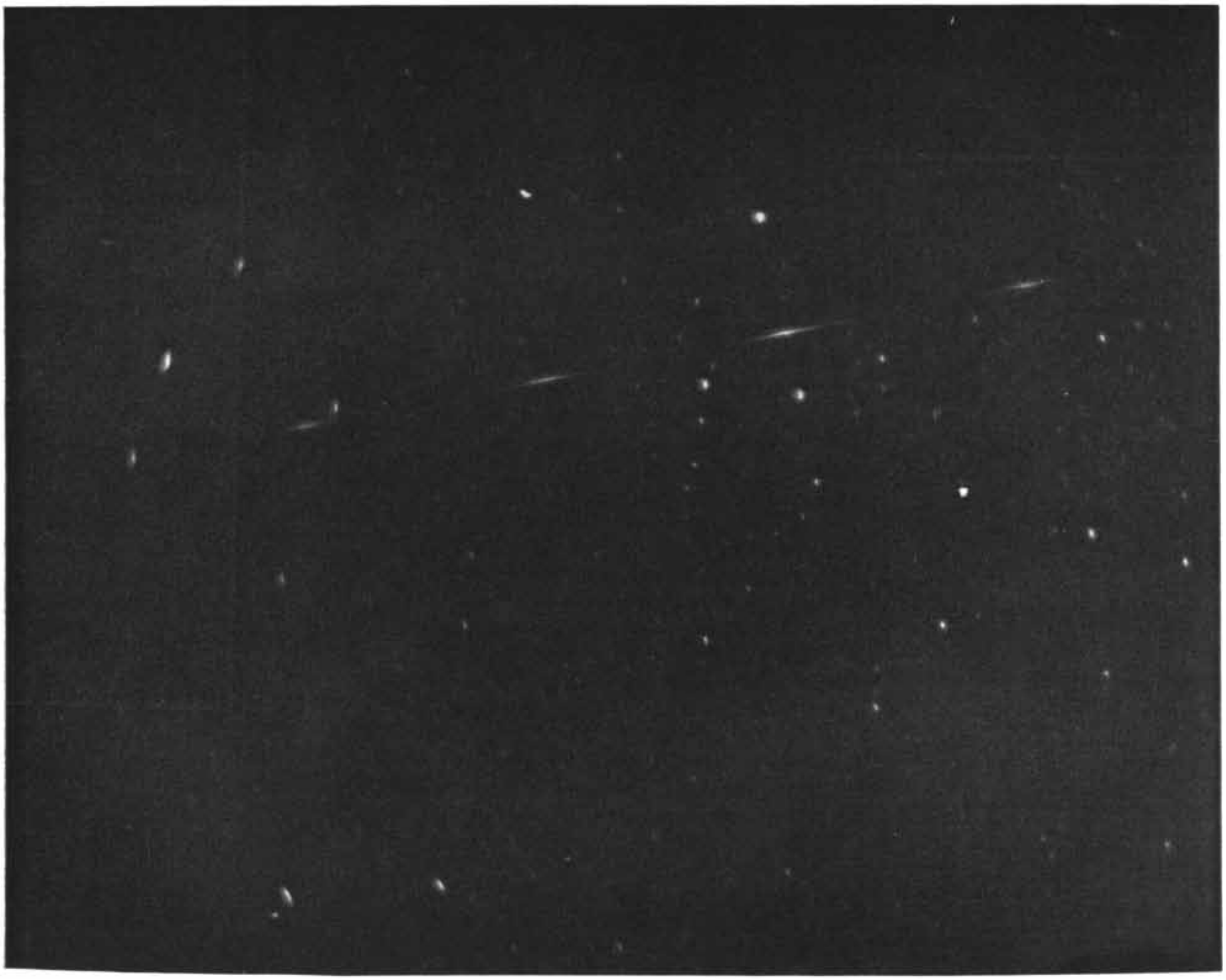
read from the charts after the satellite had passed out of sight.

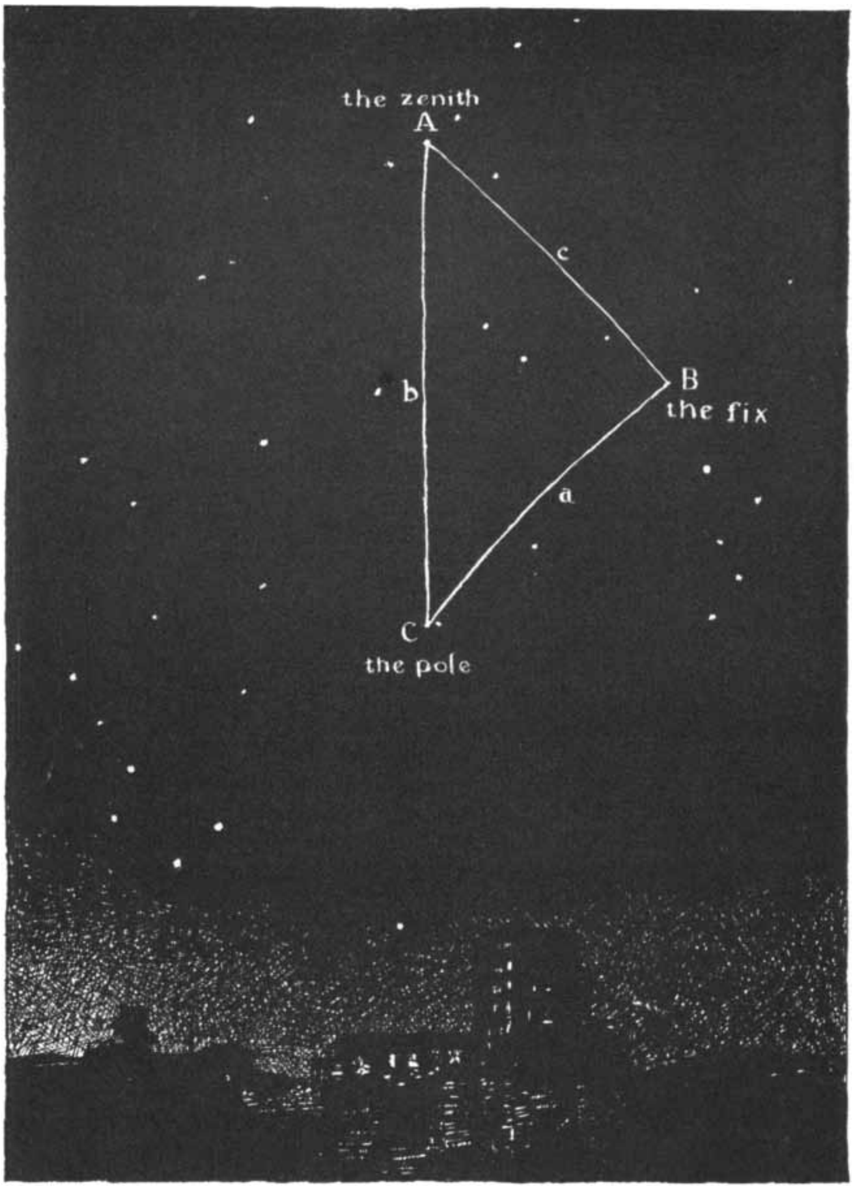
"Four good fixes of the third-stage rocket of Sputnik I were recorded on the morning of October 15, 1957. The following morning we made several good fixes on the rocket and also one on the satellite itself. The data were forwarded immediately to the Smithsonian Astrophysical Observatory as a possible check on the orbit calculated from reports submitted by the official Moonwatch teams.

"My objective was to learn as much about the orbit as possible from the observations made by the Teaneck team. The observations had been plotted as hours, minutes and seconds of right ascension, and degrees and minutes of declination. This is the system used to designate the positions of stars. The celestial sphere is divided by imaginary coordinates resembling the lines denoting latitude and longitude on the earth. Celestial latitudes are measured in degrees, minutes and seconds of the angle made by the earth's axis and an imaginary line connecting the object with the center of the earth. Longitude on the celestial sphere is measured in *hours*, minutes and seconds from the meridian which passes near the right-hand star in the 'W' of the constellation Cassiopeia. This is designated $0^h\ 00^m$ (0 hours and 00 minutes) right ascension. Observations made in this way were converted into those of the so-called 'horizon' system. In this system the point beneath the observer is called the nadir; and the one directly overhead, the zenith. The altitude of a stellar object is specified in the system as the height of the object above the horizon in degrees. Its azimuth with respect to the observer is its compass direction measured in degrees away from true north. Because of the earth's rotation the position of zero longitude on earth with respect to celestial zero longitude changes with the clock. Hence in computing the positions and motions of celestial bodies, time must be taken into account.

"The hour angle which was on the meridian at the time of our observations was calculated from the fact that the sun entered the constellation Libra at 2:27 a.m. Eastern Standard Time on September 23. This meant that on that day right ascension $0^h\ 00^m$ was on the meridian at 00:00 hours (midnight) E.S.T. Teaneck is less than one degree from the 75th meridian—so close that no correction for local time is necessary. Star time, as measured by the $0^h\ 00^m$ celestial meridian, differs from sun time by a little less than four minutes per day. So four minutes for each day since September 23 were subtracted from our local time. To this I added the time after midnight. The result showed that at 5:55 a.m., the time at which we began our observations on October 15, the



S. I. Gale of Plainfield, N. J., made this photograph of the rocket carrier of Sputnik III on August 8



Celestial triangle made by an artificial satellite, the zenith and the celestial north pole

hour angle on the meridian at Teaneck was $7^h 55^m$.

"When it is plotted on a globe, the position of a satellite forms one corner of a triangle on the celestial sphere; the other two corners are formed by the observer's zenith and the celestial north pole [*see illustration on this page*]. The angular distance between the zenith [*'A' in the illustration*] and the North Pole [*'C' in the illustration*] is the complement of the observer's latitude [*'B'*]. Similarly the line *a* is the complement of the satellite's declination, and the angle at *C* is the difference between the hour angle on the meridian and the right ascension of the satellite. The complement of the altitude of the satellite is *c*, and the angle at *A* is the satellite's azimuth if the object is in the eastern half of the sky, or 360 degrees minus the angle of azimuth if it is in the western half of the sky.

"The angle at *C*, and *a* and *b* are known. The unknowns can be found by simple arithmetic employing the values of the sines and cosines of the three known quantities, as taken from a table of trigonometric functions. The cosine of *a* is multiplied by that of *b*. The sine of *a* is next multiplied by the sine of *b*, and the product is multiplied by the cosine of the angle at *C*. The sum of the two products is equal to the cosine of *c*. The angle at *A* is determined in the same way. Its sine is equal to the sine of the angle at *C* multiplied by the sine of *a*, the product then being divided by the sine of *c*.

"The positions thus found are then plotted on an ordinary globe of the earth. If the land markings are ignored and only the coordinates used, this is an excellent way to visualize positions on the celestial sphere. A thread stretched through the points as accurately as possible on a great circle makes interpolation easy. By this means I found the points on the globe where the satellite crossed an east-west line through the zenith, and estimated the times at which the crossings occurred on each morning. The interval was 23 hours, 53 minutes and 51 seconds, which gave a figure of 95 minutes, 35 seconds for the orbital period of the satellite, a result which is probably accurate to within two or three seconds.

"By extrapolating the apparent path of the satellite to the two points where it crosses the horizon, I found the angle at which the satellite crossed an east-west line through the point of observation. The orbit of the satellite, together with the meridian passing through Teaneck and the equator, forms the sides of a spherical triangle, as shown in the accompanying illustration [*page 134*]. Here *g* represents the orbit, *f* the meridian and *e* the equator. Because the angle at *E* as well as *f* (the latitude of Teaneck) and the right angle at *G* are known, the inclination of the orbit to the equator can be found. The cosine of the angle at *F* is equal to the cosine of *f* multiplied by the sine of the angle at *E*.

"This calculation gave a value of 68 degrees for the inclination of the orbit. The method is not too accurate unless the satellite passes nearly overhead and the observations are made close to the horizon.

"Having established the period of the satellite, I calculated its average height and velocity by means of the elementary formulas of mechanics. The gravitational pull acting on the satellite must just equal the force necessary to keep a body at that altitude. The two forces may therefore be equated:

$$\frac{GMm}{R^2} = \frac{mV^2}{R}$$

"In this equation *G* is the universal constant of gravitation (6.66×10^{-8}). *M* is the mass of the earth (5.975×10^{27} grams). The mass of the satellite (*m*) appears on each side of the equation and hence cancels out. *V* is the velocity of the satellite, and *R* is the radius of the orbit. Because the velocity of the satellite is also equal to $2\pi R/T$, in which *T* is the period of the satellite in seconds,

it is possible to write an equation for the height (h) of the satellite in which T is the only variable quantity:

$$h = 6.2137 \times 10^{-6} \times \sqrt[3]{\frac{GMT^2}{4\pi^2}} - 3{,}959$$

"The average velocity of the satellite in miles per second is given by the equation: $V = (2\pi/T) \times (h + 3{,}959)$. Performing the indicated arithmetic gave values of 325 miles as the average height of Sputnik I, and 4.68 miles per second (17,200 miles per hour) as its average velocity.

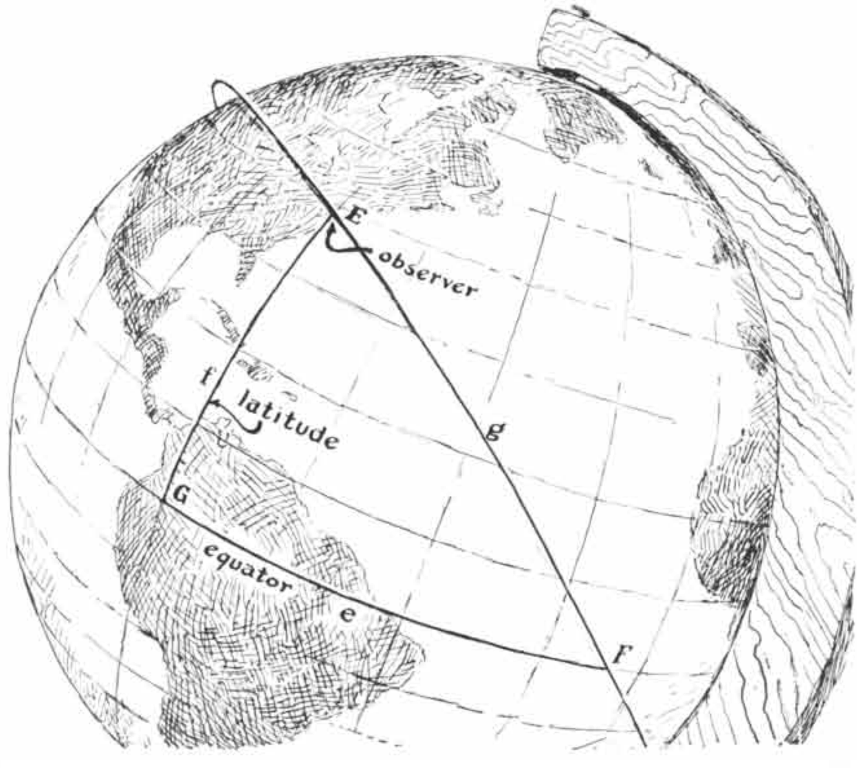
If the amateur does not wish to recruit observers, he can record satellite transits with an ordinary camera. The shutter is opened at the beginning of the transit and closed at the end. The time is noted at the beginning and end of the exposure. The stars appear as short trails, as shown in the photograph on page 131. At a film speed of A.S.A. 650 (Royal X Pan) the aperture should be set at $f/4.5$.

For amateurs who prefer to study satellites indoors, David Berger, who is 14 and lives in Croton-on-Hudson, N. Y., submits an "orbit simulator."

"This simulator," he writes, "consists of a rubber sheet stretched over a circular hole in a piece of plywood, the rubber being depressed in the center by a short stick as shown in the accompanying illustration [*page 136*]. The depression forms a three-dimensional curve and represents the gravitational field in the vicinity of a body in space. Assuming that the edge of the depressed sheet is level, a freely rolling body such as a steel ball, when placed near the edge of the sheet, will roll toward the center of the sheet. In effect the ball is 'attracted' to the center by a 'force' which depends on the depth to which the center is depressed. If the freely rolling ball is brought near the edge and given a circular push, it will orbit around the depression as a 'planet.' The push simulates the kick given to a satellite by the final-stage rocket.

"The friction of rolling simulates the drag of the atmosphere on a satellite. The ball accordingly spirals closer to the center of the depression. As the average radius of the orbit decreases, the curve becomes tighter and the ball speeds up, just as a satellite does when it spirals closer to the earth and is acted upon by the increased pull of the earth's gravitational field. One can also demonstrate the eccentric orbit of a comet and an orbit in which a body escapes.

"The effect of two bodies acting on a satellite in space can be simulated by inserting two sticks spaced a few inches apart under the supporting bridge. With

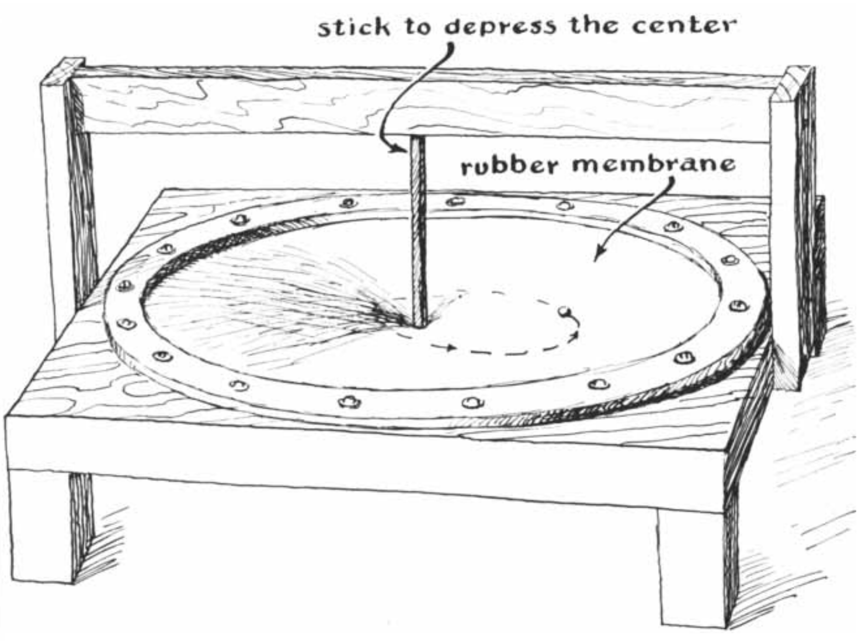


Spherical triangle made by a satellite orbit, the equator and a meridian this arrangement and variations of it a variety of orbits can be simulated: an earth-to-moon orbit in the form of a figure eight in which the satellite returns to earth, an S-shaped earth-to-moon orbit which terminates on the moon, and an earth-to-moon elliptical orbit which returns to earth."

Roger Hayward, who illustrates this department, admits to being something of a table-top-satellite enthusiast. "David Berger," he writes, "deserves a real pat on the back for calling the attention of high-school-physics teachers to this nice demonstration of celestial mechanics. In the interest of strict accuracy, however, the curve can be improved. The displacement of a point on a circular membrane of rubber which is loaded with a force at the center is equal to (2F/T) ln (a/r). *F* and *T* have to do with the forces applied and the character of the membrane, *ln* is the natural logarithm, *a* is the radius of the membrane and *r* is the radius of the point in question. This formula indicates that the force acting toward the center on a ball rolling on the curve would vary inversely with the radius. Such a force would give rise to elliptical orbits. But the 'attracting' body would be at the center of the ellipse instead of at one focal point, and thus would present a most uncelestial appearance.

"The required surface has a profile of the form $x=1/y$, the slope of which varies inversely as the square of the distance. The difference between this profile and that of the rubber membrane is shown in the accompanying illustration [*top of page 138*]. I turned such a surface in a disk of plaster with a lathe. The actual shape required is a petal curve which is removed from the $x=1/y$ curve by a distance equal to the radius of the ball. Such a curve is difficult to compute but easy to make if the face of the cutter has the same radius as the ball. In making my surface I turned a series of rings in the plaster with the tool depicted here [*bottom of page 138*]. The rings were spaced 1/10 inch apart. The compound rest of the lathe was used to set the depth of each cut, and the ridges between cuts were subsequently smoothed off by hand. Plaster cuts nicely but corrodes steel, so the lathe should be covered for protection.

"It is not always easy to prepare a plaster-cast free of bubbles. This difficulty can be overcome by proper mixing. Fill a container of adequate size with water and sprinkle the plaster into the center of the bowl by hand. This enables you to feel and remove any lumps. Plaster should be added until



An amateur's device to simulate the orbits of artificial satellites

the pile rises about an inch above the water in the center. The dry heap acts as an escape duct for trapped air. Allow about five minutes for the air to escape. Then the mixture may be stirred gently. Under no circumstances should the plaster be stirred before water has penetrated to the center of the pile, because the dry portion will be broken into small volumes from which air cannot escape.

"I cast the disk from which my surface was turned in a mold formed by wrapping a strip of gummed paper around a thick metal disk so that half the strip extended above the edge of the metal. The resulting cast was attached by sealing wax to a faceplate for machining. Never pat or trowel wet plaster or it will harden unevenly and increase the difficulty of accurate machining. Permit it to dry thoroughly. Wet plaster loads sandpaper quickly.

"Perhaps some amateur might like to investigate an orbit simulator based on the attraction of a magnet for a small sphere of soft iron. The magnetic force varies as the square of the distance, as in the case of gravitational attraction. Such an arrangement might consist of a carefully leveled plate of glass with a magnet below its center. If the magnetic field is generated by a solenoid, perhaps the current could be pulsed to keep the 'satellite' going. If the pulse is relatively light, it should not greatly distort the shape of the orbit."

As previously pointed out in this department, the two telescopes of a binocular must be parallel, both vertically and horizontally, to within 3.75 minutes of arc for convergence and 1.3 minutes for divergence ["The Amateur Scientist"; SCIENTIFIC AMERICAN, October, 1951, and July, 1954]. Otherwise the use of the binocular will result in severe eyestrain. Because a binocular gives the false impression of rugged construction, many owners are inclined to treat the instrument as though it were a piece of luggage. In fact, the editor of this department once saw the proprietor of an optical-goods store use a binocular as a tack hammer! Fully half of the new binoculars are out of adjustment at some position of the hinge by the time they are sold; I have yet to find one in good condition after a year of use. That anything can be seen through the average glass is a tribute to the marvelous accommodation of the eyes.

The procedure of aligning the telescopes of a binocular is called "collimation," and consists in repositioning the lenses and prisms of the instrument according to the results of an optical test. Both the test and adjustment are simple in principle. The mechanical work may prove difficult, however, because many binoculars are sealed against moisture by a preparation which tends to freeze the threaded parts. This may discourage some from attempting to adjust their own instruments. But one can at least make the test for collimation and, if desired, have the work performed by an optical repair shop.

A simple and reasonably precise test is described by Allen Naber of Pittsford, N. Y. "Basically," he writes, "this test in-

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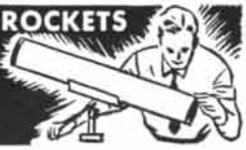

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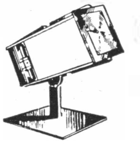

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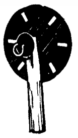

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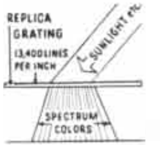

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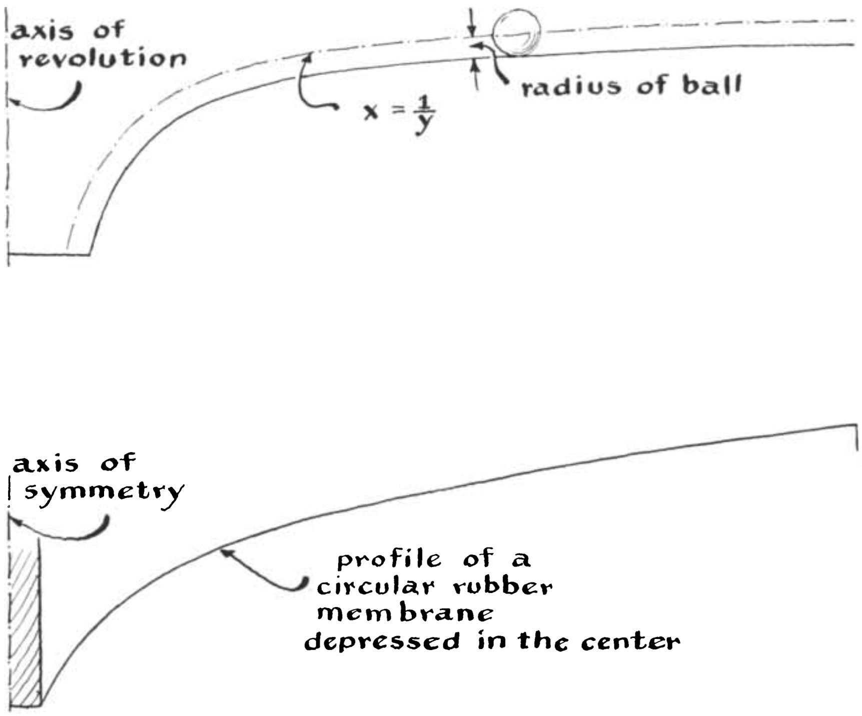


The profile of two curves used in orbit simulators

volves pointing the objectives of the binocular directly toward the sun when it is at a low altitude and projecting the beams from the eyepieces on a white screen in the shade. When the instrument is focused on infinity, images of the sun will appear as two overlapping disks of light on the screen. If the instrument is supported so that the two telescopes are level with each other, the images will appear at the same height on the screen and the space between their centers will match the space between the centers of the eyepieces—if the instrument is in good adjustment.

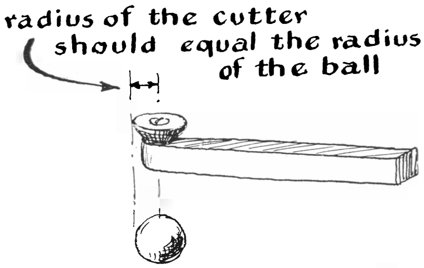
"Although a wall may be used for a quick check, accuracy can be increased by providing a screen, perhaps two by three feet in size, which has been ruled with horizontal reference lines an inch or so apart. A pair of vertical rulings spaced three inches apart near one side are also useful as references. The binocular may be supported by a conventional tilt-top tripod or even a block of wood clamped to the window sill. Any method of support is satisfactory which permits the glass to be kept pointed toward the sun and level laterally. The screen may be tipped forward or backward as much as 10 degrees without affecting the accuracy, but it must be kept as close to a right angle with the sun as possible.

"In normal use one's eyes never diverge, either laterally or vertically, although they do converge from zero in looking at a fairly distant object to as much as six or eight degrees in close reading. This should be kept in mind when collimating a binocular. Errors should be in the direction of convergence, not divergence. In other words, the distance between the images on the screen should be equal to or slightly greater than that between the eyepieces, never less. Incidentally, the measurement may be made between the edges of the images and the corresponding edges of the eyepiece lenses instead of at the respective centers. It is a good idea to mask one of the objectives while observing the images to make sure that the beams do not cross. Masking the right-hand objective, for example, should cause the right-hand image to disappear. In the case of the average binocular placed 10 feet from the screen, a convergence or divergence of three degrees results in a difference of about an eighth of an inch in the distances between the eyepieces and the images.

"The objective lenses of most binoculars are clamped by retaining rings in a short length of internally threaded brass tubing bored off-center. These 'eccentric cells,' in turn, telescope into and are secured by eccentric rings, also short brass tubes with an off-center bore. One or more thin slots usually appear in the edge of the retaining rings that faces outward. These slots take the spanner wrench used for loosening or tightening the retaining rings. Such wrenches may either be made or procured from an optical supply house. When the retaining rings are loosened, the eccentric cell and ring may be rotated with respect to each other. This adjusts the radial position of the lens in any desired direction. The image on the screen will move in the same direction as the lens. The collimation procedure consists in finding the position of the lenses that yields the desired image-separation as described.

"In the case of many instruments, particularly the inexpensive imported variety, the retaining rings are made of soft aluminum and the metal may tear away at the slots when pressure is applied with the wrench. When this happens the ring must be cut with a sharp chisel such as a hand-engraving tool, removed, and replaced with a new ring. Usually replacements are not available, so you have to make them yourself. In some designs the rings are locked by small set-screws. They are loosened with a watchmaker's screwdriver. Frequently the heads twist off. The old screw is then drilled out and, after the hole has been retapped, replaced by a larger screw.

"Aside from these complications, it is relatively easy to align a glass for a single position of the hinge. But collimation at other hinge positions may require a lot of time and patience. For good collimation at all positions of the hinge, the barrel of each telescope must be parallel to the hinge. Begin by collimating at an intermediate hinge position. The relative position of the images is then observed at the ends of the hinge movement. The subsequent procedure entails finding an adjustment of the eccentric rings which will maintain the relative position of the spots throughout the desired range of hinge movement. The eccentrics are then rotated symmetrically to produce the desired image separation which, if maintained at the end position, completes the job. The operation is one of 'cut and try,' and requires time and patience. Having been through it, the amateur will forever after handle his binoculars with care."



A tool to machine an orbit simulator

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BOOKS

A new description of the history of mathematics

by Ernest Nagel

A HISTORY OF MATHEMATICS, by J. F. Scott. Taylor and Francis (63 shillings).

The history of mathematics represents in miniature important stages in the genesis of liberal civilization, and illustrates a pattern of development repeated by many human activities that become prized institutions in advanced societies. In its origins mathematics was a menial practice, concerned with a narrowly delimited set of special problems in agriculture and architecture, and consisting of unanalyzed rules of thumb for performing measurements and calculations. It was gradually transformed into a liberal art, having an unbounded range of application and a reasoned basis for its products, and widely pursued not primarily for its immediate practical values but largely because of the intrinsic intellectual delights its cultivation yields.

The decisive first step in this transformation occurred when men became aware that the miscellaneous collection of practical rules for mensuration could be systematically ordered, improved and augmented by exhibiting them as the inevitable consequences of a few general principles. A type of necessity was thus recognized that has the force neither of a despot's arbitrary commands, nor of socially sanctioned habits, nor of the compulsion of physical events, but has the distinctive constraint of rational proof. The principles constituting the ultimate premises of mathematical demonstrations were regarded during many centuries as self-evident axioms, alternatives to which are inconceivable. Indeed, mathematics thus conceived served as the model to which every genuine science, as distinct from mere opinion, must conform. Comprehensive philosophical theories of the universe and of human cognition were devised in order to account for the apparent power of human reason to grasp with finality the basic constitution of the physical and moral cosmos.

The belief in the intuitive certainty of first principles limited the scope of mathematical analysis for more than two millennia, even though the grounds for this belief and for the philosophies based upon it were eventually undermined by fresh developments within mathematics itself. Meanwhile, however, and despite this limitation, an impressive structure of demonstrated relations was erected upon axiomatic foundations. Even in ages dominated by superstitious dogma, mathematics thus kept alive the liberal idea of reasoned discourse and rational proof. But it also supplied indispensable intellectual tools for the theoretical exploration of nature during more propitious times, its own researches being in turn stimulated by the needs of theoretical science.

However, a further step of cardinal importance in the emancipation of the human intellect was taken when consistent alternatives to the established systems of mathematics were discovered, so that the conception of self-evident axioms was radically challenged. The traditional domain of mathematics was in consequence enormously expanded. Heightened standards of rigor and new techniques of analysis were introduced. And a limitless realm of possibilities was opened up for exploitation, yielding in unceasing abundance creations of the human imagination that are both intellectually enlightening and esthetically satisfying. These developments within mathematics had repercussions elsewhere, most conspicuously in the natural sciences, but also in the general climate of opinion. Potent critical fire came to be directed against entrenched social and ethical philosophies which derived their intellectual authority from the common belief that their ultimate premises, like those of mathematics as traditionally understood, could not be denied without logical absurdity. Among thoughtful men, at any rate, the realization grew that claims to factual and moral truth could not be adequately founded on appeals to intuitive certainties, but had to be supported by a responsible consideration of empirical evidence. The recognition that there are logical alternatives even to our most cherished beliefs is a sobering thought. But it is also an idea that can emancipate men from intolerant dogma and illiberal provincialism. As the late Justice Holmes once observed, no one can count himself as civilized who has not at some time questioned his first principles. To this emancipation, and to the development of a temper of mind that is both rational and skeptical, mathematics has made profound contributions.

A history of mathematics can accordingly be written with different primary emphases. It can be written in a broadly philosophical spirit, stressing the role of mathematics as a civilizing agency, and discussing among other things the impact of mathematical discoveries upon art, religion and philosophy in general. It can be expounded in a sociological vein, with a view to exhibiting the influences changing social and scientific needs have had on the direction of mathematical research, the uses to which mathematical inventions have been put in different areas of human concern, and the cultural conditions under which mathematics has made significant headway. It can be elaborated in terms of individual biographies, describing the influences of persons, books and circumstances upon creative effort. It can be presented with chief accent on the logical and methodological questions with which different periods of mathematics had had to cope and to which answers have been found. Finally, and this is the form it usually takes, the history of mathematics can be an account of topically classified mathematical achievements, selected because of their technical importance and discussed in order of their discovery in successive historical periods. The various approaches are clearly not exclusive alternatives; no one of them is inherently superior to the others, and in fact most discussions of the subject have something to say about materials drawn from several of them.

The present volume belongs, by and large, to the last of these alternative ways of writing the history of mathematics. Except for relatively brief descriptions of mathematics in ancient science and in modern mechanics, and apart from occasional references to philosophical issues raised by new departures in mathematical thought, the book is essentially an informative and scholarly account of major achievements in pure mathematics from ancient times to the beginning of the 19th century. The author, who is vice-principal of St. Mary's College in Middlesex, England, and has contributed previously to this field, makes good use of secondary studies in the areas he surveys, especially of recent researches on Babylonian and Oriental mathematics. However, he bases his account primarily on a first-hand familiarity with the mathematical literature he discusses. Although he nominally ends his story with the work of mathematicians born in the 18th century, ostensibly because he does not feel equal to presenting an exhaustive survey of the enormous and highly specialized mathematical output since then, he does in fact describe the main developments far into the 19th century—including the discovery of non-Euclidean geometry, the elaboration of the "new" projective geometry, the introduction of a greater rigor into mathematical analysis by the French mathematician Augustin Louis Cauchy, and the beginnings of mathematical logic. Moreover, while no history of a science can be intelligible to anyone totally untrained in the systematic content of the discipline, the present one explains and illustrates important ideas and theorems with which a reader who is not a professional mathematician is not likely to be familiar. The book breaks no fresh ground, and offers no novel interpretations of the materials it presents. But Scott writes clearly, and he gives unusually full descriptions of segments of mathematical history that are otherwise not readily accessible. Moreover, by a happy use of paraphrase and quotation, he succeeds in conveying the flavor of various styles of mathematical thought; and although he does not discuss at great length any of the logico-methodological problems that emerge in the course of his story, his account of some of this material is often perceptive and suggestive. All in all, his book is a useful addition to the library of general histories of mathematics.

Approximately a third of the volume deals with developments prior to the Renaissance. The ancient Babylonians possessed mathematical skills much higher than was suspected 50 years ago. There seems no doubt, for example, that in their ability to handle problems in effect requiring the solution of quadratic equations they excelled the later Greeks. Nevertheless Scott makes out a convincing case for the older view that it was the Hellenes who first created demonstrative mathematics, and that it is therefore with them modern science must still be said to begin. Like the ancient Egyptians, the Babylonians were often talented empirics. They devised workable solutions for a large number of particular problems; but unlike the Greeks, they apparently had no conception of the nature of a general proof, and not even a glimmer of the idea of a generalized deductive system. An essentially similar judgment is offered on the mathematical contributions of Oriental antiquity.

Scott's account of Greek mathematics includes an unusually full and valuable discussion of the progress achieved in trigonometry, and of the part this discipline plays in Ptolemy's *Almagest*. He also explains in some detail the method of exhaustion for evaluating irrational geometrical magnitudes, and the way the Greeks incorporated the irrationals into the number system. However, his story of this important problem falls short of being adequate, since he avoids explicit discussion of the philosophical and methodological assumptions underlying the Greek view of irrationals and nonterminating processes. Indeed, Scott is obviously more at home with the details of technical developments in mathematics than with the relevant philosophical ideas that often control those innovations. For example, he declares that Plato had only a secondary interest in ethics and politics, and that the Platonic philosophy was in consequence a "mathematical philosophy." Such an assessment not only ignores the intimate relation between Plato's concern with mathematics and his passionate involvement in moral and social questions; it also underestimates the influence of moral considerations upon the norms of mathematical procedures adopted by Plato's followers. Moreover, Scott's own stand on a major technical issue is surprisingly insensitive to the philosophical import of developments within mathematics itself. In commenting on the rationale for the repeated attempts to prove Euclid's parallel postulate, he asserts: "It is not that anyone questions the truth of it; the important point is that it is not self-evident, as an axiom should be." His apparent acceptance of the assumption that axioms must be self-evident, in the face of his own subsequent account of the discovery of non-Euclidean geometries, raises legitimate doubts about his book as a reliable guide to the philosophic significance of the story it tells.

Little space is devoted to the mathematics of the "Dark Ages." Scott examines neither the question of why they were dark, nor the issue of whether they were quite as dark as has been commonly supposed. But he does attempt to explain the revival of mathematical activity during the Renaissance, in terms of the familiar account of the gradual rediscovery of the Greek mathematical writings. Of greater interest is his comment that with the invention of printing and the consequent replacement of the written by the printed word, an improved mathematical symbolism was required which contributed essentially to the power of mathematical analysis. However, he does not expand upon this comment; and he does not do justice to the importance of an adequate notation both for making complex mathematical operations manageable, and for suggesting new generalizations and constructions. Much modern mathematics has undoubtedly been generated under the influence of notational analogies, and a detailed study of the history of such influences remains to be written. Moreover, Scott omits all reference to the stimulus that the requirements of an expanding commerce provided to mathematical thought, and to the greater leisure for the pursuit of pure science which an improved European economy made available. Indeed, he just about inverts what is surely the true causal order in declaring that "the increased interest in mathematics is reflected in the revival of interest in navigation, especially in maritime countries." It is of course absurd to claim that the development of mathematics is simply a response to the changing demands of practical life. It is no less absurd to suppose that advances in mathematics by themselves produce social transformations. In any event, mathematical research is not an entirely self-contained activity; and the direction of its progress is not completely unaffected by other human concerns. The expansion of certain branches of mathematics to meet the needs of current social science is impressive contemporary evidence for this fact.

Scott's survey of the mathematical contributions of the 16th and 17th centuries is rich in detail. Much valuable information is supplied on the work of

"FORCES OF NATURE," another in a collection of paintings by Simpson-Middleman, two talented artists who find in the natural sciences the subject matter for their contemporary expressions. Courtesy John Heller Gallery, Inc.

Conquest of space

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the early algebraists; and the achievements of some of them, such as the gifted Dutchmen Simon Stevin and Albert Girard, are presented more fully than in most general histories. There are excellent descriptions of anticipations of coordinate geometry, and of the great strides taken toward the invention of general methods for drawing tangents and calculating volumes—problems that are now handled by the differential and integral calculus. An unusually full treatment is also accorded to the invention of decimal fractions and logarithms. Scott rightly assigns great importance to these innovations as indispensable steps toward making mathematics a tractable instrument in the solution of physical problems. He gives his readers a vivid sense of the obstacles John Napier had to overcome in arriving at the notion of logarithm. Napier had no conception of fractional or negative exponents, and he developed his ideas in terms of kinematic considerations, involving correspondences between arithmetic and geometric series of velocities.

The discussion of René Descartes's contributions is especially illuminating. As is well known, Descartes was by no means the first to use coordinates in the study of geometry. His originality consisted, as Scott makes clear, in devising a better notation for this purpose, in referring several curves to a single set of axes, and above all in establishing a general correspondence between geometrical and algebraic problems, so that the former can be handled uniformly by the more powerful algebraic methods. In this connection Descartes also emancipated mathematical analysis from the then current assumption that the square of a quantity, for example, must represent an area and never a length; and more generally, that a quantity raised to a power greater than unity must represent a configuration with a dimensionality greater than one. Because of their acceptance of this assumption, mathematicians had been understandably puzzled by quantities raised to powers greater than three, and were in consequence reluctant to employ them. Scott is admirably perceptive in calling attention to the increased freedom in mathematical construction that followed the relaxation of this restrictive principle.

Readers unfamiliar with Isaac Newton's method of fluxions, and with his ideas on the foundations of the differential and integral calculus, will find Scott's careful presentation of these and related matters highly instructive and rewarding. Newton first approached the problems of drawing tangents and calculating areas and volumes in terms of the notion of infinitesimals (magnitudes supposedly neither finite nor vanishing); and Gottfried Wilhelm Leibniz remained permanently wedded to it as the basis for his independently discovered calculus. However, Newton became dissatisfied with the idea of infinitesimals. He never completely freed himself of this idea, and never found a rationale for his procedures of differentiation and integration. But he eventually worked out his method of fluxions, which did not require the overt use of infinitesimals but was founded on the notion of "prime and ultimate ratios" that bears a strong resemblance to the modern notion of limit. As it turned out, the notation Newton used in expounding his method proved to be a serious handicap in the further development of the calculus in England, and it was replaced by the superior symbolism Leibniz had devised in presenting his own approach. However, neither Newton nor Leibniz were able to supply a logically rigorous foundation for the operations of differentiation and integration. Both of them, especially Leibniz, were inevitably opportunistic in employing an undoubtedly obscure mathematical technique that nevertheless was felt to be justified by the "correct" results it yielded. Bishop Berkeley's derisive critique of Newton's method of fluxions as resting on "the ghosts of departed quantities" was in principle sound. But Berkeley's criticism was entirely destructive. It did not advance the solution of any mathematical problems, and it was generally ignored by practicing mathematicians. Despite its admittedly faulty foundations, the infinitesimal calculus continued to be widely and fruitfully used until a better foundation was constructed for its operations two centuries later. This instance of an intellectual technique, recognized by those who employed it as supported by dubious credentials but enjoying nevertheless a distinguished and fertile scientific career, is not unique in the history of science; other examples can be found in Scott's book and elsewhere. A systematic study of such ideas, and of the effects upon their use of essentially negative criticisms, would be a fascinating and valuable contribution to the analysis of the human mind.

The final part of the book discusses, among other things, the development of analytical methods by followers of Newton such as Leonhard Euler, Joseph Louis Lagrange and Pierre Simon de Laplace; the growth of probability as a branch of mathematics; the previously mentioned innovations in various parts of geometry; and the invariably fascinating story of the progress made in systematic number theory. In connection with the latter theme, there is an admirable account of Karl Friedrich Gauss's *Disquisitiones Arithmeticae;* and a good survey is given of other remarkable contributions by Gauss. Surprisingly enough, however, neither here nor elsewhere in the book is differential geometry mentioned; the subject of topology is in effect also ignored. Useful thumbnail sketches of the lives of eminent mathematicians are contained in one appendix; in another, brief notes expand some of the topics belonging to later parts of mathematical history. Six plates handsomely reproducing famous passages from important mathematical works add to the value of the book.

Scott notes in passing that while during a given period the center of mathematical activity has sometimes been located in one country, such eminence in mathematical achievement has often shifted from one nation to another. He does not explore the question why this has been so, nor the cognate query as to why there has been such an impressive frequency of independent discoveries in mathematics, even during centuries when mathematicians did not constitute an organized fraternity. It is perhaps a failing in his presentation that it throws no light on questions that are certainly pertinent to the history of mathematics. But in any event Scott's book has the merit of suggesting them.

Short Reviews

People of Coal Town, by Herman R. Lantz. Columbia University Press ($5.75). The story of a coal-mining community, based on a two-year team project of interviewing the inhabitants, examining town records and observing town life. Coal Town—situated, one supposes, somewhere in Illinois—is a one-industry community which has had a wretched past and faces a bleak future. It is not untypical. It was founded at the beginning of the 19th century in a barren area. The majority of settlers were of mixed Scotch, Irish and English descent, and had migrated from the hill country of the South. They exchanged a rocky, unproductive soil for one which afforded a submarginal agricultural living. Grain, castor beans, hogs and horses were the principal products. Thus the economy maintained itself precariously. For the great majority of the people life was characterized by three major themes: "resignation, violence and superstition." When coal was found about 1900, certain major changes in the community took place. The economy was transformed; the need for labor increased. There ensued a large influx of Negroes and of immigrants from central and southern Europe. This brought new problems. The natives hated the Negroes and the immigrants, a feeling which was reciprocated. For a time the mines were owned by six brothers; later a company took over. Under both regimes the miners were ruthlessly exploited until unionization secured them better wages and other rights. Lawlessness and violence marked the normal life of Coal Town until the 1920s and manifested itself intermittently thereafter. Suspicion and hatred brooded over the community. Despite the operation of the mines, Coal Town never enjoyed real economic health, although now and then, and especially from 1940 to 1948, there were boom years. One of the two mines closed down in 1948; the other, in 1956. Whether they will ever open again is uncertain. The population, down to about 2,300, continues to dwindle. Coal Town is not a ghost, but it is half dead. The author sets forth what he believes to be a "common orientation" of themes and values present in those who have lived there. Human relationships in the main are devoid of warmth and respect; "human personalities are viewed as commodities to be used or manipulated." The majority of residents lack self-respect and are self-depreciating. Contemptuous of themselves and of one another, they feel isolated: not only separated from people but also alienated from "any consistent set of life goals or purposes." Paradoxically there is coupled with their rebelliousness a passion for conformity to majority values, which at least serves as a substitute for a true sense of belonging. Anti-intellectualism, hopelessness, cynicism are, as one might expect, other aspects of the atmosphere which pervades a large section of the population. This is a disturbing book. Without generalizing about life in a small community as compared with life in a larger setting, it is clear that many of the ills of Coal Town afflict other contemporary U. S. communities, large as well as small. Lantz has depicted an example of social pathology which is unfortunately far from unique.

Indian Art of Mexico and Central America, by Miguel Covarrubias. Alfred A. Knopf ($17.50). This interesting and attractive book is the second of a trilogy on Indian culture (the first was *The Eagle, the Jaguar and the Serpent,* dealing with the Indian art of North

America) which Covarrubias did not live to complete. Though not a professional archaeologist, Covarrubias spent years of his life studying prehistory and Indian civilizations. He pored over the ancient writings, directed field explorations and, as a gifted artist, had a feeling for the connections between creative forms which conferred a special quality upon his archaeological speculations. In this volume he examines the preclassic cultures: the first agriculturists, the mysterious and exciting sculpture of the Olmecs (*i.e.*, the "people of the rubber country") and the works of the little-known people of western Mexico; the classic period, marked by "the great theocracies" which produced the famous architecture and sculpture of Teotihuacán, Monte Albán, Mitla and of the Maya area of Yucatán, Chiapas, Quintana Roo and Guatemala; the historical period of the Toltec Renaissance, the Mixtecs and Tenochtitlán (now Mexico City), the seat of the Aztec empire. Hundreds of the author's illustrations in black and white and in color portray statues, jewelry, masks, frescoes, tomb decorations, figurines, steles, glyphs, vases, bowls, facades, shields and other art objects; also included is an album of 64 pages of striking photographs. The photographs, it must be said, are much better than the color plates, which, whether because the originals or the reproductions are at fault, do not convey the vivid impression of Covarrubias' best work.

Animal Behavior, by John Paul Scott. The University of Chicago Press ($5). This book is described as both an introduction for the general reader and a text for students. It is not easy to combine these different purposes, but the author has been highly successful. His survey is clear, simply written and unfailingly interesting. It draws upon his own researches at the Roscoe B. Jackson Memorial Laboratory and the studies of many other workers in the engrossing field of ethology. Among the topics discussed are various ingenious methods of studying adaptive, "agonistic" and "allelomimetic" behavior of birds and mammals; the measurement of motor capacities of arboreal monkeys, lobsters, earthworms, sticklebacks and octopuses; behavior as physiologically determined by fluctuations in blood sugar; the relationship between hormones and fighting in cats, mice and other animals (fighting does not seem to occur in the absence of external stimulation, so it would appear that there is no basic drive to fight); the learning abilities of a one-celled animal such as a Stentor, and of rats, dogs and wolves; the theories of Pavlov and B. F. Skinner; experiments in crossing the barkless basenji and the cocker spaniel to determine whether timidity, crouching, jumping and other traits are inherited; social behavior, social organization, intelligence and communication in animals; behavior and evolution. A remarkable series of experiments involved the tiny wasp *Habrobracon*. The fact that the male and female of this species show markedly different sex behavior led the geneticist P. W. Whiting to collect some 50 gynandromorphs (animals who because of accidents to the chromosomes are part male and part female in appearance), and to test their behavior with females and caterpillars. Strange antics followed: wasps with female heads and male bodies were indifferent to females, and even though they had no stingers went through the male motion of stinging caterpillars; when the head was male and the body female, the creature flipped its wings at females but paid no attention to caterpillars. Scott's book is filled with such fascinating items.

A Comprehensive Dictionary of Psychological and Psychoanalytical Terms, by Horace B. English and Ava Champney English. Longmans, Green and Co. ($8). A discipline cannot live without words, but words can corrupt and destroy it. This explains the importance of good science dictionaries, which are as much works of criticism as they are guides to usage. No subjects are in greater need of such services than psychology and psychoanalysis. The vocabularies of both these wildly flourishing branches of study are plagued by amateurishness, pretentiousness and a general professional weakness for fancy terms. As Goethe wrote in *Faust:* "When ideas fail, words come in very handy." English's *Student's Dictionary of Psychology,* first published in 1928, was well received, and he now presents, in collaboration with his wife, a compendium based on 30 years of study and compilation. The present volume appears to be a most refreshing, sensible and witty guide. The authors recognize that a lexicographer cannot "sweep back a tide of usage"; however, he need not be what Samuel Johnson in self-derision called a "harmless drudge." In addition to giving thousands of definitions of terms from *astasia-abasia* through ZYZ (a nonsense syllable used in memory experiments, "with which it seems suitable to end this dictionary"), the work offers several hundred brief encyclopedic articles which comment on groups of related terms and terminological problems. Included in this list are such diverse terms as *aggressiveness, mathematical model, consciousness, narcissism, zenoglossophilia* (a passion, not unknown to the professionals for whom the dictionary is intended, for words of foreign origin), *sex education, fiducial limits, bogus erudition, theory-begging, Nordic race, factor analysis, traumatophilic diathesis* (a barbarism for accident-proneness), *hydrophobophobia* (fear of hydrophobia!), *positivism, peer group, libido, noise, entropy, intelligence quotient, miscegenation, morals, information theory, indecency.* Examples of definitions: *Adiadochokinesis* means (1) the inability to make rapid alternating movements, and (2) incessant movement. The Englishes' comment: "Alas, all this struggle for a precise word, only to have it end up in a contradiction.

Ad-i-ad-o-cho-KIN-e-sis
Is a term that will bolster my thesis
That 'tis idle to seek
Such precision in Greek
When confusion it only increases."

Folie à deux means insanity in pairs. But why, ask the authors, resort to French? One might use "double psychosis" or even "gruesome twosome." *Formication:* "a sensation as of ants or other insects crawling on the skin. Distinguish from 'ants in the pants.' "

ANTON VAN LEEUWENHOEK AND HIS "LITTLE ANIMALS," by Clifford Dobell. Russell & Russell, Inc. ($10). An unaltered reprint of a noted biography, published in 1932, of the first man to describe bacteria. Dobell, himself a well-known worker in the microbiology which was founded by Leeuwenhoek, for 20 years stole odd hours from an extremely busy schedule to discharge this "labour of love." He had to teach himself Latin and 17th-century Dutch and even palaeography to be able to read and translate the Leeuwenhoek manuscripts in the library of the Royal Society. A large part of the book consists of English renderings of all Leeuwenhoek's famous letters pertaining to microbiology. Leeuwenhoek had little schooling, but he had extraordinary skill as an instrument-maker, a marvelous imagination and an unquenchable curiosity. Above all he wanted to see how the tiny things of nature are made and how they work. Unaided and impelled by a divine madness, he literally discovered a new world. He made more than 200 microscopes with magnifying powers of 40 to 270 diameters. He observed insects, rotifers and a host of other "animalcules." He investigated and described blood corpuscles, the capillary circulation, the lens of the eye, muscle fibers, the tubules of dentin. His comparative studies of spermatozoa are a landmark of biology. He contributed to anatomy, histology, physiology, embryology, botany, zoology, chemistry, crystallography and physics. With a specially devised apparatus he watched the explosion of gunpowder under the microscope; though he nearly blinded himself, he succeeded in seeing what he wanted to see. He discovered protozoa and bacteria "in organic infusions in the course of a crazy attempt to find out, by the microscopic examination of macerated peppercorns, why pepper is hot!" Dobell remarks that Leeuwenhoek was "terribly short of words, and could only talk in the commonest and most ungrammatical and old-fashioned language." But this did not stop him from saying everything he wished to say. To the *Philosophical Transactions* of the Royal Society of London alone he made 112 contributions, and for the Paris Academy of Sciences he wrote 27 memoirs. His style is homely, discursive and delightful. In 1931 the Royal Netherlands Academy of Sciences made arrangements to publish a 20-volume edition of Leeuwenhoek's letters. Only four volumes have appeared thus far, and the project is in danger of collapsing for lack of subscribers. This would be a pity, as C. B. van Niel says in his introduction to the reissue of the Dobell biography. Leeuwenhoek was one of the great figures of science—a questing spirit interested in knowledge for its own sake.

THE UNIQUENESS OF THE INDIVIDUAL, by P. B. Medawar. Basic Books, Inc. ($4). Graceful and informative essays by a noted British biologist. The subjects include aging and natural death, scientific method, Lamarckism and imperfections (biological) of man. The final essay (which gives the book its title) reports on researches by the author and his associates on skin grafting, which have produced valuable and far-reaching knowledge bearing on the "detection and assay of individuality, whether in goldfish, mice or men." Every human being, says Medawar, is genetically unique, and the "texture of human diversity is almost infinitely close-woven." Inborn diversity makes for versatility, which is the key to survival in a changing environment. Individuality, however, is not one of man's "higher" or "nobler" qualities, for in this respect he is "nearer kin to mice and goldfish than to the angels; it is not his individuality but his awareness of it that sets man apart."

THE MATHEMATICAL THEORY OF EPIDEMICS, by Norman T. J. Bailey. Hafner Publishing Company ($6.75). The mathematical theory of epidemics was founded about 50 years ago with the work of William Hamer and Sir Ronald Ross. Considerable progress has since been made, especially with the help of new mathematical methods of handling random processes. This monograph by a University of Oxford reader in biometry surveys the results which have been attained, considering both deterministic and stochastic theories of epidemic phenomena.

PLATO'S COSMOLOGY ($1.75), PLATO'S THEORY OF KNOWLEDGE ($1.75), PLATO AND PARMENIDES ($1.60); edited by Francis MacDonald Cornford. The Liberal Arts Press, Inc. Francis Cornford, the late Laurence Professor of Ancient Philosophy in the University of Cambridge, was the translator and editor of a number of Plato's dialogues. Several of his authoritative and valuable editions, enriched by extensive commentaries, are here reprinted in paperbacks. Included are *The Theaetetus* and *The Sophist* (Theory of Knowledge); *The Timaeus* (Cosmology); *The Parmenides* and its fragment *Way of Truth*. Scholars will appreciate the republication of these writings in a well-printed, inexpensive format.

A PICTURE HISTORY OF SHIPS, by C. Hamilton Ellis. The Macmillan Company ($5.95). More than 400 pictures make up this history. They illustrate, among other things, Mekhet Rā's traveling boat, Noah's Ark, Eskimo kayaks, the Oseberg ship, the *Santa Maria*, Spanish galleons, British shipyards, Chinese junks, Nelson's *Vanguard*, the naval bombardment of Copenhagen, the first steam tug, H.M.S. *Agamemnon* (which laid the first Atlantic cable), the *Great Eastern*, the famous hydrographic survey ship *Challenger*, Mississippi stern-wheelers, the *Monitor* and *Merrimac*, several great ship fires, the London East India docks, the grotesque ship *Cleopatra* (which was built around the obelisk of Thutmose III and carried it from Alexandria to London), clippers, tankers, channel packets, royal yachts, whalers, Sir Ernest Shackleton's *Endurance*, early and modern submarines, the battle of Jutland, the sinking of the *Lusitania*, sundry aircraft carriers, landing craft, destroyers and other warships, lightships and lighthouses, and the U.S.S. *Missouri.*

Notes

MICROWAVE MEASUREMENTS, by Edward L. Ginzton. McGraw-Hill Book Company, Inc. ($12). A textbook treating the basic forms of electrical measurements encountered in the microwave region of the electromagnetic spectrum.

AND THERE WAS LIGHT: THE DISCOVERY OF THE UNIVERSE, by Rudolf Thiel. Alfred A. Knopf ($6.95). A translation of a German history of astronomy for the general reader. The emphasis is on personalities and dramatic episodes; the hard ideas have been carefully processed so as not to bruise anyone.

PRIMITIVE ART, by Franz Boas. Dover Publications, Inc. ($1.95). An unabridged reprint, including more than 323 photographs, drawings and diagrams, of a classic of art history and anthropology first published in 1927.

INTUITIONISM: AN INTRODUCTION, by A. Heyting. North-Holland Publishing Company ($3.60). An introduction to the intuitionist philosophy of mathematics by one of the leaders of this school.

CLOUD STUDY, by F. H. Ludlam and R. S. Scorer. The Macmillan Company ($2.95). An attractive pictorial guide to clouds from *cumulus mediocris* to *cirrostratus nebulosus*, selected from the large collection of photographs owned by the Royal Meteorological Society.

THE PLANET JUPITER, by Bertrand M. Peek. The Macmillan Company ($8.50). Gathered in this volume are the observational data that have been slowly accumulating, the theories based upon them, and the known facts regarding the physical features of the largest of the nine planets that revolve around the sun. For the serious student of astronomy.

OCKHAM: PHILOSOPHICAL WRITINGS, edited and translated by Philotheus Boehner. Nelson (21 shillings). A selection, presented in facing Latin and English text, from the logical, ethical and metaphysical writings of the 14th-century English scholastic philosopher William of Ockham. Ockham is best remembered for his principle (Ockham's Razor) which holds that an argument must be shaved down to its simplest and essential terms ("Entities must not be multiplied beyond what is necessary").

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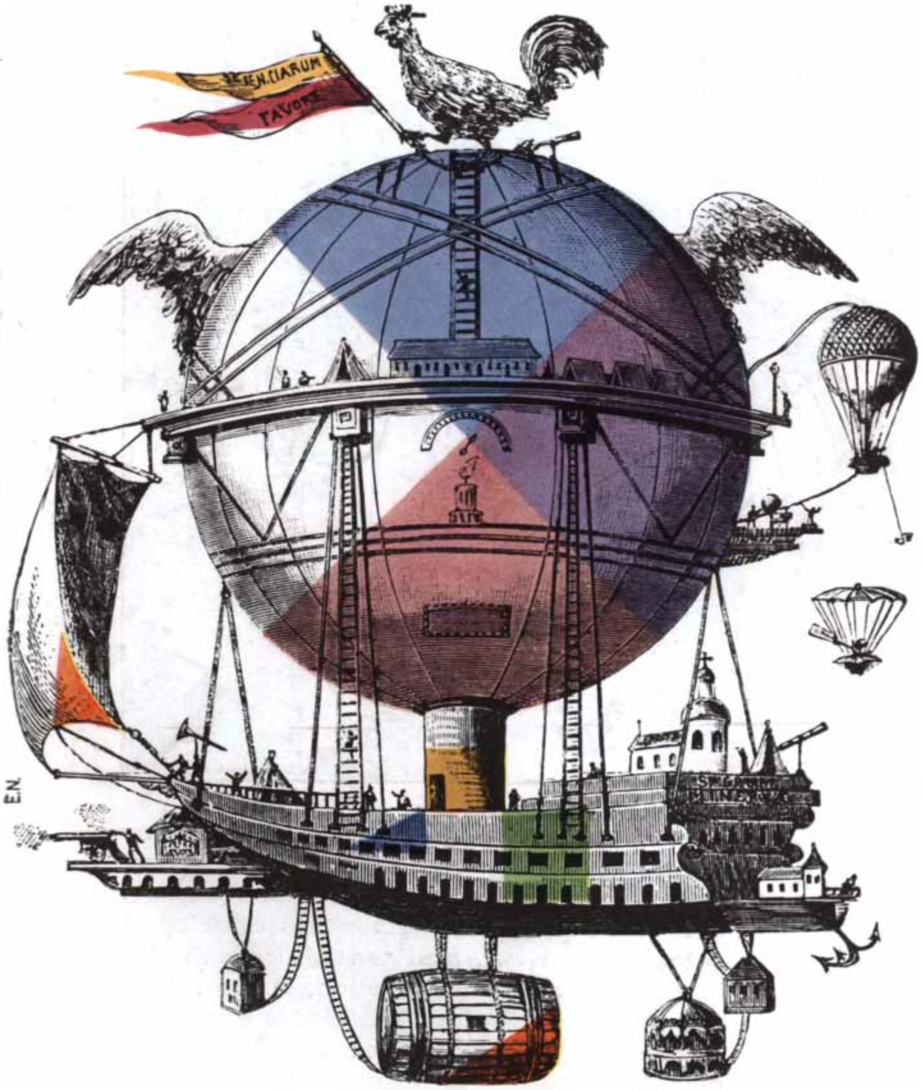

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Wild schemes proliferated after the Montgolfier brothers sent their first balloon aloft in 1783. The most gloriously fantastic was *La Minerve*, proposed in 1804 by Etienne Gaspard Robertson, a Paris aeronaut. This aerial gingerbread specified a hydrogen balloon 150 feet in diameter, accommodations for 60 people and lavish appointments—promenades, theatre, observatory, clinic and gymnasium. Robertson suggested that a group of scientific gentlemen spend several months aboard to explore the possibilities of flight. *La Minerve* never got beyond the pamphlet stage.

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GENERAL DYNAMICS