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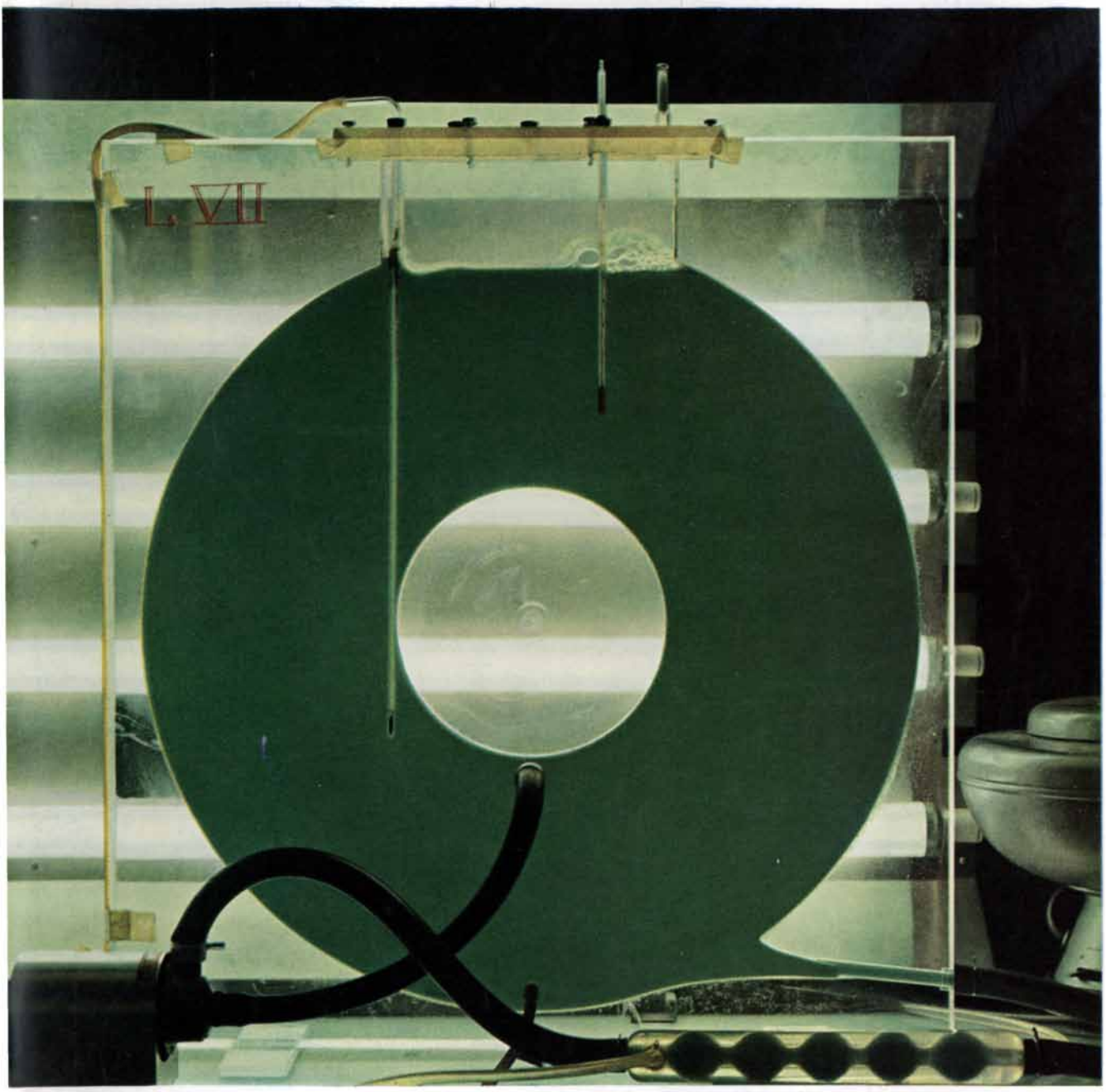

BIOLOGY OF DEUTERIUM

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July 1960

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But now Shell Chemical's Epon® resin-based coatings form an imp-proof armor that tames corrosive attacks for keeps. Used as a coating, only one-fifth as thick as the cellophane on your cigarette pack, an Epon primer is impervious to corrosion vapors—even to pickling solutions of salt and vinegar. And on bottle caps, despite heavy pressures used to crimp and seal, Epon resin coatings remain uncracked, unchipped, and uninvaded.

Result: Better eating for everyone but the bottle imp. His appetite for metal lids and caps is effectively curbed by Shell Chemical's Epon resin.

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NEW YORK

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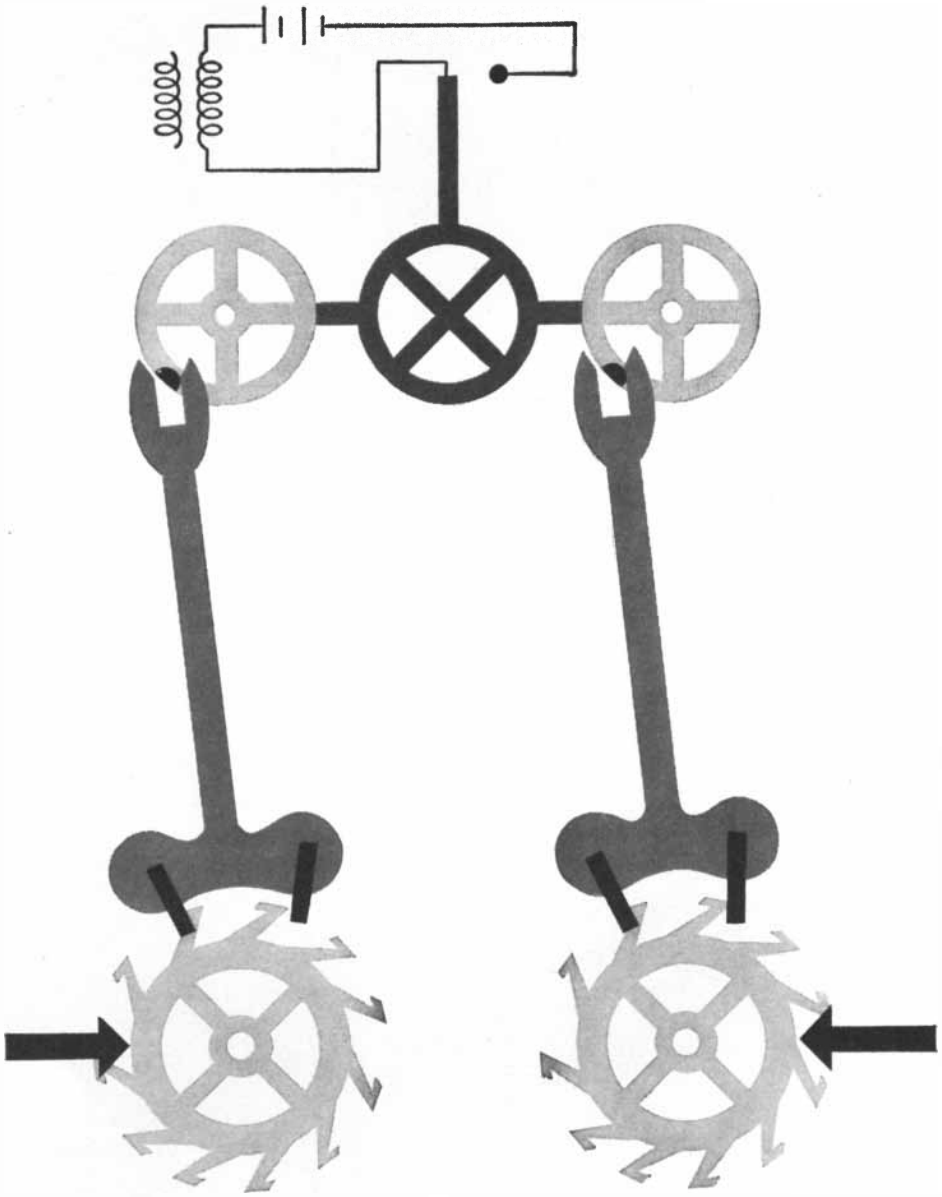

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Bulova's talent for design, engineering and production of reliable timing devices has secured an important place for these critical mechanisms in our nation's industrial and defense communities.

The timing regulation of the sophisticated system shown above is based on the action of a simple balance wheel escapement. For every complete oscillation of the balance wheel, the levers permit scape wheel to advance one tooth according to the following.

In any given escapement, the principal variables which must be established are:
balance wheel frequency, f_b;
the gear reduction from scape wheel to mainspring, R;
and the torsional spring constant, Q, of the balance wheel hairspring.

The desired time per balance wheel cycle is determined by

$$(1) \qquad t = \frac{\beta n R}{2\pi f_b}$$

For optimum scape wheel functions over the range of mainspring torques, it is desirable to use the maximum balance wheel amplitude, just short of overbanking. Thus the balance wheel will have sufficient amplitude, Q, at lower mainspring torques.

The maximum energy imparted to the lever by the scape wheel must not exceed the energy absorbed by the balance hairspring. Therefore

$$(2) \qquad \tfrac{1}{2}Q(\triangle\emptyset)^2 \geqq \eta \frac{T_m\ (\triangle\theta)}{R}$$

where η is the efficiency of energy transmission from mainspring to hairspring, T_m, the maximum torque at hairspring, and θ, the angular displacement of the pallet. The factor, η, must generally be experimentally determined.

The third equation takes into account the fact that the balance wheel vibration system exhibits, by its nature, simple harmonic motion. Thus

$$(3) \qquad f_b = \frac{1}{2\pi}\sqrt{\frac{Q}{I}}$$

Where I is balance wheel inertia (constant for a given system).

The design procedure involves the choice of a convenient gear ratio and the definition of Q. Once Q is determined, f_b can be found by using Equ. (3). The R and f_b selected must be compatible with t.

Bulova's mastery of time and the high order of precision demanded in its regulation, materially contributes to our national well being.

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As for its action, one group says it is purely physical, operating under such laws as capillary attraction and surface tension. Another group maintains the phenomenon is based on chemical and electrochemical action.

Whichever theory is correct, the fact remains that Davison Silica Gel works . . . it is used for gas and liquid dehydration, petroleum cracking, and hydrocarbon recovery from natural gas. It finds wide use in the paint industry, coated paper industry, adhesives, and as the newly developed non-toxic, sorptive dust insecticide. And Davison Silica Gel still remains the preferred desiccant in packaging applications. Discover how industry's most versatile chemical can prove helpful to you. Write today:

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ARTICLES

DEPARTMENTS

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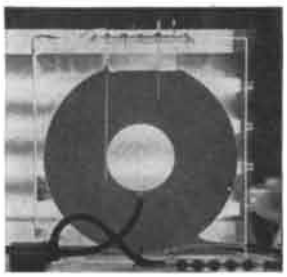

THE COVER

The photograph on the cover shows a plastic tank used for the large-scale cultivation of green algae in heavy water (*see page 106*). The pump at the left keeps the algae moving through the tank, the shape of which keeps cells from settling. Lamps behind the tank provide illumination.

THE ILLUSTRATIONS

Cover photograph by Gordon Coster

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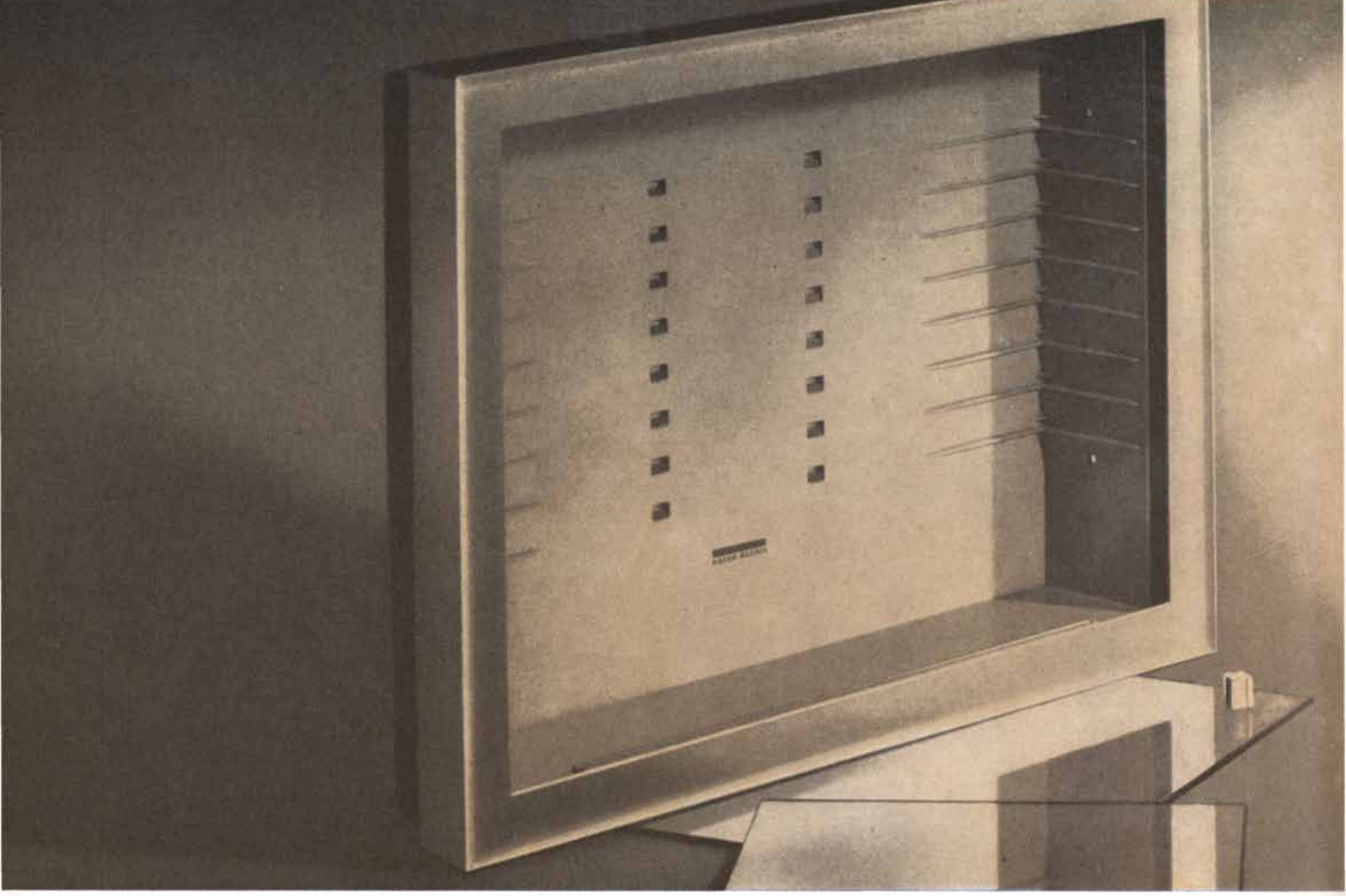
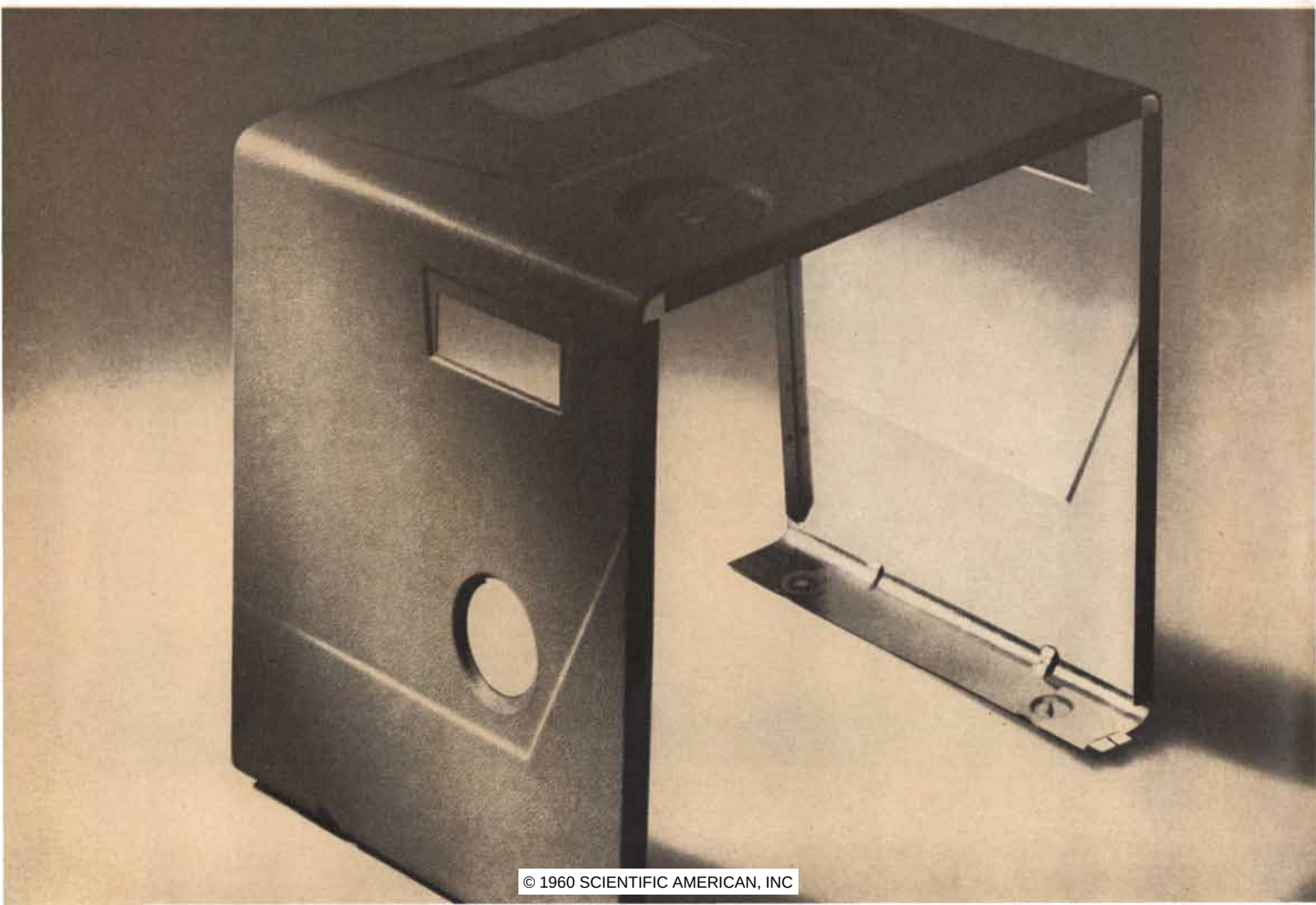
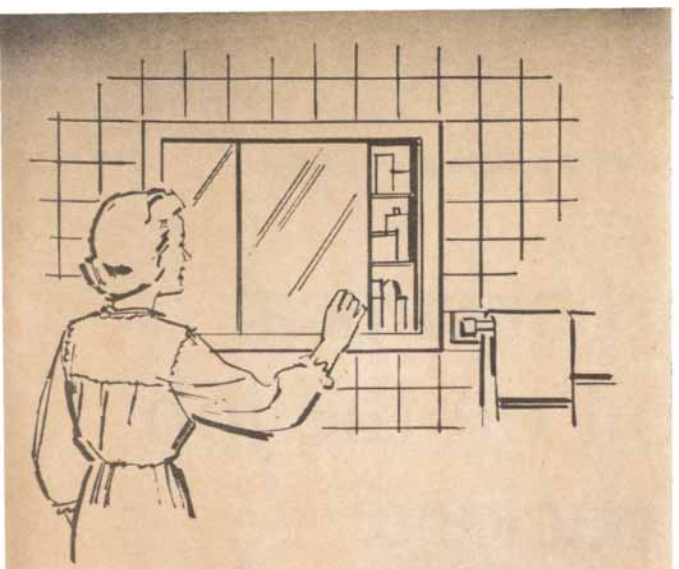
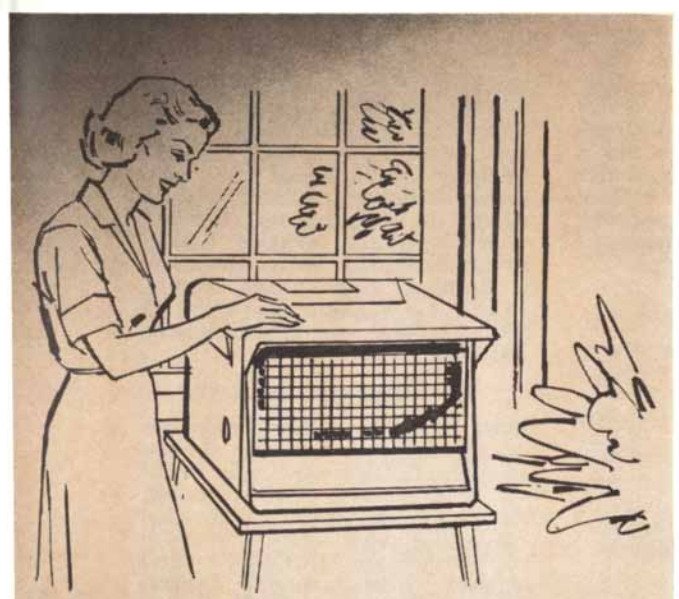






MOLDED . . . This attractively functional medicine cabinet plays a part in a leading builder's program to construct quality homes that require minimum care. The cabinet—including shelf supports and grooves for sliding mirror-door—is custom-molded in one piece of Lustrex® styrene. It has no seams or joints. The color is already molded in and permanent. This cabinet won't rust, corrode, stain, or discolor. Its hard smooth surface wipes clean with a damp cloth.



OR FABRICATED . . . This handsome streamlined air-cooler cabinet was "finished" before it was started! Stamped out of vinyl-fused-on-metal, then formed, it required little or no finishing, since it already had a tough, colorful finish, grained and embossed, that was washable with soap and water, and unusually resistant to abrasion, acids, and alkalis.

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Plastics can lower manufacturing costs, improve product performance, increase consumer acceptance. Some times one or another; many times, all profit-making three!

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The air-cooler capitalizes on the decorative and protective qualities of plastics, the strength of metals, and the fabricating short cuts of vinyl-on-metal. Chairs, desks, luggage, walls, and partitions are some of the many other products now being made of this versatile new material.

New and improved families of plastics are making profitable things happen in many manufacturing fields. Let two new Monsanto booklets bring you up-to-date. Write for your free copies of "How To Buy Custom Molded Plastics," and "Vinyl-on-Metal," to Monsanto Chemical Company, Plastics Division, Room 765, Springfield 2, Mass.

Monsanto does not make finished plastic products. For leading molders, extruders, and fabricators, who make these products, Monsanto has developed a broad range of Lustrex styrene, Monsanto Polyethylene, and Opalon® vinyl compounds.

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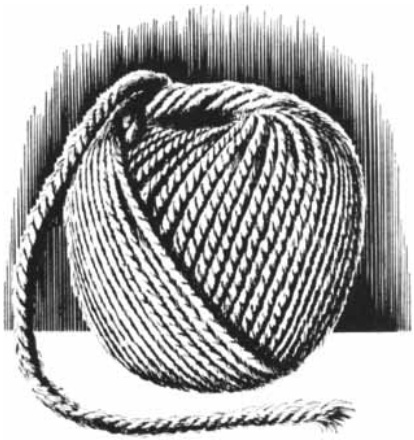
THE RAW MATERIALS OF PROGRESS *in packaging*

How a 3M Fluorochemical keeps baler twine oil on the job —and off the package

Baler twine must remain oily for good service. Yet on the shelf, the vital oil bleeds through most twine containers rapidly. For 70 years, every attempt to stop this bleeding was either ineffective, or too costly. Then a cure was found.



The answer came back in the form of a new product from the Chemical Division of the 3M Company . . . SCOTCHGARD® Brand Grease and Oil Repellent Paper Size. And baler twine now reaches customers in clean, bright packages, factory fresh for a minimum of seven months.

A Paper Size With Many Virtues

SCOTCHGARD Paper Size brings benefits to the packaging industry in many areas. Its use not only stops grease and oil penetration into paper; it also permits use of thinner-than-normal polycoating and prevents unnecessary wax penetration on waxed papers. Grease crawl and staining at seams and closure in multi-wall bags can be eliminated with SCOTCHGARD Paper Size. So, too, can asphalt penetration. Even carbonizing tissue is aided in resisting carbon dope strike-through because of this 3M product.

How can SCOTCHGARD Paper Size do all these things so well? Because it is a member of the 3M family of fluorochemicals. It is not laid on as a film or coating; SCOTCHGARD Paper Size treats each fibre of the paper, providing it with an invisible armor for maximum resistance. And it does this without sacrifice of color, strength, porosity, flexibility, or any other important paper characteristic.

Practical Packaging Aid

You'll find SCOTCHGARD Paper Size at work today . . . preventing loss of protective oil on packaged machine parts . . . protecting seed packages from asphalt discoloration . . . locking in the oil from baler twine and extending shelf life to a most satisfactory degree . . . helping solve packaging problems of long standing for many of America's leading manufacturers.

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Another 3M product for the packaging industry is film and tubing made of KEL-F® Brand Plastic. This flexible and transparent plastic offers positive heavy-duty protection for such products as paint, cosmetics, pharmaceuticals and chemicals. It is completely impermeable and virtually unaffected by heat, caustics, acids and wide temperature variation. KEL-F Brand Plastic withstands heavy abuse in handling, shipping and storage. It provides see-through packaging with maximum security, good looks and convenience.

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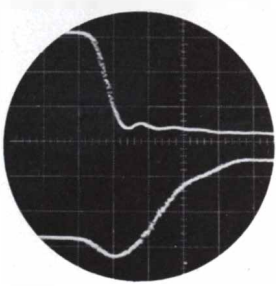
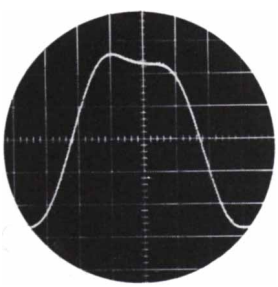


Bright, clear dual pulse presentation on -*hp*- 185A's big 5″ scope face. Top trace shows pulse from mercury pulser applied to 2N1385 mesa transistor. Bottom trace shows responding turn-on of transistor. Dip in bottom trace at start of turn-on results from capacitance. Scope sweep speed is 1 mμsec/cm.



Brilliant, steady trace of a 2 millimicrosecond pulse on the 185A 5AQP cathode ray tube face. Sweep speed (time between vertical graticule lines) is 0.5 mμsec/cm.

6362

IMPORTANT FEATURES: Less than 0.7 mμsec rise time. 500 MC pass band; bright steady traces even at rep rates down to 50 cps. Sensitivity 10 mv/cm to 200 mv/cm; vernier increases sensitivity to 3 mv/cm. Sweep times 10 mμsec/cm to 100 mμsec/cm with expander to 0.1 mμsec. Front panel delayed sync pulse for triggering circuits under test. Dual channel input. 10 cm vertical display. High sensitivity, wide dynamic range. 100,000 ohm probe minimizes circuit disturbance. X-Y recorder output. Time-amplitude calibrators, beam finder, panel similar to conventional scopes.

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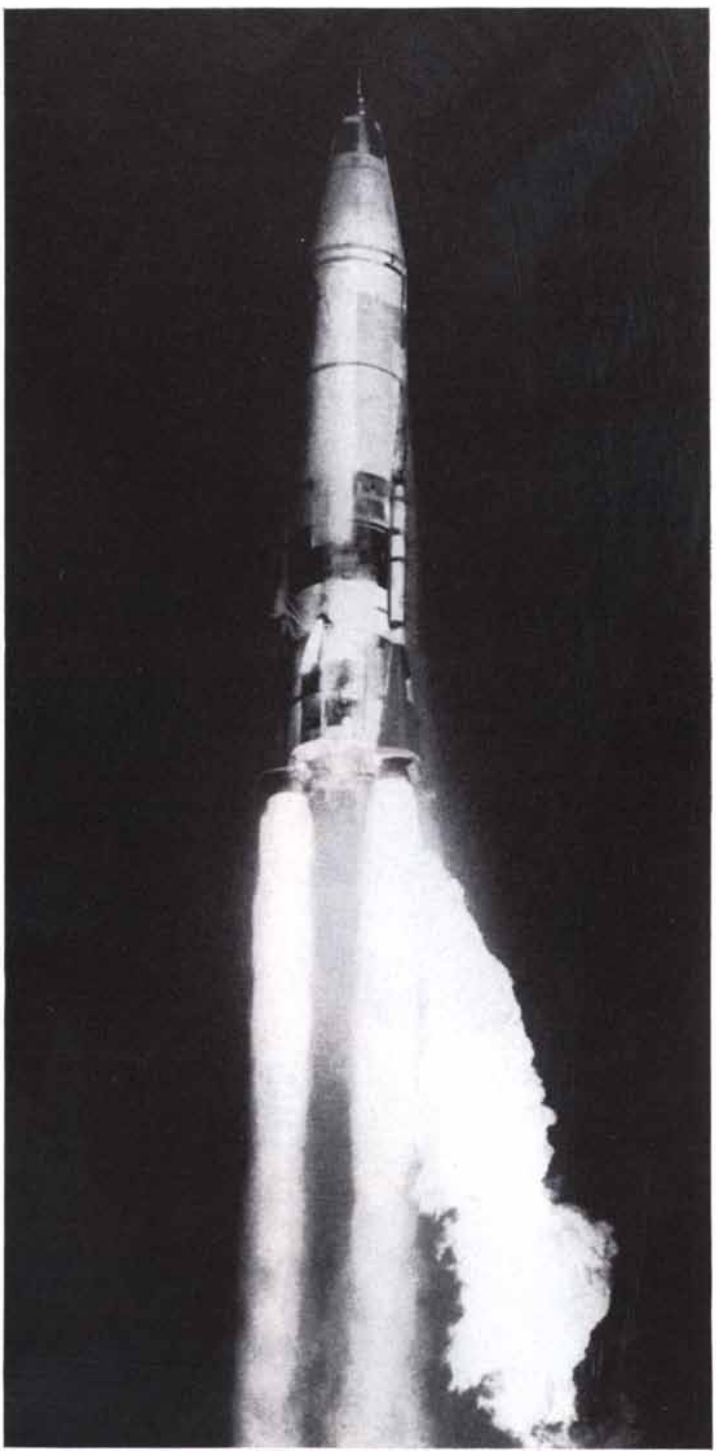

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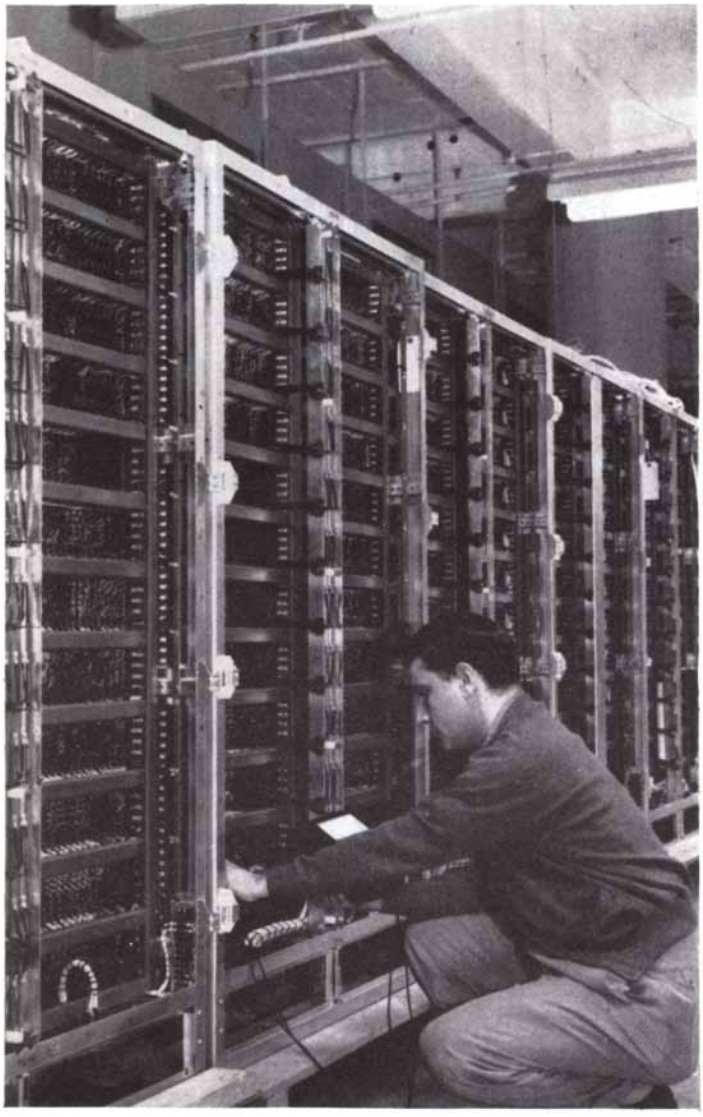

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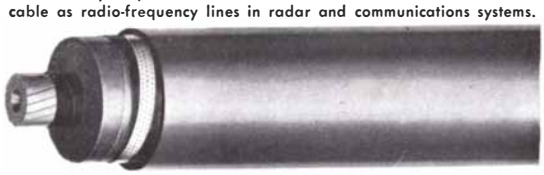

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11

LETTERS

Sirs:

Sergio DeBenedetti, in his article "The Mössbauer Effect" [SCIENTIFIC AMERICAN, April], begins by saying that Zeus, the chief deity of Olympus, was the son of Chronos, the god of time. He goes on to say this shows that the Greeks realized that time is the first of all mysteries. He is doubly mixed up. The Greek form of *chronos* does mean time, but it has nothing to do with Cronos or Kronos, who was the father of Zeus in the myth. Though the father of Zeus, he was not the first chief of the gods. That was his father Uranus (Heaven), who mated with Gaia (Earth) and produced their son Kronos, who displaced Uranus, as Zeus later displaced Kronos. If one does bring in Greek myths as evidence of the insight of the ancient Greeks, or for any purpose, one should certainly take care to get them right and not muddle up the nature of the insights.

HUGH W. HECKSTALL-SMITH, M.A.

Totnes, England

Sirs:

Sergio DeBenedetti, "an obstinate humanist and classicist" makes much of the "very old and very wise myth" according to which Zeus "was the son of Chronos, the god of time." He holds, for instance, that this "myth" demonstrates the Greeks' "deep intuitive understanding of the natural world." But this depth is no greater than that of the story of Atom and Eve. Zeus's father is Kronos (latinized Cronus); "time" (no god) is *khronos* (or *chronos,* whichever transliteration is preferred). The words were quite different to the Greeks, and are quite different to less obstinate humanists and classicists.

HENRY M. HOENIGSWALD

Swarthmore, Pa.

Sirs:

The revelation that Cronos is not the god of time was a very severe blow to one of my most profoundly rooted religious convictions. But if the Greek gods, being many, may put the faithful in a position of embarrassment and confusion, this is compensated by the fact that they have a good nature and a good humor. They do not, I hope, resent the uses and misuses of their names in the manner of the solitary God of the Hebrews.

Each legend has many classical versions; by adding some new ones we only prove that the age of legend is not yet dead.

As a partial excuse for my ignorance I want to say that I was taught Greek mythology in the Italian public-school system (where it was the only religion taught before Mussolini) and that, in the Italian language, the combination of the letters "chr" is forbidden by some kind of exclusion principle. Thus *Crono* (the god) and *cronometro* (the timepiece) are spelled in the same manner.

I hope that my very learned critics will agree with me that "Se non è vero è ben trovato" [If it is not true, it is well invented]!

SERGIO DEBENEDETTI

Carnegie Institute of Technology
Pittsburgh, Pa.

Sirs:

In your department "Science and the Citizen" for May it is stated that J. L. Brenner, R. Fulton and N. Sherman have shown that perturbations in the orbit of *Vanguard I* do not warrant the conclusion that the earth is pear-shaped.

The paper of Brenner, Fulton and Sherman is based on a misunderstanding of the significance of the orbit parameters which are published weekly by the Vanguard Center. Brenner *et al.* have made a numerical study of the *osculating* elements of satellite orbits, *i.e.,* the values of eccentricity, period, etc., which the orbit would have if all perturbations on the pure ellipse were to be removed. They find that spurious oscillations may occur in these osculating parameters, and they remark that these spurious oscillations could imitate the features of the *Vanguard* orbit on which we based our conclusions regarding the shape of the earth.

It is a well-known fact that the osculating elements may contain such spurious oscillations, but our analysis does not use osculating elements. It uses orbit elements that are actually the constants of integration in a Hansen-type theory; these have precisely the property of suppressing the spurious variations obtained in the Brenner calculation, while preserving the genuine variations produced by drag and by gravitational harmonics of odd degree. Therefore, the particular criticism of our results presented by Brenner, Fulton and Sherman is not valid.

There is, of course, the possibility that our calculations may have included some numerical or algebraic error that would invalidate our conclusions. However, Yoshihide Kozai of the Smithsonian Astrophysical Observatory has repeated and extended our work, using an orbit theory derived by him independently of work by Peter Musen. Kozai's investigation has carried our analysis to a higher approximation (terms in the square of the eccentricity), which reduces the magnitude of the "pear-shaped" component by 10 per cent. Apart from this correction, however, his calculations confirm our earlier results on the size and sign of the "pear-shaped" term.

JOHN A. O'KEEFE

Theoretical Division
Goddard Space Flight Center
National Aeronautics and Space Administration
Washington, D.C.

Sirs:

With reference to "The Exploration of the Moon," by Robert Jastrow [SCIENTIFIC AMERICAN, May], it may be of interest to point out that on May 4, 1782 Sir William Herschel, the great German-born English astronomer, noticed, while observing the dark side of the moon, a bright point of light that had "the appearance of a red star of about the fourth magnitude." It was also observed, without prompting, by a Dr. Lind and his

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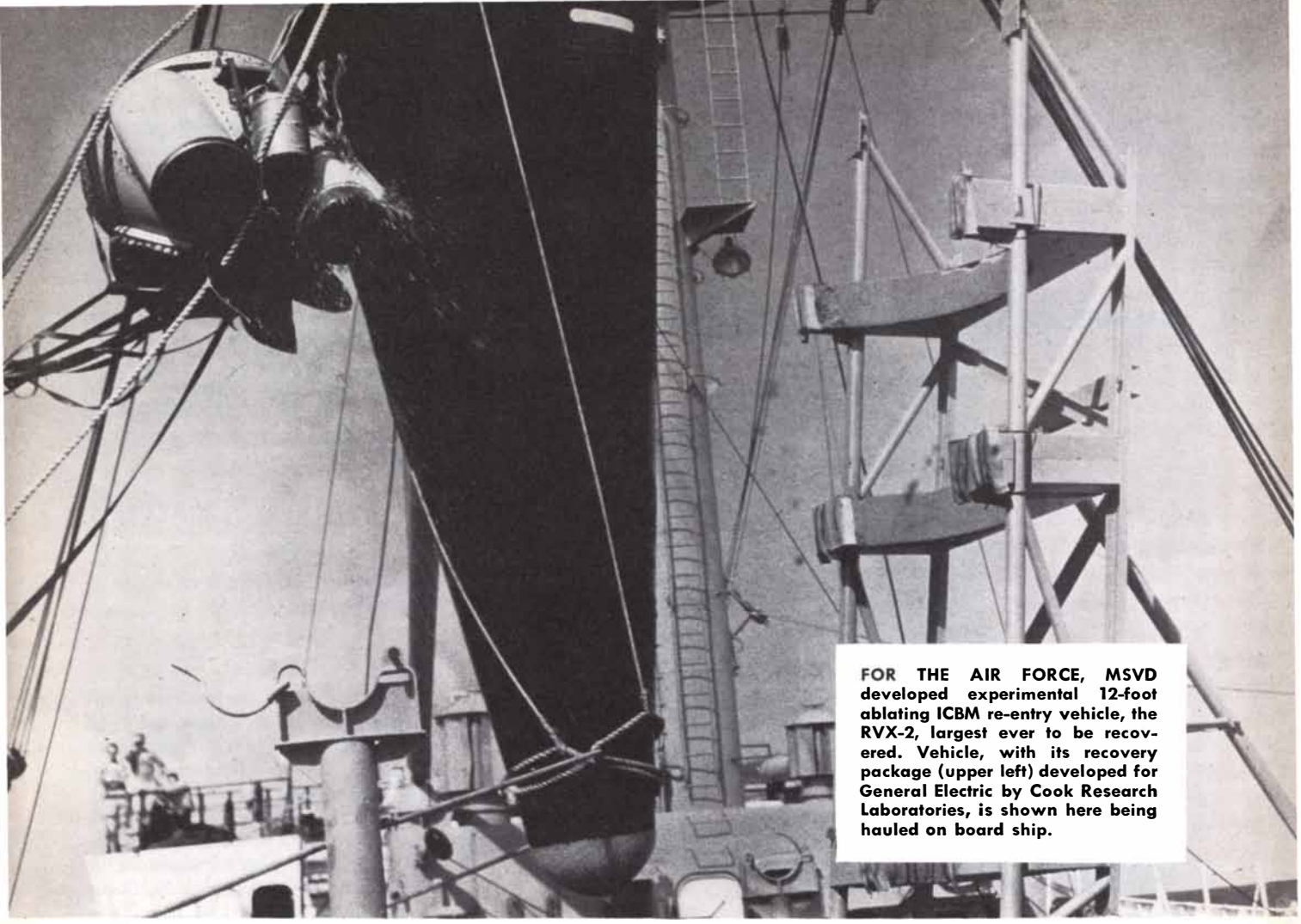


FOR THE AIR FORCE, MSVD developed experimental 12-foot ablating ICBM re-entry vehicle, the RVX-2, largest ever to be recovered. Vehicle, with its recovery package (upper left) developed for General Electric by Cook Research Laboratories, is shown here being hauled on board ship.

MISSILE AND SPACE VEHICLE DEPARTMENT

...center for missile and space technology research and development at General Electric

Progress in search and recovery

With each recovery of a space vehicle, scientists gain important new knowledge about the environment of space and its potential effect on man and the operation of vehicles and equipment. As more advanced vehicles are developed for space flight—some with life aboard—successful location and recovery become increasingly vital.

General Electric's Missile and Space Vehicle Department pioneered in the development of space vehicle search and recovery techniques as part of its re-entry and recovery vehicle program for the U.S. Air Force. MSVD developed and built the first payload to be recovered from space—an 18-inch data capsule ejected from an Air Force Thor re-entry vehicle on June 13, 1958. Many such data capsules have since been recovered from both Thor and Atlas flights—some carried cameras providing films from space. MSVD also developed and built the 12-foot long, one-ton re-entry vehicle shown above which the Air Force recovered on July 21, 1959—the largest to be returned to date. Today, as MSVD builds and flight tests more complex vehicles, it is continually expanding and improving its already successful search and recovery program.

Currently, this search and recovery experience is being applied to the development of such important space programs as the Air Force "Discoverer" recovery satellites and NASA's radiation research recovery vehicles (NERV).

For more information about MSVD's work in search and recovery, write to Section 160–79A, General Electric Co., Missile and Space Vehicle Department, Philadelphia 4, Penna.

GENERAL ELECTRIC

MISSILE AND SPACE VEHICLE DEPARTMENT

A Department of the Defense Electronics Division

Scientists and Engineers interested in career opportunities in Space Technology, contact Mr. T. H. Sebring, Dept. 160, MSVD

wife, who were visiting him. Herschel concluded that he had observed a volcano in eruption, and examined the same location when it was illuminated later, recording on 23 May: "I saw two small conical mountains, which I suppose to have been thrown up in the last eruption of the volcano. They are situated just by a third much larger which I have often seen before and remarked, tho' the two small ones were never before perceived in that place nor expressed in a drawing I had made of the spot." His paper, "On Three Volcanos in the Moon," appeared in the *Philosophical Transactions of the Royal Society of London,* 1787.

E. Scott Barr

Department of Physics
University of Alabama
University, Ala.

Sirs:

I read with keen interest your report on the work of R. F. Legget and T. D. Northwood in the psychobiophysics of the cocktail party ["Science and the Citizen"; Scientific American, April]. Though they have apparently been primarily concerned with alcoholic acoustics, they should also be aware of the study made by Professor C. Northcote Parkinson on the rate and direction of flow at cocktail parties.

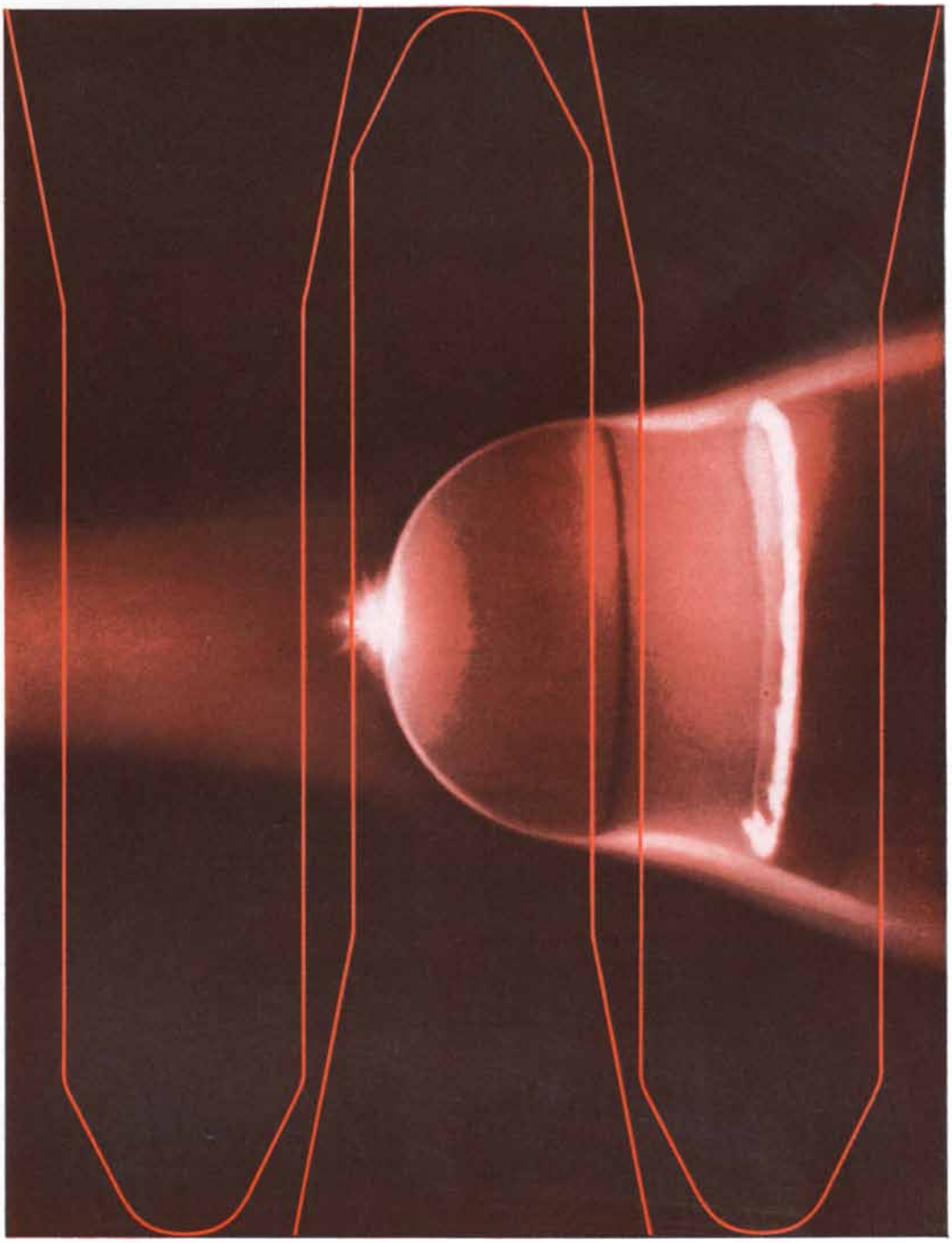
Parkinson, who was at the time Raffles Professor of History at the University of Malaya, found that the typical cocktail party in and around Singapore was conveniently "stained" by black-clothed government officials. This permitted him to plot the location of the important people at a cocktail party for any given amount of elapsed time.

He noted an almost invariable tendency towards a leftward drift that amounts to a clockwise flow around the edges of the room, leaving the most important guests in the area of the right-hand corner of the room, 75 minutes after the party begins. His conclusions, which have a theoretical interest as well as important practical applications, are presented in some detail in the book *Parkinson's Law. . . .*

As book publishers we are naturally unusually interested in cocktail-party dynamics and welcome such studies as those made by Legget and Northwood.

Austin Olney

Houghton Mifflin Company
Boston, Mass.



Blasting new materials to make missile nose cones. The first ICBM nose cone ever to be recovered after flight was protected by a new, high-temperature material. Its name: Avcoite. Its construction: specially reinforced ceramic. Avcoite was the first of a family of new heat-shielding materials. They were developed for re-entering nose cones and satellites by Avco's Research and Advanced Development Division. Newest addition to this materials family is Avcoat, a plastic heat-shield here ablating smoothly in a hydrogen-oxygen jet simulating satellite re-entry temperatures.

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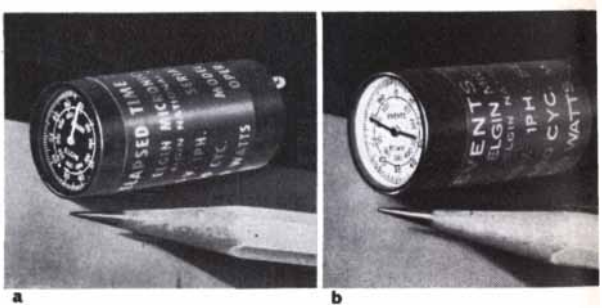
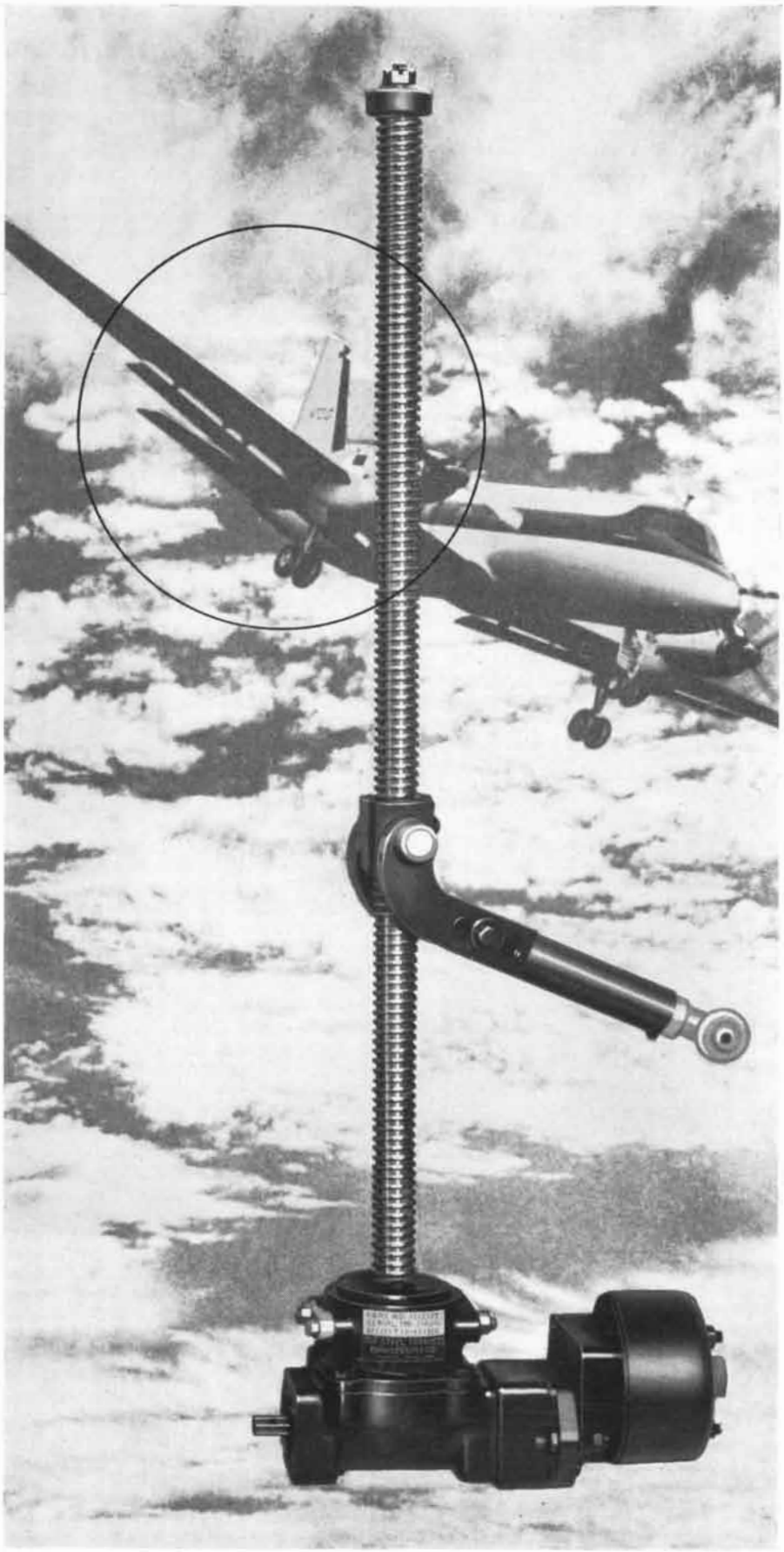


a b

for instruments that read out reliability

ELGIN MICRONICS

DIVISION OF ELGIN NATIONAL WATCH COMPANY, ELGIN, ILLINOIS



Grumman Gulfstream

newest business aircraft equipped with Kelsey-Hayes wing-flap actuators

This new twin turbo-prop business airplane carries up to 12 passengers in pressurized comfort well above 30,000 ft. and at airspeeds exceeding 350 mph.

Capable of operating from short runway airports, Gulfstream gets its wing flap action from a hydro-mechanical actuation system designed and produced by our SPECO Division in Springfield, Ohio.

SPECO, supplier to the aircraft industry for over 40 years, also produces helicopter transmissions, lightweight special hoists, precision radar antenna mounts, precision gears and gear assemblies for the aerospace industries. Kelsey-Hayes Company, Detroit 32, Michigan.

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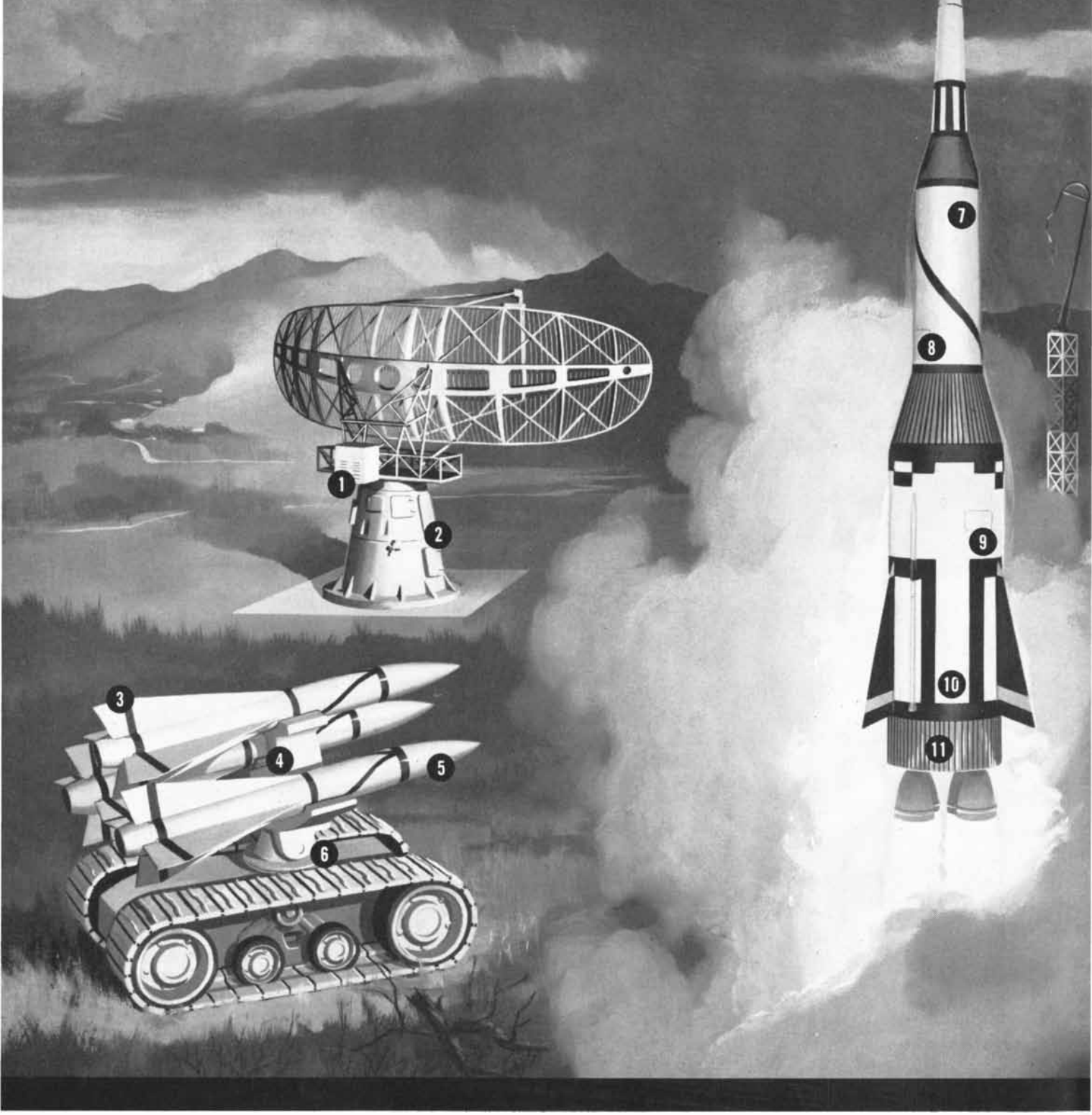
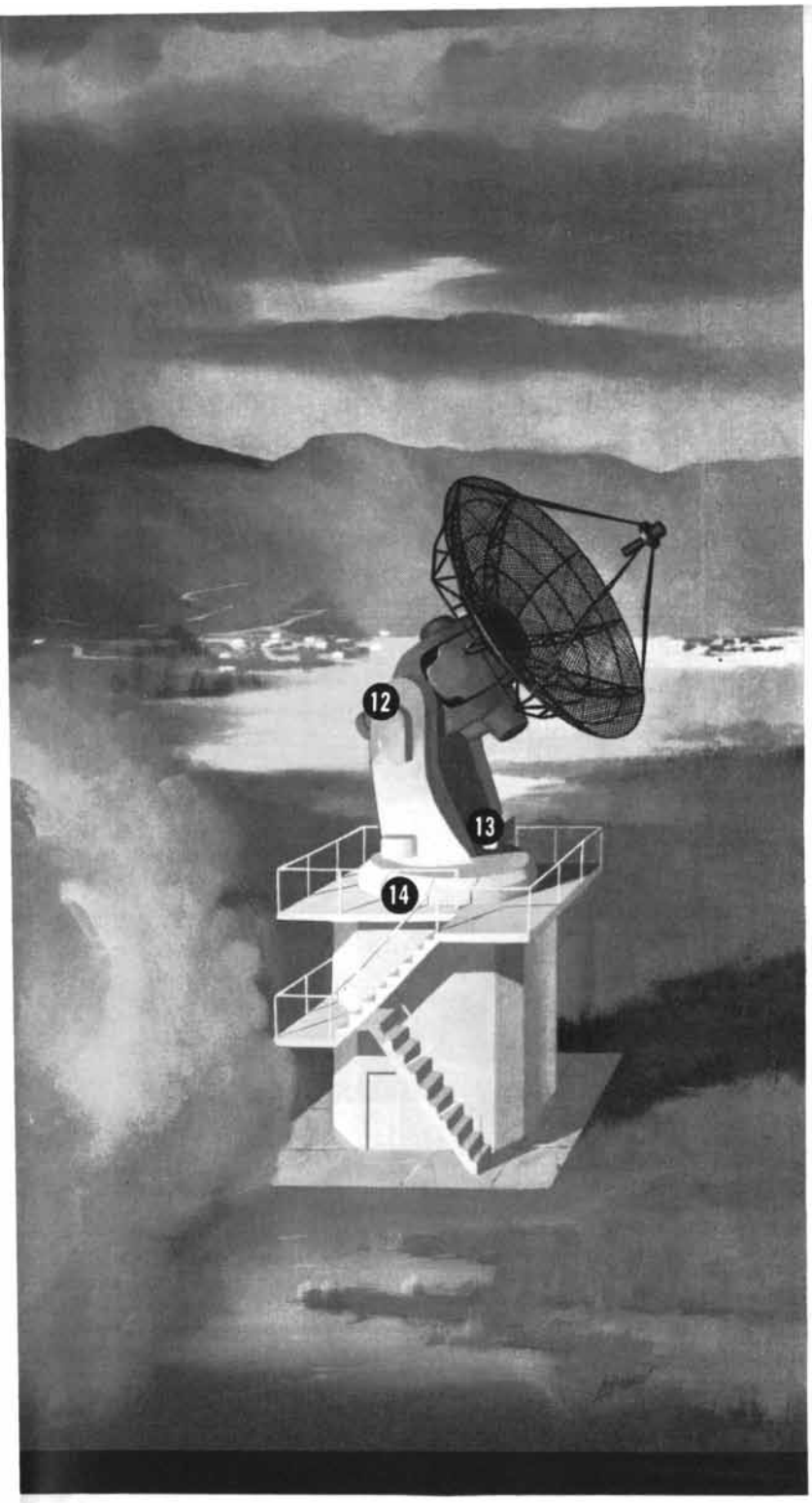
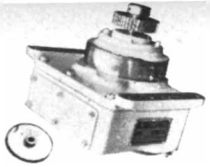


IN THE AIR...ON THE GROUND...HERE'S HOW

WESTERN GEAR

SERVES THE AEROSPACE INDUSTRY





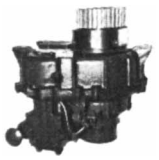
1 RADAR AZIMUTH DATA BOX

2 MAIN ANTENNA DRIVE

3 ROTARY CONTROL SURFACE ACTUATOR

4 LAUNCHER ELEVATION DRIVE

5 GUIDANCE SENSING UNIT



6 LAUNCHER AZIMUTH DRIVE

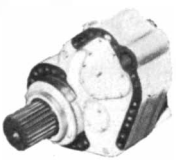
7 GUIDANCE SERVO MECHANISM

8 TURBOPUMP DRIVE

9 LINEAR CONTROL SURFACE ACTUATOR

10 TURBOPUMP DRIVE

11 NOZZLES AND THRUST COMPONENTS



12 ANTENNA ELEVATION DRIVE

13 ANTENNA AZIMUTH DRIVE

14 ANTENNA BEARING ASSEMBLY

Western Gear Precision Products like those shown might well be called the electro-mechanical brains and muscles of the space age. Western Gear supplies launcher drives, radar drives, control surface drives, servo mechanisms and super-precision assemblies to perform vital functions in everything from missiles to ground support equipment. In these areas, where there can be no substitute for absolute precision, there is no substitute for Western Gear experience—over 70 years of design and manufacturing experience. Moreover, Western Gear products must perform reliably under a range of exacting tests in the Western Gear Metrology Laboratory, acknowledged as one of the nation's finest. To meet such rigid requirements as surface finishes to .027 microns, accuracies to ten-millionths of an inch and gear tooth tolerances to 5 seconds arc, inspections are conducted with such instruments as auto collimators, air micrometers, interference microscopes and microcaters. For detailed information on products and capabilities, write Western Gear Corporation, Precision Products Division, P.O. Box 192, Lynwood, California.

WESTERN GEAR CORPORATION

WG PRECISION PRODUCTS DIVISION

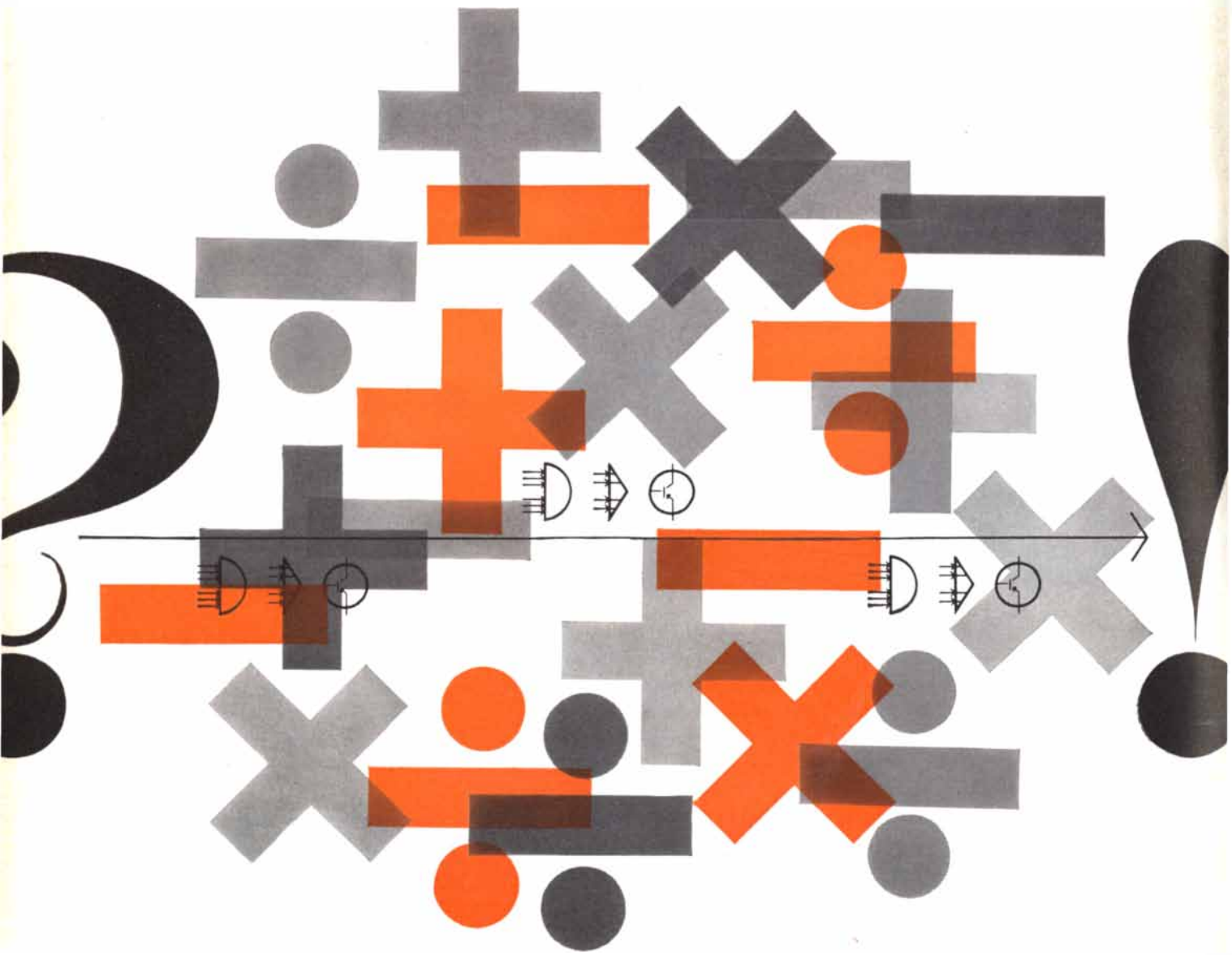
PRECISION PRODUCTS DIVISION

COMPUTENCE

total competence in computation and data processing—the breadth, the brains, and the background

The term: the essence of Burroughs Corporation, expanding the meaning of computation to new and unique dimensions for the contract team program and airborne, space, surface and underwater systems. **Its breadth:** total competence, ranging from basic research through production to the broadest field service support. **Its background:** total competence, from 75 years devoted to computation and data processing; from membership on the Polaris and Atlas teams, system-management of the ALRI team. **Its brain-children:** current crop includes the Atlas guidance computers, high-speed data processing for Polaris and miniaturized airborne computers for ALRI. **The point of purpose:** "Computence"—total competence in computation and data processing, closing in on a problem with an intensity and range all its own.

Burroughs Corporation Burroughs *"NEW DIMENSIONS / in computation for military systems"*



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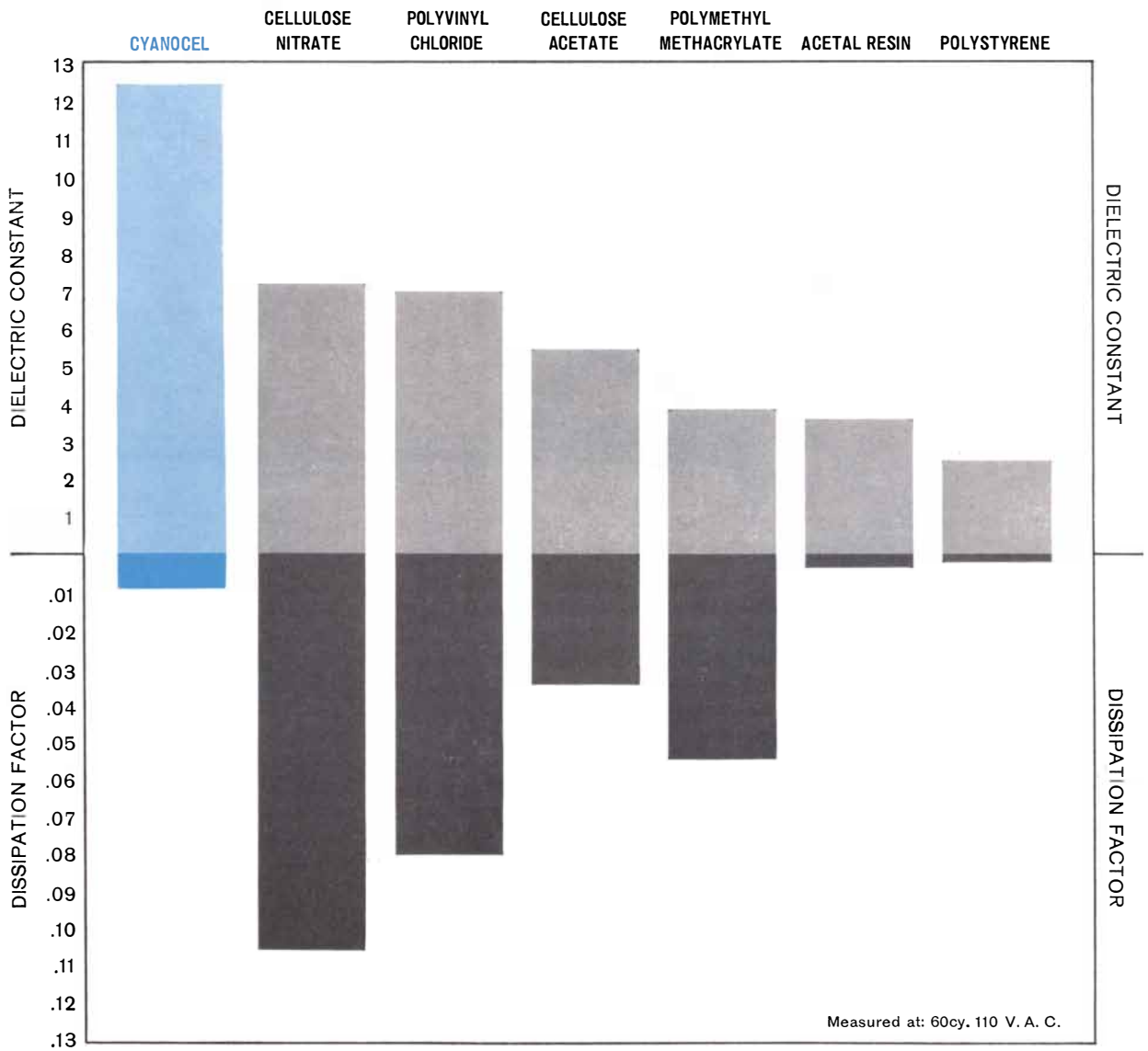

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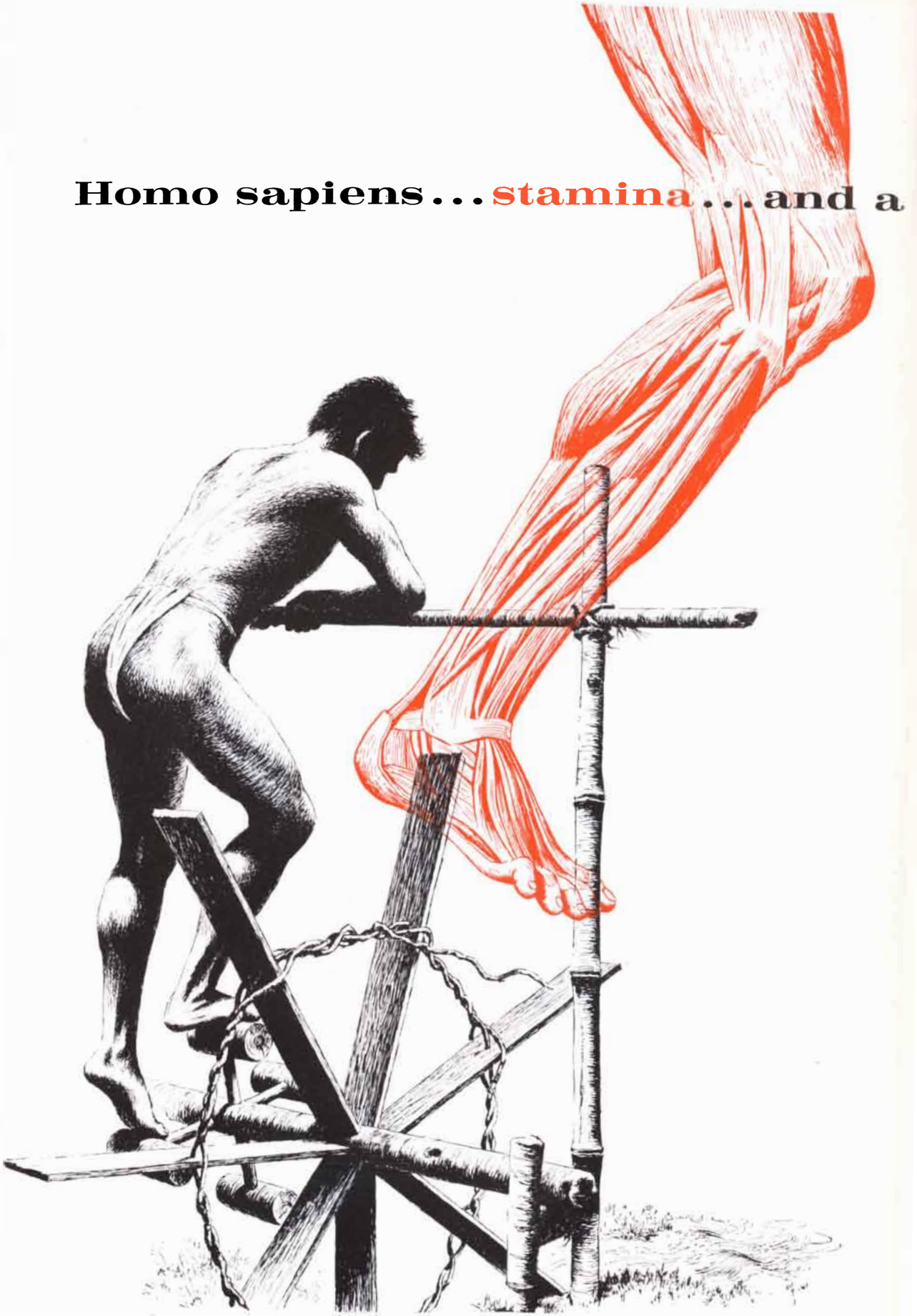
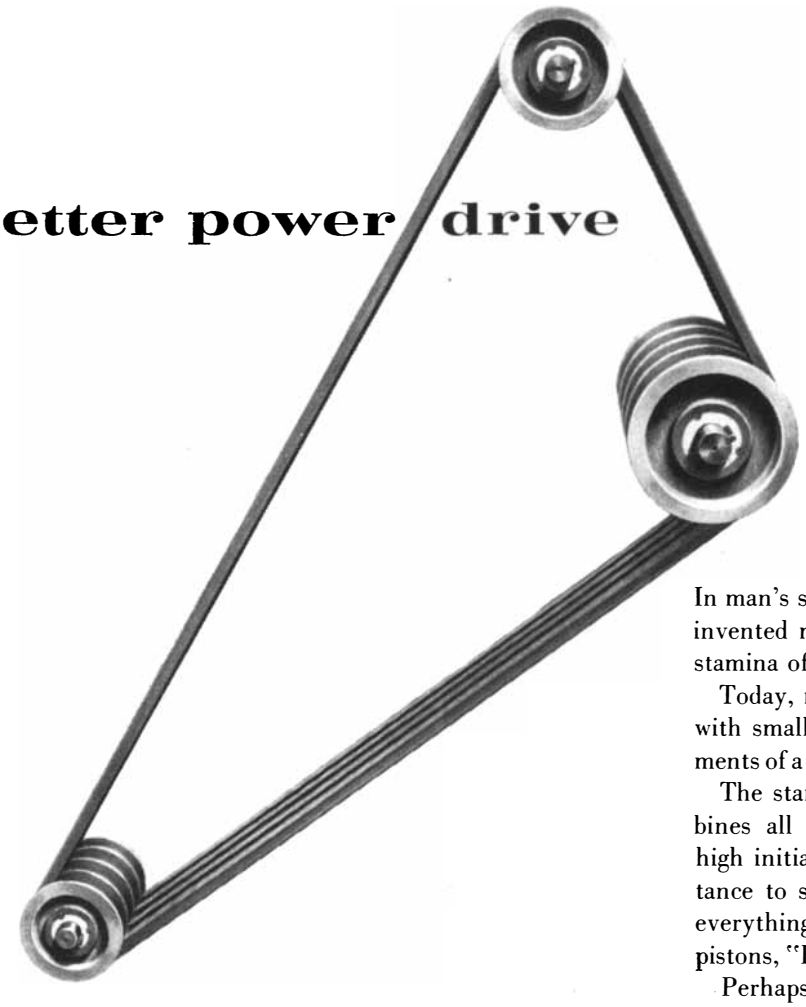
CYANAMID

Homo sapiens... stamina... and a



better power drive



In man's struggle to master his environment, he has invented machines to supplement the strength and stamina of his own muscle fibers.

Today, man boosts the efficiency of his machines with smaller, stronger V-belts, thanks to reinforcements of a synthetic fiber— "Dacron" polyester fiber.

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BETTER THINGS FOR BETTER LIVING...*THROUGH CHEMISTRY*

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23

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1910: "The successful 300-mile trip of the new Zeppelin passenger airship and the 109-mile flight of a Farman biplane with two army officers are forcible auguries of the practical utilization of both lighter-than-air and heavier-than-air craft for the carrying of passengers. The new airship *Deutschland*, piloted by Count von Zeppelin himself, carried no less than 20 passengers from Friedrichshafen to Düsseldorf in about nine hours, at an average speed of 33.33 miles an hour. The passengers were carried in a mahogany-finished cabin that had all the comforts of a Pullman car. Most significant of all, the trip was made on schedule and with all the regularity of an express train."

"One of the greatest additions to the pleasure and convenience of night motoring is an improved electric lighting system recently perfected. By means of it a greatly increased efficiency for all the lights of the auto is secured, as well as a much safer and more convenient system than has heretofore been furnished by means of gas or oil. The new system consists of a small generator having a positive drive from the engine, a load regulator and a small storage battery. The generator produces the required current to light all the lamps and also furnishes the ignition spark for the engine. If the engine is running at high speed, the load regulator diverts the excess current generated into the storage battery, thus keeping it fully charged and able to supply current for the lamps when the machine is standing idle."

"The results of the 1910 aeronautical meetings at Rheims have demonstrated the progress that has been made in the last eleven months. At the 1909 meeting the longest distance flown without coming in contact with the ground was 111 miles, accomplished by Henri Farman in his biplane. This record has been left far behind, for René Labouchère, piloting an Antoinette monoplane, covered a distance of 212 miles in a single flight. A year ago experts were amazed at the audacity of Hubert Latham, who rose to the record height of 508 feet. This year the same pilot established a height record of 4,540 feet. The fastest time in public competition a year ago was made by Glenn H. Curtiss when he flew 12.42 miles in 15 minutes 50⅘ seconds (47.04 miles per hour). This year Leon Morane flew the same distance in 12 minutes 45⅘ seconds (58.4 miles per hour). Every other speed record established last year has been wiped out of existence. In every competition the first place has fallen to a monoplane. The single plane machines were decidedly the fastest; they could fly the highest, and they were able to come forth in wind and rain that kept the biplanists in their sheds."

Scientific American.

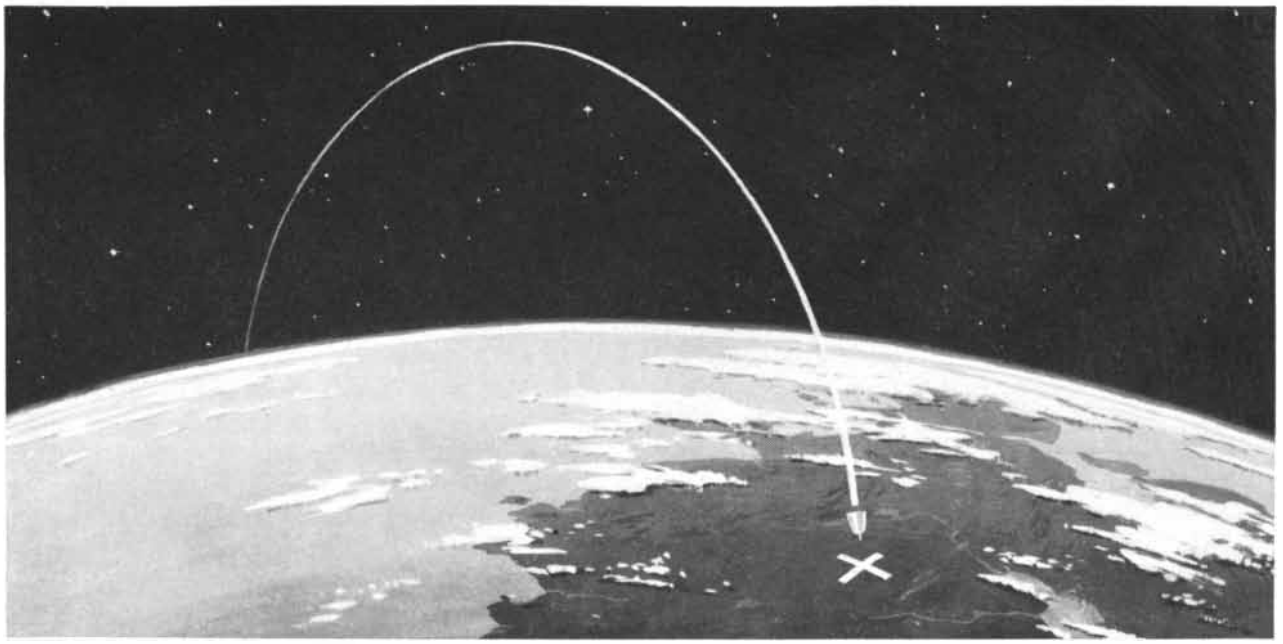
JULY, 1860: "Rickett's steam carriage, which was recently submitted to Prince Albert and the Queen, is a private carriage, with room for three persons in front and a fireman behind. It is arranged to run at an average speed of 10 miles per hour; indeed, on good roads, 16 miles per hour has been easily attained. The carriage is mounted on three wheels, one small wheel in front, for steering, and two behind, which are employed in propelling. The engine is built upon a tank, which contains 90 gallons of water, sufficient for 10 miles' run. The boiler is worked at a pressure of 150 lbs. to the square inch, and supplies steam to a pair of 3½-inch cylinders with seven-inch stroke."

"A method of employing steam, lately introduced, is the 'Wethered system.' It consists in using superheated and common steam in combination in the cylinders of engines. Mr. J. Wethered, of Baltimore, recently read a paper on the application and advantages of his system before the Institution of Civil Engineers in England. As applied to the British screw frigate *Dee*, it was stated that the result of 20 experimental voyages gave, with combined steam, 500 H.P. in the engine; with superheated steam alone, 409 H.P.; and with common steam, but 404 H.P. It was also stated that the combined steam had also been applied to a non-expansive engine, in which the consumption of fuel fell from 35 to 24 cwt. per week."

"After many disappointments, the *Great Eastern* has at last safely and slowly breasted the billows of the Atlantic and is now moored in Manhattan waters. There are three leading features connected with the *Great Eastern* which naturally excite attention. These are, first, her great magnitude—she being 692 feet in extreme length, 83 feet beam, and of 27,000 tuns actual capacity; second, her peculiarity of construction—being of iron, and double cased to about three feet above the water line, and built on the cellular principle; third, she is propelled by the combination of paddle wheels at the sides and a screw at the stern. She can carry 4,800 passengers, with good and full accommodations; or an army of 10,000 men, in a superior manner to any troop ship. The *Great Eastern* left Southampton on Sunday morning, June 17th, at 8 A.M., and arrived at Sandy Hook, outside of New York Bay, at 7:20 A.M., on Thursday, the 28th ult. Allowing for the difference of time, the actual period of passage was 11 days and 2 hours."

"It has just been ascertained that an amendment was incorporated into the civil appropriation bill, on the eve of the adjournment of the Congress, by Senator Jefferson Davis, of Mississippi, which strikes directly at the mechanical genius of the country. It positively prohibits the purchase, either by the Navy or War Department, of any patented article, however necessary it may be, for the use of those departments, without special authority of Congress, naming, at the same time, the article required. It seems to us to be an exceedingly harsh and unwise provision, because an exigency may arise in which an important invention for war purposes may be imperatively demanded, and yet it could not be purchased by either the Navy or War Department without calling a special session of Congress to make a specific appropriation for it. The idea of collecting tolls at the Patent Office from inventors, and then making a law forbidding the purchase of their inventions, is not only ridiculous but severely unjust. This law of Senator Davis's may have grown out of the fact that when he was Secretary of War he purchased Maynard's primer, at a cost to the government of $75,000, which has proved a total failure."

"The law has gone into force in New York State forbidding any person to sell or give any poisonous substance without making a record of it in a book, taking the name and residence of a witness to the sale. The penalty for disobeying it is $50 in each case."

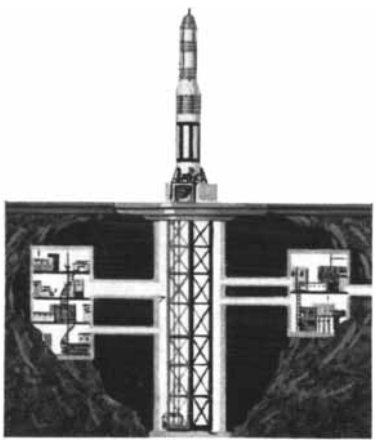


ASSIGNMENT: HIT A TARGET 6000 MILES AWAY

Can you guide a 110-ton Air Force Titan missile far up into the sky, to bring its nuclear warhead down with pinpoint accuracy on a target one-fourth the way around the globe—a target you not only can't see but which continually moves with the spinning earth?

This was the problem in missile guidance the Air Force presented to Bell Telephone Laboratories and its manufacturing partner, Western Electric. The answer was the development of a command guidance system which steers the Titan with high accuracy.

Unlike self-contained systems which demand complex guidance equipment in the missile itself, Bell Laboratories Command Guidance System keeps its master control equipment on the ground where it can be used over and over again. Thus a minimum of equipment is carried in the missile, and the ground station has full control of the missile during its guided flight. Techniques drawn from the communications art render the system immune to radio jamming.



Bell Laboratories scientists and engineers designed the transmission and switching systems for the world's most versatile telephone network, developed much of our nation's radar, and pioneered in missile systems. From their vast storehouse of knowledge and experience comes the guidance system for the Titan.

BELL TELEPHONE LABORATORIES

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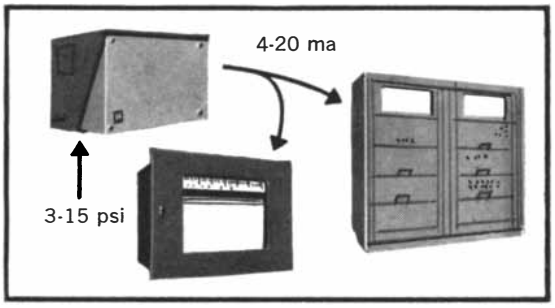
Whether you're controlling or recording

. . . now you can mix electric and pneumatic components

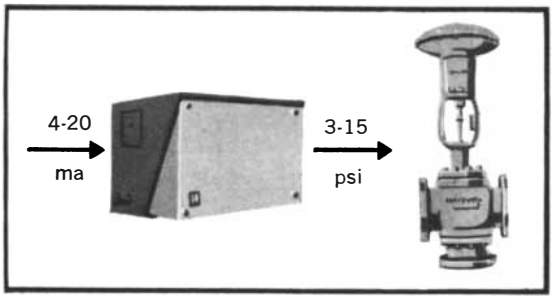
The introduction of Honeywell's complete line of *ElectriK Tel-O-Set* instruments makes electric and pneumatic components completely compatible.

Now you can add the advantages of electric instrumentation to your present *pneumatic* systems. Or, if you are designing a new system, you can use your favorite pneumatic components in an otherwise completely electric system.

Here's an example: You have a pneumatic system but want to record a key variable on an *ElectroniK* strip chart recorder. The answer is an *ElectriK Tel-O-Set* pressure-to-current (P/I) transducer which converts the standard 3-15 psi signal to a standard 4-20 ma signal which can be fed to a data logger or computer as well as to a potentiometer.

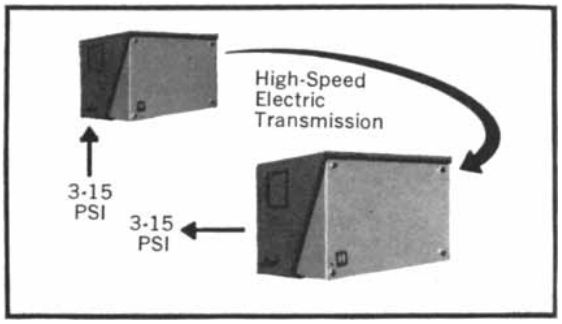


Now let's assume that you are putting in an all-electric system but prefer pneumatic control valve operators. Here the answer is an easily installed *ElectriK Tel-O-Set* current-to-pressure (I/P) valve operator which converts the standard 4-20 ma signal to a standard 3-15 psi signal.



Used separately, *ElectriK Tel-O-Set* transducers allow you to easily intermix electric and pneumatic components. Used together, in pneumatic loops, they give you long distance high-speed transmission and eliminate the lags inherent in long runs of pneumatic tubing.

75th YEAR PIONEERING THE FUTURE



These twins have a calibrated accuracy of ± ¼% of span. They're completely transistorized for long, reliable service. Only two wires, forming a series circuit between the two transducers, are needed to carry the signal as well as the system's power. Line power is not required in the field.

Transducers are just part of the story. *ElectriK Tel-O-Set* transmitters are available to convert temperature, pressure, differential pressure, and other process variables into a current signal. To complete your system, you have a wide choice of different types of electric control . . . readouts including meters, indicators, and large case recorders . . . and final control elements.

Get complete details from your nearby Honeywell field engineer. Call him today . . . he's as near as your phone.

MINNEAPOLIS-HONEYWELL, Wayne & Windrim Avenues, Phila. In Canada, Honeywell Controls Limited, Toronto 17, Ont.

Honeywell

First in Control

SINCE 1885

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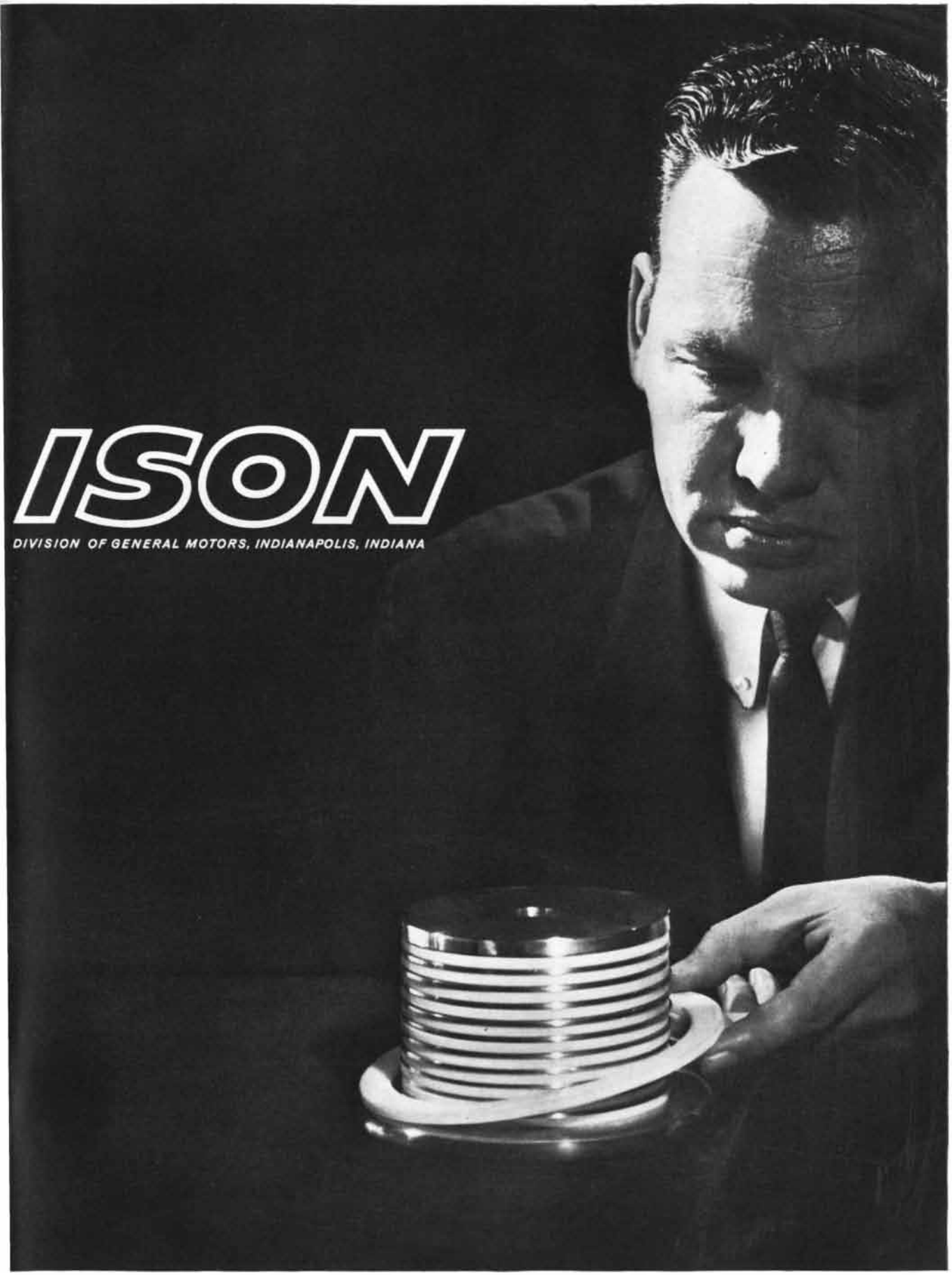
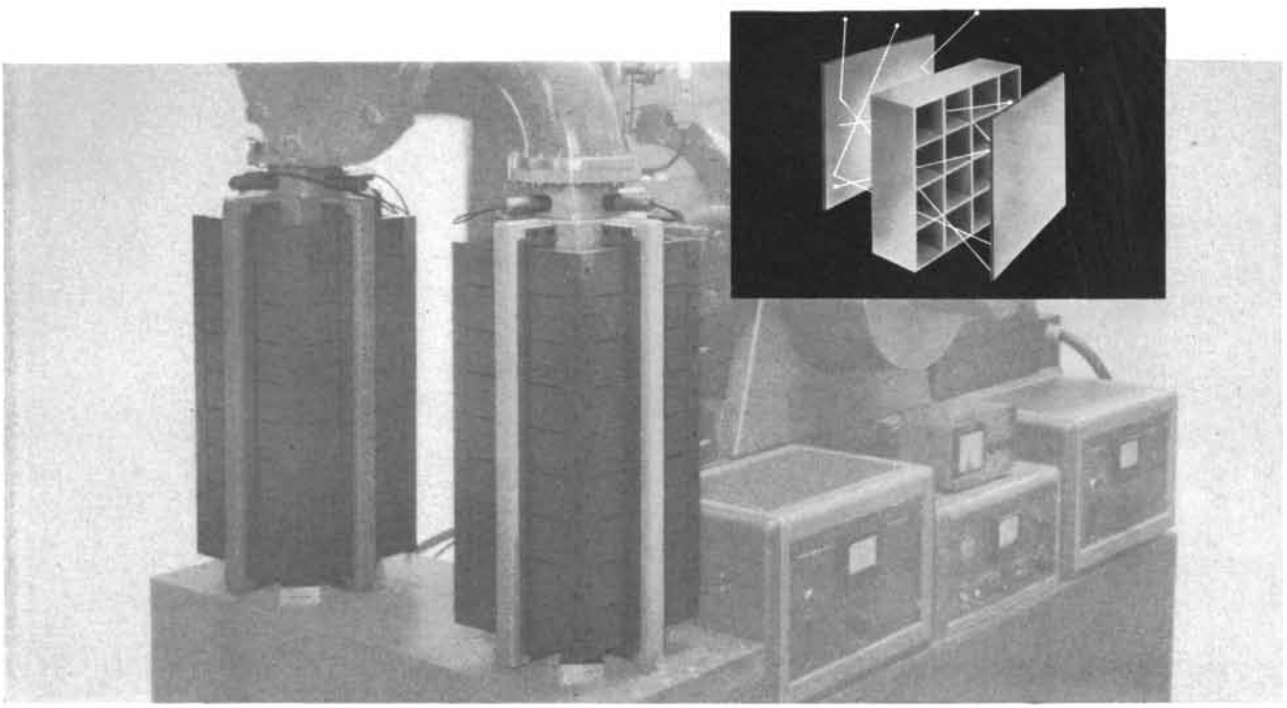


THE VALUE OF INCIDENTAL DISCOVERY



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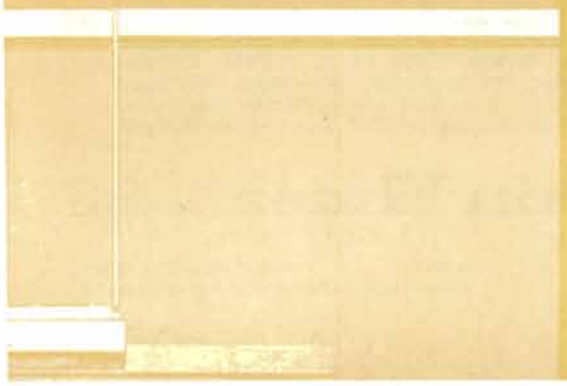
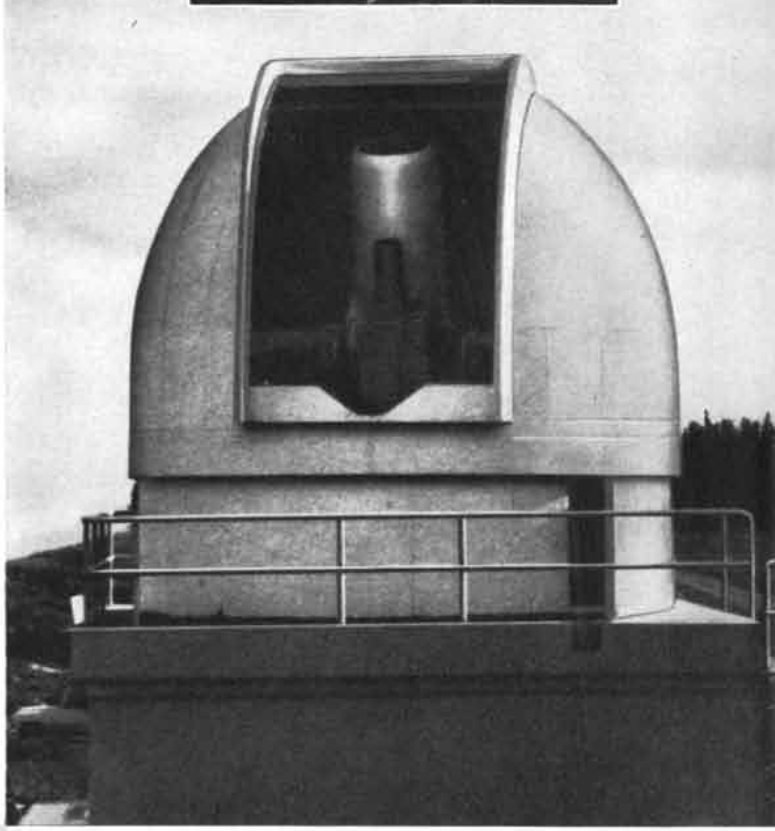


THE P-E SPECTRUM

news of advanced systems and instruments from Perkin-Elmer



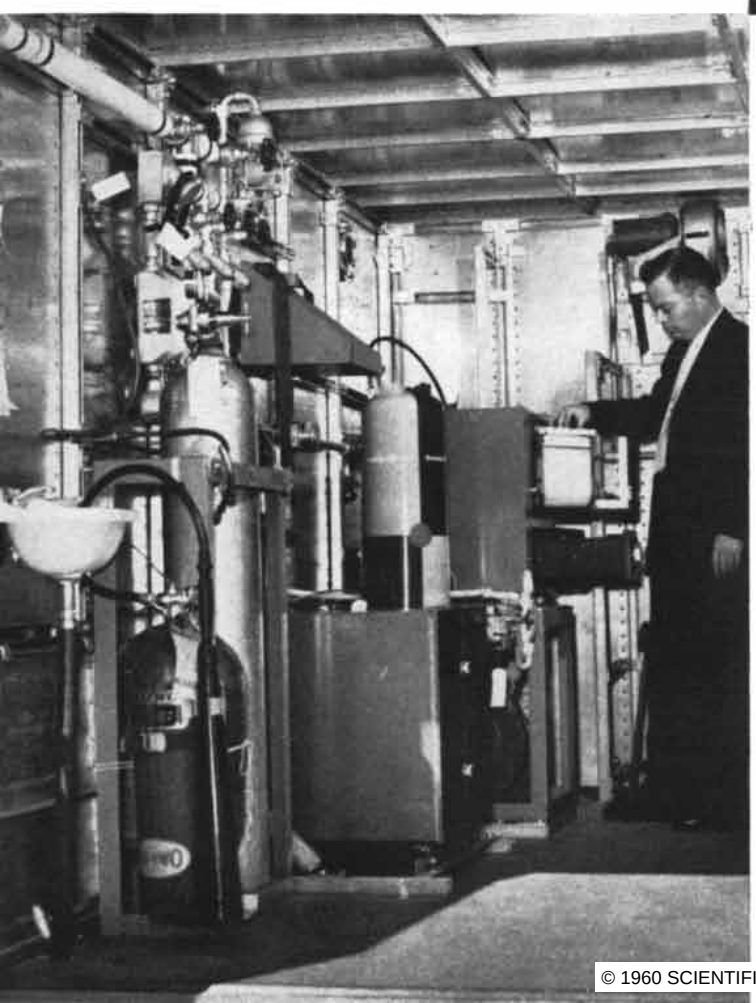
P-E'S TRACKING SYSTEM AND IR RAPID SCAN TEAM UP FOR IN-FLIGHT SPECTRAL STUDIES OF MISSILES

Spectrometric studies of in-flight missile plumes are currently being made on the Atlantic Missile Range by Perkin-Elmer in a project under contract from the Air Force Cambridge Research Center.

Data on the missile flights are obtained with a combination of two P-E systems: A ROTI (Recording Optical Tracking Instrument) tracks and photographs the missile in flight; simultaneously, an IR Rapid Scan System measures the spectral characteristics of the missile's plume. (Both instruments can be seen at right, in place in an observation dome, and in close-up.)

IR Rapid Scan, a new concept developed by P-E over the past several years, has made the present studies possible. Basically it is a spectrometer designed to analyze a particular wavelength region of the spectrum in very short periods of time. With it, progressive spectra of a reaction (such as burning rocket fuel) can be obtained while the reaction is going on, and a record can be obtained of various components throughout the course of the reaction.

While the potential of this method is only just beginning to be recognized, information gained from measurements of this kind could be pertinent to such advances as the development of more efficient fuels and engines, development of homing systems for anti-missile-missiles, improvement of nose cones, and even for the development of characteristic missile "signatures" for detection and identification.



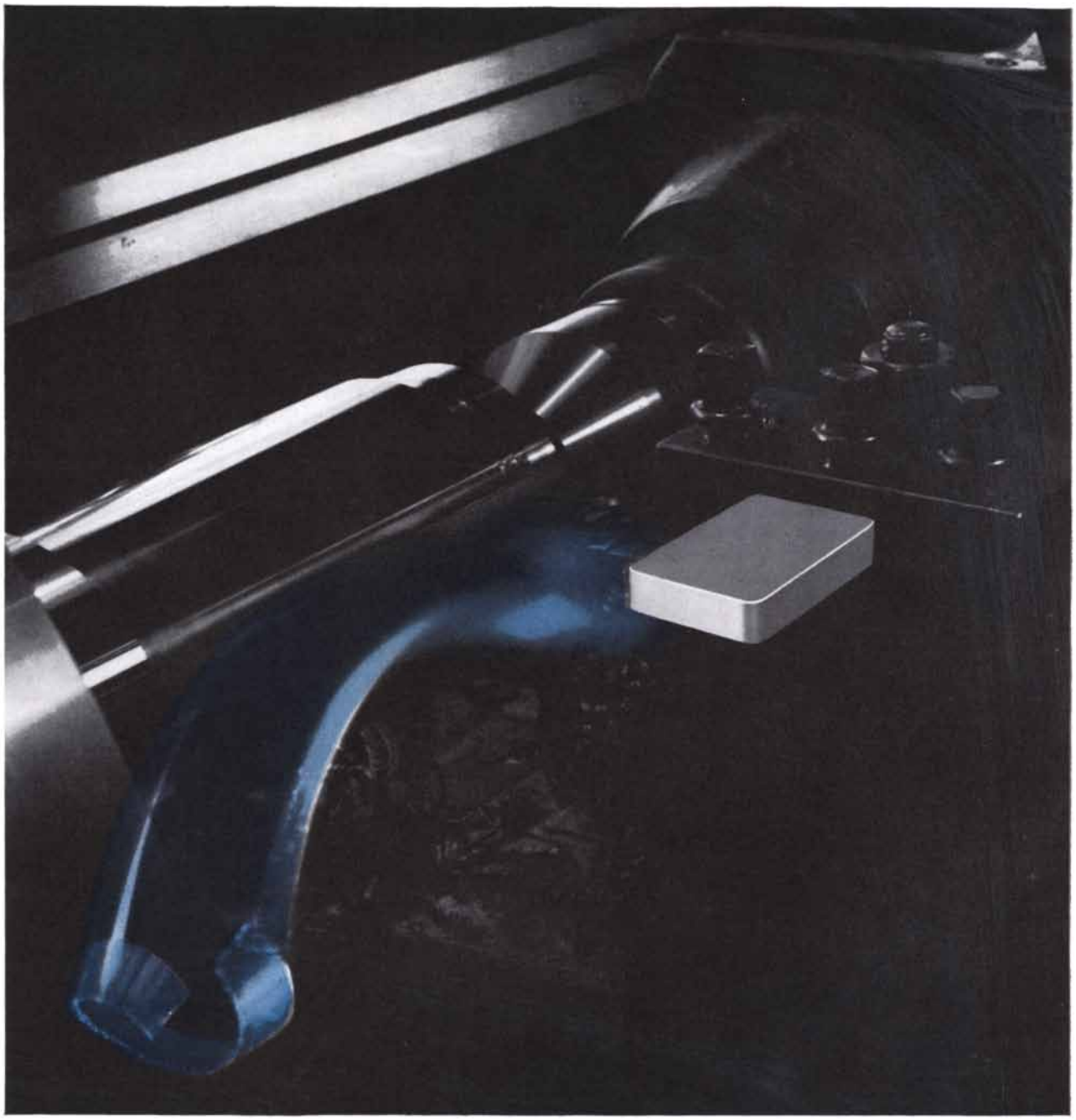
PORTABLE LAB EXPLORES APPLICATIONS FOR CONTINUOUS STREAM ANALYZERS

Taking a cue from Mohammed and his mountain, Esso Research and Engineering Co. has come up with a unique answer to the problem of distance. It has designed a portable laboratory to be shipped to the parent company's refineries for on-the-spot exploration of possible new process analyzer applications.

The new unit, housed in an aluminum truck body, was built by Perkin-Elmer to Esso specification. Heart of the unique lab is a P-E Process Vapor Fractometer, which continually monitors, qualitatively and quantitatively, up to 12 components in a process stream.

At each location, Esso hopes to document the economies of successful analyzer applications as well as establish where analyzers should be installed. This will be done by comparing *before* data with data taken *after* analyzer results have been used for corrective action.

* * * *



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Here you see one more example of the remarkable things ceramics can do when ceramists mix imagination with Alcoa Aluminas. To discover others, send for our booklet, *Ceramics —Unlimited Horizons*. Aluminum Company of America, Chemicals Division, 701-G Alcoa Building, Pittsburgh 19, Pa.

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THE AUTHORS

BORIS V. DERJAGUIN ("The Force between Molecules") is the founder and director of the Laboratory of Surface Forces in the Institute of Physical Chemistry of the Soviet Academy of Sciences. He has held the title of Academician since 1946. From 1935, when he founded the Laboratory of Surface Forces, until 1941 he worked with Academician M. M. Kusanov investigating the forces involved in the coagulation of material suspended in solution. His studies have included the molecular theory of friction and the theory of adhesion of particles. He is 58 years old.

D. E. BLACKWELL ("The Zodiacal Light") has since 1949 been assistant director of the Solar Physics Observatory at the University of Cambridge. In October he will become Savilian Professor of Astronomy at the University of Oxford. He was born in 1921, attended Merchant Taylors' School and took his degree in physics at Sidney Sussex College in Cambridge. After studying physiological optics for three years at the Royal Aircraft Establishment in Farnborough, he returned to Cambridge to work on infrared spectroscopy and the properties of diamond, and acquired his Ph.D. in 1949. "Most of my astronomical work," he explains, "has been done on expeditions from England. In 1952 I went to Khartoum to observe the total eclipse, and I saw the zodiacal light there for the first time. In 1954 I observed the total eclipse from an open R.A.F. aircraft flying at 30,000 feet near the Faroe Islands." Blackwell was aboard a seaplane near the Fiji Islands during the 1955 eclipse, but clouds prevented observation. Accompanying D. W. Dewhirst and A. Dollfus, he made two 18,000-foot balloon flights from Paris to photograph the sun under good atmospheric conditions. Blackwell's latest astronomical expedition took him to the Andes in 1958, and he plans another journey for this year.

S. S. BRENNER ("Metal 'Whiskers' ") is a member of the metallurgy and ceramics research department at the General Electric Research Laboratory in Schenectady, N. Y. A native of Nuremberg, Germany, he went to England in 1939 at the age of 12, and came to the U. S. in 1940. From 1945 to 1947 he was in the Army. Then he went to the Massachusetts Institute of Technology, where he took his B.S. in metallurgy in 1951. He had intended to become a practicing foundry-metallurgist, but, he reports, "after spending the summer of 1950 doing research at Brookhaven National Laboratory, I decided that research would be more to my liking." He joined the General Electric Laboratory in 1951 and has done experimental work on corrosion, electrochemistry, crystal growth and the mechanical properties of solids. He also studied in the evening division of Rensselaer Polytechnic Institute, which awarded him a Ph.D. in 1957. Brenner entered the whisker field, he says, "about six years ago, shortly after iron whiskers were accidentally discovered in our laboratory."

EGON GLESINGER ("The Mediterranean Project") is director of the Forestry and Forest Products Division of the United Nations Food and Agriculture Organization in Rome and leader of the group responsible for the imposing program that is the subject of this article. Glesinger was born in 1907 in Austria and attended school in Austria and Czechoslovakia. He graduated in business administration at the University of Geneva in 1928, received a doctorate in law at Prague in 1929 and a doctorate in social science at the Geneva Institute for International Studies in 1932. His thesis was on European forests. From 1933 to 1940 Glesinger was secretary-general of the International Timber Committee, a League of Nations body. For help with the present article he wishes that special acknowledgement be made to his colleagues Daphne Wilson and Luis Gimenez-Quintana.

JOSEPH J. KATZ ("The Biology of Heavy Water") is a senior scientist at the Argonne National Laboratory. He was born in Detroit in 1912, took his B.S. in chemistry at Wayne State University in 1932 and his Ph.D. at the University of Chicago in 1942. He joined the Metallurgical Laboratory in Chicago, and since World War II has been a member of the chemistry division of its successor, the Argonne National Laboratory. In 1955 he served as a technical advisor to the U. S. delegation to the United Nations Conference on the Peaceful Uses of Atomic Energy. Wayne State honored him in 1955 with its Distinguished Alumnus Award. During 1956 and 1957 he held a Guggenheim Fellowship to the University of Cambridge. In addition to his work on the effects of deuterium on living organisms, he has carried out extensive researches on uranium and on transuranium elements and is the co-author and co-editor of several standard works on the subject.

ERIC DENTON ("The Buoyancy of Marine Animals") is a physiologist on the staff of the Marine Biological Association Laboratory in Plymouth, England. He acquired his degrees at the University of Cambridge and University College London. His field was physics, and during World War II he worked on aircraft radar. "At the end of the war," he reports, "I had the good fortune to be one of three young physicists taken on by A. V. Hill, the physiologist who is one of England's kindest as well as greatest scientists. He at once sent me down to Plymouth 'to learn biology through the skin.' This period was followed by seven happy years with E. W. H. Cruickshank at the University of Aberdeen, Scotland, and one year in Paris with Y. Le Grand."

DOUGLAS W. SCHWARTZ ("Prehistoric Man in Mammoth Cave") is associate professor of anthropology and director of the Museum of Anthropology at the University of Kentucky. He was born in Erie, Pa., in 1929 and acquired his Ph.D. at Yale University in 1955. His explorations of the Grand Canyon, begun in 1949, resulted in an article "Prehistoric Man in the Grand Canyon," which appeared in SCIENTIFIC AMERICAN for February, 1958. Grants from Yale and the Wenner-Gren Foundation helped him pursue his studies of the Canyon, which continue. After receiving his Ph.D., he taught for a year at the University of Oklahoma. He has been at Kentucky since 1956. Three research contracts from the National Park Service enabled him to investigate the prehistory of Mammoth Cave and the surrounding area.

MILTON A. ROTHMAN ("Things That Go Faster Than Light") is a research physicist at Project Matterhorn, which is investigating fusion power at Princeton University. He was born in Philadelphia in 1919 and obtained his B.S. degree at Oregon State University in 1944, his M.S. at the University of Pennsylvania in 1948 and his Ph.D. in physics at Pennsylvania in 1952. From 1952 to 1959 he was associated with the Bartol Research Foundation in Swarthmore, Pa., where he investigated nuclear energy-levels by means of inelastic neutron scattering. In 1959 he went to Project Matterhorn. There he studies methods of heating an ionized gas to very high temperatures.

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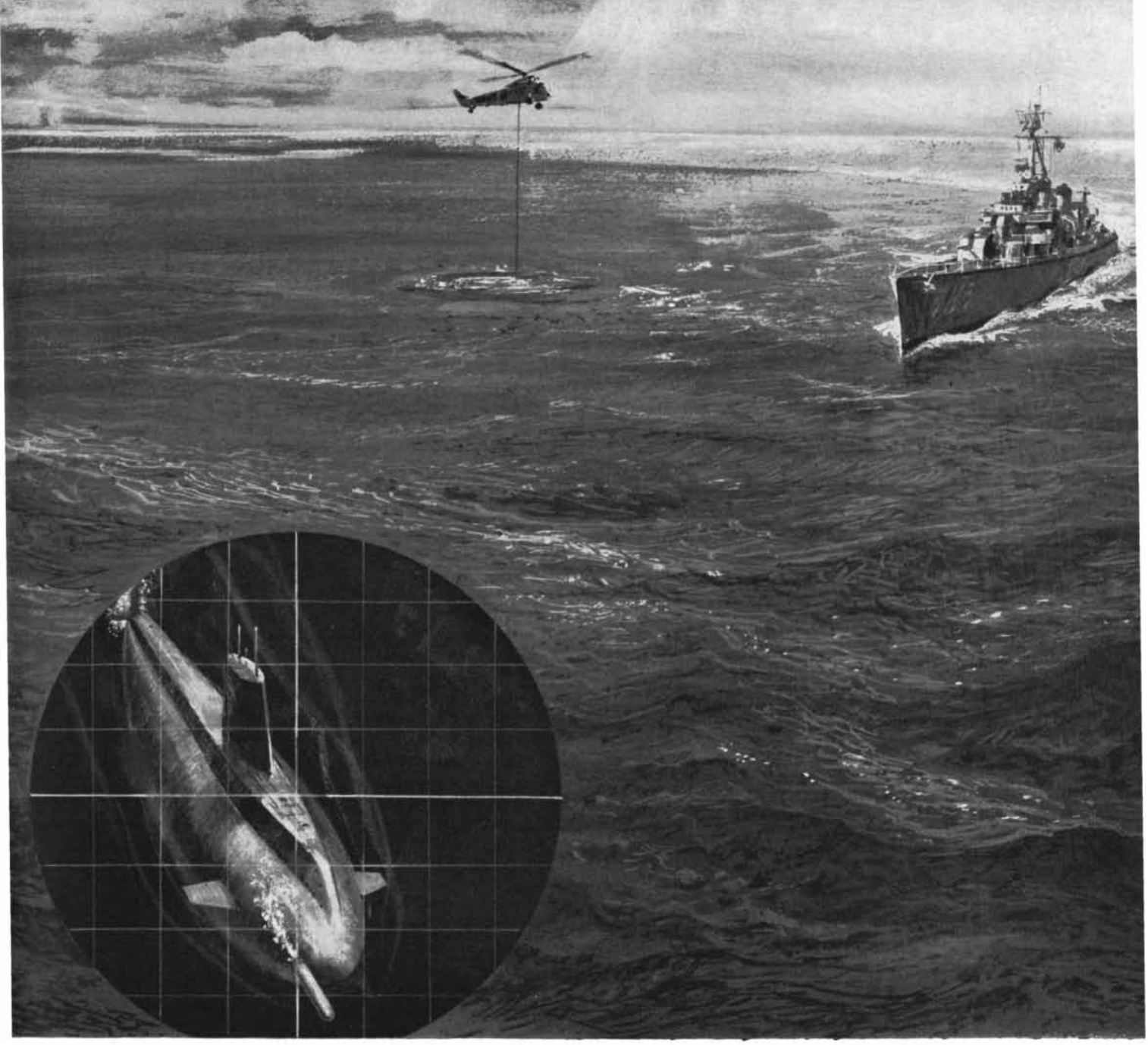

The challenge of silence

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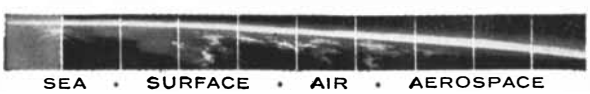

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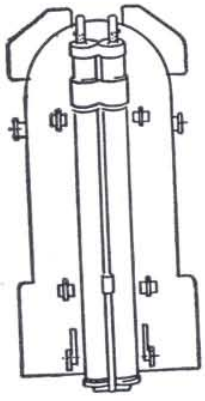

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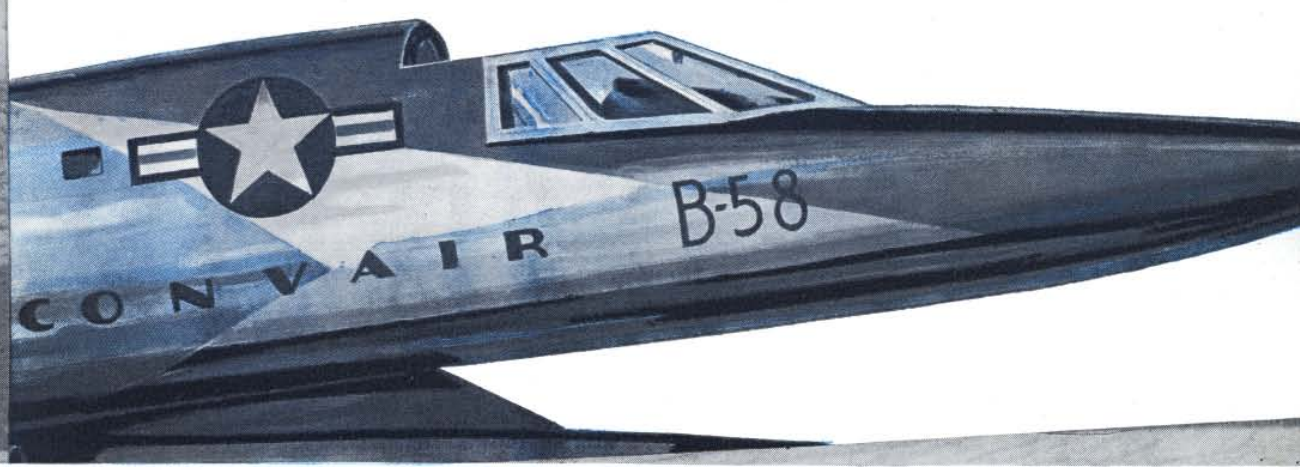

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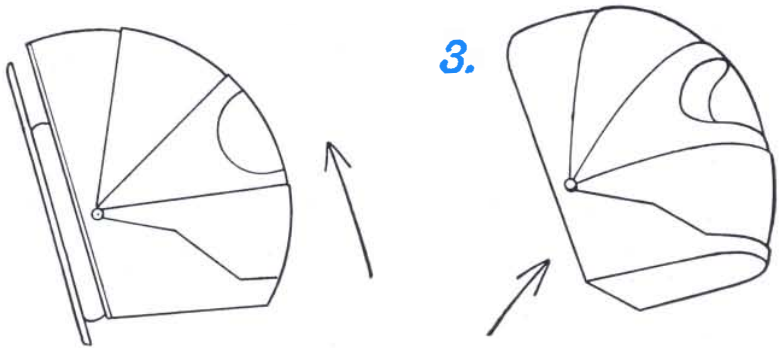

$$m\ddot{y} = F_Y - \alpha W \cos\chi - \mu(|N_1| + |N_2| + |N_3|) + F_E + F_R \cos\phi \quad \cdots\cdots \quad y \ll (l_n - d_z)$$

$$I_B\ddot{\theta} = M + F_Y d_{11}\cos(\beta+\theta) + F_X d_{11} \sin(\beta+\theta) - F_R d_B \sin(\phi-\theta) - \alpha W d_{12}\cos(\chi+\lambda+\theta) - m\ddot{y} d_{12}\cos(\lambda+\theta)$$

$$m[\ddot{y} + d_{12}\ddot{\theta}\cos(\lambda+\theta) - d_{12}\dot{\theta}^2 \sin(\lambda+\theta)] =$$

$$\underline{V}_C = iu + jv + kw$$

$$\underline{\Omega}_C = ip + jq + kr$$

$$F = m\frac{(\delta \underline{V}_C)}{(\delta t)}$$

$$F_X = m(\dot{u} + wq - vr)$$

$$F_Y = m(\dot{v} + \dot{u}r - wp)$$

$$F_Z = m(\dot{w} + vp - uq)$$

Fig. 1. Pilot sits and works in escape unit. THIOKOL two-barrelled catapult powered by dual rocket engines attached to back of capsule.

Fig. 2. At start of escape cycle, THIOKOL slow burning propellant activates catapult. Acceleration control built into propellant saves occupant from injury. Capsule is propelled from airframe.

Fig. 3. Rocket motors, ignited automatically at end of catapult stroke, propel capsule to safe area above airframe—clear of vertical tail. In high or zero altitude escape, capsule attains sufficient height for parachute to open and arrest fall.

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Max Planck...on problems

"The world is teeming with problems. Wherever man looks, he encounters some new problem — in his home life and in his job, in economics and in technology, in the arts and in the sciences. And some problems are very stubborn; they refuse to leave us in peace. They torture our thoughts, sometimes haunting us throughout the day and even robbing us of sleep at night. If by lucky chance we succeed in solving a problem, we experience a sense of deliverance and rejoice over the enrichment of our knowledge. But it is a different story, and highly annoying, to discover after tedious efforts that the problem is incapable of solution — either because there exists no indisputable method of solving it or, because soberly looked at, it is void of meaning — a *phantom problem* on which our labors and thoughts were wasted. There are a good many such phantom problems — in my opinion, far more than is ordinarily assumed — even in the sciences."

— *Scheinprobleme der Wissenschaft, 1947*

Established 1845 SCIENTIFIC AMERICAN July, 1960 Volume 203 Number 1

The Force between Molecules

Its nature has long been a mystery. Physicists in the U.S.S.R. have now succeeded both in measuring the intermolecular force and in demonstrating that it is purely electromagnetic in origin

by Boris V. Derjaguin

One of the great traditions of science has been the study of the forces that hold the parts of the material world together. The tradition runs from Isaac Newton's work on gravity and celestial mechanics to the modern examination of the nucleus of the atom. In this long line of inquiry there has been, until very recently, an odd gap. The smallest units of matter, in its everyday forms, are molecules; and the force between molecules determines many characteristics of the substances with which we are familiar. Yet physicists have been unable either to measure intermolecular forces experimentally or to deduce them from theory.

These forces are not the chemical attractions, or valence bonds, that link atoms in compounds. They are forces of longer range that draw together the molecules of solids and liquids, and, to a much smaller extent, of gases. Valence forces can be "saturated"; when the available bonds of an atom are fully satisfied by attachment to its partners in a compound molecule, it exerts no force on other neighboring particles. Thus the oxygen atoms in two molecules of water do not attract each other. On the other hand, every molecule in a sample of water exerts some attraction on every other molecule.

Without these long-range forces there would be no sharp boundary between liquids and their vapors. Intermolecular forces are responsible for surface tension, capillary action, adsorption and other surface phenomena. They determine most of the properties of liquids: viscosity, heat of evaporation, solubility in other liquids. They cause colloids to coagulate. Each of these phenomena has been intensively studied for years. But without an understanding of their underlying principle there could be no fundamental and unifying theory.

In the U.S.S.R. during the past few years there have been two significant break-throughs. Irene Abrikossova and the author have succeeded in measuring the molecular force directly. Following this development the theoretical physicist E. M. Lifshitz derived a mathematical formula for the force of molecular attraction from very general principles.

To put these developments in proper perspective let us begin with some history. The earliest speculations about molecular forces were those of the 18th-century French mathematicians Alexis Claude Clairaut and Pierre Simon de Laplace. Theirs was the triumphant era when Newton's law of universal gravitation seemed capable of explaining the motions of heavenly bodies down to the minutest detail. By analogy with gravity Clairaut and Laplace assumed the existence of an attractive force acting along the line between the centers of molecules. It was apparent, however, that such a force must fall off not as the square of the distance of separation, as in the case of gravity, but more sharply. Furthermore, the constant of proportionality could be different for different molecules.

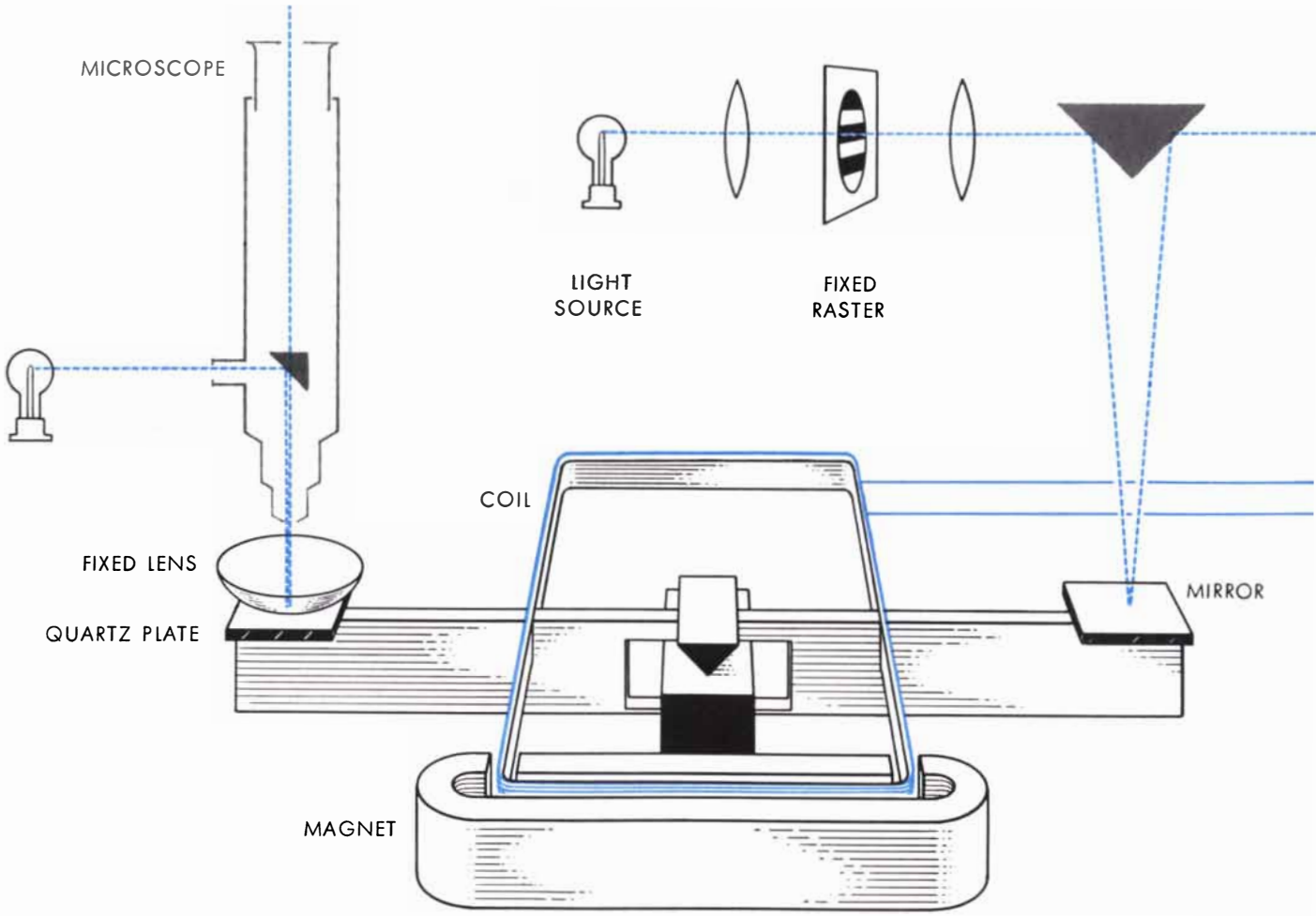
In arithmetical terms Newton's law contains the fraction G/r^2, where G is the constant of proportionality. What makes gravity comparatively easy to deal with is that G is a universal constant whose value is determined for all masses simply by measuring the force between any two known masses at any known distance (r). On the other hand, the assumed law of molecular force has the form C/r^n, where both C and n are unknown, and where C presumably differs for different kinds of molecules. It is of course impossible to pick out two individual molecules, hold them at a known distance and measure the force between them. Hence the unknowns cannot be directly determined. Nor, it turns out, can they be determined indirectly through bulk properties that depend on molecular forces. Measurements of surface tension and similar quantities cannot even settle the power law, let alone establish the constant C. No real progress could be made without a better theoretical platform from which to attack the problem.

At the end of the last century it seemed that the classical theory of electromagnetism could provide such a platform. The laws governing electric and magnetic fields and their interactions with material bodies had been worked out. Molecules were known to be composed of electrically charged particles. The visible radiation given out by

molecules had just been proved to be electromagnetic waves. Perhaps electromagnetism could account completely for the intermolecular force. (It should be realized that this was just an assumption. It was also possible that some new force, previously unknown, might come into play at the molecular level, as has since proved to be the case at the nuclear level.)

One of the first workers to see clearly the implications of electromagnetic theory was the Russian physicist P. N. Lebedev, best known as the first experimenter to measure the pressure exerted by light. In 1894 he wrote, with prophetic insight: "Hertz's research into the interpretation of light waves as electromagnetic processes conceals another problem, as yet untouched. This is the problem of a radiation source, of those processes which a molecular vibrator undergoes when it emits light energy to its surroundings. On the one hand this problem leads into the field of spectroscopic analysis. On the other hand, almost entirely unexpectedly, it leads to one of the most complicated questions of modern physics, the science of molecular forces. This situation results from the following concepts. From the point of view of the electromagnetic theory of light one may state that two radiating molecules are two vibrators in which electromagnetic vibrations are excited. They must therefore experience forces resulting from the electromagnetic interactions of the varying electrical currents (according to Ampère's law) and varying charges (according to Coulomb's law) in them. We may therefore also assert that there must then exist molecular forces whose origin is directly related to radiative processes. . . . The most interesting as well as the most complicated case is that of a physical body in which many molecules act simultaneously on one another and are so closely packed that their vibrations are not independent. If it ever becomes possible to solve this problem completely, we will be able to use spectroscopic data to predict the magnitude of the molecular forces due to the mutual radiation of the molecules, to calculate the temperature dependence of these forces, and by comparing these calculated quantities with experiment to solve the problem at the root of molecular physics. This problem is whether all so-called molecular forces reduce to the already known and above-mentioned action of radiation—to electromagnetic forces—or whether they involve other forces whose source is still unknown."

Lebedev came as close to the latest views on the nature of molecular forces as was possible before the development of quantum mechanics. But his statement, while ahead of its time, was very far from a quantitative law. As so often happens in science, the next step was backward. The first quantitative theories of molecular forces treated them as entirely electrostatic rather than electromagnetic. These static theories began to be developed shortly after



CONTROLLED BALANCE for measuring the molecular attraction between macroscopic bodies is illustrated schematically. The broken colored line at left is the path of the light beam used to determine the width of the gap between the bodies. The broken colored line at top right is the path of light beam by which the position of the balance arm is set and automatically stabilized. Solid

Ernest Rutherford, by his discovery of the nucleus, showed how electric charge is distributed in the atom. However, they did not reach their final form until 1930, when the German physicist Fritz London applied to them the newly discovered principles of quantum mechanics.

According to London's theory, the force between two molecules is C/r^7. The force varies inversely as the seventh power of the distance between their centers. The constant C depends on certain electrical properties of the molecules, including their "polarizability." This measures the degree to which an electric field distorts a molecule, shifting its electrons with respect to the positive nuclei of its atoms.

Unfortunately the polarizabilities of individual molecules are themselves unknown quantities, so we cannot use London's formula to calculate the absolute value of the force. If it were possible to compare molecular forces at various distances, the seventh-power law could at least be tested, but for a long time there was no way of doing this either. Attempts were made to verify the formula indirectly, for example by measuring the amount of heat energy required to vaporize a liquid (*i.e.*, pull its molecules apart). However, it can be proved that most of the energy is used up in the interval when the molecules are still within a diameter or two of each other. At such close distances London's theory is not strictly applicable, and even the concept of distance between molecules (which are not really spheres) is not clearly defined.

Despite the lack of experimental confirmation, or perhaps because of it, the London theory was generally accepted for almost 20 years. Yet it was clearly unrealistic for large distances of separation as well as for very small ones. Being an electrostatic theory, it regarded force as communicated instantaneously between molecules. In fact electric forces travel at the finite speed of light (186,000 miles per second).

Now the "large" distances just mentioned are large only compared with molecular diameters. On the everyday scale of distance the attractive force between molecules falls away to essentially nothing at a very small separation indeed—a few ten thousandths of a millimeter. The time required by an electromagnetic impulse to travel such a distance is of the order of a ten-million billionth of a second. How can so tiny an interval make a difference in the force?

To understand this let us recall Lebedev's picture of "molecular vibrators" sending out radiation. The molecules are like radio antennas in which oscillating electric charges emit a train of electric and magnetic vibrations. When the vibrations from one antenna reach a second, they set its charges into oscillation. These oscillations become in turn a source of waves that reach back to the first antenna, exerting a force on its moving charges. Thus the two antennas interact by exchanging radiation. The strength of the interaction varies with the relative phase of the arriving waves and the oscillating charges; the interaction is stronger if the waves and particles swing back and forth together rather than being totally or partially out of step. But the relative phase depends on the distance between antennas and on the frequency of the vibrations; in other words, on the number of wavelengths in the distance of separation. If, for example, the antennas are half a wavelength apart, the emitted and absorbed waves will be exactly out of phase. At smaller (or larger) fractions of a wavelength the shift will be correspondingly less. At very small fractions of a wavelength the phase shift is negligible.

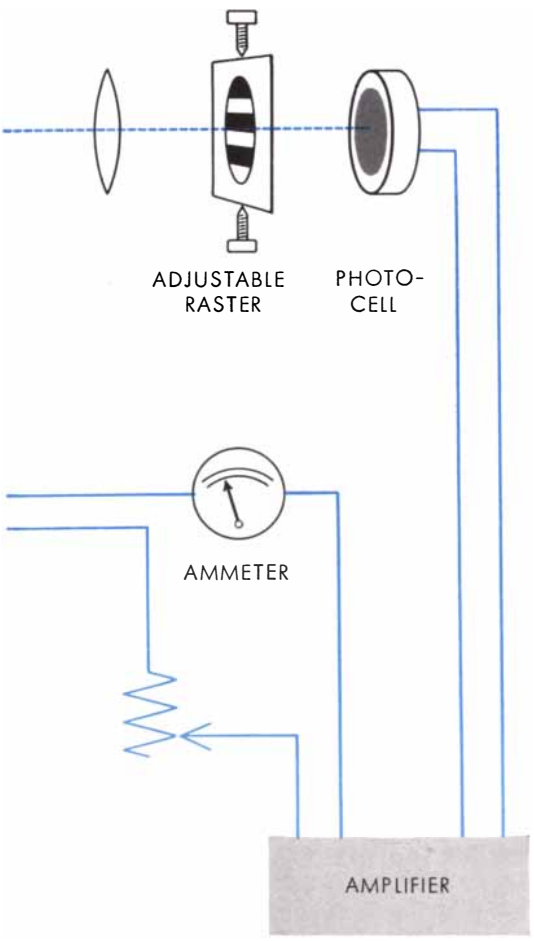
The wavelength of most radio waves is measured in meters or centimeters. But the radiation sent out and absorbed by molecules are light waves, only a ten thousandth of a millimeter long. Thus if two molecules are separated by a ten thousandth or even a hundred thousandth of a millimeter, there will be considerable phase shift in the exchanged radiation. The shift must be considered in computing the force.

The first theoreticians to take the phase shift into account in their calculations were the Dutch physicists H. B. G. Casimir and D. Polder, who worked out an electromagnetic theory of molecular force in 1948. In their calculations they did not, of course, use the classical picture of radiation that we have just outlined but rather the ideas of quantum electrodynamics. These differ from the older view in two important respects. First, molecules do not radiate (or absorb) continuously, but in discrete amounts. Moreover, the waves they send out travel in packets or photons. Second, molecules can interact electrically without actually emitting or absorbing energy. In that case they are said to exchange "virtual" photons.

At relatively large distances the Casimir-Polder electromagnetic theory gives the formula K/r^8 for the attractive force between two molecules. Thus when the effects of phase shift are allowed for, the force decreases with the eighth power of the distance rather than with the seventh, as in London's formula. The constant K is different from London's C, but it also contains the polarizability of the molecules. Therefore it cannot be evaluated directly either.

We shall see shortly that each of the two formulas appears to be correct for an appropriate range of the distance r. London's formula applies when the distance is small enough to make the phase shift of the exchanged radiation negligible. The Casimir-Polder result describes the force at larger distances, where the phase shift cannot be disregarded.

Both theories, however, concern only pairs of isolated molecules. They do not themselves give the force of molecular attraction between two condensed bodies, each containing many molecules packed close together. Yet this is the only force one can hope to observe directly, for example by measuring the at-



colored lines trace the electrical portion of the control circuit. The operation of the system is described in detail in the text.

traction between two solids separated by an extremely narrow gap. (This is precisely the measurement that my colleagues and I have finally succeeded in making.) Furthermore, it is this force that presumably causes the tiny particles of a colloid (which are nevertheless large enough to contain many molecules) to stick together and coagulate. Thus it is fundamental to the theory of the colloidal state.

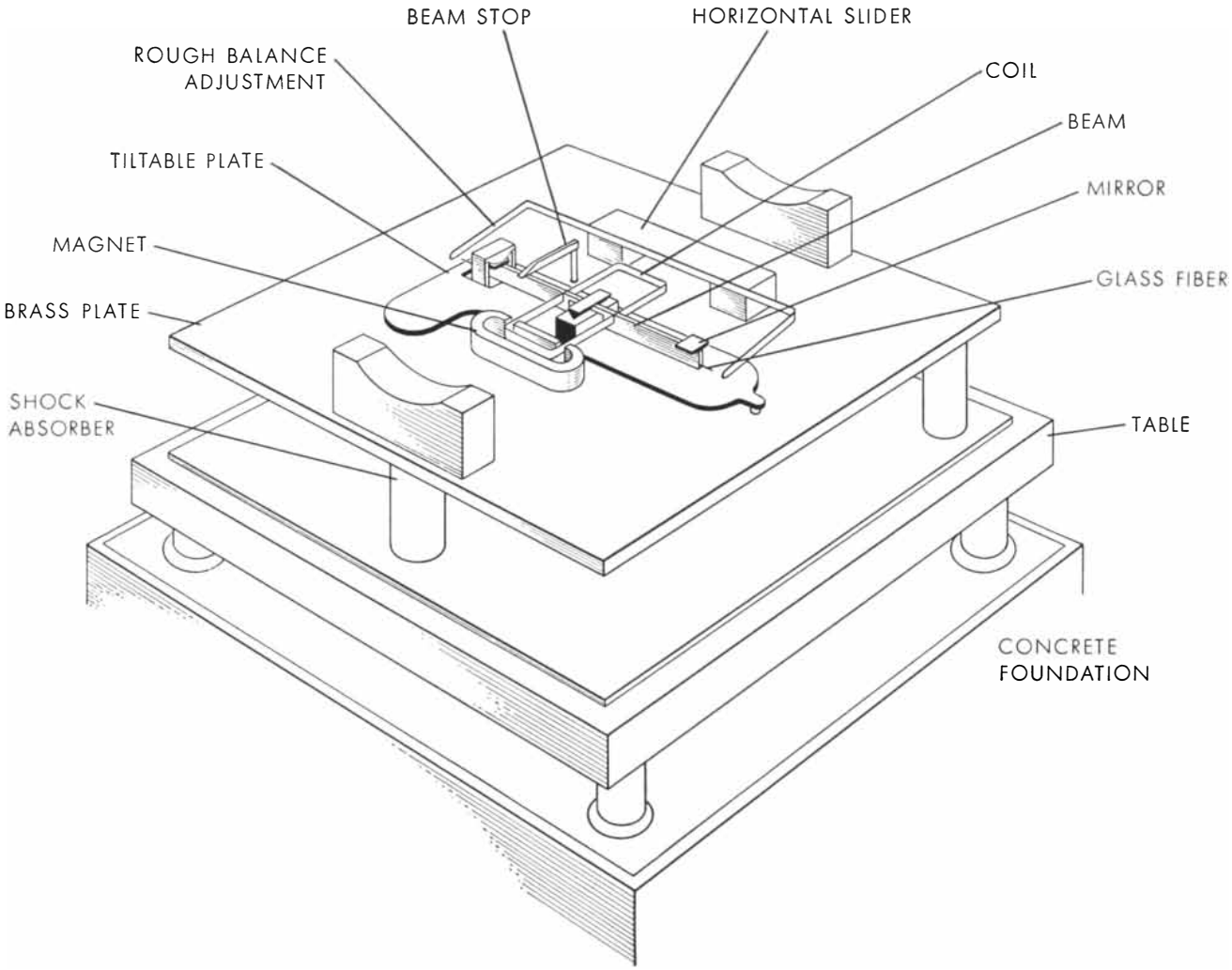
If we assume that molecular forces are not influenced by interactions with neighbors, that each molecule in one dense body exerts the same force on each molecule of a nearby body as if they were so many separate pairs, then it should be possible to obtain the total force simply by addition. Some workers have made this assumption and have proceeded to compute the total force between condensed bodies both by the London and the Casimir-Polder formulas. However, there is good reason to believe that the forces are not strictly additive, so these computations cannot give the right answer.

Clearly the individual-particle approach to molecular forces had proved unprofitable. Its formulas contained unknown quantities, and so could not be evaluated. Even if they could, there was no way of proceeding from isolated pairs of molecules to the gross samples of matter with which experimenters are obliged to deal.

This was the unsatisfactory state of theoretical knowledge when Mrs. Abrikossova and I set out in 1951 to measure the molecular attraction between a pair of solid objects. With the help of Fanny Leib, a colleague at the Academy of Sciences in Moscow, we were able to design an apparatus that met the stringent, and in some ways contradictory, requirements of the job.

In the first place we were trying to measure a small force—as little as a ten thousandth of a gram. This in itself is not too difficult; microchemists routinely deal with far smaller forces. But in our problem the attraction to be measured shows up only when the two bodies are extremely close together—within a few ten thousandths of a millimeter, or little more than a thousandth the thickness of a human hair. Furthermore, the force varies enormously as the distance of separation is changed. It is precisely this variation that we wanted to determine. Thus we needed a way to set the width of the gap accurately at any desired distance, and to maintain the separation against the attraction force being measured. Not only that; the equilibrium had to be extremely stable so that chance variations in the gap were corrected before they could build up.

The requirements of sensitivity, stability and rapid response are not easy to reconcile. A sensitive balance tends to



BALANCE IS MOUNTED on a brass plate connected through shock absorbers to a table, which in turn rests on a concrete foundation. Tiltable plate allows the entire balance to be rotated, changing the position of the gap with respect to the surfaces of the objects whose attraction is being measured. Glass fiber extending through the balance arm can be shifted for rough balancing.

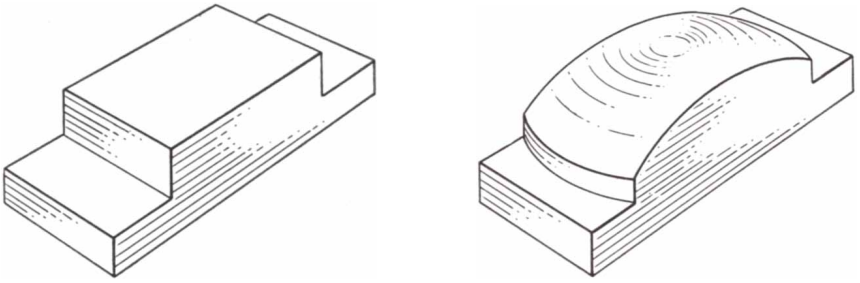
swing widely in response to a small change in force. Our apparatus achieved these diverse aims by means of automatic control.

The bodies whose mutual attraction we measured were a flat plate and a plate with a spherical surface. (It is easier to set the distance between a sphere and a plane than between two planes, which must be held parallel.) The flat plate was fixed to one end of a balance arm three centimeters long, weighing about a tenth of a gram and balanced on a fulcrum made of a wedge-shaped agate bearing. Above the flat plate was mounted the rounded plate in an adjustable bracket [*see illustration on pages 48 and 49*].

To determine the width of the gap between the two surfaces we made use of the optical phenomenon known as Newton's rings. When light of a single color shines through a lens-shaped disk held near a flat surface, interference between the rays reflected from different surfaces produces a pattern of concentric light and dark circles [*see top illustration on next page*]. The diameter of the circles depends on the distance between the surfaces. We observed the Newton's rings in our sample through a microscope, accurately determining their diameter and thus measuring the gap width.

The automatic-control circuit, which is the heart of the arrangement, accomplishes a quadruple purpose: (1) it allows us to set the gap at any desired distance, (2) it maintains the separation by producing a force equal and opposite to the attraction, (3) through negative feedback it corrects any drift in the balance arm away from the preset position and (4) it provides a means of measuring the opposing force, and thus the attraction.

The circuit works as follows. A beam of light shines through a grid, or raster, of alternate opaque and transparent stripes. A mirror on the balance arm reflects the beam through a lens, forming an image of the grid. The image falls on a second identical grid, beyond which is a photocell. Light passing through the second grid and reaching the cell sets up an electric current that is amplified and fed into a coil of wire rigidly attached to the arm. This coil is pivoted between the poles of a magnet and thus tends to turn, like the coil in an ammeter, carrying the arm with it. The turning force depends on the amount of current passing through the coil, and is arranged to be opposite in direction to the turning force on the arm due to molecular attraction.



TEST BODIES for the measurement of molecular force were a highly polished flat plate (*left*) and an equally smooth spherical lens (*right*). In most trials the bodies were made of quartz, but some other materials were tested. The lens diameter was also varied.

The current in the coil is determined by the amount of light that reaches the photocell. Let us see what controls this. If the image of the first grid falls on the second grid in such a way that the transparent stripes of the image exactly cover the black stripes of the grid, no light gets through. The current through the coil is zero. Rotating the arm slightly shifts the angle of the mirror, thus moving the image. Now part of the transparent stripes in the image overlap the transparent stripes on the second grid, and some light passes through. The farther the arm turns, the more light passes, and the stronger the current.

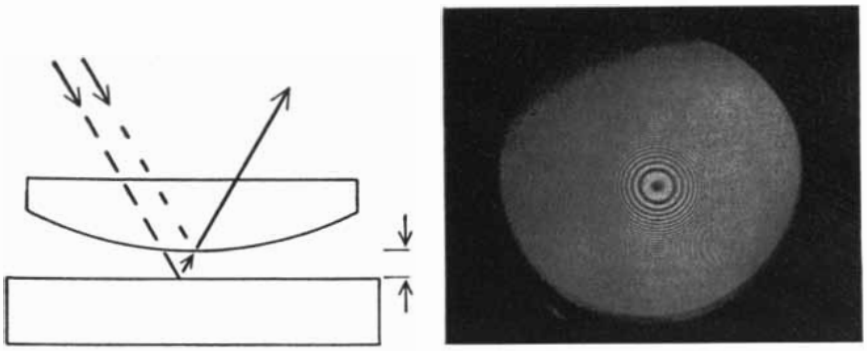
In setting the gap initially at the desired width, we shift one grid by means of a micrometer screw forcing the arm to turn as the equilibrium position varies. We then read the current on an ammeter, thereby determining the force at this gap width. If a stray vibration alters the distance of separation, the current changes in such a way as to bring the arm back to its initial position. Without the control circuit, the balance arm takes several seconds to swing back and forth when it is displaced from equilibrium. When the control is switched on, this period is reduced to a thousandth of a second.

Fluctuations of the current in response to outside vibrations set the eventual limit on the accuracy of our measurement. To minimize the disturbances we mounted the balance on a heavy pedestal, connected by means of a hydraulic shock-absorber to a cement pier sunk in the ground. Air currents were eliminated by enclosing the apparatus in an evacuated chamber. This also reduced the viscous drag of the air in the narrow gap on the motions of the balance arm.

The most annoying and persistent difficulty we encountered in getting the balance to work properly was in trying to keep the surfaces of the plates free from both electrostatic charge and dust particles. Electrostatic forces are thousands of times stronger than the molecular attraction, and would completely obscure it. Dust particles on the surfaces would change the effective gap width.

To eliminate dust we cleaned the plates with cotton dipped in ether. Charge was removed by ionizing the air in the gap with a radioactive material. Repeated treatments were often re-

OVERLAPPING GRIDS, or rasters, determine the amount of light reaching the photocell in the balance-control circuit. Image of opaque bands (*colored stripes*) on one grid falls on second grid (*circle*). Light transmitted varies from a maximum when the two sets of bands coincide (*left*) to zero when image bands wholly fill transparent spaces (*right*).



NEWTON'S RINGS (*photograph at right*), used to determine gap width in the author's experiment, are formed when monochromatic light passes through a lens and is reflected from a flat plate. Some light is also reflected from lens surface, and the rays at any given point reinforce or interfere depending on the width of the gap between lens and plate.

quired, because the surfaces tend to become charged as they are cleaned, and to get dusty when the charge is removed.

In our first experiments in 1951 we measured forces that were about 5,000 times as large as predicted by any theory. Experimenters in the Netherlands got the same sort of result at this time. When we finally were able to get rid of all electric charge, however, the spurious forces disappeared. Other workers have duplicated our results.

We measured the force between two quartz plates, between a quartz and a chromium plate and between crystals made of a mixture of thallium bromide and thallium iodide. For gaps ranging from about two to four ten-thousandths of a millimeter the force varied from approximately 20 to two ten-thousandths of a gram [*see graphs on opposite page*]. The force obviously depended on the types of molecule of which the plates were composed.

When we obtained our first successful measurements, we could compare them only with the London and Casimir-Polder theories. It was at once apparent that the Casimir-Polder formula fit our results better than did London's. (A gap of a ten thousandth of a millimeter is, of course, large on the scale of molecular diameters.) However, we could not check the formula absolutely, for the reasons already mentioned: it contained undetermined constants, and there was no rule for applying the microscopic equation to macroscopic bodies.

When Lifshitz heard of our results, he was encouraged to attack the theoretical problem anew. In 1955 he developed a remarkable method for finding the molecular interaction of two macroscopic bodies. The method ignores the individual particles completely, and depends only on macroscopic properties, which can be measured experimentally. We can do no more here than give a hint as to the basis of his highly abstract, mathematical approach.

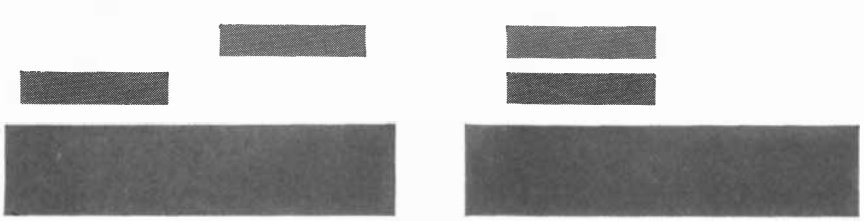
As every amateur radio-operator knows, the effort to receive extremely weak signals from distant stations is in the end frustrated by noise originating in the receiver itself. This noise arises out of the thermal vibrations of the molecules in the wiring and other parts of the set. The resulting electromagnetic fluctuations are noticeable when a radio receiver emits a hiss. But they exist silently in any material body. The only way to suppress them completely is by cooling the bodies to absolute zero and thus removing all their thermal energy.

According to quantum theory, however, there must be fluctuations in the electromagnetic field even at absolute zero. These fluctuations are the result of the so-called zero-point energy of the electrons. By definition this energy cannot be detected or extracted from matter; it is represented entirely by the emission and absorption of virtual photons. Nevertheless it is there, and it is a means of interaction of the particles.

Lifshitz realized that such universal zero-point vibrations should in fact account for the molecular force. In his theory, however, he does not deal with discrete particles and light quanta, or photons, but with continuous matter and fields, along the lines of classical electromagnetic theory. He considers two closely spaced bodies and calculates the electro magnetic fields produced in the narrow gap between them and in the space around them by the fluctuations in the various regions of the material. From the difference between the field strength in the gap and in the surrounding space the force can be calculated.

The formulas are very complicated, but they do not contain any quantities that cannot be measured. To find the force it is necessary to know only the wavelengths absorbed by the materials (*i.e.*, their absorption spectra in the infrared, visible and ultraviolet regions) and their polarizabilities or "dielectric permeabilities." Unlike the polarizability of individual molecules the dielectric permeability of a macroscopic sample of a substance is easily determined.

Not only does the theory account for a force at absolute zero; it also shows that thermal oscillations contribute very little to the force at higher temperatures. In the range near absolute zero the force is almost independent of temperature. As the temperature is increased, the force does vary, but only through an indirect effect. Changing the temperature changes the quantum state of the electrons in the bodies, altering their absorption spectra and hence the force.



NONADDITIVITY of molecular force on the macroscopic scale is demonstrated by the fact that the total force of attraction between the large block and the small ones is changed by shifting the small blocks from the arrangement shown at left to the one shown at right.

It is surely remarkable that a purely molecular effect can be calculated by ignoring the very existence of particles. (They are ignored except for one point:

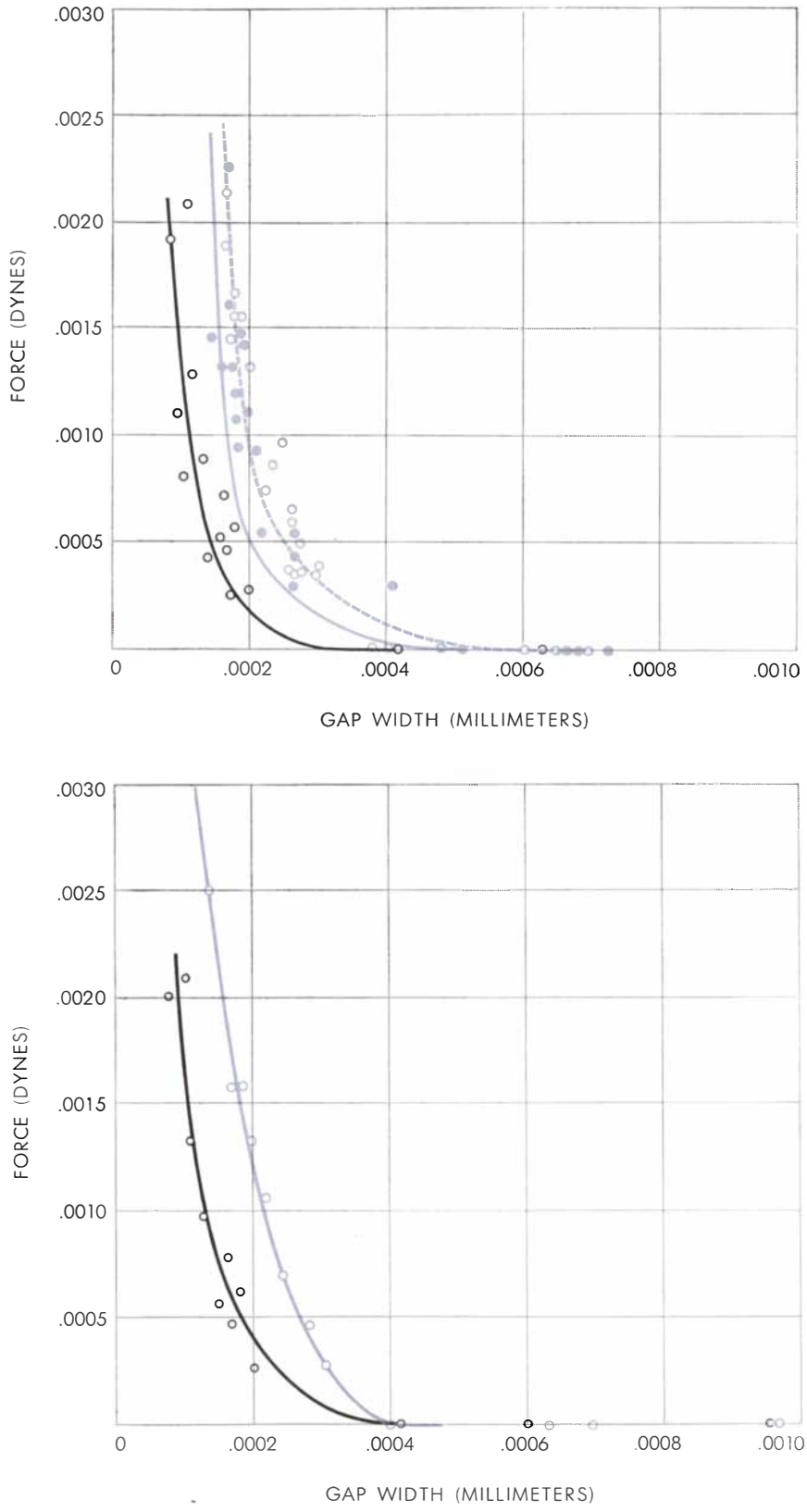
The theory is valid only for gap widths substantially greater than the molecular diameter.) But there is an even greater surprise. Whereas it is impossible, as we have seen, to pass mathematically from a microscopic, two-molecule theory to the macroscopic situation, the reverse transition is straightforward. The attraction between a pair of isolated molecules comes out of the Lifshitz theory as a special limiting case. For small distances it reduces to the London seventh-power law, and for larger distances, to the Casimir-Polder eighth-power law. And these equations are reached more easily by the roundabout method of Lifshitz than by the earlier direct calculations!

Furthermore, the calculations settle definitely the question of whether the force is additive. It is not. The attraction between two bodies is not the simple sum of the attraction between all pairs of their molecules. In fact, even on the macroscopic scale the force does not add [*bottom illustration on opposite page*].

In the case of macroscopic samples of matter the force depends on many factors, including the shapes of the bodies. When two flat, parallel plates are separated by a gap much smaller than the wavelengths of their main absorption lines, the complex formula reduces to a comparatively simple expression: The force varies inversely as the cube of the gap width. When the separation is much greater than the absorption wavelength, the force varies inversely as the fourth power of the distance. (These formulas correspond respectively to the inverse seventh- and eighth-power laws for pairs of individual molecules.)

As soon as Lifshitz announced his results, we applied them to a calculation of the force between the bodies we had used in our experiments. The curves at right represent the theoretical predictions. As can be seen, our experimental points cluster quite closely around the curves. This agreement between theory and experiment is particularly convincing because the theory contains no undetermined constants; the comparison is absolute and applies successfully to several different substances.

Although our experiments verify the Lifshitz formulas only for the special case of "large" gaps, they tend to support the whole theory. And so the electromagnetic nature of molecular forces and their relation to spectra, so long ago postulated by Lebedev, have now been demonstrated. He would be glad to know that the attraction between molecules does not "involve other forces whose source is still unknown."



EXPERIMENT AND THEORY are compared in these graphs. The curves show the variation of the molecular force of attraction with distance for the bodies used in the author's experiments, according to the Lifshitz theory. The points represent experimental values. The upper graph refers to experiments on a flat plate and a spherical lens 10 centimeters in radius. Data for quartz bodies are in black; for thallium halide, in solid color; for a quartz and chromium body, in broken colored line and open dots. Lower graph shows data for a 10-centimeter quartz sphere (*black*) and for a 26-centimeter sphere (*color*).

THE ZODIACAL LIGHT

On a clear, dark night in the tropics a luminous pyramid is seen in the sky after sunset and before sunrise. The phenomenon seems to be caused by the scattering of sunlight by interplanetary dust

by D. E. Blackwell

About an hour after sunset on a clear, moonless night in the tropics a faint pyramid of light glows in the western sky. About as luminous as the Milky Way, the pyramid is broadest and brightest at the horizon and fades out toward the zenith. Because it stretches along the zodiac (the imaginary belt in the sky that contains the paths of the sun, the moon and the major planets), the glow is known as the zodiacal light.

As the earth turns on its axis, the glowing pyramid sinks beneath the horizon, the last and faintest vestige disappearing a few hours after sunset. Toward morning the spectacle is repeated in reverse order in the eastern sky. The faint apex appears a few hours before dawn; the entire pyramid attains its full splendor about an hour before sunrise. Thereafter the sky brightens, and the zodiacal light vanishes from sight. Away from the equatorial regions the zodiacal light can be seen occasionally, but at higher latitudes it is tilted at a sharp angle to the horizon, and so is quite difficult to detect except during certain seasons.

The origin of the light has been a subject of speculation for centuries. The classical explanation was worked out nearly 300 years ago by the French astronomer Jean-Dominique Cassini, who began a 10-year study of the phenomenon in 1683. Although some of his contemporaries argued that the zodiacal light was an atmospheric phenomenon, Cassini observed that its position in the sky was the same when it was viewed from different locations, and concluded that it must originate somewhere in space. He speculated that the light is caused by a disk-shaped cloud of interplanetary dust that reflects the light of the sun. Such a cloud would scatter sunlight in much the same way that a cloud of moths scatters the light from a street lamp at night: to an observer some distance away the lamp seems to be surrounded by a luminous haze. Because the zodiacal light appeared to be symmetrical about the plane of the sun's equator, Cassini postulated that the dust cloud was also symmetrical about this plane and extended to the outer limits of the solar system.

When Cassini proposed this explanation of the zodiacal light, John Dalton's atomic theory of matter was still more than a century in the future. Cassini could scarcely have imagined that the light of the sun might also be scattered by particles or atoms much smaller than dust. It has been only in the past century that physicists have demonstrated that the atom itself is composed of still smaller particles, such as protons and electrons, and that the atoms in the sun and in other stars are highly ionized, that is, many of their planetary electrons are removed. In the immediate vicinity of the sun the free electrons in the solar atmosphere scatter sunlight to give rise to the corona that is visible around the sun during a total eclipse. A number of investigators have postulated that the solar atmosphere reaches outward from the sun for millions of miles, perhaps even beyond the orbit of the earth [see "The Earth in the Sun's Atmosphere," by Sydney Chapman; SCIENTIFIC AMERICAN, October, 1959]. They have therefore been amending Cassini's explanation, contending that the zodiacal light is an extension of the solar corona and represents the scattering of sunlight by electrons rather than by dust.

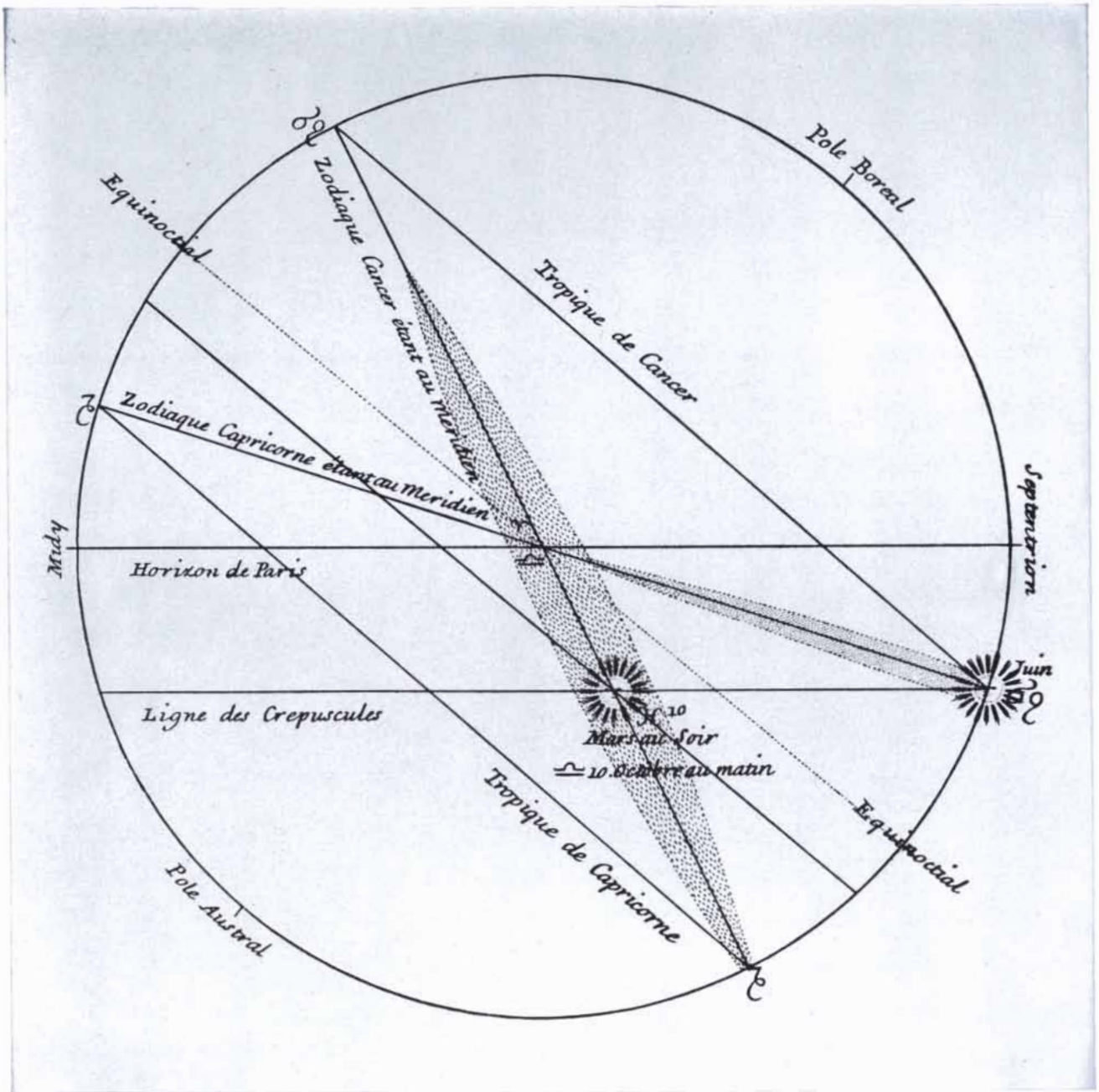
Quite apart from the question of what kind of particles are involved, there are observers who hold, as some did in Cassini's time, that the zodiacal light originates in the earth's atmosphere. In deference to these workers it must be admitted that the evidence connecting the zodiacal light to the corona is indirect. In a photograph such as the one on page 58 the corona seems to end a relatively short distance from the sun. When the corona is seen from the ground under favorable conditions, it is scarcely perceptible beyond about two degrees of arc from the solar disk. (The apparent diameter of the solar disk is half a degree.) But at high altitude the sky during a total eclipse appears darker than it does on the ground, and the corona seems much larger. I photographed the eclipse of June 30, 1954, from an open aircraft flying at 30,000 feet, and my plates showed the corona extending 13.5 degrees from the sun. No doubt it could be traced outward even farther if it were photographed from higher altitudes. The zodiacal light, on the other hand, cannot be seen closer than 18 degrees from the sun: the sun must be that far below the horizon before the brightest portion of the pyramid becomes visible in the morning or evening sky. If the zodiacal light is indeed an extension of the corona, it is impossible to see it as such during an eclipse. The sky during an eclipse is much brighter than a moonlit sky, and even a trace of moonlight obliterates the zodiacal light. Thus there is a gap be-

ZODIACAL LIGHT was photographed by the author and M. F. Ingham from Chacaltaya in the Bolivian Andes, at an altitude of 17,100 feet. Stars caused the narrow streaks as the earth turned during the 10-minute exposure. Dark line in middle was caused by cross hair in telescope system.

tween the inner edge of the zodiacal light and the observed outer edge of the corona.

The gap can be seen in the diagram on page 59, which plots the brightness of the corona and the zodiacal light as a function of angular distance of the sun. The values for the zodiacal light are those obtained by Franklin E. Roach and his colleagues on Cactus Peak in California, at a latitude of 36 degrees North; the values for the inner corona are my aerial measurements from the eclipse of 1954. The two sets of measurements form two straight-line curves. Were it not for the gap in the region where no observations are available, the two curves would join quite smoothly to form a single one. They would hardly match so well if the corona and the zodiacal light were of different origin. This piece of indirect evidence therefore weighs against the possibility that the zodiacal light is an atmospheric effect.

Another item of evidence in favor of extraterrestrial origin is the position of the zodiacal light in the sky. When there are no conspicuous eruptions on the sun's surface, the glow is symmetrical about a line that is close to the ecliptic: the projection of the plane of the earth's orbit in the sky. To produce such a pattern the earth's atmosphere would have to be extended in some way in the plane of the earth's orbit. This is not an impossible idea; indeed, some Soviet investigators have supposed that the earth does possess such a gaseous tail.

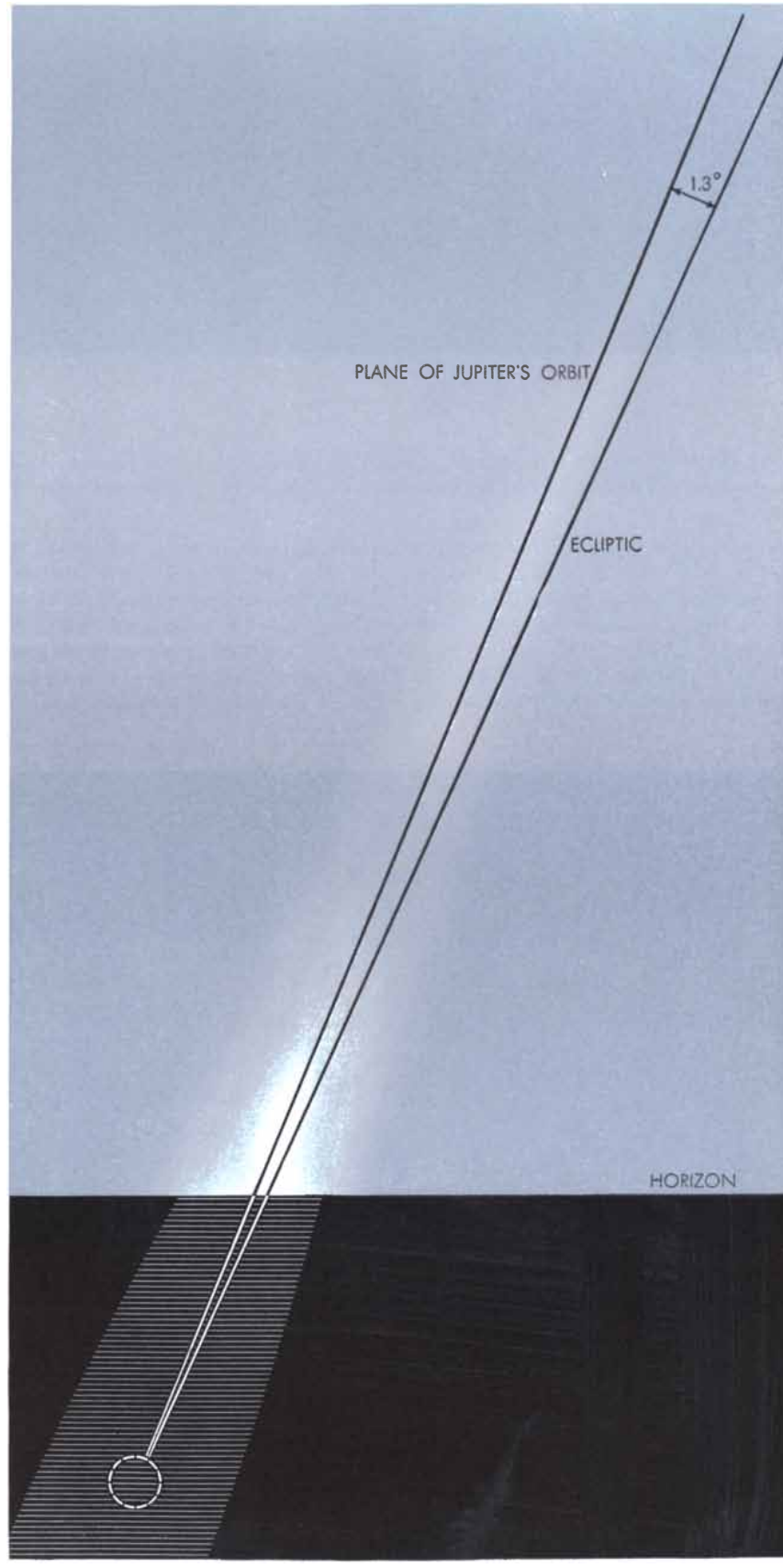


CLASSICAL VIEW of the zodiacal light was developed by the 17th-century French astronomer J. D. Cassini. His diagram of the zodiacal light is basically correct, although he was mistaken in his beliefs that the light was symmetrical about the plane of the solar equator and that the light was broader in March than in June. He argued that the light was due to a dusty nebula around the sun.

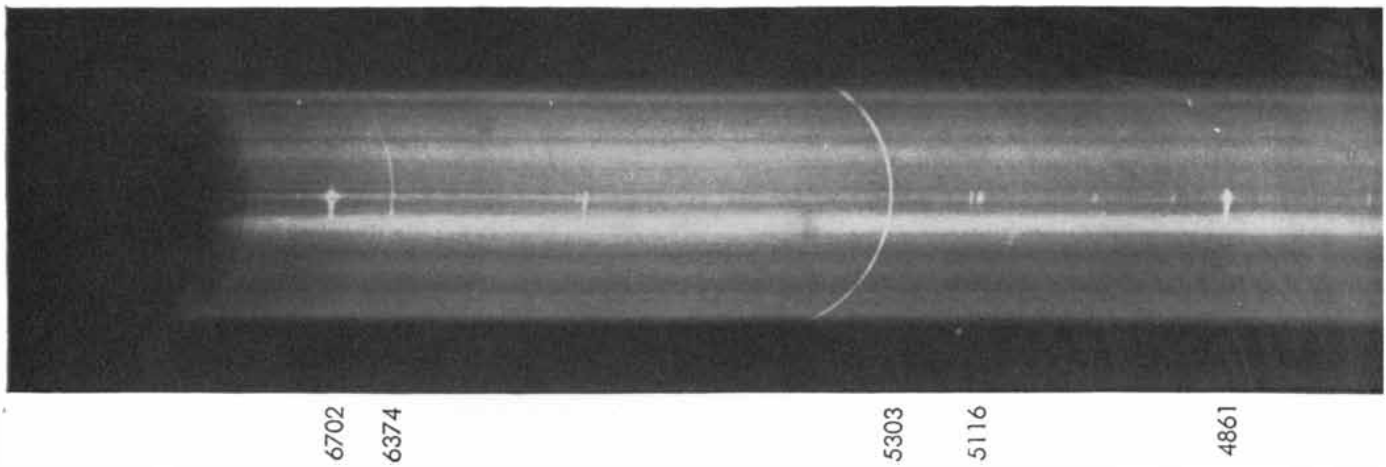
But the axis of symmetry of the zodiacal light does not lie precisely on the ecliptic. The pyramid of light is more nearly symmetrical about the plane of the orbit of Jupiter, which lies at an angle of 1.3 degrees to the ecliptic. In placing the axis of symmetry on the solar equator Cassini was about 7 degrees off, an error that is understandable in view of the fact that he made his observations in northern latitudes. But the orbital plane of Jupiter comports even better with his model of an interplanetary dust cloud. The gravitational forces accounting for the distribution of the cloud would logically find their plane of symmetry close to the orbital plane of Jupiter, the most massive planet. Thus it is safe to conclude that, although scattering by the atmosphere may play a small role in the zodiacal light, the major part of the light is scattered by matter in interplanetary space.

The question that remains is whether the scattering agent is dust, as Cassini proposed, or some other kind of particle. To make this choice it is necessary to consider the nature of the solar corona and to compare it to the zodiacal light. When the sun is photographed with a telescope, the edge of the solar disk appears to be perfectly sharp. Studies of the corona have shown, however, that the density of solar material does not change so abruptly as this would suggest, but diminishes gradually. The sharp difference in brightness is due to a change in the mechanism of radiation. Up to the edge of its clearly visible disk the sun radiates light simply because it is hot. Beyond the edge of the disk, in the region of the corona, the solar atmosphere is even hotter, but it is too thin to radiate much light; it can be seen during an eclipse chiefly because it scatters the light of the visible disk. The behavior of the flame of a gas stove illustrates the difference between the two regions. When the air supply is limited, the flame is luminous but opaque; when the air supply is increased, the flame becomes hotter and more transparent but less luminous. The analogy should not be carried too far, however, because conditions on the sun are quite different from those in stoves.

Karl Schwarzschild of the Potsdam Astrophysical Observatory first advanced (in 1905) the notion that free electrons in the atmosphere surrounding the sun scatter sunlight and thus give rise to the faint luminosity of the corona. He observed, in the first instance, that the color of the coronal light is almost iden-

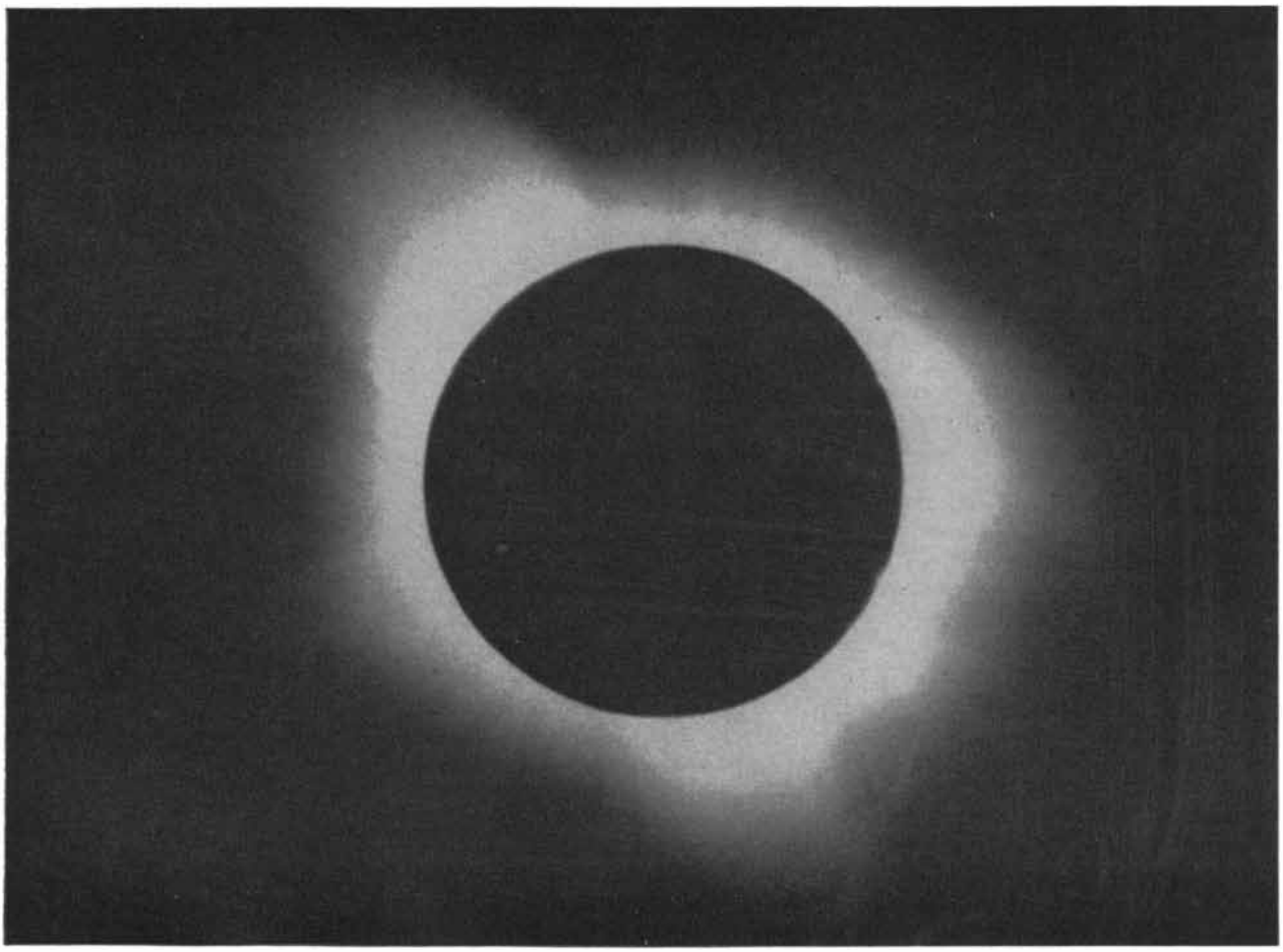


MODERN VIEW depicts the zodiacal light as the outer fringe of the solar corona, visible only when the sun (*broken circle*) has sunk beneath the horizon. The light is symmetrical about the plane of Jupiter's orbit, which lies at an angle of 1.3 degrees to the ecliptic.

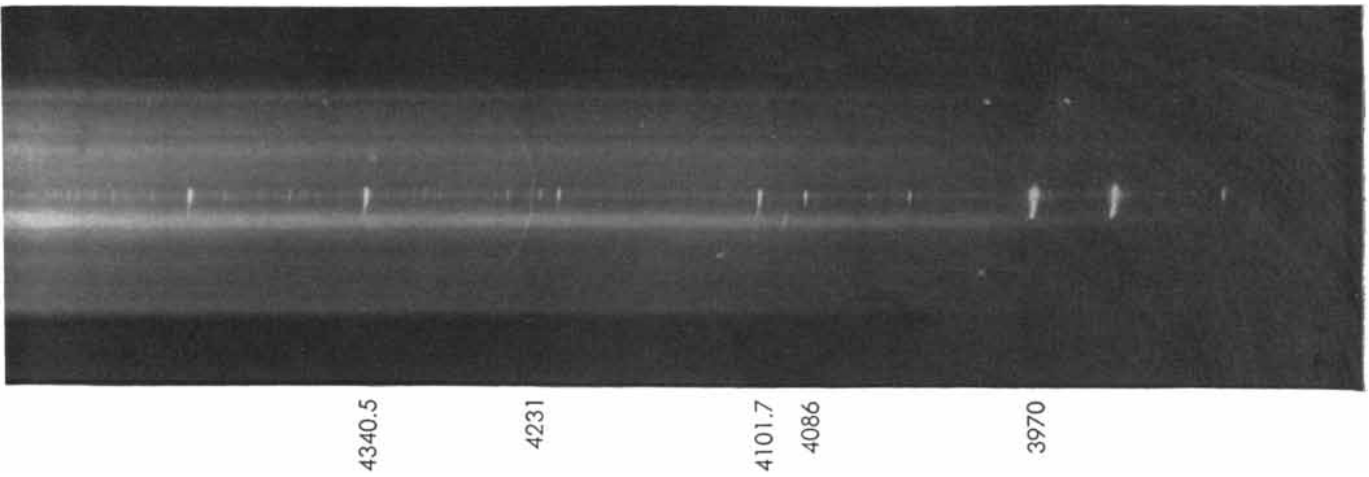


SPECTRUM OF SOLAR CORONA was photographed during the total eclipse of February 25, 1952, by Bernard Lyot and M. K. M. Aly. Spectrum is almost continuous, shading without interruption from red (*left*) through violet (*right*). The labels indicate the

tical with that of sunlight; accordingly he concluded that the corona is not an independent source of thermal radiation, but a region in which sunlight is scattered by electrons. This view is supported by the fact that the light of the corona is polarized. And because the spectrum of the corona, unlike that of the solar disk, is continuous (that is, grading almost uninterruptedly from red through green to violet) he concluded that the electrons must be moving at high speeds, equivalent to a temperature of the order of a million degrees Fahrenheit. If the temperature were much lower, the spectrum of the scattered light would be interrupted by the same dark absorption lines—the Fraunhofer lines—that cross the spectrum of the solar disk. In a gas at a million degrees F., however, the velocity of the

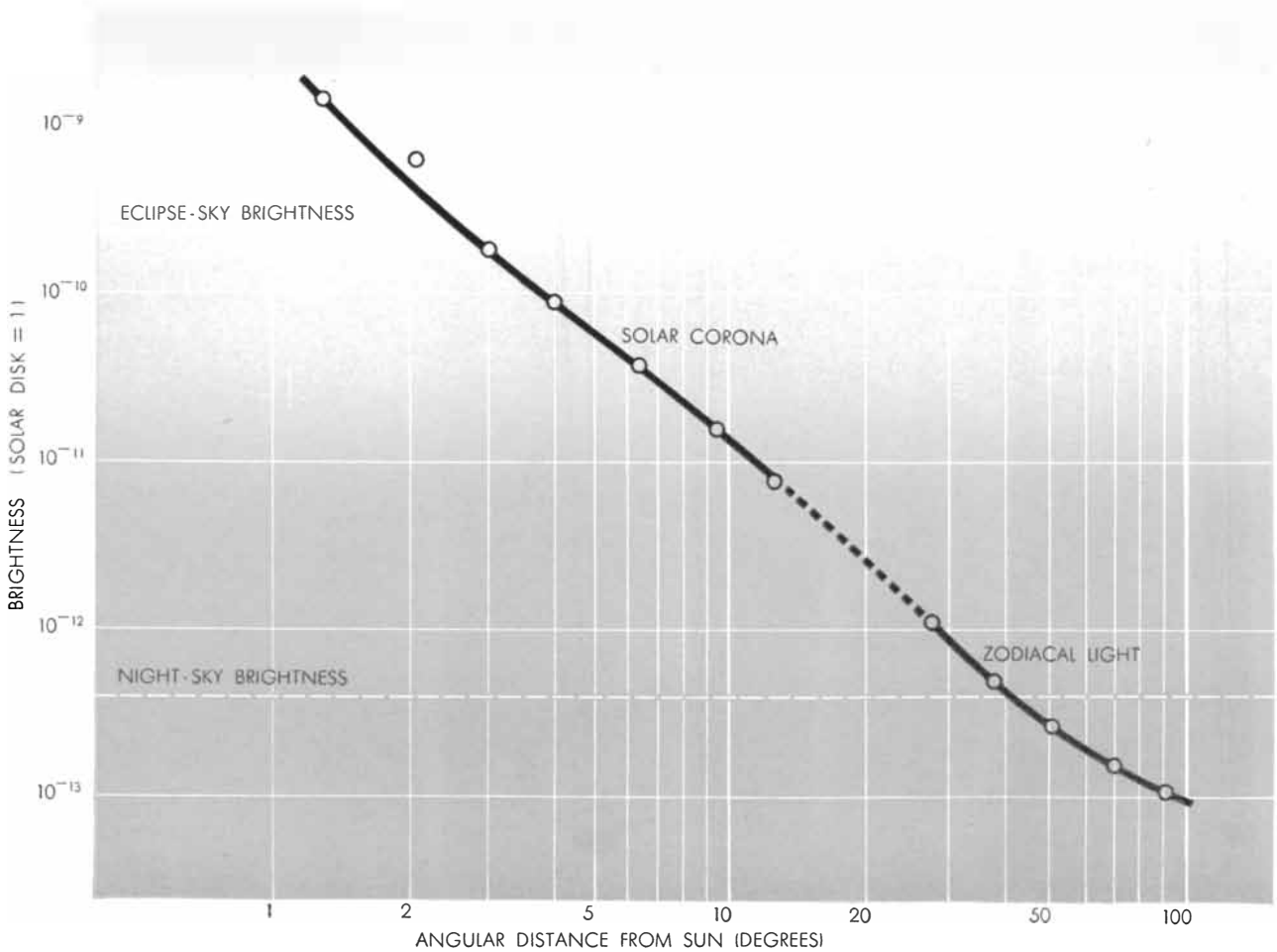


SOLAR CORONA was also photographed during the eclipse of 1952. The brightness of the eclipse sky makes the corona appear to end a short distance from the sun. Photograph was made by H. Von Klüber during the Cambridge expedition to Khartoum.

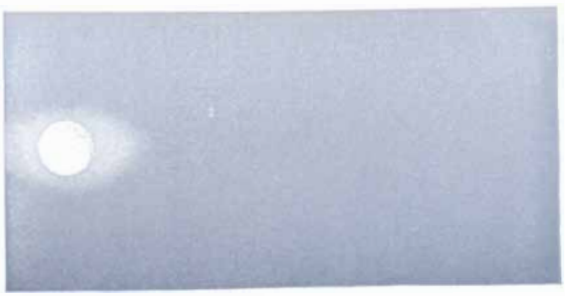


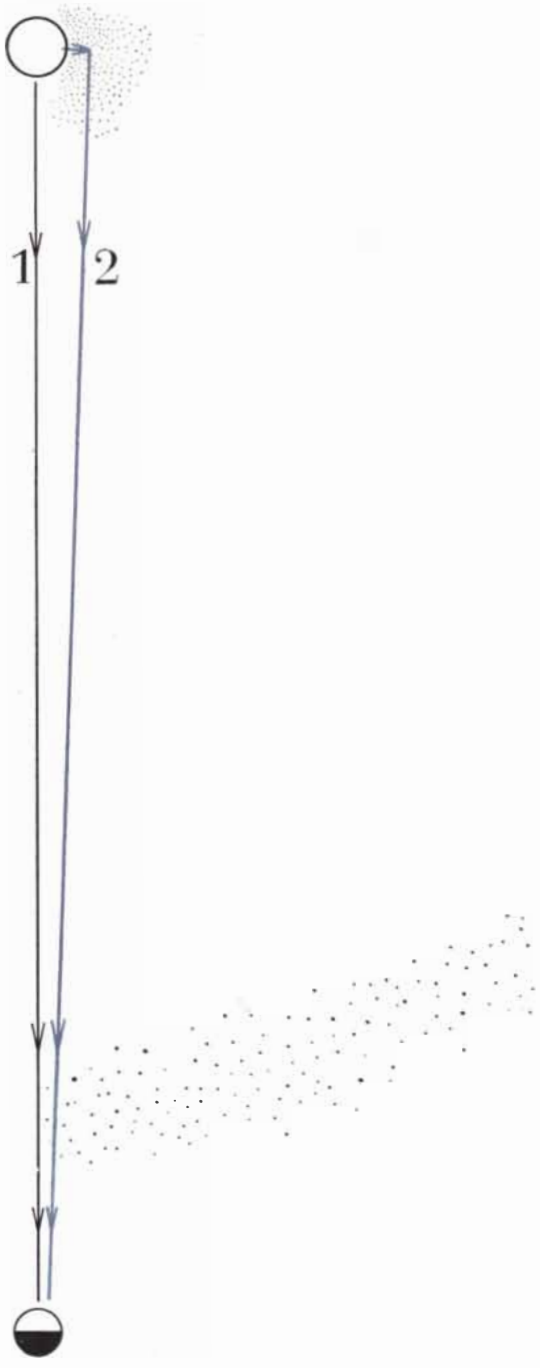
wavelength (in angstroms) of the bright spots and lines. The lines are bent, because the slit of the spectrograph is curved to fit the edge of the sun. Both the lines and the spots are produced by hydrogen and ionized heavier atoms in the atmosphere of the sun.

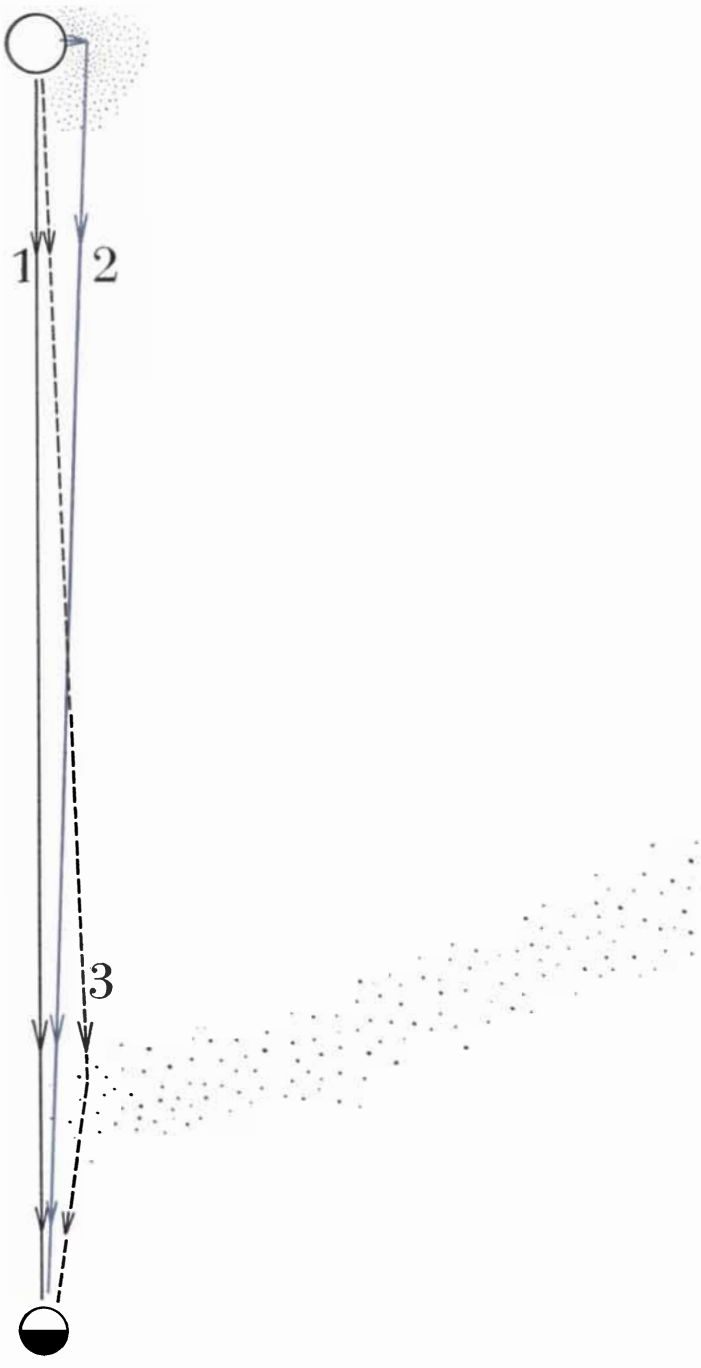
electrons is high enough to induce a Doppler shift in the light incident upon them. An electron traveling at a high velocity away from an observer shifts the wavelength of light toward the red end of the spectrum; conversely, an electron moving toward the observer shifts the wavelength toward the violet. The random motion of electrons in a gas at a million degrees would scatter light of a given wavelength over a band of wavelengths 250 angstrom units wide. Since most of the Fraunhofer lines in the solar spectrum are less than one angstrom wide, the scattering of light by electrons in a gas at this temperature would obliterate all but perhaps the broadest of them, producing a continuous spectrum. The extent to which the Fraunhofer lines are suppressed thus provides a measurement of the coronal temperature. Spec-



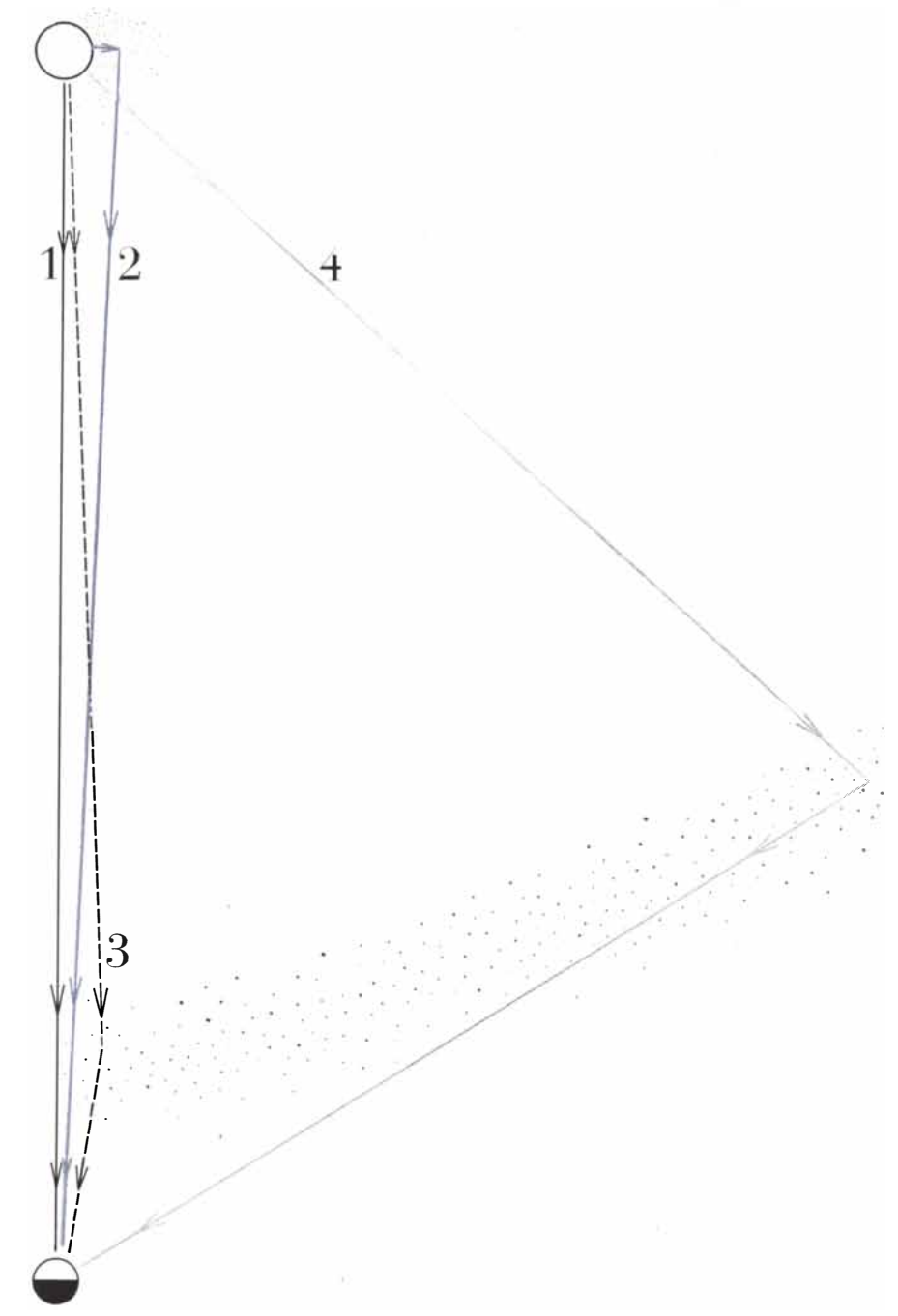
BRIGHTNESS CURVES of the solar corona and the zodiacal light almost join to form a single straight-line curve. Broken line indicates region where no observations are available. Shading indicates brightness of the sky at night and during total eclipse.







SUNLIGHT IS SCATTERED by particles in interplanetary space, and so reaches the earth via several optical paths (*arrows*). Most of the sunlight travels in a straight path (1). The diagram at left shows how some light is scattered (2) by electrons near the sun (*small dots*) to produce the inner corona (*top left*). The diagram at center shows how sunlight is diffracted (3) by dust particles



(*large dots*) near the earth, thus increasing the size of the solar corona (*top center*). The diagram at right shows how sunlight is reflected (4) by dust particles farther from the earth to give rise to the outermost or zodiacal-light region of the corona (*top right*).

trograms of the inner corona, within about a quarter of a degree of the edge of the solar disk, show that the temperature there is about a million degrees F., which agrees with Schwarzschild's calculations.

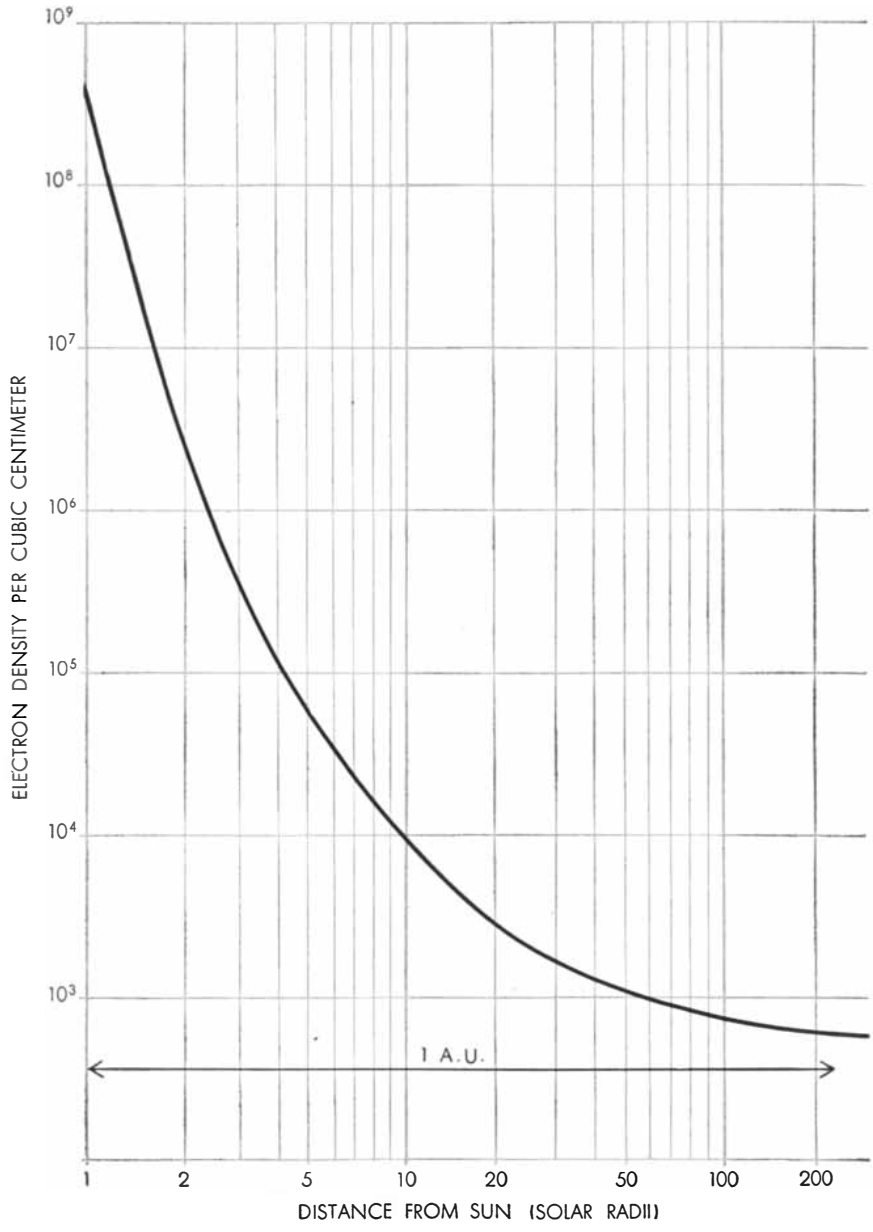
Such a high temperature makes it clear where the electrons in the gas come from: they are torn from atoms in high-speed collisions. Practically every hydrogen atom is stripped of its single electron, and some iron atoms lose as many as 13 electrons. These iron atoms can be detected spectroscopically because of their characteristic emission lines, but the stripped hydrogen atoms (protons), although much more abundant, cannot be detected, because naked atomic nuclei cannot radiate. Electrons thus account for most of the light of the inner corona. From the total brightness of the corona it is possible to calculate the coronal electron-density and so derive an estimate of the total density of the solar atmosphere. Within one degree of the edge of the solar disk the electron density comes to about a million electrons per cubic centimeter, but at greater distances the density falls off rapidly.

This decrease is reflected by a gradual change in the spectrum of the corona. Beyond a quarter of a degree from the solar disk, in the region sometimes called the middle corona, Fraunhofer lines begin to appear. Although the lines are weak, they are just as sharp as those in the solar spectrum. Their presence indicates that not all the light of the corona can be explained by electron scattering; at larger angular distances from the sun most of the corona appears to be due to scattering by larger, slow-moving particles—probably dust—in interplanetary space. This explanation was first suggested by Walter Grotrian of the Potsdam Astrophysical Observatory in 1934, but it immediately encountered a major difficulty. It was originally supposed that the dust involved in the middle corona is mixed with electrons, protons and ions such as compose the inner corona; yet the high temperatures encountered so close to the sun would instantly vaporize any dust particles.

In 1946 the difficulty was resolved almost simultaneously by two astrophysicists, C. W. Allen of the Commonwealth Observatory in Australia and H. C. van de Hulst of the Leiden Observatory, who suggested that the sunlight in this region is not scattered by reflection but by diffraction. The angle at which the light is diffracted makes the dust particles appear to be closer to the

sun than they actually are [*see illustration on preceding two pages*]. Allen and van de Hulst postulated that the dust cloud forming the middle corona is situated far enough from the sun to permit the particles to remain intact. The middle corona thus arises in much the same way as does the halo that sometimes encircles the moon or the sun when they are seen through a thin layer of cloud. The only difference is that in one case the particles are in interplanetary space, while in the other they are in the earth's atmosphere.

By measuring the brightness of the middle corona it is possible to calculate the size of the dust particles and their distribution in space. On the assumption that the particles are the same size, their diameter turns out to be about one micron (.001 millimeter) and their density about one particle per cubic kilometer. A more refined calculation, which allows for particle sizes ranging from one to 300 microns, gives a somewhat greater number of particles per cubic kilometer. But the number is still so small that a space vehicle six feet in diameter traveling through the region would collide with perhaps one particle every 200,000 miles. Such thinly distributed particles produce a perceptible scattering effect only because of the great length of the optical path from the sun to the earth.

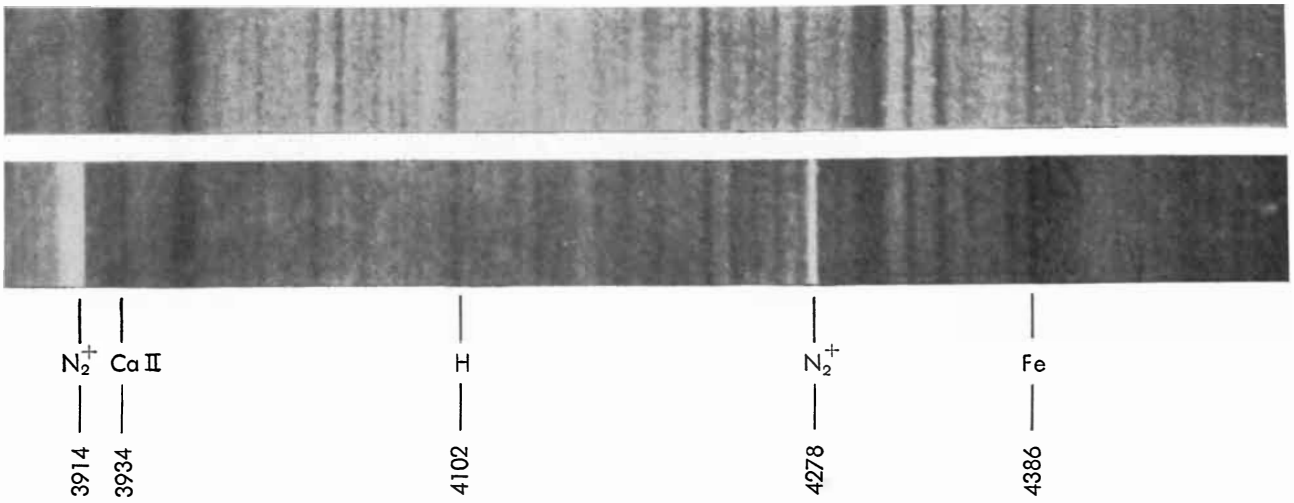


ELECTRON DENSITY of interplanetary space decreases with increasing distance from the sun. Arrow indicates one astronomical unit, the distance from earth to the sun. This curve is deduced from polarization of zodiacal light and from data on "whistlers." Author and M. F. Ingham found density at one astronomical unit lower than value shown here.

Thus free electrons close to the sun and interplanetary dust farther away from the sun both contribute to the scattering of sunlight in the corona. Moving outward to the zodiacal light, the question of what causes it may now be rephrased. Do electrons as well as dust particles contribute to the scattering of sunlight in this region of space? Or, to put the question still another way, can the study of the zodiacal light help determine how far the atmosphere of the sun reaches into space?

The most compelling evidence in favor of the idea that free electrons in interplanetary space contribute significantly to the zodiacal light was adduced by the German astronomer H. Siedentopf in 1953. From a station on the Jungfrau, 11,000 feet above sea level, he made a study of the polarization of the light and found that the degree of polarization increases with angular distance from the sun. According to his measurements, it reaches a maximum of about 22 per cent approximately 35 degrees from the sun, and then gradually decreases. In other words, if it were possible to view the zodiacal light through a Polaroid screen, the apparent brightness of the light would change over the ratio of 1.22 to 1 with the rotation of the screen. (It would change in the ratio of 1.5 to 1, or 50 per cent, if the experiment were performed in an artificial satellite, where the zodiacal light would not be diluted by night-sky radiation.)

Siedentopf believed that such a high degree of polarization could not be attributed to dust scattering alone, and he proposed electron scattering as the most likely mechanism to account for it. From his results he calculated that the electron density at the distance of the earth from the sun is roughly 600 electrons per cubic centimeter. This value is unexpectedly high, although an electron density of this order of magnitude had been predicted seven years earlier by Fred Hoyle, R. A. Lyttleton and Hermann Bondi of the University of Cambridge. Their "solar accretion" theory explained the corona as an effect incidental to the accretion of mass by the sun; the solar gravitational field was supposed to be drawing in matter from interstellar space. In line with this idea, the gas would gradually increase in density clos-



SPECTRUM OF ZODIACAL LIGHT (*bottom*) resembles the absorption spectrum of the sun (*top*) rather than the continuous spectrum of the solar corona (*shown at top of pages 58 and 59*). The labels indicate the wavelengths of the spectral lines (in angstroms) and the elements that emit them: hydrogen (H), iron (Fe), ionized molecular nitrogen (N_2^+), and calcium with one electron removed (Ca II). The bright emission lines that appear in the spectrum of zodiacal light are due to night-sky radiation.

er to the sun, and in the vicinity of the earth's orbit it would have a density of approximately 1,000 electrons per cubic centimeter.

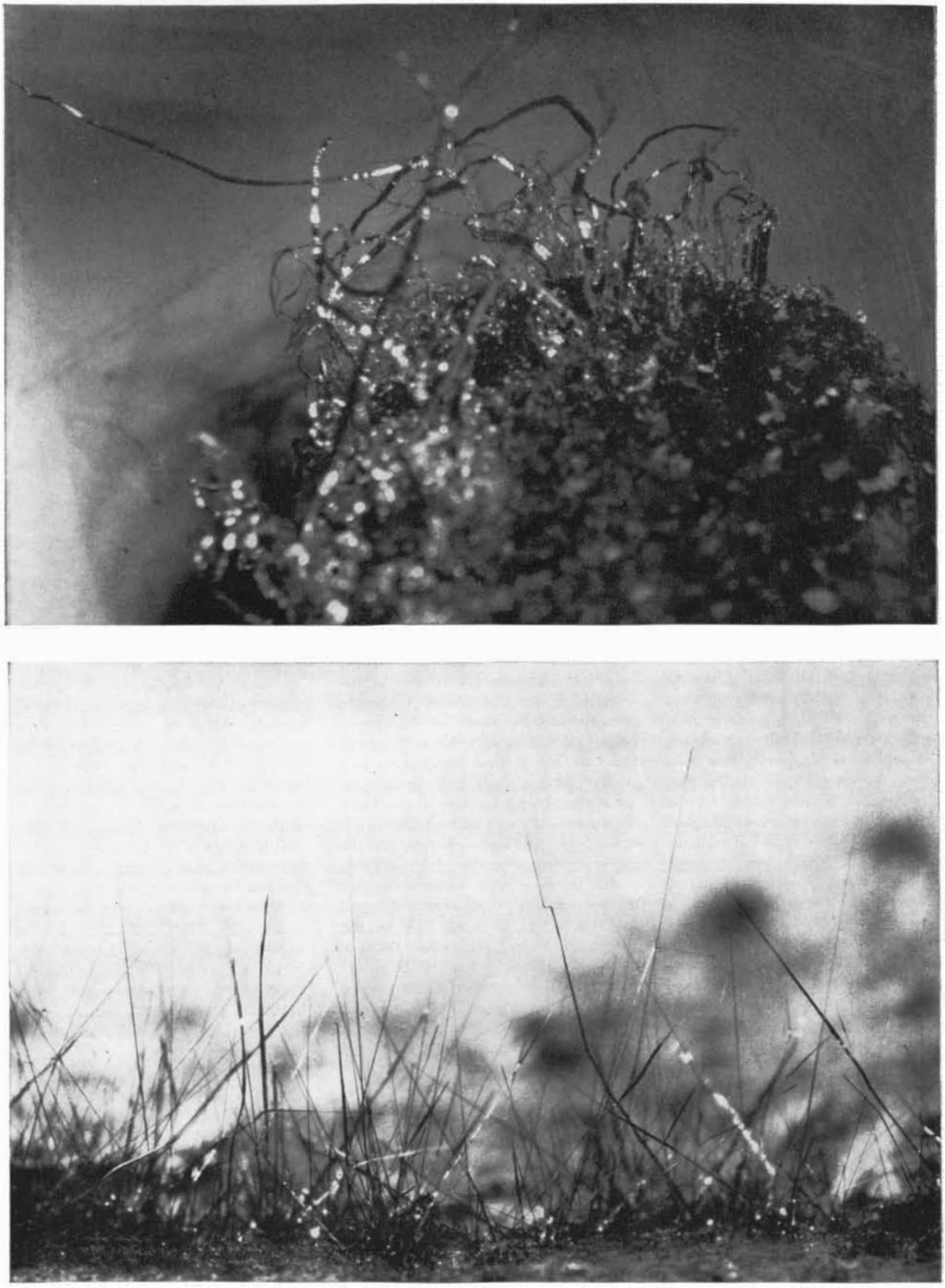
There was soon an apparent confirmation of this value from still another unexpected source. In 1953 L. R. O. Storey of the Cavendish Laboratory Radio Group at the University of Cambridge was investigating a curious radio phenomenon called whistling atmospherics, or whistlers; he showed that these whistling noises originate in lightning discharges in the hemisphere of the earth opposite the hemisphere in which they are detected. The disturbance caused by the lightning stroke is propagated along a line of force in the earth's magnetic field that arches from hemisphere to hemisphere. In the course of propagation the original "white" radio noise of the stroke is sorted out according to frequency: the higher frequencies arrive first, and the noise is heard as a whistle of descending pitch [see "Whistlers," by L. R. O. Storey; SCIENTIFIC AMERICAN, January, 1956]. Storey found that the particular sorting of frequencies depends on the number of electrons along the path of the disturbance, and thus provides a measure of the electron density in the vicinity of the earth. As a result he was able to estimate that the electron density at a distance of 1.7 earth radii (about 7,000 miles) is about 400 electrons per cubic centimeter. If the electron density at this distance from the earth can be taken as representative of interplanetary space, then the agreement with Siedentopf's conclusions is excellent.

It is remarkable that the three lines of argument developed independently by Siedentopf, Storey, and Hoyle and his colleagues all indicate the presence of an interplanetary gas, and that all give approximately the same value (within an order of magnitude) for the electron density at the distance of the earth from the sun. But there are also powerful arguments against the existence of this gas. One of these is especially persuasive: Since the plane of symmetry of the zodiacal light is close to the plane of Jupiter's orbit, it follows that if the light is scattered by an electron gas, the gas must also lie in this plane. But this is difficult to believe, because the distribution of a gas composed of charged particles would be controlled by the magnetic fields that are known to exist in the solar system. These fields would distribute the particles in a sphere around the sun and not in the plane of Jupiter's orbit.

M. F. Ingham and I, working at the University of Cambridge, found such arguments so convincing that we decided to carry out a detailed study of the spectrum of the zodiacal light to determine whether any of it could be ascribed to electron scattering. Since the experiment required the best possible viewing conditions, we undertook an expedition to the cosmic-ray station of Chacaltaya in the Bolivian Andes. Here the air is so transparent that the zodiacal light can be traced to the zenith. Our method was similar to that used in the studies of the inner and middle corona. We reasoned that if the zodiacal light is caused by dust scattering alone, its spectrum would be identical with that of the solar disk, but if it is caused by electron scattering it would show a continuous spectrum. Previously Sydney Chapman had shown that even at the distance of the earth from the sun the temperature of an electron gas should be high enough to scatter light in a continuous spectrum. By comparing the spectrum of the solar disk with that of the zodiacal light, we hoped to settle the question of which mechanism is chiefly responsible for the zodiacal light.

With the help of the most sensitive photographic plates, a very fast spectrograph and exposure times up to seven hours we obtained several successful spectrograms. Since the zodiacal light can be observed for only an hour each evening, each spectrum required multiple exposures over the course of a week. The spectrograms of the zodiacal light show quite clearly the Fraunhofer lines of the solar spectrum [*see illustration above*].

Although the spectrograms are still being studied, we can already say that the electron density in the vicinity of the earth is far lower than has hitherto been supposed, and that electron scattering can make only a small contribution to the zodiacal light. It seems, therefore, that Cassini is right after all; the zodiacal light is due to dust scattering. By the same token the much-discussed interplanetary gas is too thin to be of significance.



SILVER AND IRON WHISKERS of varying shapes are shown in these photographs. The silver whiskers at top (magnified 6.5 diameters) were grown by heating silver sulfide; iron whiskers at bottom (magnified seven diameters), by reducing iron bromide.

Metal "Whiskers"

They are tiny filamentary crystals that grow from the surfaces of metals (as well as other crystalline solids). Their unusual properties are aiding investigators in many areas of research

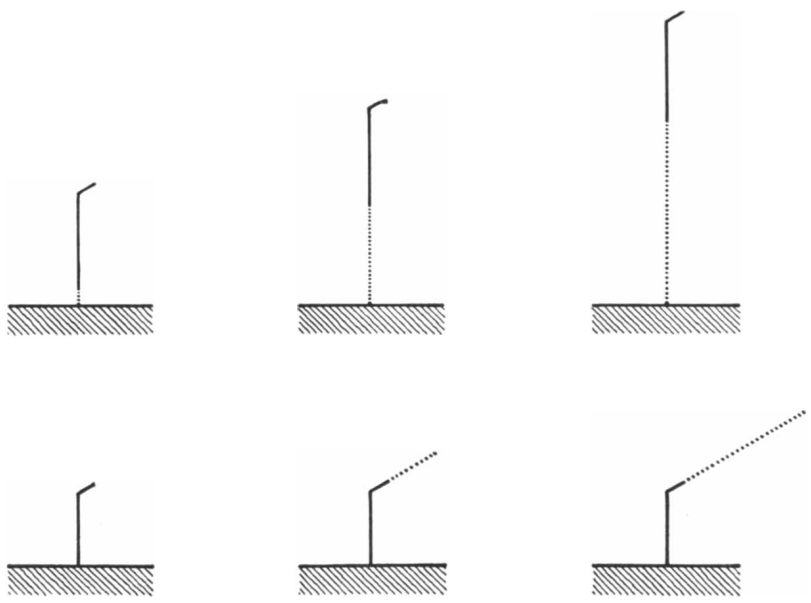
by S. S. Brenner

During the middle 1940's designers of electronic equipment were confronted with an annoying puzzle. As they attempted to build smaller and smaller devices, leaving less space between neighboring metallic components, mysterious short circuits occurred with increasing frequency. The cause of the trouble, when it was identified, presented an even deeper mystery. The metal surfaces were sprouting tiny metal "whiskers." These whiskers, only .0001 inch thick (less than a tenth the thickness of a human hair) and several hundredths of an inch long, were making the unwanted electrical contacts in the miniaturized circuits.

Bell Telephone Laboratories instituted a thorough investigation to find out what causes metal whiskers to grow, and how their growth can be prevented. Then in 1952 interest in the subject took quite a different direction when W. Conyers Herring and John K. Galt of Bell Laboratories made an unexpected discovery. Working with tin whiskers from a faulty piece of telephone equipment, they found that the whiskers were as much as 1,000 times stronger than ordinary tin crystals. The discovery helped resolve a problem that had confounded investigators for almost half a century: the discrepancy between the actual and the theoretical strength of solids.

Most solids exhibit only a fraction of their ideal strength. The weakness of pure single crystals is especially striking. Crystals of copper, tin and aluminum deform at stresses 100 to 1,000 times smaller than those suggested by theory. Iron crystals, the basic units of structural steel, begin to deform at stresses of a few thousand pounds per square inch (p.s.i.). Theoretically iron crystals should resist deformation at stresses approaching several million p.s.i. Such an extreme departure from the ideal was explained in due course by defects in real crystals and the interactions of these defects. Metallurgists and other workers seeking stronger metals and alloys concentrated on developing methods of turning the interactions to advantage [see "Dislocations in Metals," by Frank B. Cuff, Jr., and L. McD. Schetky; SCIENTIFIC AMERICAN, July, 1955]. By such means the strength of some steels has been raised to as much as 400,000 p.s.i. But this strength, while quite high, not only falls far below the theoretical estimate for crystals without defects, it is also metastable: it disappears with increased temperature.

The large and apparently unbridgeable gap between the real and the ideal seemed to indicate that the theoretical strengths were too high. Investigators began to ask whether the theoretical estimates might not be wrong. The answer, provided by the whiskers of tin, was a definite no. The small dimensions of these whiskers apparently allow little room for the defects that weaken larger crystals, and their strength closely approximates the prediction of theory. The growing of metal whiskers, and the study of the process by which these nearly ideal crystals grow, have led to deeper understanding of the relationship between crystal structure and many of the gross properties of solids, includ-



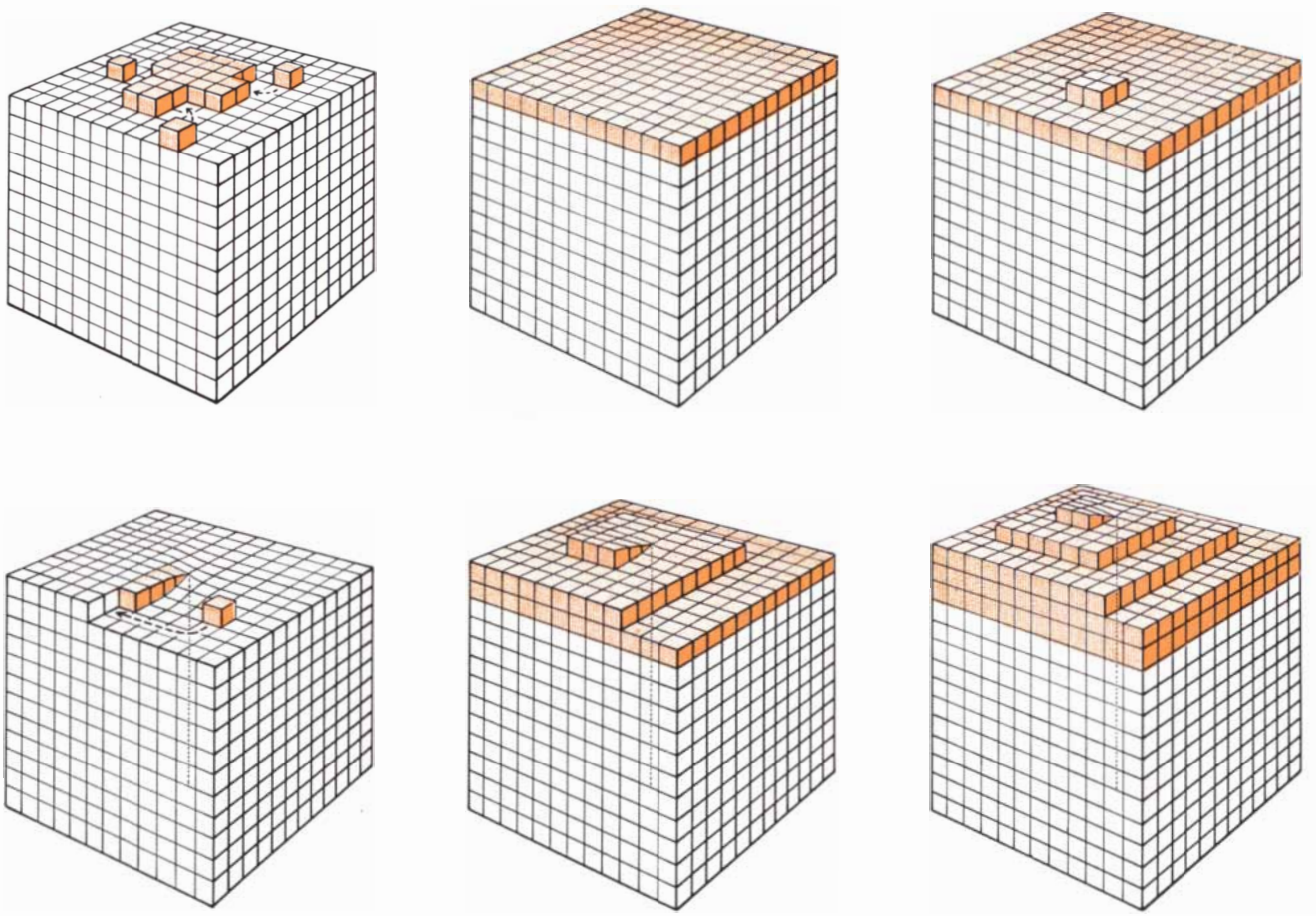
BASAL AND TIP GROWTH of whiskers are depicted schematically. The two kinds of growth are differentiated by position of kink in the whisker. In basal growth (*top*) new material (*broken line*) is added at the base. The whisker is thus extruded and the kink rises. In tip growth (*bottom*) kink remains fixed, new material being added only at tip.

ing their magnetic as well as their mechanical behavior.

The workers at Bell Laboratories were by no means the first to observe the growth of metal whiskers. As early as 1580 Lazarus Ercker recorded in his *Treatise on Ores and Assaying* the curious phenomenon of the growth of metal hairs from minerals containing silver and copper. In 1661 Robert Boyle's *The Sceptical Chymist* gave a third-hand account of how "in the Joachimsthal valley silver is squeezed out from the mineral rocks in the form and manner of grass as long as a finger, as if from the root." The many speculations on the nature of these filamentary growths even included a few attempts to show that they were a link between the mineral and vegetable worlds. Some time later the silver whiskers described by Ercker and Boyle were grown in the laboratory by heating silver sulfide in air. Around 1930 the German physicists H. W. Kohlschütter and Carl Wagner provided a reasonable description of this type of whisker growth in chemical terms.

The early investigations at Bell Laboratories disclosed that whiskers frequently appear in profusion on thin coatings of zinc, tin or cadmium applied by one of the standard techniques such as electroplating or hot-dipping. The whiskers grow extremely slowly; it sometimes takes months or even years for a whisker to extend to a length of an eighth of an inch. Thin protective coatings of lacquer or varnish will not restrain their growth, and thicker coatings can do so only so long as they are free from cracks.

More recently, as interest in the subject has increased, whiskers have been found growing from many materials. It was thought, for example, that the reaction of oxygen with metals formed a uniform coating of oxide on the metal surface. Electron micrographs made in 1954, however, revealed the presence of thin oxide filaments less than .004 inch in length [*see top illustration on opposite page*]. Such filamentary growth is not peculiar to metals or their oxides. Organic as well as inorganic crystalline solids form whiskers, either spontaneously or under experimental inducement. J. E. Gordon of the Tube Investment Laboratory in England found that many of the familiar organic and inorganic salts which crystallize as needles initially precipitate as very thin whiskers. When an aqueous solution of hydroquinone, resorcinol or nickel sulfate evaporates slowly, filaments less than .0001 inch in diameter can be seen weaving their way through the solution. As each filament grows in length it thickens at some constant distance behind the advancing tip, which thus acts as a "leader" for the rest of the crystal. The leader is very strong and may with-



TWO TYPES OF CRYSTAL GROWTH are shown schematically. Classical crystal growth (*top*) requires a highly supersaturated solution or vapor of the crystal material because new atoms (*colored cubes*) condense with difficulty on a smooth crystal surface. After several atoms have condensed on the surface (*top left-hand drawing*), the layer is soon completed (*middle*). To start a new layer, the process must repeat itself (*right*). Most crystals (including whiskers) grow by means of one or more screw dislocations (*bottom*). The screw dislocation, which is a line of atomic misfit (*broken line*), provides the crystal with a permanent growth step where atoms are able to condense at low supersaturation (*bottom left-hand drawing*). As atoms condense and the crystal grows, the step spirals around the dislocation line, forming a continuous crystal layer (*colored areas in middle and right-hand drawings*).

stand stresses of 500,000 p.s.i. or more. After thickening to many times the diameter of the leader, the needle becomes considerably weaker, breaking at stresses only a thousandth as great.

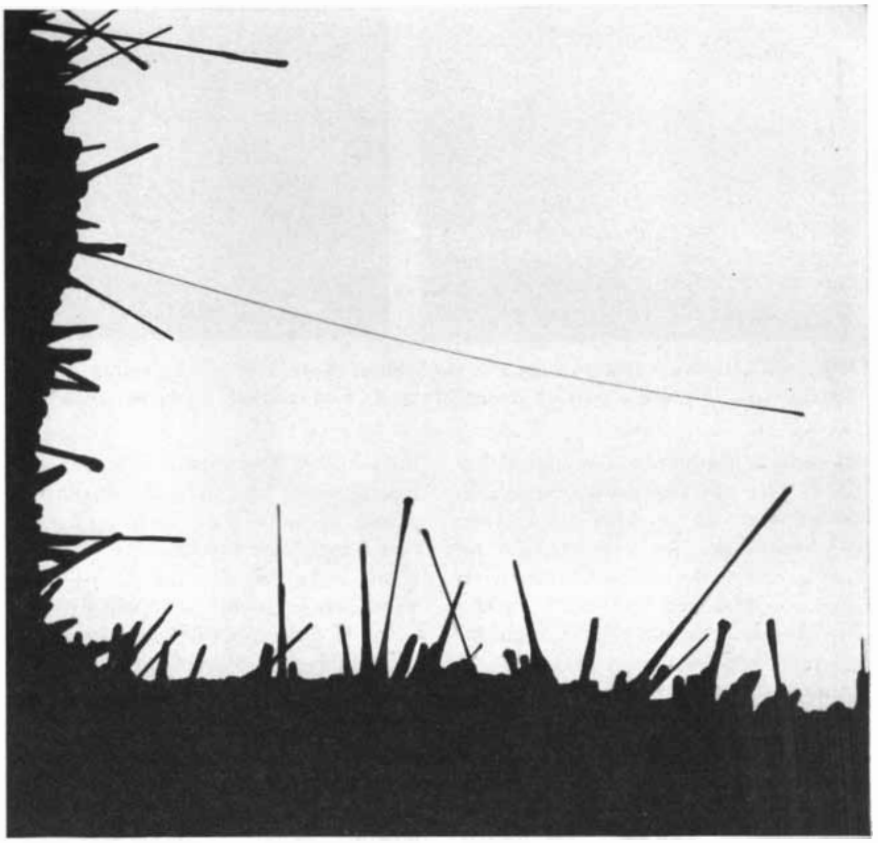
Even common table salt, which normally consists of small cubic crystals, will form whiskers if it is allowed to precipitate slowly out of solution. Evaporation of a salt solution from a covered porous ceramic dish causes both cubic and whisker crystals to form. One method of growing whiskers frequently used today was devised during the early part of this century to purify enzymes by separating salts from them. In its present form the method requires only that a solution of chemically pure salt be put in a thin cellophane bag, which is suspended in air. In a few hours the outside of the bag is covered with numerous whiskers of solid salt, some of which are more than half an inch long.

Mercury, zinc, cadmium sulfide and graphite form whiskers when supersaturated vapors of these substances condense. The supersaturated vapor is obtained by vaporizing the material in an evacuated tube and permitting it to drift into a cooler region; the greater the difference between the evaporation and condensation temperatures, the greater the degree of supersaturation. Whiskers form at low supersaturations. At high supersaturations small plates, large crystals and continuous films of the material predominate.

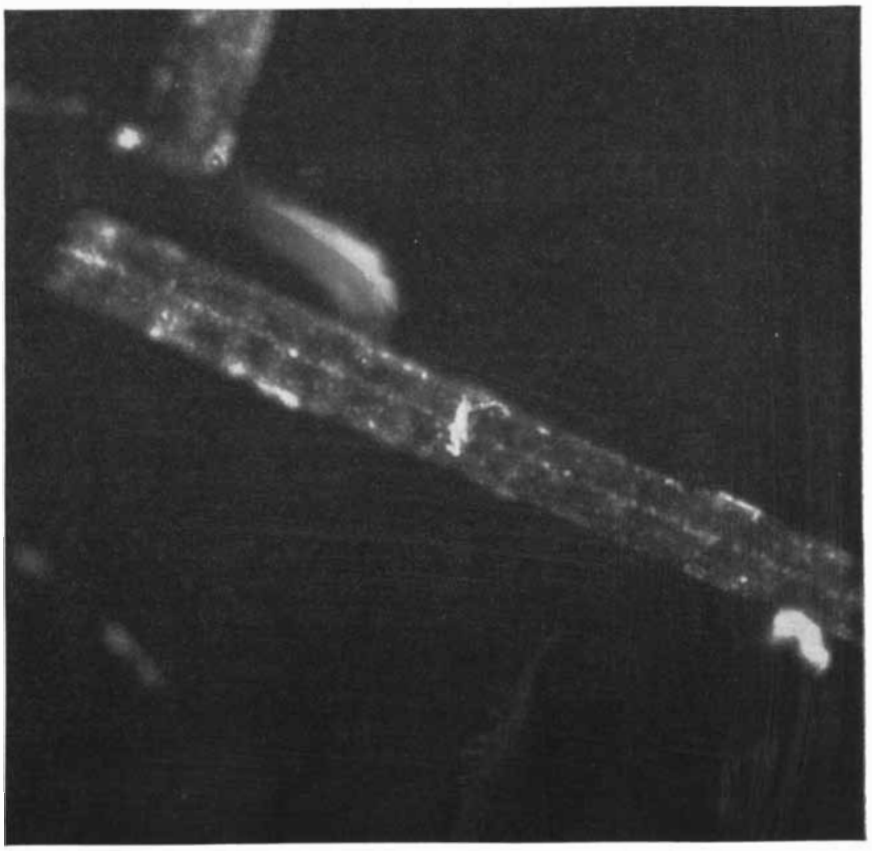
For experimental purposes the reduction of metal halides provides a quick means of obtaining whiskers. When iron bromide, silver chloride or copper iodide is heated in the presence of hydrogen, the reduced metal forms whiskers in a few hours. Larger whiskers result if the reaction takes place over longer periods. With this method it is possible to grow whiskers several inches long.

Despite their diverse origins, whiskers have a number of properties in common. Most of them are single crystals. They are often polygonal in cross section and generally have a smooth, mirror-like finish. All whiskers grow much faster in length than in diameter, some of them as much as 10,000 times faster. Many whiskers, regardless of origin, are far stronger than the strongest alloys. A few even resist a stress of several million p.s.i.

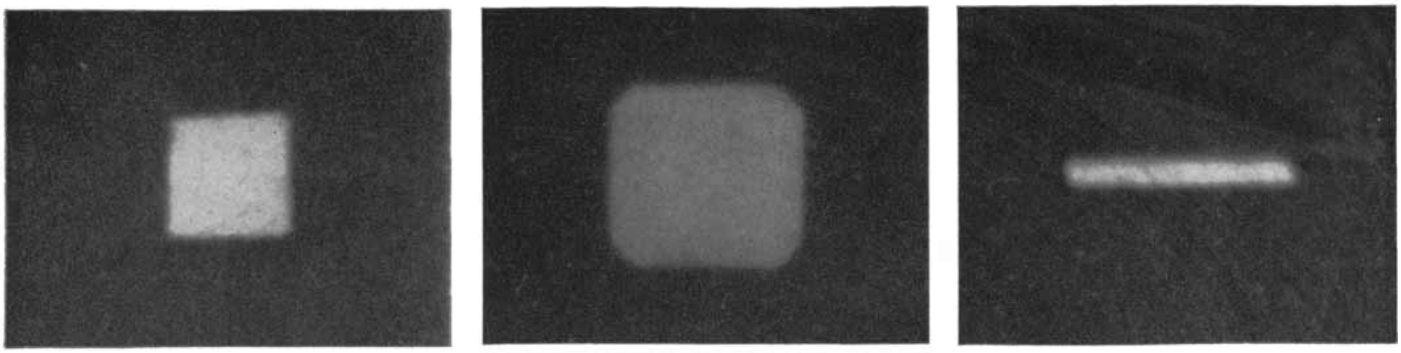
Two kinds of whisker growth can be distinguished: tip growth and basal growth [*see illustration on page 65*]. Tip growth may be promoted by simple condensation and precipitation or by a number of chemical reactions; in any case it



EXTREMELY SMALL WHISKERS are frequently found growing from the surfaces of uniform oxide coatings, as shown in this electron micrograph of copper oxide whiskers. The whiskers, which attain a maximum length of .004 inch, have been magnified 4,000 diameters.



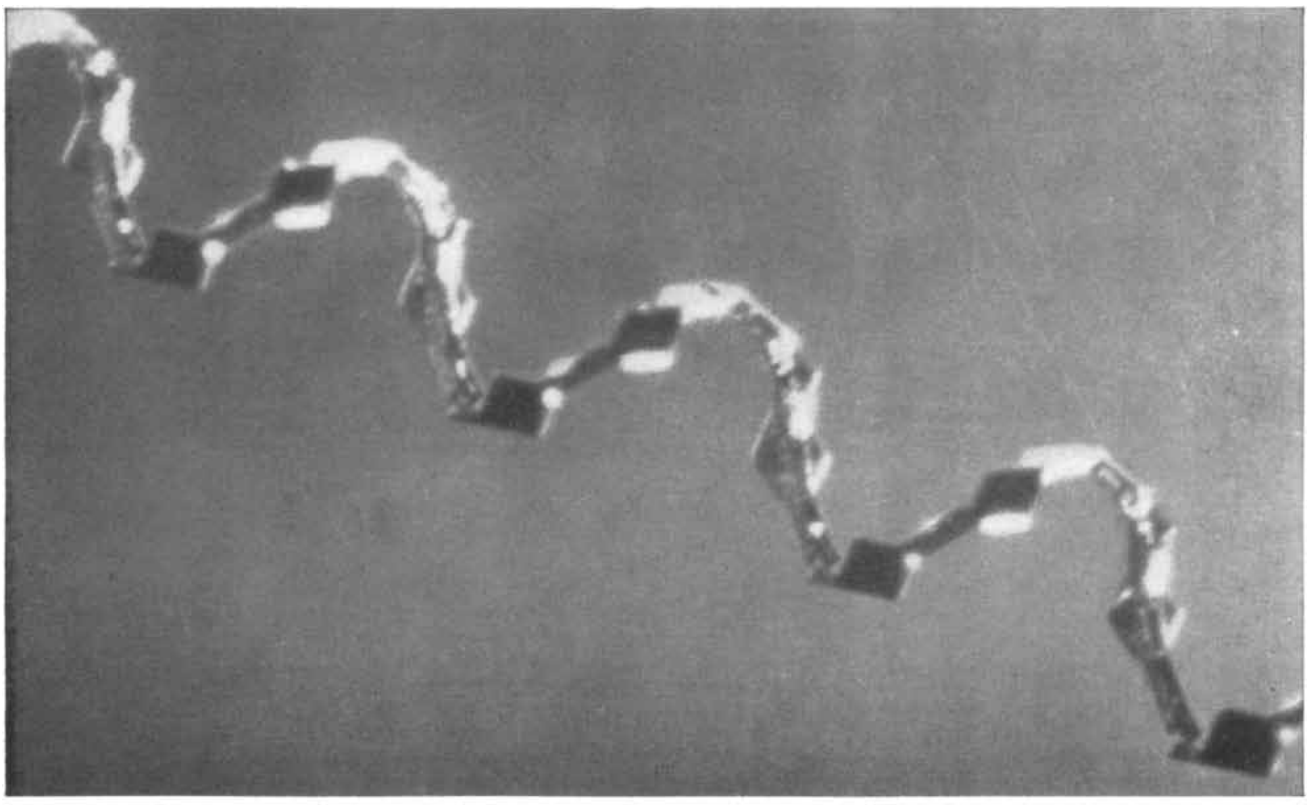
SCREW DISLOCATION in rock salt whisker (magnified 210 diameters) is "decorated" with gold particles (*thin line along central axis of whisker*). Bright areas show gold that precipitated at random. S. Amelinckx of the University of Ghent made photomicrograph.



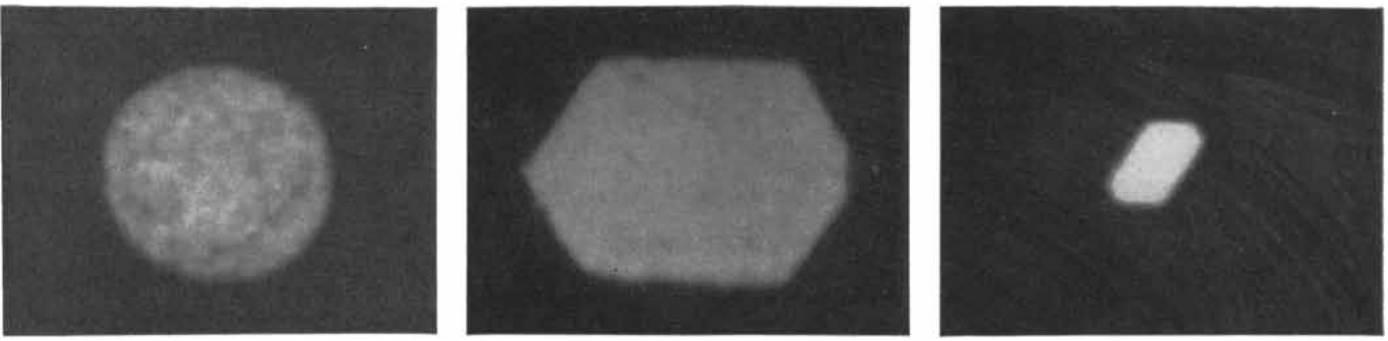
CROSS-SECTIONAL VIEWS of some of the various shapes that different types of whisker take are shown in the six photographs at the top of these two pages. The two photographs at left reveal the square and polygonal cross-sections often found in iron whisk-

reflects the addition of new material at the whisker tip. This preferential addition of material at the tip implies a structural difference between the tip and the rest of the whisker. In some organic and hydrated inorganic whiskers the difference is quite clear. Crystalline materials such as trioxane consist of thousands of parallel columns of molecules. The bonding forces within each column are very strong, while between columns they are very weak. When the molecules condense from the vapor, they prefer to attach themselves at sites of strongest bonding, that is, at the tip rather than along the sides. Occasionally a molecule condenses on the side, thus starting a new column and thickening the whisker. The growth of most whiskers, however, requires a different explanation, since the cohesive forces in metal and ionic crystals are more uniform and less directional. Although variations in growth may still exist because of differences between individual crystal faces, many whiskers are bounded on all sides by identical crystallographic surfaces.

The reason for the preference for growth at the tip becomes clear when one considers the surface structure of a growing crystal. Crystal growth occurs in one of two ways. According to the classical mechanism the crystal continuously forms new layers one on top of another [*see top drawings on page 66*]. Such growth requires heavily supersaturated vapors or solutions, because it is difficult to nucleate a new layer each time one has been completed. As an atom from the vapor condenses on a smooth, completed surface, it can bond itself only to a single neighboring atom—the one immediately below it—and may return to the vapor before another atom arrives. Once a few atoms have condensed on the surface, each additional atom has neighbors both below and around it. Starting a new layer is like starting a new housing development. The difficult part is to get the first few tenants to move in. After that it is relatively easy to attract others. When the layer is completed, the process begins



COPPER WHISKER in the form of a circular helix is magnified 120 diameters in this photograph. The dark blocks on the helix are facets, and number six per turn in the example shown, though they may appear less or more frequently in different helices.



ers. The third photograph, also of an iron whisker, shows a rectangular cross-section. Silver whiskers may be circular (*fourth photograph*) or like a slightly truncated hexagonal polygon (*fifth*). At right is the rhomboidal cross-section of a copper whisker.

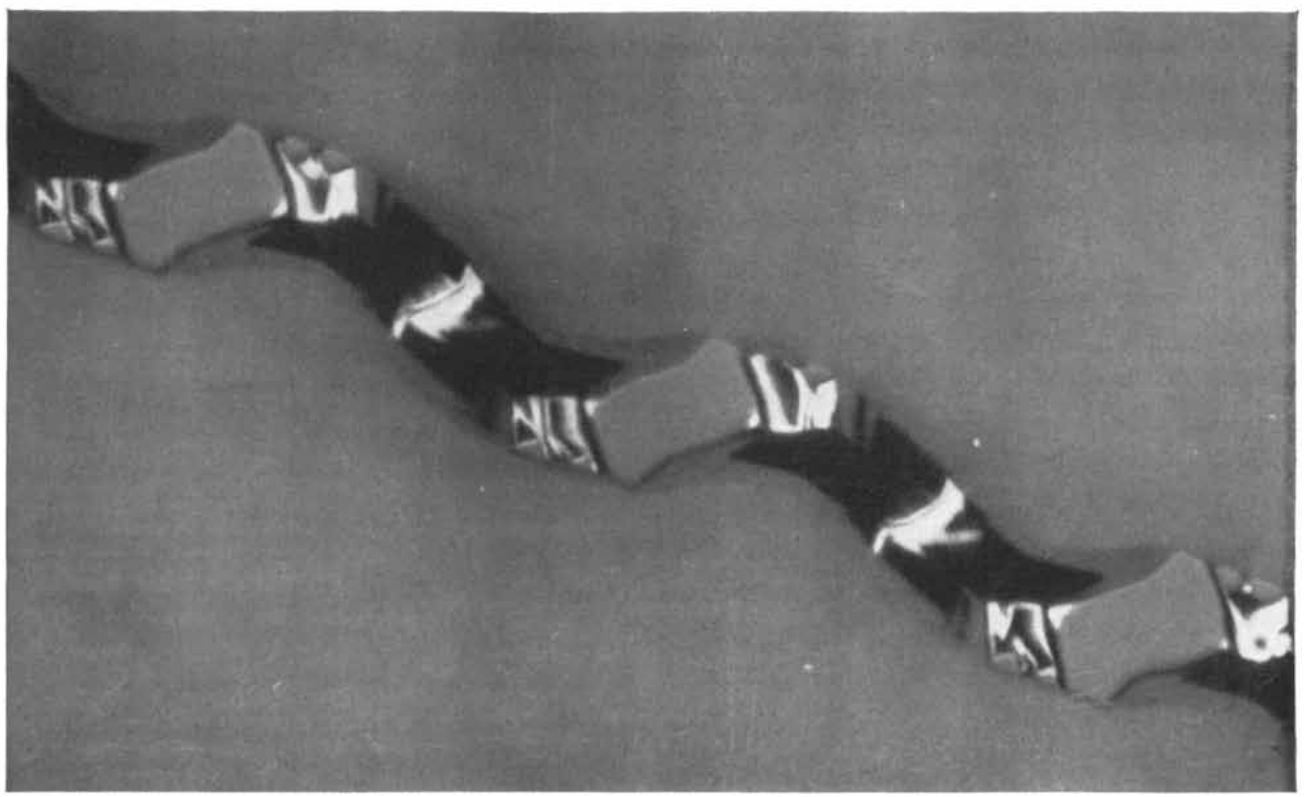
over again [*see illustration on page 66*].

But this mechanism could not explain crystal and whisker growth at low supersaturations. In 1948 F. C. Frank of the University of Bristol accounted for growth at low supersaturations by postulating that a type of crystal imperfection known as a screw dislocation facilitates crystal growth. A screw dislocation is essentially a line of atomic misfit, slightly shearing one section of a crystal with respect to another [*see bottom drawings on page 66*]. As Frank pointed out, so long as this dislocation intersects the surface, the crystal contains a permanent growth step. The atoms condensing or precipitating on the surface are thus able to deposit in a region where there are more neighbors, that is, at the steps arising from the dislocation. The growing layer spirals around the line of misfit.

It remained for G. W. Sears of the General Electric Research Laboratory to combine the concepts of classical and screw-dislocation growth and to suggest a reasonable theory of whisker growth. He proposed that crystals grow into whiskers if they contain only a single screw dislocation or, at most, a few parallel dislocations. The surface perpendicular to the dislocation—the tip—will have permanent growth steps, and the sides, which are parallel to the dislocation, will not. When the emergent whisker is exposed to its vapor at low supersaturations, the tip grows rapidly by the Frank mechanism, while the sides grow very slowly, if at all, by the classical mechanism.

S. Amelinckx of the University of Ghent has recently demonstrated the validity of Sears's theory. Dislocations in ionic crystals (*e.g.*, common salt) can be "decorated" by adding impurities that precipitate preferentially along the dislocation lines. Using whiskers of sodium chloride "doped" with gold, Amelinckx has made photomicrographs which show that some of the thinner whiskers contain only one or at most a few dislocations along their axes.

Basal growth, though apparently a



TWISTED IRON-WHISKER with flat facets is shown here magnified 120 diameters. The whisker's configuration is a natural one and is not the result of artificial twisting. The photograph was made by R. W. DeBlois of the General Electric Research Laboratory.

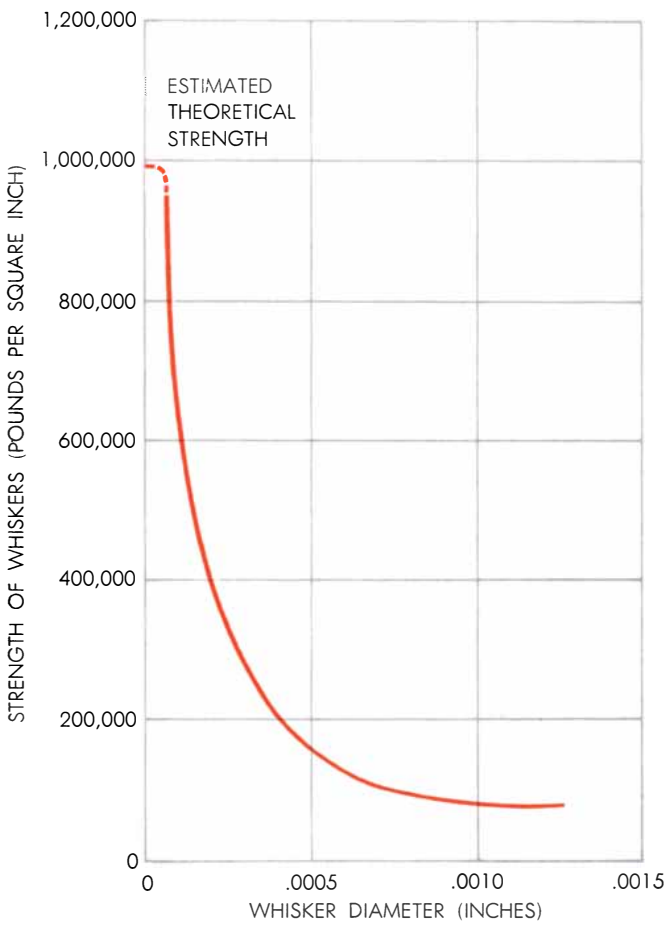
simpler mechanism, is not so well understood. In the case of silver whiskers on silver sulfide and tin whiskers on electroplated tin, small crystallites form just below the surface of the crystal. In silver sulfide the crystallite is a small precipitated silver particle, while in tin it is a recrystallized grain. For a reason still unknown, lateral growth of the crystallites is prevented, and the additional material deposited at the base causes the whisker to extrude from the surface. Investigators are not certain that basal growth requires a screw dislocation and recent evidence indicates that it may not be necessary in every case.

Both tip growth and basal growth can explain the appearance of straight, uniform whiskers. But the shape of some whiskers presents something of a puzzle. Some are kinked, others are curved and still others grow in flat spirals or broad ribbons. Perhaps the most fascinating are the twisted and helical whiskers, which occur as open helices or closed ones resembling a machine screw. The helix may make right-angle turns and so have a square configuration, and the surface of the crystal may have facets spaced at regular intervals. The pitch of the helix varies from a few turns per inch to as many as 10,000 turns per inch. Often the pitch abruptly changes. Sometimes the helix becomes a solid straight whisker, and sometimes the reverse takes place. In other cases a whisker appears to lose its "memory" and takes off haphazardly to end as a distorted, nondescript fiber. Certain protein crystals possess similar helical shapes. The protein in the outer coat of the tobacco-mosaic virus, for example, crystallizes in open helices 3,000 angstrom units long and 150 angstroms in diameter. (One angstrom unit is a hundred millionth of a centimeter.) Efforts are now being made to explain this helical configuration on the basis of whisker growth.

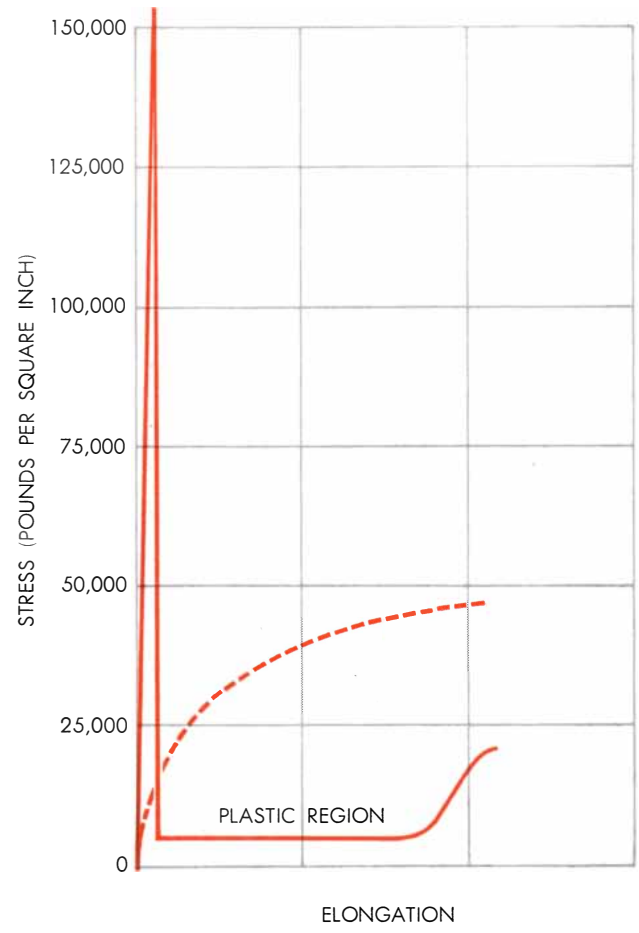
Graphite whiskers grown at high temperature and high pressure show another unusual structure. They form as tightly wound scrolls. The scroll leaves are sheets of strongly bonded carbon atoms, and some of these graphite whiskers possess strengths in the neighborhood of two to three million p.s.i.

In addition to explaining whisker growth, Sears's theory also suggests why whiskers are so strong. Normal crystals deform easily because they contain numerous dislocations of two types: screw and so-called edge dislocations. Under stress these lines of atomic mismatch move easily, causing the crystal to elongate every time a dislocation moves completely through it. The resulting deformation may be compared to wrinkles in a rug. To move the rug all at once requires a large force, but a single wrinkle can be moved quite easily, and the rug moves forward with little resistance. To move the rug a considerable distance many wrinkles would have to be introduced. Similarly, any appreciable crystal deformation requires millions of dislocations. In large crystals the dislocations interact to generate new ones.

In contrast, the size of whiskers and the means by which they grow greatly



WHISKER STRENGTH is a function of whisker diameter and drops sharply within the first .0005 inch, slowly decreasing with further increases in diameter. The curve shown represents the relationship of strength to diameter in one type of iron whisker.



ELASTICITY in a copper bar (*broken line*) is compared with that in a specific copper whisker (*solid line*). The bar turns plastic almost at once (*bottom of broken line*). The whisker elongates about 1.5 per cent of its length before it turns plastic suddenly.

limit the number of dislocations that can occur. The few dislocations present cannot themselves cause any measurable deformation, and they are too few to interact and generate others. Thus a whisker's strength is equal to the external force needed to introduce new dislocations. This has been estimated to be between 500,000 and four million p.s.i. in the common structural materials.

To conclude that whiskers are synonymous with high strength, however, would not be entirely correct. There are great variations in whisker strength, and for every strong whisker there are others that are weak by comparison. Generally the thinnest whiskers have the greatest strength; the larger the diameter, the weaker the whisker.

The dependence of strength on size may be due to the presence of surface defects. During crystal growth it is possible that cracks and other defects form sites at which active dislocations develop. The longer and thicker the whisker, the greater will be the number and size of the defects it contains. Whiskers are comparable to a chain with a few weak links; most of the links are stronger than the chain as a whole. Consequently if a whisker is broken in half several times, the strength of each succeeding half rapidly increases.

In addition to their strength, whiskers have other properties that differ from those of commonly encountered materials. When an ordinary copper bar is stretched, it first elongates elastically about .1 per cent of its original length. If the stress is released, the bar returns to its original form. Up to this point, in accord with Hooke's law, the strain or change in length is proportional to the stress producing it. But if the stress is increased beyond the elastic limit, the deformation becomes permanent, and the bar behaves plastically. The transition from elastic to plastic behavior occurs gradually. As a greater number of dislocations are generated under increased deformation, they begin to impede and block one another's movement; the bar thus becomes stronger and more resistant to further deformation. The final strength is many times what it was at the transition point.

In copper whiskers the region of elastic behavior is much wider; a single whisker may elongate 5 per cent of its original length before becoming plastic. Beyond a certain point, however, elastic deformation in some whiskers ceases to obey Hooke's law. Further stress no longer produces the proportional strain predicted by the law even though the whisker regains its original dimensions when the stress is removed. Furthermore, transition from elastic to plastic behavior is not gradual but sharp, and the whisker's strength drops precipitously to as little as a hundredth of its strength before transition. At the transition point the stress is large enough to introduce new dislocations, which can then generate others at much lower stresses. The whisker hardens somewhat under further deformation (as the dislocations multiply enough to interfere with one another), but never regains its original strength.

MATERIAL	NORMAL STRENGTH (POUNDS PER SQUARE INCH)	WHISKER STRENGTH (POUNDS PER SQUARE INCH)
IRON	4,000	1,900,000
COPPER	200	400,000
GOLD	200	230,000
SILICON	5,000	550,000
SODIUM CHLORIDE	100	160,000
ALUMINUM OXIDE	80,000	1,800,000
GRAPHITE	40,000	3,000,000

WHISKER'S STRENGTH is compared with normal strength in different materials in the table above. By "normal strength" is meant the stress at which large crystals of a given material begin to deform permanently (ductile materials) or fracture (brittle materials).

The relation between dislocations and strength has its counterpart in the magnetic behavior of crystals. Dislocations, which are regions of distortion between perfect sections of a crystal, correspond to the boundaries between "domains," the portions of a crystal where all the individual atomic magnets are aligned in the same direction. But whereas dislocations are only a few atoms thick, the boundaries, or domain walls, may extend more than a hundred atomic layers. In an unmagnetized material the directions of magnetization of the various domains are generally disordered, and the net magnetization is zero. But when a magnetic field is applied, the domain walls begin to move, and domains favorably oriented with respect to the field grow at the expense of those that are unfavorably oriented. When a crystal is itself a single domain, higher field-strengths are required to nucleate a domain wall and to reverse the direction of magnetization.

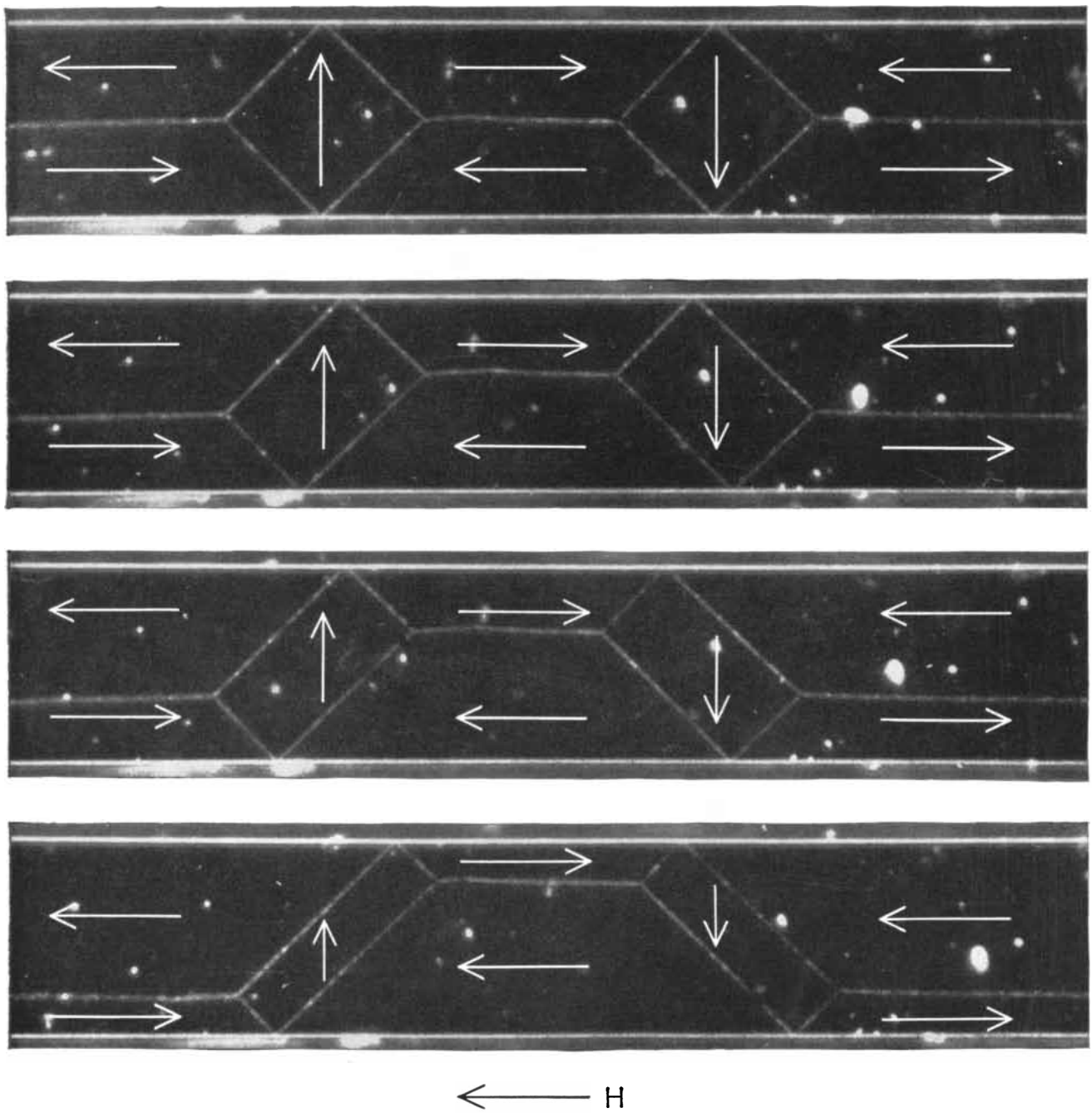
Before whiskers had attracted scientific interest it had been observed that domain walls form in fields 100 times smaller than theory predicted. This at first cast doubt on the whole domain-wall theory. Investigators later pointed out that imperfections such as voids, pits and cracks could create strong localized magnetic fields and that domain-wall formation at these points would require a much lower applied field. In 1957 Charles P. Bean and R. W. DeBlois of the General Electric Research Laboratory confirmed that high field-strengths are required to nucleate domain walls. Using single-domain iron whiskers, they found it necessary to apply fields of the predicted strength in order to nucleate a domain wall and thus reverse the magnetization. When the whiskers contained visible defects, domain walls nucleated at lower fields, depending on the severity of the defects. Because of their greater width, domain walls are influenced by coarser defects than dislocations are. Thus a magnetic material such as iron may have high magnetic "strength" and still be mechanically weak.

Another study that whiskers have made possible is the measurement of the rate at which domain walls move in fields of varying strength. This relationship has practical interest, since many of the components in large-scale computers must reverse their magnetization very rapidly. Until recently, however, the movement of domain walls could be studied only at low speed, because a single domain wall could be followed only in low-strength fields. Crystal defects caused the formation of extraneous domain boundaries at fields of higher

strength and confused the picture. The structural perfection of iron whiskers eliminates this complication, and boundary speeds of up to 120,000 miles per hour have been measured. The speeds observed previously had been less than 250 miles per hour.

Metal whiskers have thus served their students well. The inevitable question is whether whisker strength can be exploited in technology. It has been suggested that whiskers might be woven into cables for suspension bridges. This seems farfetched at the moment, but it may be feasible to use whiskers in high-strength reinforced laminates. Such laminates, while costly to manufacture, would be valuable in applications that require a high strength-to-weight ratio. The development of whisker-reinforced laminates will depend on a number of factors. The load to be carried must be transmitted efficiently to all the whiskers so that the strength of the whole approaches that of a single whisker. Moreover, the whiskers will require special handling, since their strength falls catastrophically once defects are introduced.

It is not inconceivable that further investigation of whiskers may find ways to harness a greater part of the ideal strength of solids and bring about a revolutionary change in materials technology. In the meantime whiskers will continue to be useful in the study of the solid state.



MAGNETIC-DOMAIN MOVEMENT in an iron whisker under an applied magnetic field is shown in these four photographs. Arrow at bottom shows direction of applied field (H); other arrows show magnetic directions. As the field increases from 0 (*top*) to 20 oersteds (*bottom*), domains favorably oriented (*arrows pointing left*) grow in size, while unfavorably oriented domains decrease in size. The photographs were made by R. W. DeBlois and C. D. Graham, Jr., of the General Electric Research Laboratory.

Kodak reports on:

photography for biologists . . . the parts-per-billion business . . . what to do with wiggle-bearing paper . . . a commercially interesting four-membered ring

Four of us at Woods Hole

Four of us expect to put in a rugged week on Cape Cod, beginning early on the morning of August 1. It's not exactly an exhibit or symposium or anything as formal as that. It's just that the management of the Marine Biological Laboratory at Woods Hole has given us to understand that if we want to hang around for five days dispensing free advice on how to use photography to communicate results of biological investigation, they will probably refrain from calling the cops to throw us off the premises.

We figure any time spent feasting on Homarus americanus *is time lost from showing our movie of* Homarus americanus *hatching in glorious Eastman color.*

Spectroscopy in electronics

We wish we could inspire several dozen more persons to enter the craft of emission spectrography. They would become customers for *Kodak Spectrum Analysis Plates* and *Films* as well as occupants of a secure place in technical society, one of waxing importance.

To convince that the importance indeed waxes we could send copies of a disquisition written by one of our dealers, a gent willing to undertake some deep thinking and digging out of useful information in hope of the favor of an order.

Think of the old days, he suggests, when electronics meant radio and the man at the end of the radio assembly line was given plenty of adjustable resistors, capacitors, and coils on the chassis to adjust in compensation for the unpredictable characteristics of the vacuum tubes. Electronics isn't that way any more, he implies. Today electronics is supposed to assume that its solid-state devices and the cathodes of its vacuum tubes will behave predictably within very narrow limits.

And what sets these limits?

Among other things, the presence or absence of certain chemical elements in the range of parts per billion.

How determined?

By emission spectrography.

Is this easy?

Not particularly.

What's one way to start surveying the techniques?

Writing for a copy of "Spectroscopy in Electronics" to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y.

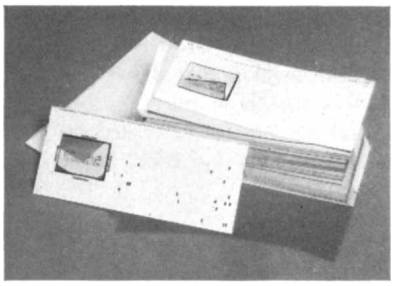
Back from the brink

When visitors come shuffling through your laboratory, it makes a terrific impression to show you are equipped for:

- Infrared absorption spectroscopy
- Ultraviolet absorption spectroscopy
- Visible absorption spectroscopy
- X-ray diffraction
- Nuclear magnetic resonance spectroscopy
- Fluorescence spectroscopy
- Raman spectroscopy
- Mass spectroscopy
- Gas chromatography
- Miscellaneous analytical methods like polarography
- Miscellaneous physical testing methods

Aside from creating an impression, these procedures generate strips of paper bearing wiggles. That there would be produced many such useful strips of wiggles to keep and compare had justified the acquisition of the instrumentation. The truer this has proved, the worse you may need help. We ourselves did. Fortunately, as we approached the brink of madness in coping with the sheer volume of spectrophotometric curves generated at the research laboratories of our division, Tennessee Eastman Company, we were able to call on our subsidiary, Recordak Corporation.

The Recordak people are experts at working out systems that combine micro-



Neat, like this.

filming with punched cards. They say they would be willing to help you, too. They suggest you write them at 415 Madison Avenue, New York 17, N. Y., for a copy of "The Use of Aperture Cards for the Consolidation of Spectrophotometric Data."

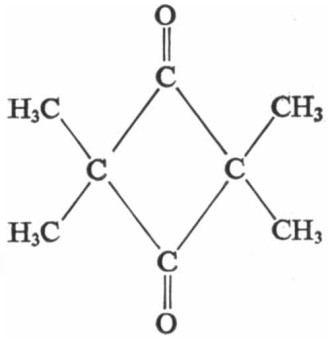
Smells like menthol

Our pilot plant for *Tetramethyl-1,3-cyclobutanedione* from dimerized ketene has gone on stream.

It is a promising organic intermediate. This is a colorless way of saying that even if we knew the route by which Joe Public eventually buys it, it would be too long a story to tell. If Fortune smiles, some chemical descendant of this dione, a remote descendant very likely, will have a part in pleasing Joe. It may wash cars, kill weeds, scare sharks, shed rain, smell good, fight fires, heal the sick, or die on the vine.

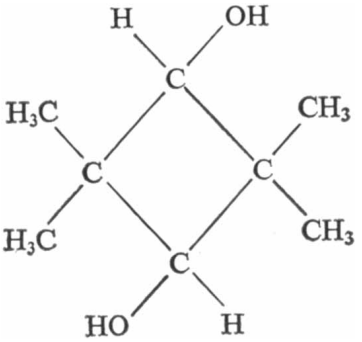
Such language is unsuitably direct. At this stage, sales talk must be kept scholarly. Our chemists proceed like a chef with a fresh, fat partridge and an armory of herbs and spices for sauce.

We offer



the first four-membered ring at a price we believe commercially interesting. It can be left a ring or be split open in interesting ways. It reacts with the usual carbonyl group reagents, but the reaction can proceed further to yield heterocyclics. It resembles menthol and camphor in odor and volatility.

We also offer the ring hydrogenated to the secondary glycol, *2,2,4,4-Tetramethyl-1,3-cyclobutanediol,*



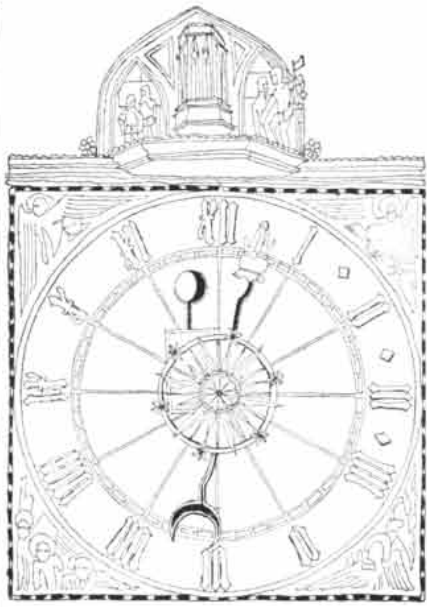
which forms very stable diesters, as for plasticizers and lubricants. It forms both saturated and unsaturated polyesters. Not the least of its charms is the white, translucent, waxy polymer in which silicon atoms can link it.

To get a line on price, one writes Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company) and thus gives us an opportunity to send the scholarly details complete.

Kodak
TRADEMARK

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

SCIENCE AND



Funds for University Research

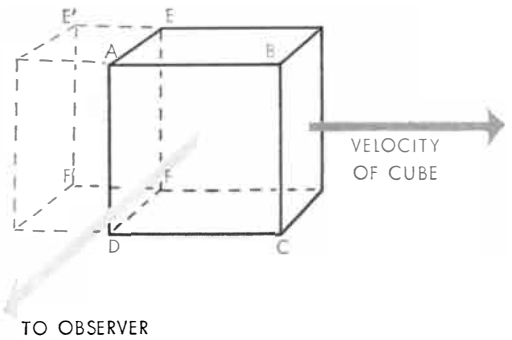
To allow universities greater freedom in planning their scientific-research programs, the National Science Foundation will for the first time make unrestricted grants during the coming academic year. Previously it has given funds only for specified projects. Each institution is to receive 5 per cent of the amount it got from the Foundation for the year just ended. On this basis 230 colleges and universities will share $2.9 million in unrestricted funds.

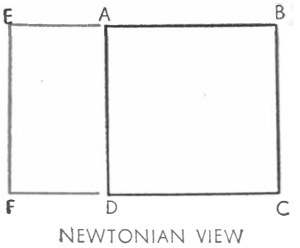
The Foundation's latest report on research and development shows that expenditures for these purposes by colleges and universities increased 80 per cent between 1954 and 1958. In the latter year the amount was $735,800,000, of which 72 per cent came from the Federal Government. More than half the money went to agriculture experiment-stations and contract research-centers, for applied research. Colleges and universities proper spent $327,500,000, 74 per cent of it for basic research. Of the Government's share of the cost, 42 per cent was contributed by the Department of Defense; 33 per cent by the Department of Health, Education and Welfare; 15 per cent by the Atomic Energy Commission and 7 per cent by the National Science Foundation.

Relativity and the Backside

Although the special theory of relativity is 55 years old, it still seems a wonderland of paradox to laymen. Now it appears that even physicists, for whom the theory has become just another tool of the trade, have not fully appreciated its subtleties.

This was made clear recently when J. Terrell of the Los Alamos Scientific Laboratory, writing in *The Physical Review*, reopened a question that most authorities considered to have been answered long since. The question: In view of the FitzGerald contraction (the shrinking of moving bodies in the direction of their motion), what would objects moving at nearly the speed of light look like if we had eyes, or cameras, fast enough to form an instantaneous picture of them? It has generally been supposed that they would simply appear squashed in the direction of motion. Thus the square side of a cube traveling horizontally across the field of view and seen directly broadside would presumably look like a rectangle as high as the cube, but narrower. At speeds very close to that of light the horizontal dimension would shrink almost to nothing and the cube would look like a vertical knife edge.





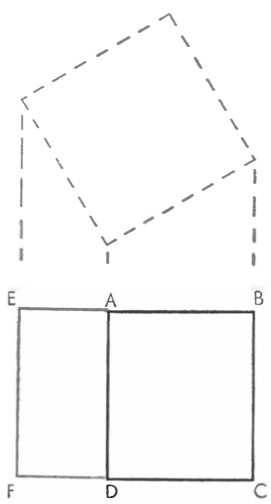
In a Newtonian system an observer would see the cube at left as it appears

THE CITIZEN

Not so, says Terrell. His reasoning, as summarized by V. F. Weisskopf of the Massachusetts Institute of Technology in an article to be published in *Physics Today*, runs as follows: The instantaneous picture of an object on the retina or on a photographic plate is formed by light photons that arrive simultaneously from all visible points on the object. This means that photons from more distant parts of the object started on their journey earlier than those from the closer parts. When the object is stationary, the difference in travel time does not matter. But when it is moving, the lag causes a distortion of the image.

The distortion is exhibited, for example, by a cube moving from left to right across the field of view of an observer [*see illustration on these two pages*]. The object is assumed to be small enough so that the rays from all of its parts are very nearly parallel. Neglecting relativity, when the cube is directly opposite the observer, its side face ABCD appears as a square.

At the instant that a group of photons starts out from the edge AD there are photons abreast of it, which started out a short time earlier from the back edge EF of the trailing face ADFE. At that time the edge was in the position E′F′. (Of course, at that time the trailing face was pointed slightly away from the observer so it might seem that no light



RELATIVISTIC VIEW

in middle; in a relativistic system, as at right

from it could reach him. However, the photons emitted or reflected by that surface can have a rightward component of motion because of the motion of the cube.) Hence at the same instant that the observer sees the edges AD and BD, he also sees the edge EF in its earlier position. The net effect, if relativity is not taken into account, is that the side face is seen as a square, and the trailing face as a rectangle, as though the cube had been rotated.

But relativity steps in to alter the image. The FitzGerald contraction shortens the distance between AD and BC so that the side face also looks rectangular. When the contraction is calculated, it turns out to be just the right amount to make the cube appear as it would if it had really been rotated by the amount necessary to bring the trailing edge into view. Hence the object looks not squashed, but turned.

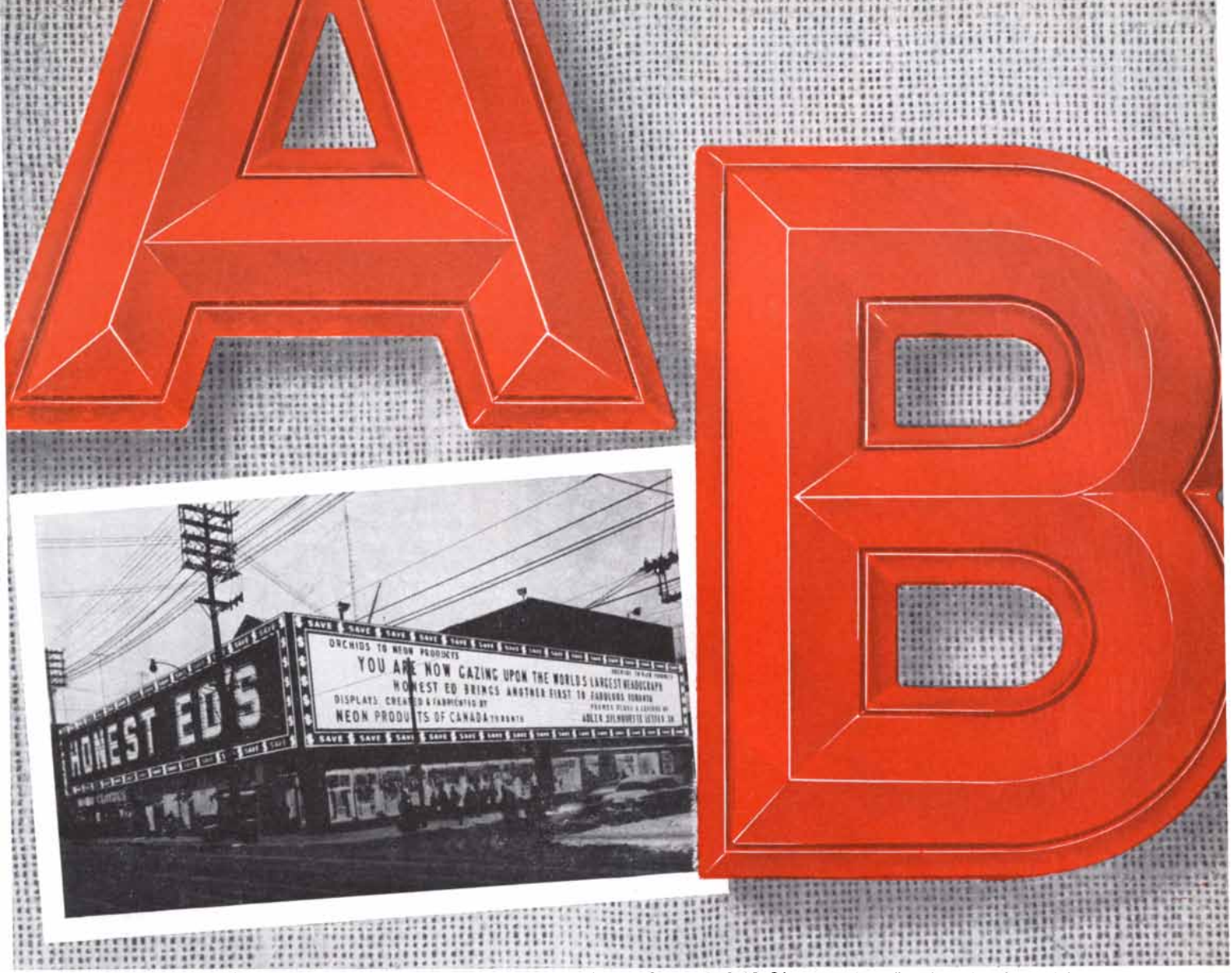
In the extreme case, when the cube travels at the speed of light, the side face shrinks to zero. But the cube moves a full edge-length to the right while light from the back edge advances to be even with the front. Thus the trailing face now looks like a perfect square, and the cube appears to have been rotated a full 90 degrees.

A similar argument applies even before the cube has arrived opposite the observer. While it is still far to his left, if the speed is great enough, he can see some of the trailing face, and the side face is appropriately foreshortened. The leading face, which the observer would seem to be looking at, is invisible. At very high speed, then, the cube seems to turn its back to the observer while it is still far in front of him. It retains this aspect as it draws up even with the observer and as it recedes into the distance.

East-West Exchanges

As negotiations on a nuclear-test ban resumed in Geneva, following a recess for the abortive summit meeting, physicists from the U. S. and the U.S.S.R. were exchanging visits to research facilities in the two countries. The tours were part of a program for cooperation in the peaceful uses of atomic energy set up by the U. S. Atomic Energy Commission and its Soviet counterpart last September. The Soviet party inspected centers of research on thermonuclear power, while the one from the U. S. toured high-energy physics laboratories. Subsequently a second pair of groups were to make the reverse tours.

The members of the first U. S. group



Letters molded of Tenite Butyrate by Adler Silhouette Letter Co., 11843 W. Olympic Blvd., Los Angeles 64, California.

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Up in Toronto, you can find the world's largest changeable-letter sign, or as it's known north of the border—"readograph." The red, green, and black letters of this sign, 10,000 pounds of them, are all molded of a special weather-resistant formulation of Tenite Butyrate plastic.

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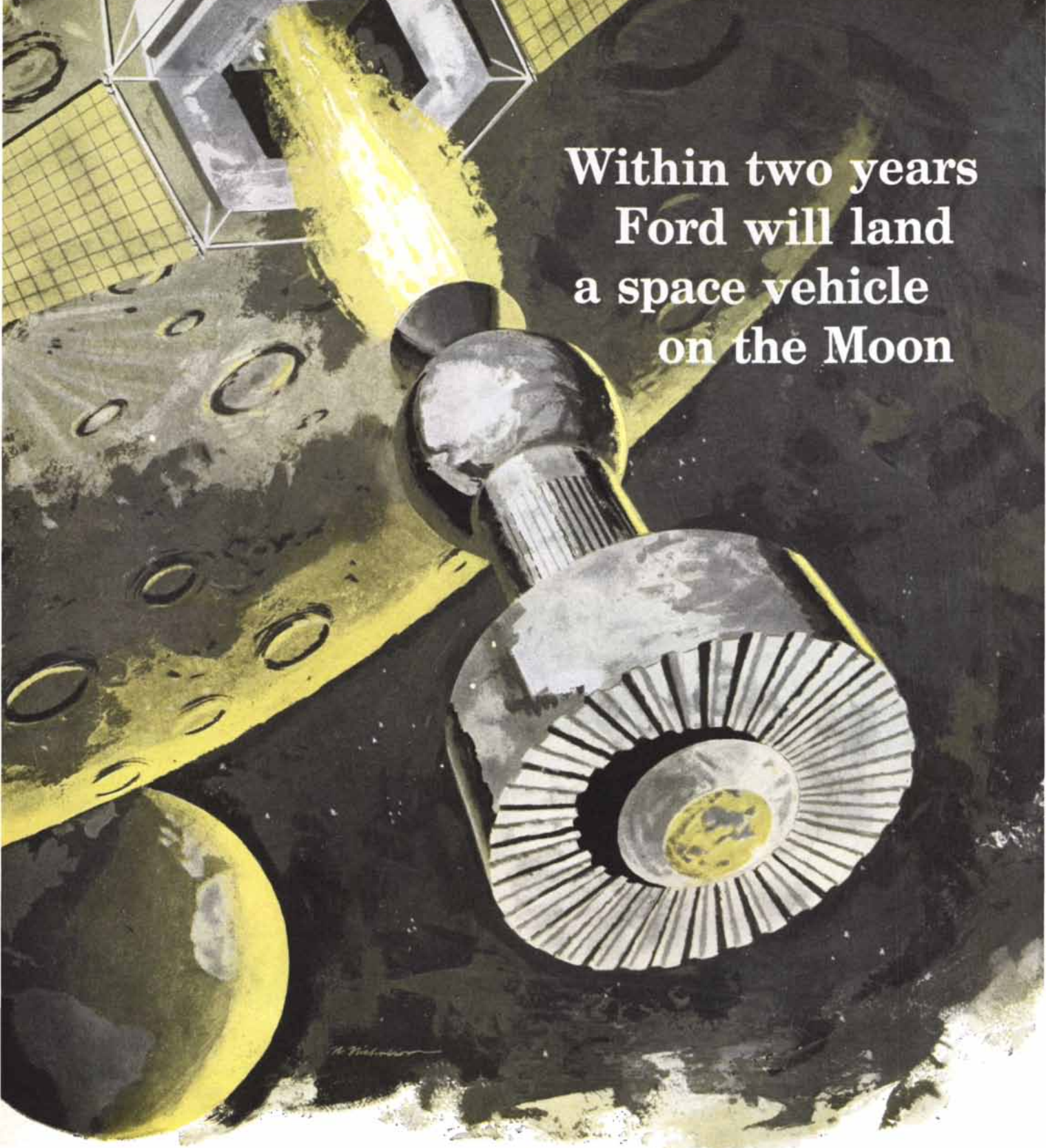


A 300-pound Lunar Capsule containing scientific instruments will soon make a "rough" landing on the Moon. It will be carried by a larger spacecraft to a location about 25 miles from the Moon's surface, then released. A retro-rocket will cushion its impact. The Lunar Capsule will transmit vital scientific data back to Earth for a month or more. This unique space vehicle will be the product of Ford Motor Company's Aeronutronic Division.

were: Robert F. Bacher of the California Institute of Technology, George A. Kolstad of the A.E.C., E. J. Lofgren of the University of California, Robert E. Marshak of the University of Rochester and Robert R. Wilson of Cornell University.

The Satellites

The number of artificial earth satellites in orbit reached a dozen with the launching of a five-ton "space ship" by the U.S.S.R. and the 2½-ton *Midas* by the U. S. Air Force.

As a prelude to manned space-flight, the giant Soviet vehicle was fitted out with a pressurized, fully equipped cabin complete with dummy astronaut. Scheduled to slow down on command from earth, the ship speeded up when its retrorockets apparently misfired, the low point of its orbit jumping from 189 miles to 195 miles, and the high point from 225 to 429 miles.

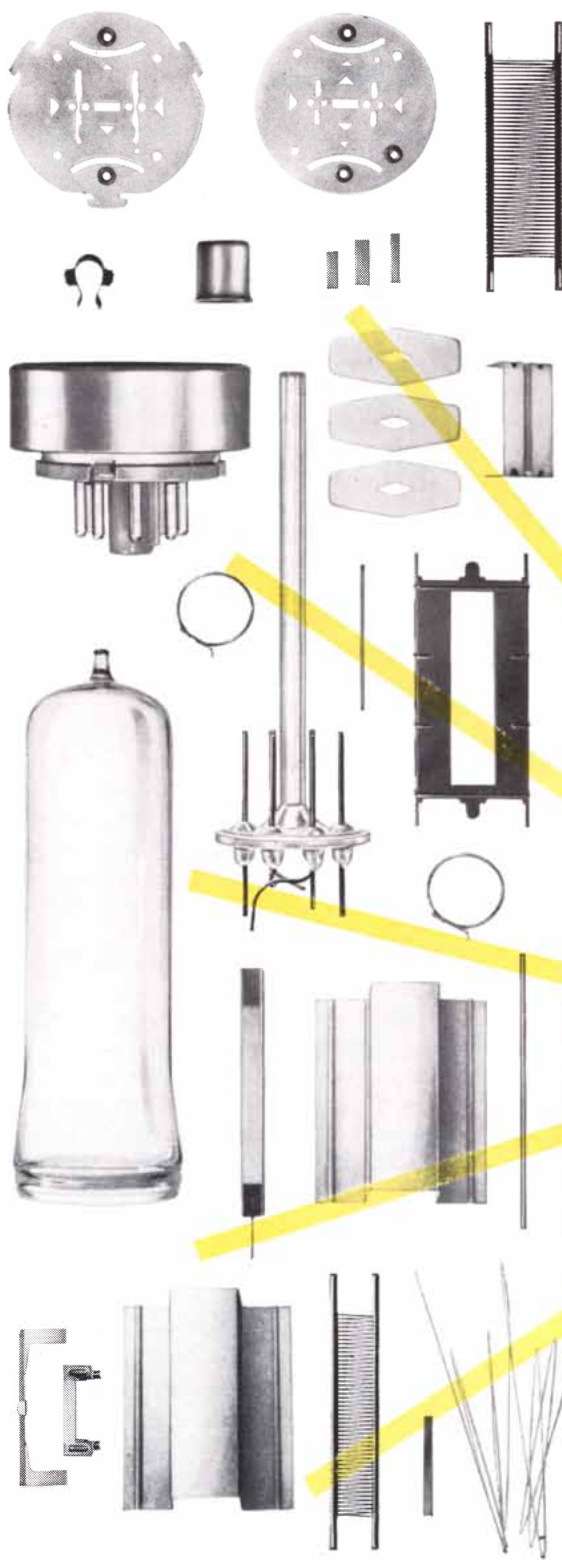
A more successful remotely controlled maneuver was carried out by the U. S. weather satellite, *Tiros I*. At a radio command two small rockets on its surface were fired, increasing the rate of its stabilizing spin from 9.4 to 12.85 revolutions per minute. It continued to photograph the earth's cloud cover.

The five-watt transmitter aboard *Pioneer V*, in orbit around the sun, was still sending back signals at 13.3 million miles from the earth. The satellite's 150-watt transmitter, turned on by order from earth, quickly cut itself off, indicating that power was low because of a storage-battery leak.

The 12 earth satellites after the launching of *Midas* (and their maximum distances from the earth) were: the U. S. vehicles *Explorer I* (1,250 miles), *Vanguard I* (2,450 miles), *Vanguard II* (2,050 miles), *Explorer VI* (26,000 miles), *Vanguard III* (2,330 miles), *Explorer VII* (670 miles), *Tiros I* (468 miles), *Transit IB* (479 miles), *Midas II* (316 miles) and the Soviet spaceship. In orbits around the sun were the Soviet *Lunik I* and the U. S. *Pioneer IV* and *Pioneer V*. Radios were still functioning on *Vanguard I, Explorer VII, Pioneer V, Tiros I, Transit IB* and the new Soviet vehicle.

Radiation Information

The U. S. Public Health Service has begun to issue a monthly report on levels of radioactivity in the environment. The first issue of the publication *Radiological Health Data*, which appeared in April, contained figures on the



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strontium-90 content in milk samples, and on radioactivity in air and surface water from various parts of the country.

Although it presented the data without comment, the report contained a section entitled "Interpretations of Radiation Levels." (Levels reported were below current maximum permissible concentrations.) Every third issue will contain "interpretive statements."

New Biology Course

Sixty high-school and college biology teachers, together with a group of consulting artists, editors and psychologists, are currently meeting at the University of Colorado to rewrite the high-school biology curriculum. They are preparing textbooks, laboratory equipment and other teaching aids for a new course, to be presented in three versions for children of different intelligence levels. The material will be tested during 1960 and 1961 in 28 school systems throughout the country.

The program, known as the Biological Sciences Curriculum Study, is directed by a committee of the American Institute of Biological Sciences headed by H. Bentley Glass of Johns Hopkins University. Like similar programs in physics, mathematics and chemistry, it is financed by the National Science Foundation.

Jovian Van Allen Belt

Measurements at the California Institute of Technology on radio waves from Jupiter have established "almost conclusively the existence of a belt of Van Allen radiation," according to a recent announcement. The Jovian signals have been found to be polarized, a sign that they are produced by electrons (and other charged particles) temporarily trapped in a planetary magnetic field and spiraling along it. The acceleration resulting from the spiral path produces the characteristic polarized "synchrotron radiation."

The new observations were made by two visiting workers, V. Radhakrishnan of India and J. A. Roberts of Australia. They have also calculated that Jupiter's Van Allen belt is 200,000 miles above the planet and is giving off 10^{14} times as much radio energy as the Van Allen belts around the earth.

Infant Mortality

The death rate of U. S. infants, after a long and precipitous decline, has leveled off in the last few years, according to a study of Iwao M. Moriyama of

the National Office of Vital Statistics. In some states it has even risen slightly. From 1933 to 1949 the infant mortality rate decreased by an average of 4.3 per cent per year. In 1950 the annual decrease dropped to 2 per cent, and, after reaching an all-time low of 26 per 1,000 live births in 1956, the death rate among infants has changed little.

Most of the reduction in mortality of children under one year of age is attributable to control of infectious diseases, primarily influenza and pneumonia. In 1946, when penicillin became available to the public, the deaths from infectious diseases dropped about 30 per cent. However, infectious disease still accounts for about half of the deaths among infants between one month and one year old.

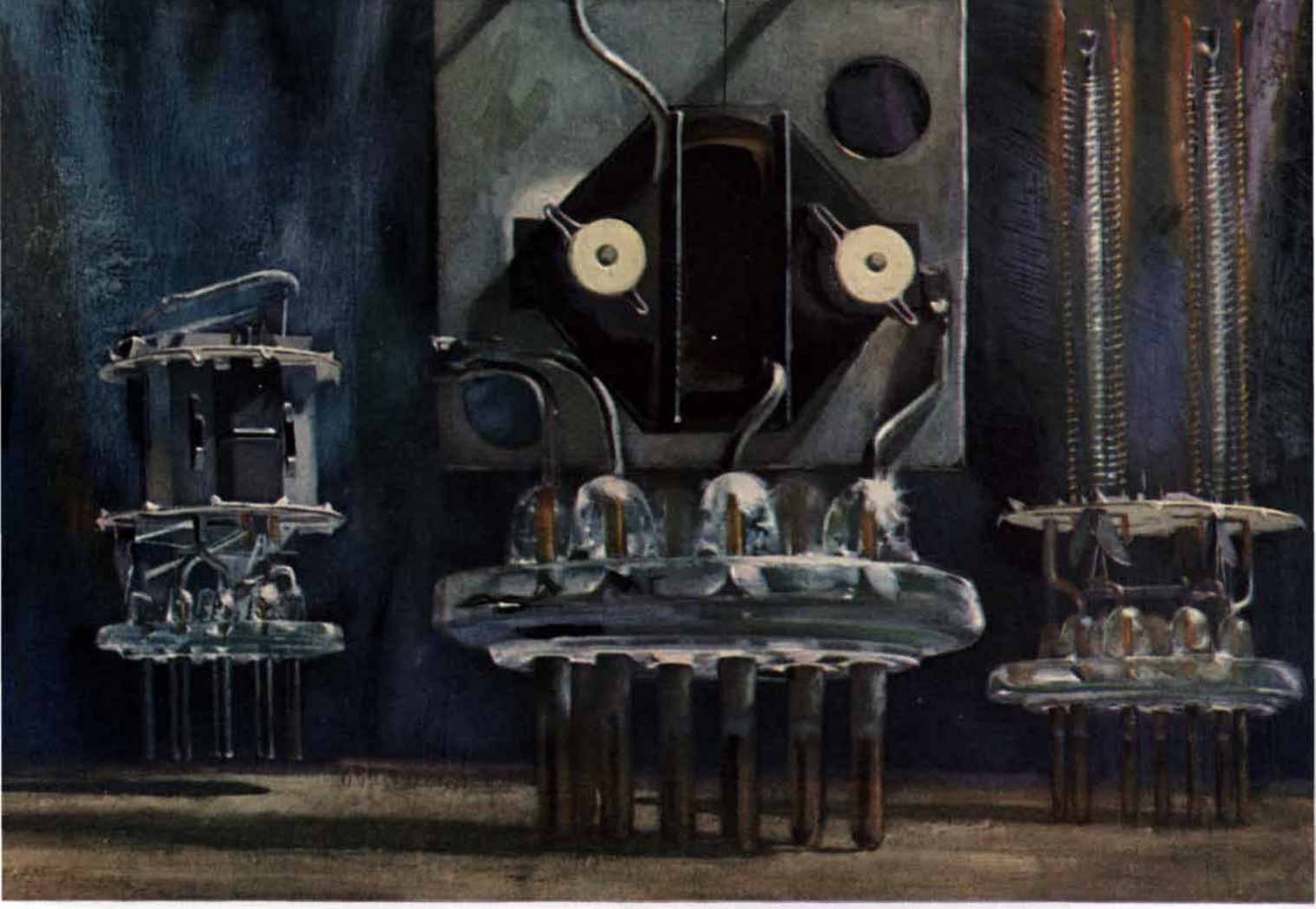
The death rate for younger infants reflects the heavy toll taken by noninfectious conditions such as congenital malformations, birth injuries, postnatal asphyxia and premature births. In his discussion in *Public Health Reports*, Moriyama predicts that the present rate of infant mortality will not be substantially reduced until there is a breakthrough in dealing with these problems.

Genetic Code Cracking?

New insight into the way in which living organisms carry out genetic instructions coded on nucleic acid molecules was reported last month by two biologists at the University of California. In the *Proceedings of the National Academy of Sciences* A. Tsugita and H. Fraenkel-Conrat described a breeding experiment on the simplest of organisms —viruses—which consist of a single chain of ribonucleic acid (RNA) carrying the genetic code, surrounded by a protein coating made according to the coded directions.

Working with tobacco-mosaic virus, Tsugita and Fraenkel-Conrat stripped off its protein and treated the bare RNA with nitrous acid. This is known to produce small chemical changes (*i.e.*, mutations) in the nucleic acid. Then the original protein "overcoats" were put back on, and the reconstituted virus was rubbed into growing tobacco plants. Mutant forms were readily identified by differences in the disease symptoms they caused and by their ability to infect plants normally immune to tobacco-mosaic virus.

Selecting a mutant that differed from the parent type both in the disease symptoms it produced and in its choice of hosts, the experimenters allowed it to multiply in a tobacco leaf. In this process



NEW "EARTH CREATURES" FROM SYLVANIA

These are the structures typical of new and unusual electron tubes under development at SYLVANIA. They are inanimate, silent. Yet they are capable of comprehending every language of the universe. Electron tubes are vital components of electronic devices and systems. They are essential ingredients in man's explorations of time, space, and matter.

Advanced tube structures such as those shown here will one day be basic components in "sophisticated" designs for reliable electronic computers, industrial electronics, communications, TV sets, radios, and monophonic and stereophonic music systems.

New materials, new techniques, new concepts of electron tube designs are being constantly created at SYLVANIA. No wonder SYLVANIA electron tubes are setting new standards for performance and reliability in electronics.

The exciting story of SYLVANIA electron tubes is told in the booklet, "A New Era . . .". For your copy please write to Sylvania Electronic Tubes, a division of Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.

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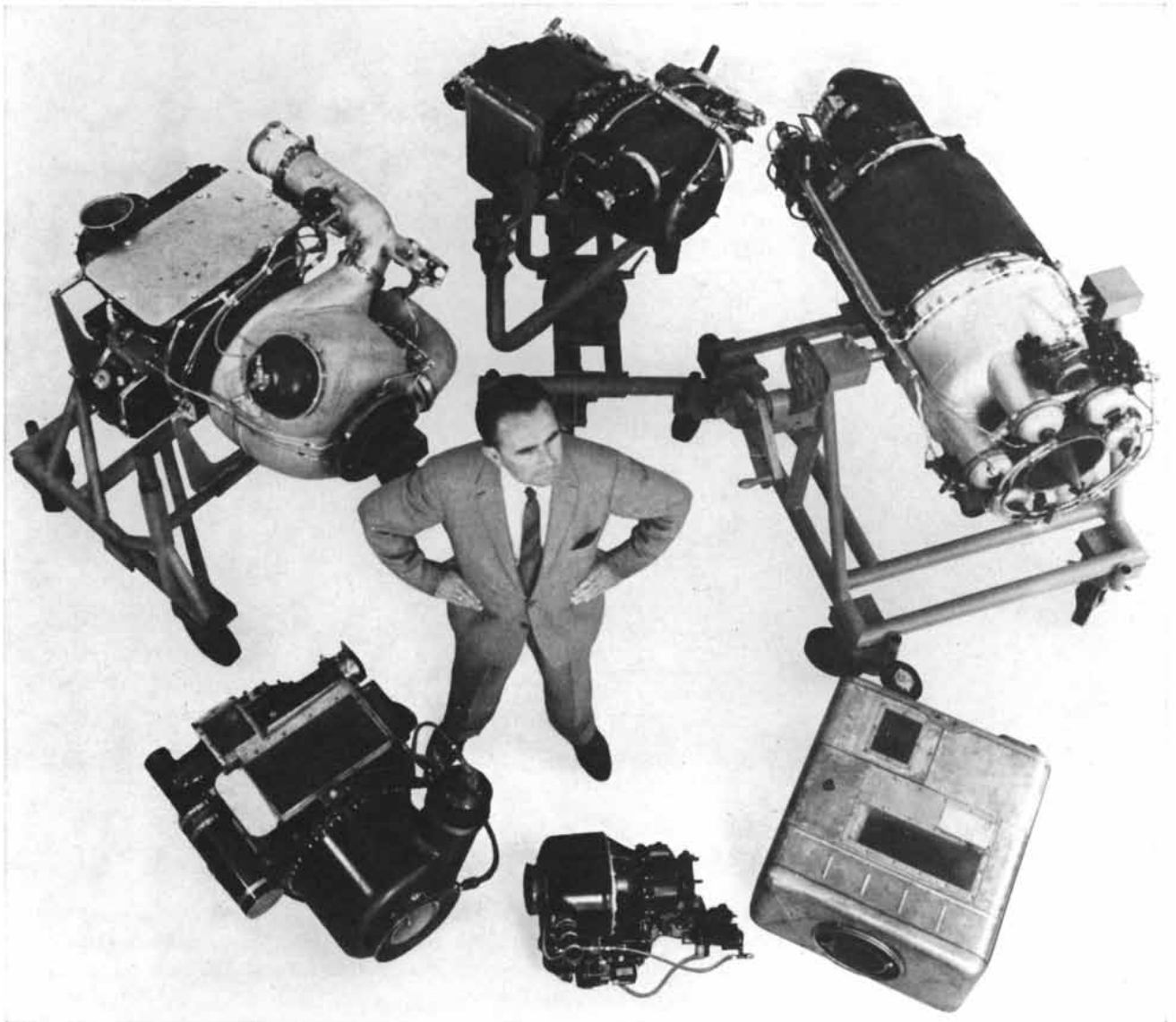

Helmut Schelp, chief engineer, AiResearch Manufacturing Division of Arizona, Phoenix, surrounded by typical gas turbines now in production ranging in size from 30 to 850 hp. Clockwise from the top: GTC 85-28 GTCP 105 · GTP 70-6 · GTP 30-1 · GTP 70-10 · GTU 85-2.

AiResearch Gas Turbine Engines, the most widely used power source for the starting, air conditioning, cooling and heating of jet aircraft, now are becoming a prime power source for industry.

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the virus RNA shed its old protein, entered a plant cell and directed the formation of a new protein coating. The new protein was separated and analyzed, and compared with the original. The new and old molecules contained the same number of amino acid units (158) but three of the acids were changed: one unit each of proline, aspartic acid and threonine had been replaced by leucine, alanine and serine respectively.

By good luck it was even possible to locate the site of one of the replacements. This was done by using an enzyme that splits off amino acids from a protein chain until it comes to a unit followed by proline, whereupon the action stops. When applied to the normal tobacco-mosaic virus, the enzyme splits off only a single amino acid from one end of the chain, showing that there is a proline in the third position. In the mutant protein, however, 15 units are split off. Thus the proline in the third position must be the one replaced by leucine.

The identification of a specific alteration in a protein is half the battle. Now it remains to determine how the nucleic acid itself was changed. The two pieces of information together will constitute the first translation of the genetic code.

Primitive Coexistence

An early variety of modern man apparently lived almost side by side with Neanderthal man about 50,000 years ago in the Near East. So concludes T. Dale Stewart of the Smithsonian Institution after studying human remains from the cave of Shanidar in Iraq and the caves of Mount Carmel in Palestine. It has generally been thought that Neanderthal man preceded modern man by tens of thousands of years.

The Shanidar cave contained Neanderthal bones, while the caves at Mount Carmel contained both Neanderthal and modern skeletons. Carbon-14 dating indicates that all the cave dwellers lived in the same general period, although the Mount Carmel skeletons appear to be somewhat older.

Fragments of a female pelvis from one of the Mount Carmel caves, and a male pelvis from Shanidar have proved to be almost indistinguishable from the classic Neanderthal skeletons of central Europe, Stewart reported in *Science*. But the bones found in the other Mount Carmel cave were remarkably similar to those of modern man. Stewart suggests that the two human varieties occupied the caves at slightly different times, and did not interbreed.

THE MEDITERRANEAN PROJECT

The seat of Western civilization for 6,000 years, the Mediterranean is now an "underdeveloped" area. The 15 nations of the region have joined with FAO in a plan to double their food output by 1980

by Egon Glesinger

From the dawn of human history until the Industrial Revolution began in England some 150 years ago, the Mediterranean basin region was the undisputed center of Western civilization. There is scarcely a Mediterranean nation that has not been at some time the leading power of the Western world and a center of prosperity and culture. Yet today, with their populations rising and the productivity of their lands in decline, these nations are blighted by want. The 170 million Mediterraneans, a population comparable to that of the U. S., must share a total gross output valued at $38 billion, less than a 10th that of the U. S. At one time the region drew from far and near invaders who wished to share its beauty and its material and cultural riches. Now it is inhabited by people who are longing to leave; only immigration quotas and the cost of transportation prevent millions from achieving their desire to quit their miserable homes. In a formerly verdant landscape, its mountains and hills covered by forest and rich pastures, its plains fertile and productive, the desert has taken over 1.25 billion acres and is still advancing. The Mediterranean gave the Western world its basic literature, including the alphabet itself; today it counts 100 million illiterates among its inhabitants. Ruins of proud cities that flourished hundreds and thousands of years ago are to be seen throughout the region, and yet a substantial portion of its people still live—or live again—in nomadic tribes.

The plight and the hope of the Mediterranean region occupied a principal place on the agenda of the last Conference of the Food and Agriculture Organization of the United Nations (FAO), which convened in Rome last November. On this occasion the FAO laid before its 82 member nations a plan for the integrated development of the agricultural and forest resources of the region. The FAO Mediterranean Development Project envisions balanced land-use as the key to the over-all development of the region and sets out a strategy of investment to double the per capita income of the Mediterranean peoples by 1980. Since population is rising in some countries at the extreme rate of 3 per cent per year, that objective calls for a rate of investment sufficient to achieve an increase of 150 per cent in output over the 20-year period, an achievement that would set the region on a course of self-sustained economic growth thereafter. The studies on which these hopes are based—represented by a two-foot stack of economic and technical reports that presided over the discussions from the table of the chairman—were approved by the Conference in a resolution that was unanimously passed. The resolution commended the broad philosophy of the project, and called upon the Director General of FAO to organize from 1960 onward consultations to frame specific proposals for national and international action to be undertaken as a result of the studies. It also expressed the hope that member countries outside the region would help the Mediterranean countries to achieve the objectives of the program, and instructed the Director General to help in co-ordinating such assistance when it came from more than one source. Finally, it called for the establishment, with the help of the United Nations Special Fund, of a network of pilot development-zones throughout the region. These pilot zones are to serve not only as centers for the testing of new techniques, but also as propulsive areas from which development will spread progressively outward to embrace the whole Mediterranean.

It must be conceded that elsewhere in the world people are living in even greater poverty. The per capita income in most of the countries of Southeast Asia and Equatorial Africa is between $50 and $100 a year. The Mediterranean, by comparison, is rather well off. But the failure to keep pace with the progress achieved by their neighbors to the north and west, and the growing gap between their own condition and that of people whom they once dominated and to whom they gave the first lessons in civilization, weigh heavily on the minds of all Mediterranean peoples. This aspect of the situation gives particular color to the development problems of the Mediterranean. Here economic growth is not, as in other underdeveloped regions, the joyous, enthusiastic venture of new nations. In the Mediterranean region the challenge is to see whether peoples and civilizations are in fact fated to grow old and decline, as predicted by Arnold Toynbee and other contemporary historical philosophers. The experience may not only provide a lesson for other underdeveloped regions but may indicate the shape of the future for the whole Western world.

The striking contrast between the Mediterranean past and the Mediterranean present is often attributed to a gradual change in climate. There is, however, no real evidence to support this notion. The most plausible explanation seems to be that, although Rome, Baghdad, Granada and other cities once had many more inhabitants than they do today, the population of the region as a whole, throughout most of its history, was only a fraction of what it is at present; meanwhile the region's natural resources have been declining. A vicious circle has been under way: increases in production to meet rising demand have been undermining the resources of the

ENCROACHMENT OF DESERT is to be halted by planting of hardy grasses on dunes in parts of Mediterranean. Here a planting of *Saccharum aegyptiacum* by FAO experts in Libya shows promise of success in contrast to earlier planting in background.

IRRIGATION OF TRUCK GARDEN is managed by worker in Libya, who diverts water into trenches between hillocks in which lettuce has been planted. FAO program calls for doubling of irrigated land and three-fold increase in truck-garden acreage by 1980.

region and destroying its capacity to produce.

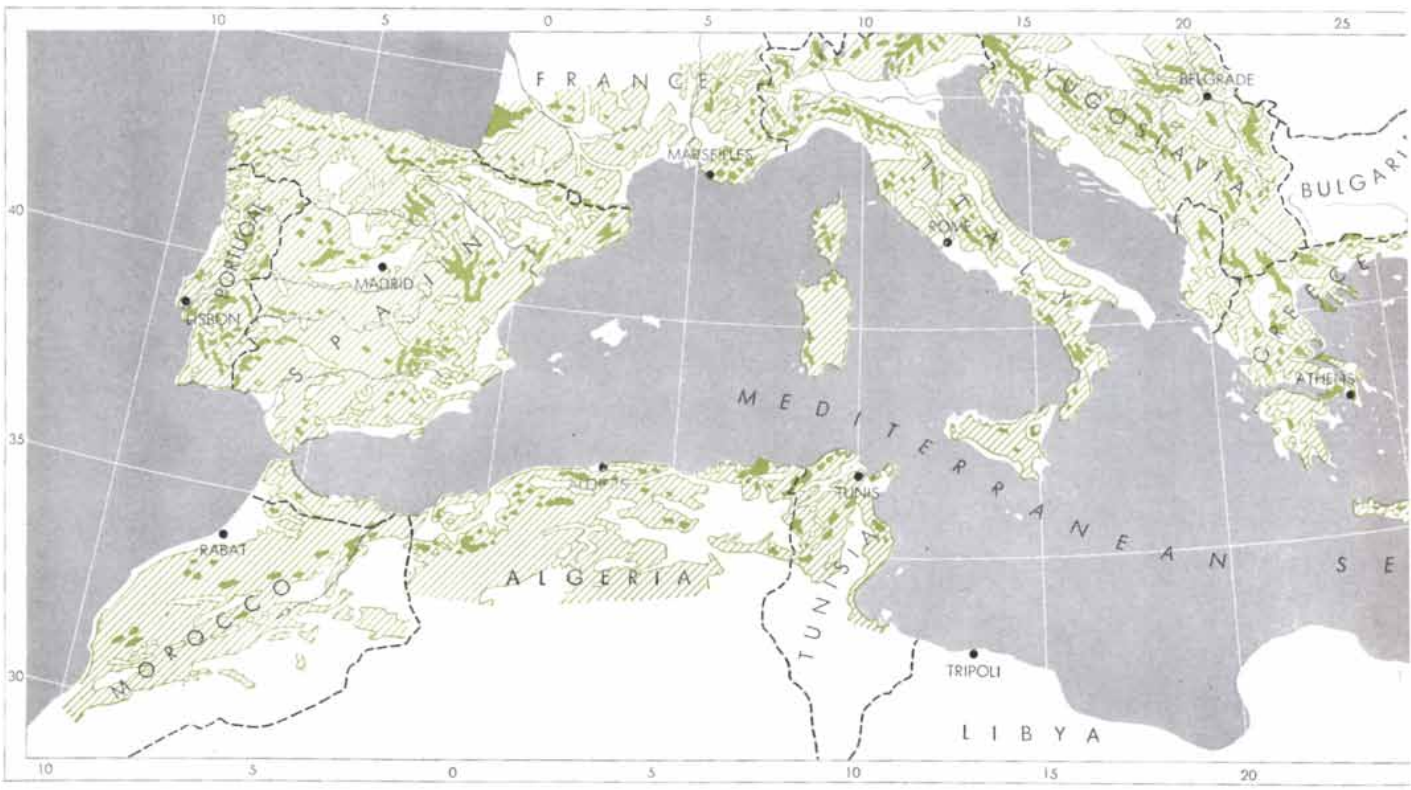
A Land Intolerant of Error

This process is not confined to the Mediterranean region. The robber economy that destroys forests and wastes the wealth of the soil has held sway in almost every part of the world. The environment of the Mediterranean, however, is less tolerant of abuse than temperate areas are. People who sometimes complain of too little sunshine and too much rain in the temperate climates of Europe and North America find it difficult to understand the tragic impact of too little rain and too much sunshine. In the Mediterranean region the weather is good, but the climate is bad. Under the arid and semiarid conditions that prevail, the misuse of land leads rapidly to extensive soil-destruction, which is difficult to repair. Hence in the Mediterranean one can witness the fulfillment of ancient prophecies of disaster. In Biblical times most of the area was green; today the ruins of old settlements are found many miles inside the desert. Mountains and hills occupy some 125 million acres, but dense forests and good grazing lands have shrunk to a fourth of that area, and the remaining acreage is either covered with degraded vegetation and brush or consists of bare rocks, denuded hillsides and deep gullies. As a result of widespread erosion, floods are becoming more and more frequent and cause increasing devastation; the disasters that have hit Baghdad, Valencia and the Po Valley during the last few years speak for themselves. The poor and underfed livestock produce only a fraction of the milk and of the meat that their vast numbers suggest they should. Crop yields are low and, even worse, recent attempts to raise these yields have failed. Spain is one of the few countries in the world where food production during the past 30 years has declined; in the region as a whole food output per inhabitant has fallen, so that the Mediterranean has had to become a net importer of food.

Many observers consider that the region has entered the last chapter in the story of deforestation and soil destruction. But the end is not yet in sight. The cycle of depredation and frustration can go on for a long time to come; it is determined by the relentless and increasing pressure of population on the land. Because there is not enough food, marginal land is being plowed and crops are being planted in hills that were formerly reserved for grazing. The herds, driven from their traditional pastures, destroy the range by overgrazing and invade the forests. Trees are cut down, erosion spreads and the area of productive land decreases every year. Studies conducted in Iraq and Algeria show that in some watersheds erosion is stripping away some 20 to 25 cubic yards of soil per acre per year, which amounts to the destruction of about 7.5 acres per square mile. In those watersheds it is feared that the soil will have entirely disappeared within a century.

The Ecology of the Mediterranean

The wastage of resources has not spared any part of the region. Thus in this period of decline the 15 Mediterranean countries are still linked by that unity of destiny which enables one to speak of a "Mediterranean civilization" of earlier times. Their unity derives basically from a broad similarity of environment that gives the term "Mediterranean" a well-established ecological meaning. Throughout the world a "Mediterranean climate" is one characterized by cold, rainy winters and long, dry summers, separated by short spring and autumn seasons during which climatic conditions are extremely unpredictable. The geographer speaks of southern California, and some parts of Chile and South Africa as "Mediterranean." Many plant



PRESENT FORESTS

ANCIENT FORESTS

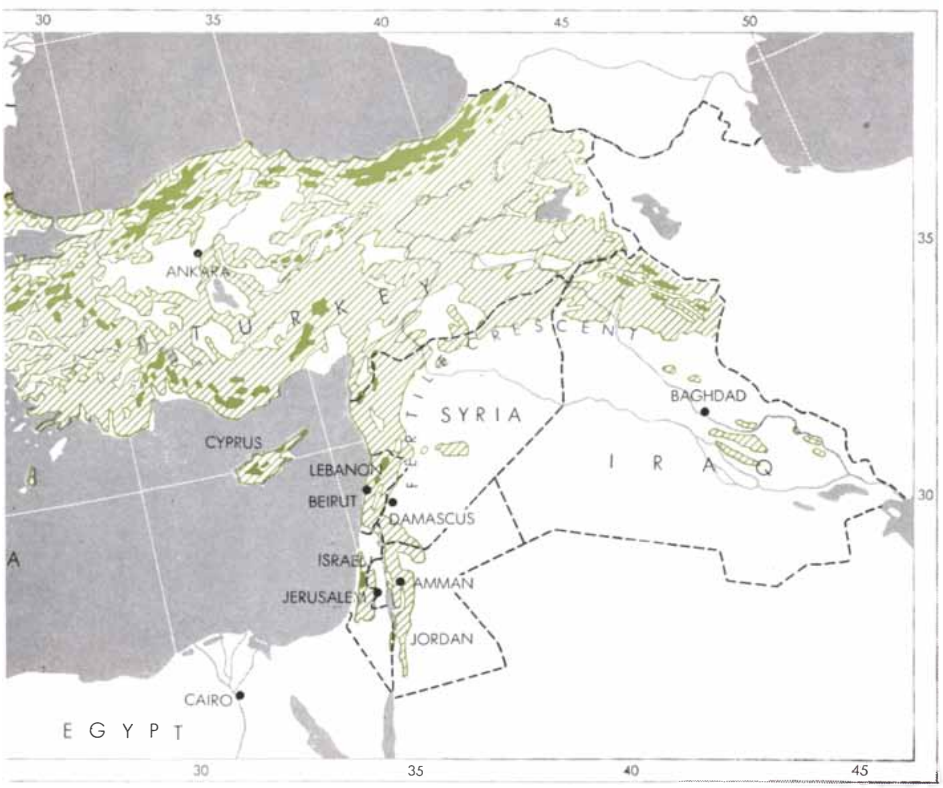
MEDITERRANEAN FOREST LANDS have dwindled during the 6,000 years of civilization from about 500 million acres (*see key at left*) to less than 50 million. The agricultural revolution that brought this change began some 10,000 years ago in the "Fertile Crescent" of the Middle East. The land was first

species—for example, the cork oak, the Aleppo pine and the olive—are peculiar to the Mediterranean region, and many soils throughout the world are classified as "terra rossa," after the typical Mediterranean soil.

The unity of the region, so firmly based on these natural foundations, is reinforced by a common heritage of memories, culture and social institutions. For these countries—hemmed in by inhospitable hinterlands of rugged mountains, deserts or steppes—the Mediterranean has constituted a meeting place, like the forums of their ancient cities, where their cultures have become closely intermingled. It is no mere chance that the best example of Gothic military architecture, the Templars' castle known as the "Krac des Chevaliers," lies in Arabic Syria, and that the finest examples of Moslem art are to be seen in Christian Spain. So throughout the region the nations contend with closely similar economic and social problems: the primitive character of agriculture, in which more than half of the Mediterranean people are employed; the enormous differences in levels of income, and the inherent tendency of upper-income groups to dissipate precious foreign exchange on nonessential imports and to hoard their excess funds in sterile savings; the predominance of the spirit of mercantilism over that of entrepreneurship, which results in a low rate of investment or no investment at all; and the intense loyalty to the family or the clan, which hampers public administration and efficient enterprise in industry. All this explains why it is not only possible but necessary to treat the region as a unified whole in any plan aimed at winning significant progress against its long-term decline.

When the FAO plan was first contemplated, the most obvious prescriptions for the Mediterranean problem appeared to be: "Turn the clock back and restore the past," or, alternatively, "Import the Industrial Revolution and move into the 20th century." According to the first idea, a vast reforestation program, aimed at re-establishing the ecological environment of the region as it was in happier times, would raise soil fertility, extend the area of productive land and relieve unemployment. Mediterranean man would be restored to the natural landscape that supported his more prosperous epochs, and the historical cycle would begin again. Unfortunately the destruction of the soil has made it impossible to restore the ancient forests within a reasonable time and at a thinkable cost. In any case the pristine resources of the Mediterranean supported a population only a fraction of the present one; restoration of former productivity would not satisfy current needs, much less meet the demand for rising living standards in an even larger population tomorrow. No plan for the Mediterranean can fail to reckon with the fact that the region—largely as the result of "death control" by elementary public-health measures—will have to feed 70 million additional mouths within a generation.

The second notion, of "overnight industrialization," has been repeatedly attempted during the past 15 years. The creation of large dams for electrification and irrigation in southern France under the Monnet Plan, the ambitious Vanoni Plan for the development of southern Italy and the industrialization program in Turkey are well known. Similar efforts have been undertaken in almost every country of the region with the help of substantial foreign aid, which together with the windfall oil revenues of Iraq have probably exceeded $33 billion over the past 10 years. Between 1945 and 1953 the national income in most of these countries rose significantly. Since then, however, progress has slowed down and in some countries has come to a standstill. The beginning of self-sustained growth that had been hoped for has not occurred. Increases in food production were obtained, but the wholesale importation of U. S. machinery and techniques accentuated even further the destruction of land. Instead of achieving more output per acre of good land and per unit of livestock, cultivation was spread too widely, and animal numbers were raised too high. In Turkey, for instance, it is estimated that at least 10 million acres should be taken out of cultivation and turned back to pasture or forest. To try to install the "20th century" overnight would therefore compromise the future of the region.



cleared for planting; when careless practice and erosion had reduced its productivity, the farmer abandoned it to the herdsman. Overgrazing by sheep, goat and camel exposed the soil to erosion. Now, especially in Spain and the Middle East, much of the former forest land is desert.

Balanced Land Use

FAO has sought a third, indigenously Mediterranean, solution to the Mediterranean problem. The FAO plan aims neither at Utopian restoration of the primeval environment nor at the imposition of alien ways of living. At the core of this solution lies the Mediterranean land. The recurrent *leitmotiv* of the study is "balanced land use." In the words of the Overall Report of the Project adopted by the FAO Conference, the first objective is to "protect the soils and crops against erosion and similar losses and to reclaim through proper measures lands now wasted and unpro-

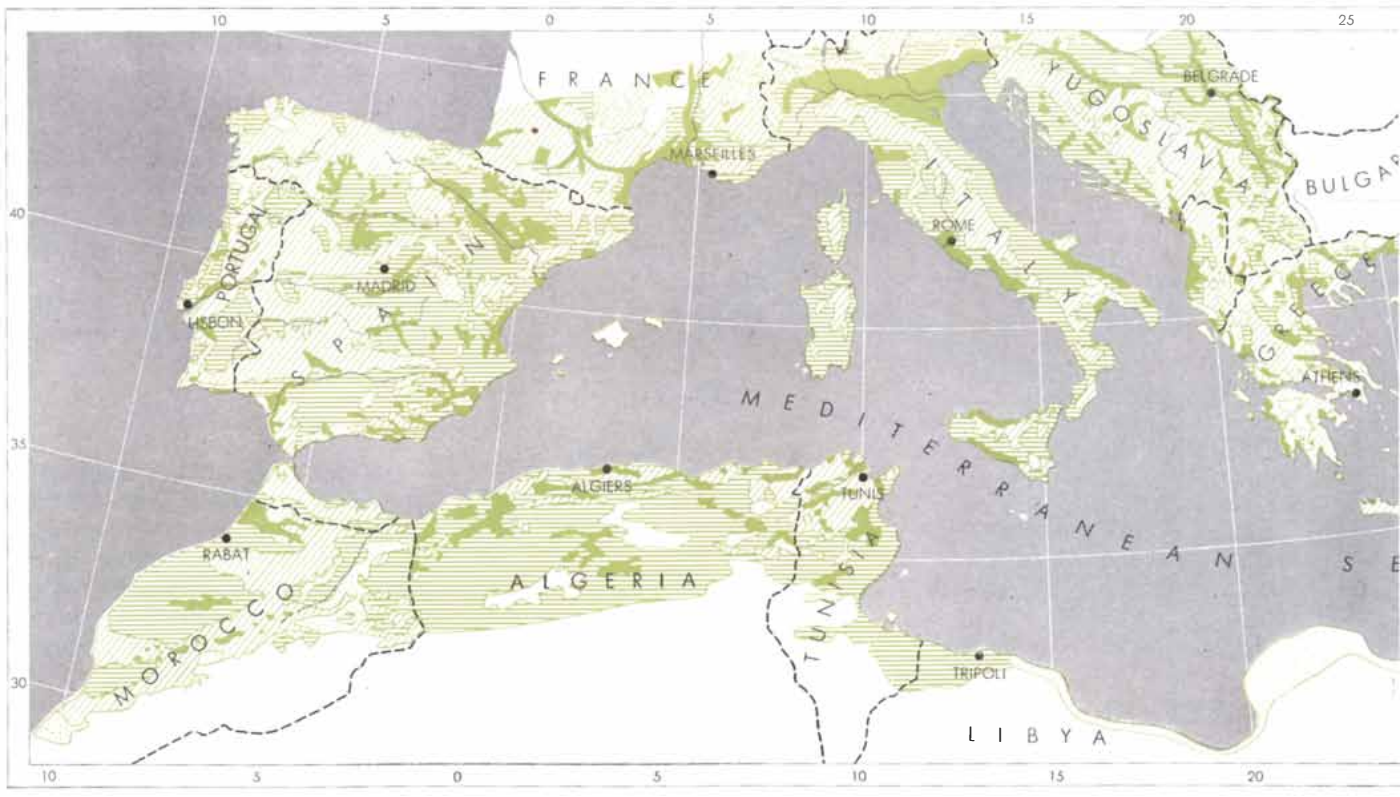
ductive." Without an immediate reversal of the process of soil destruction the entire region faces disaster. What is needed is to relieve the pressure of overgrazing on land unsuited for cultivation and to restore the forest cover and other vegetation wherever this is possible and appropriate. In time this will amount to changing the geography, the appearance and perhaps even the water cycle and climate of the entire region. To this end it will be necessary to displace shepherds and their flocks from forest and eroded range lands, and to reduce the cultivated area and perhaps even the size of livestock herds—at a time when increasing undernourishment and unemployment would seem to indicate the need for exactly the opposite action.

As its second major objective, however, Overall Report calls for measures to "raise productivity in agriculture and forestry in order to achieve increased supplies in line with the requirements of the country's inhabitants." This means increasing the output on the plains through vast schemes of irrigation, supplemented by three basic technical measures: the use of fertilizer, the mechanization of plowing and other agricultural operations and the introduction of improved seed. A considerable portion of the expanded crop-growing capacity of the plains will go to the production of forage crops to make up for the reduction in grazing area. With crops and livestock resettled on the plains, forests can be re-established on watersheds and on other lands suited for tree planting. The terracing of slopes and the extension of all kinds of vegetation should supplement the forest program until eventually the Mediterranean becomes green again. Grazing could then be considerably extended, provided it is properly controlled.

Agriculture and Animal Husbandry

The FAO plan thus implies a fundamental change in the age-long division of the land in the region into two separate exploitation patterns of crop production and livestock raising. The key idea is the integration of agriculture and animal husbandry. Two ways are proposed to bring about this integration: mixed farming, that is, the introduction of grazing crops into the agricultural rotation; and the production of fodder for delivery to herds when pastures are depleted. There are indications of the feasibility of such integration in many parts of the region. In Cyprus comparative demonstrations of traditional cropping and mixed farming have proved that the latter method can double the cash return from the land. On nonirrigated land these same pilot farms have shown that mixed farming can maintain two head of sheep per acre. Similar experiments in Spain have shown that 350 to 450 pounds of livestock can be maintained per acre on irrigated land. In general it appears realistic to expect that mixed farming can maintain four head of sheep on irrigated land and two head per acre on nonirrigated land, compared to less than one per acre even on improved range land. The present livestock population—35 million cattle and 180 million sheep—is supported on some 350 million acres of run-down range and open forest land. That same population can be supported on 45 million acres of irrigated land and 200 million acres of rainfed land, the maintenance of the herds being a by-product of the efficient land use achieved by mixed and diversified farming. It happens that these are the acreages that have been projected for irrigation and dry farming in the FAO plan.

Thus it should be feasible to free the forests and the marginal ranges from the wandering flocks that are at present laying them waste, planting some of the land to forest and undertaking the restoration of productive pasture on the rest. Thus an area larger than Alaska and Texas combined may be saved from destruction and returned eventually to pro-



IRRIGATED FARMING
DRY FARMING
GRAZING
FOREST-GRAZING

BALANCED LAND-USE envisioned by FAO would enable region to double its output of food by 1980. Expansion of irrigated acreage from 20 to 45 million acres will make it possible, at the same time, to take 40

ductive use. The golden dream of Mediterranean soil conservationists and foresters—the liberation of forest and range lands from the pressure of livestock—could therefore begin to become a reality by 1980. The FAO plan calls for immediate measures to rebuild the land as it is taken out of the range. Eight per cent of the total projected investment is set aside for forestry and soil-conservation measures.

The Question of Water

The key to all of these schemes is water. It is not only in the desert, where it transforms sand dunes into green oases of luscious vegetation, that water is regarded as a precious fluid. The scarcity and hence the value of water is felt to a considerable degree throughout the Mediterranean region. Only Mediterranean man can know what a high price is exacted by the wonderful weather enjoyed by tourists from America and northern Europe. The absence of rain during the long dry season, the excessive concentration of rainfall in the torrential winter rains and the salinity of poorly drained soils have been throughout history and remain to this day the main physical factor limiting Mediterranean agricultural production, as well as the cause of floods, erosion and the progressive losses of productive soil.

So long as agriculture remains based on uncertain and badly distributed rainfall, even good methods of dry farming will produce only limited yields, wholly insufficient to support the rapidly increasing populations or to enable them to achieve the necessary levels of productivity and employment. But as soon as water is made available in sufficient amounts and at the right times, all this changes completely. Barren, apparently bad soils begin to produce two and three crops a year; output per acre of crops and meat and milk production per animal unit rise to the level of international record yields.

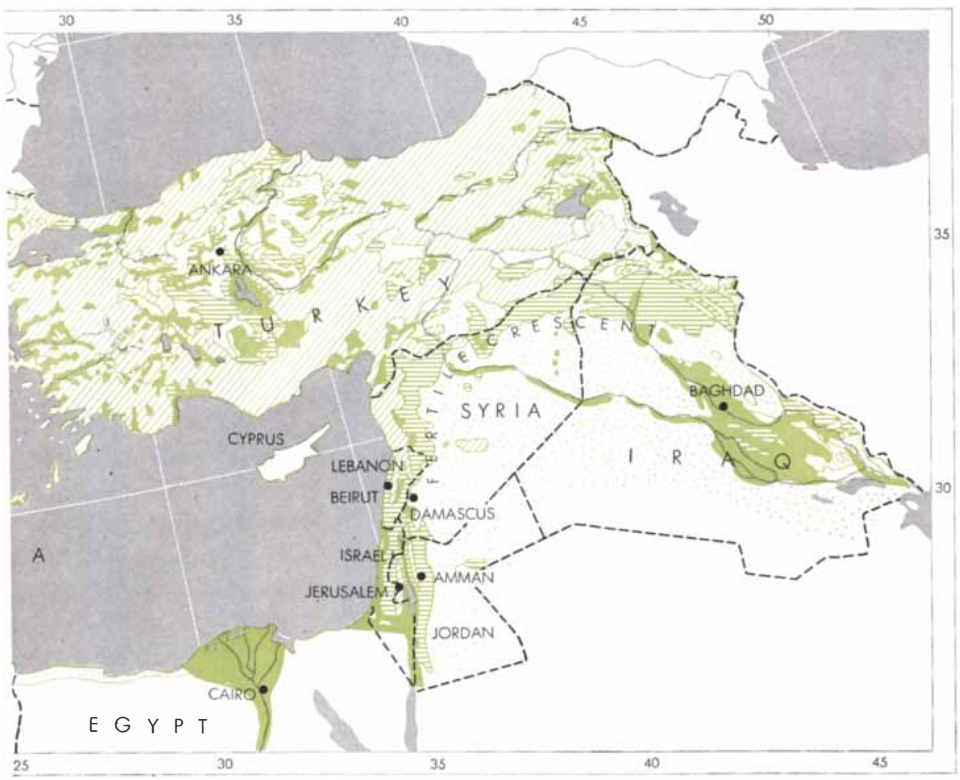
The Central Valley of California provides the best-known illustration of the spectacular transformation that the well-planned introduction of adequate water supplies and their proper distribution can bring about. There is no reason why the Mediterranean should not regain its prosperity by becoming another California. Indeed, hydrologic surveys have accumulated substantial evidence that the region possesses enough water to put practically all of its land, including substantial fringes of its deserts and steppes, to productive use and to support its prospective population. At present, irrigation extends to some 20 million acres, representing roughly 3 per cent of the total area of the region, excluding deserts. Further surveys will provide precise figures, but general studies and hydrologic surveys made so far indicate that more than 60 million acres, or 30 per cent of the arable land of the plains, may ultimately be brought under irrigation. Meanwhile, the studies already completed by FAO propose to raise the irrigated area by 25 million acres between now and 1980, bringing the total to 45 million acres, or 70 per cent of the potential [*see illustration on next page*]. This would exceed the total area irrigated in the U. S., and hence the area irrigated per capita would also be greater.

But irrigation must be carefully managed. The hazard of salinity, created by salts precipitated from water evaporating on undrained land, may render illusory all the benefits expected from an otherwise well-engineered irrigation project. In Iraq 70 to 80 per cent of all the irrigated land is now saline to some extent. Areas irrigated and cultivated for the first time in 600 years have produced only five or 10 crops before the soils became too salty. One large area near Baghdad produced only one crop before it was ruined. On the Menemen Plain in Turkey the canal system constructed in 1949 had no drainage, and substantial parts of the lower lands have already gone out of production. Detailed proposals in the FAO study cover all these supplementary measures. In Iraq, for example, it is planned to spend $280 million on drainage and on leaching the salt out of ruined soils.

The total cost of the irrigation programs recommended by the Mediterranean Development Project would amount to $7.3 billion. Fortunately perhaps as much as a third of these costs will represent wages. The second largest item is cement, which can and should be locally produced. The major irrigation dams will generate hydroelectric power, which is needed for rural electrification and as a basis for industrialization. The irrigation phase of the FAO program will thus contribute heavily to the third principal objective of the Overall Report, which is to provide employment to the vast unemployed or underemployed rural population of the region.

Irrigation Multiplies Acreage

It would be difficult to find a large-scale investment that will yield such high return as that which is proposed for the Mediterranean lands. On newly irrigated lands of the United Arab Republic in Syria the average yield of wheat has exceeded 35 bushels per acre,



million acres out of dry-land cultivation and to withdraw 350 million acres of overgrazed and eroded land from the range. Farms on irrigated as well as rain-fed land will grow fodder and forage in rotation cycle, and livestock reared on the range will be fattened on the farm.

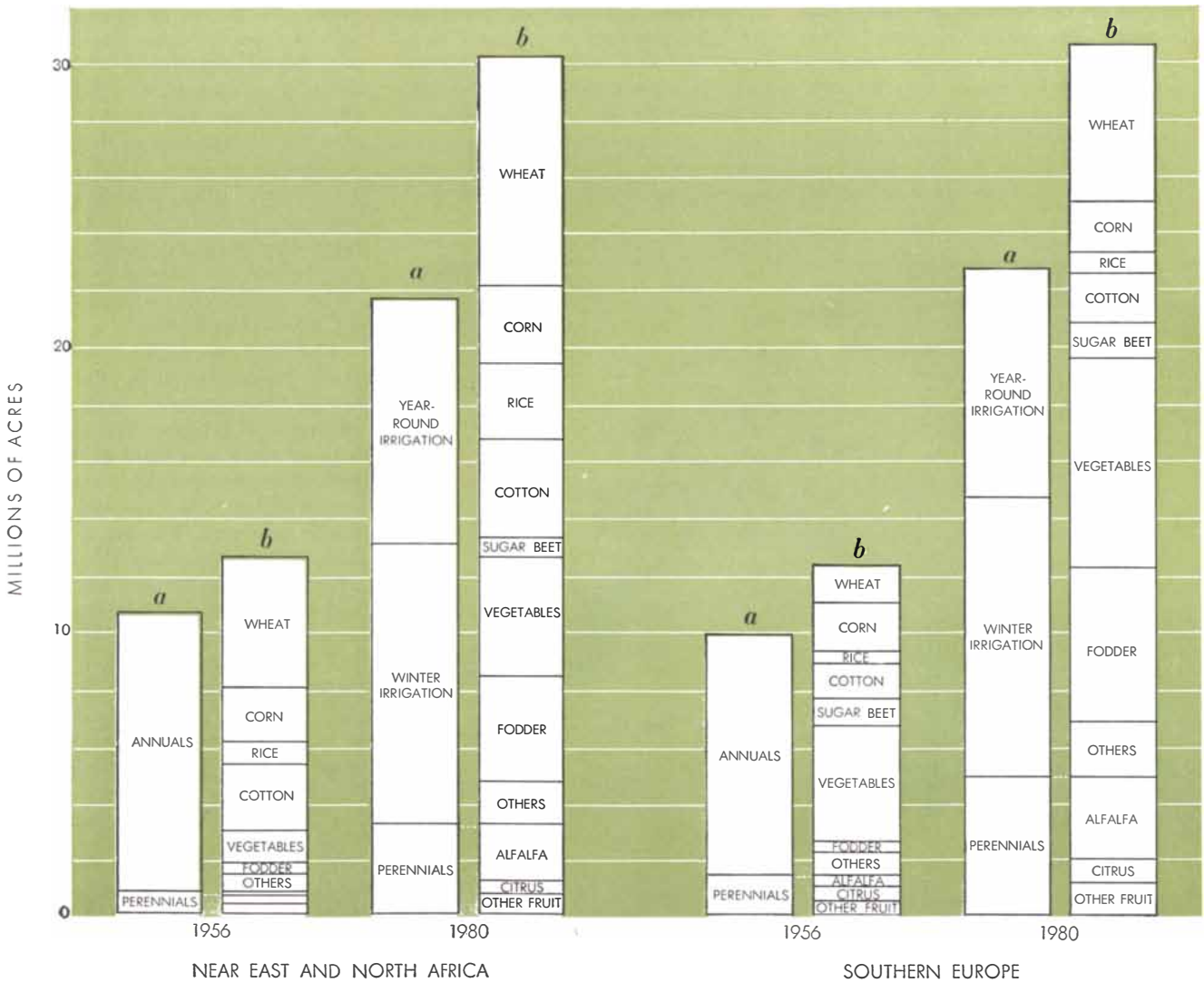
compared to the average yield of 10 bushels from the rain-fed lands of Algeria, Morocco and Tunisia. Data from Spain show that in many cases yields from irrigated land are three or four times greater than from rain-fed land. When improved methods are applied together with irrigation, the advantages of irrigated over rainfall farming are even greater, for irrigated land also responds better to fertilizer and other measures to secure larger crops.

The investment in irrigation can be further enhanced in two ways. First, high-value crops may be substituted for low-value crops; in Greece the replacement of wheat with cotton promises to increase income by three to three and a half times. Second, irrigation makes it possible to grow more than one crop per year on the same land; "double cropping," with vegetables and fodder in rotation with crops such as cereals and cotton, becomes feasible. Thus where water is available the year around, irrigation may effectively double the acreage of the best and scarcest land.

The benefits of irrigation, however, go beyond the increase in output. Where it is possible to rotate staple or cash crops with the production of fodder, irrigation can promote the integration of agriculture with livestock husbandry. But the principal cash crops on the newly irrigated lands will be fruits and high-quality vegetables. It is expected, for example, that the production of citrus fruits will rise from the present one million metric tons to some 3.2 million tons by 1980, and that the production of fresh fruits and vegetables will also increase considerably. Part of this increase will have to be diverted to meet rising home demand, but part will also help to increase foreign exchange earnings—provided an adequate system of exporting this output to the richer countries in Western Europe is established. To this effect the possibility of establishing a "cold chain" (that is, a network of refrigerator and freezing plants) is being investigated. All told, the land irrigated under the FAO plan should produce an output of $5 billion each year, as compared with the present output of $1 billion from this same land. By 1980 the total output of all irrigated lands can be safely estimated at $10 billion, some three quarters of the total value of the present agricultural output of the entire region. At that time these lands will provide four billion man-days of employment. The social dividend on the investment will be represented by the provision of homes and livelihood for 15 million families—more than 50 million people, or more than twice the number who presently enjoy the security of the stable agricultural economy made possible by irrigation.

Dry-Land Farming

On the 200 million acres of arable land that are to be kept under cultiva-



IRRIGATED LAND is to be increased from eight to 18 million acres. Area of year-round irrigation, especially, is to be extended.

Double-cropping on such land will virtually double its acreage and bring total effective irrigated acreage (*b*) up to 60 million.

tion without irrigation, new practices and techniques will bring equally profound changes. The FAO objective for these lands can be summarized as a movement away from wheat, now accounting for more than one third of the acreage, to more meat, more milk and more cash crops such as cotton and sugar beet. In addition, the land that must lie fallow each year under present practices, accounting for another third of the acreage in a given year, will be brought under sustained cultivation by diversification of crops and well-planned schedules of rotation. Since the dry-farming lands comprise by far the preponderant acreage of arable land in the region, this objective calls for nothing less than a complete modernization of Mediterranean agriculture—more specifically, for the massive use of fertilizers, for mechanization and for the introduction of better seed.

WATER FOR IRRIGATION, flood control and electric power is impounded behind Hirfanfli Dam on Kizi Irmak river in Turkey. This 300-foot-high dam was completed in 1959.

Experiments in the region have already shown how profitable fertilizer can be. In Greece, on the plain of Thessaly, fertilizers have brought increases in wheat yields of eight or nine bushels per acre. The cost of fertilizer amounted to $7 per acre, and the increased yield had a value of $20. In Tripolitania benefits from fertilization amount to more than $15 per acre on good soil and to between $4 and $5 per acre on poorer lands.

At present, the region's consumption of phosphoric acid and nitrogen, the most essential fertilizers (deficiencies in potash are rare in the region), amounts to about 700,000 tons and 600,000 metric tons respectively. According to the FAO study, these figures should be multiplied three times. In some countries (Iraq, Turkey and Spain) the production of fertilizers will depend on the availability of foreign exchange. It is the hard lot of the farmers of the region that while they are poorer than those of more developed countries, they must pay more for the means of production. An Iraqi farmer would, if he could, have to pay almost $100 per ton for sulfate of ammonia; a Danish farmer, who is more than 10 times as rich, pays only half that price.

Though there is at present a large measure of underemployment in these countries, mechanization is nevertheless of great importance. The mechanization of seeding and harvesting can greatly minimize the heavy risks of weather. Deep plowing, with the help of tractors, is essential to penetrate and loosen—almost to remake—the hard, dry Mediterranean soils. Savings of 25 to 35 pounds of seed per acre are possible when drills are used to sow grain. The present tractor force in the Mediterranean region is not more than 190,000 units. In order to put only four tractors to work on each 2,500 acres of sown land (the level of mechanization in southern Italy) it will be necessary to increase the existing force by another 130,000 units.

On the soils improved by better cultivation practices and enriched by mineral nutrients, it becomes worthwhile to plant better seed. Improved seeds and plants constitute one of the cheapest means of achieving increased yields throughout the dry-farming area. In Greece 25 per cent of the postwar increase in wheat yield can be attributed to better seed, and in Turkey it is said that increases of 15 per cent have been obtained from test plots even without the use of fertilizer. Since conditions in the region are ideally suited to seed production, there is no reason why this need should not be met locally.

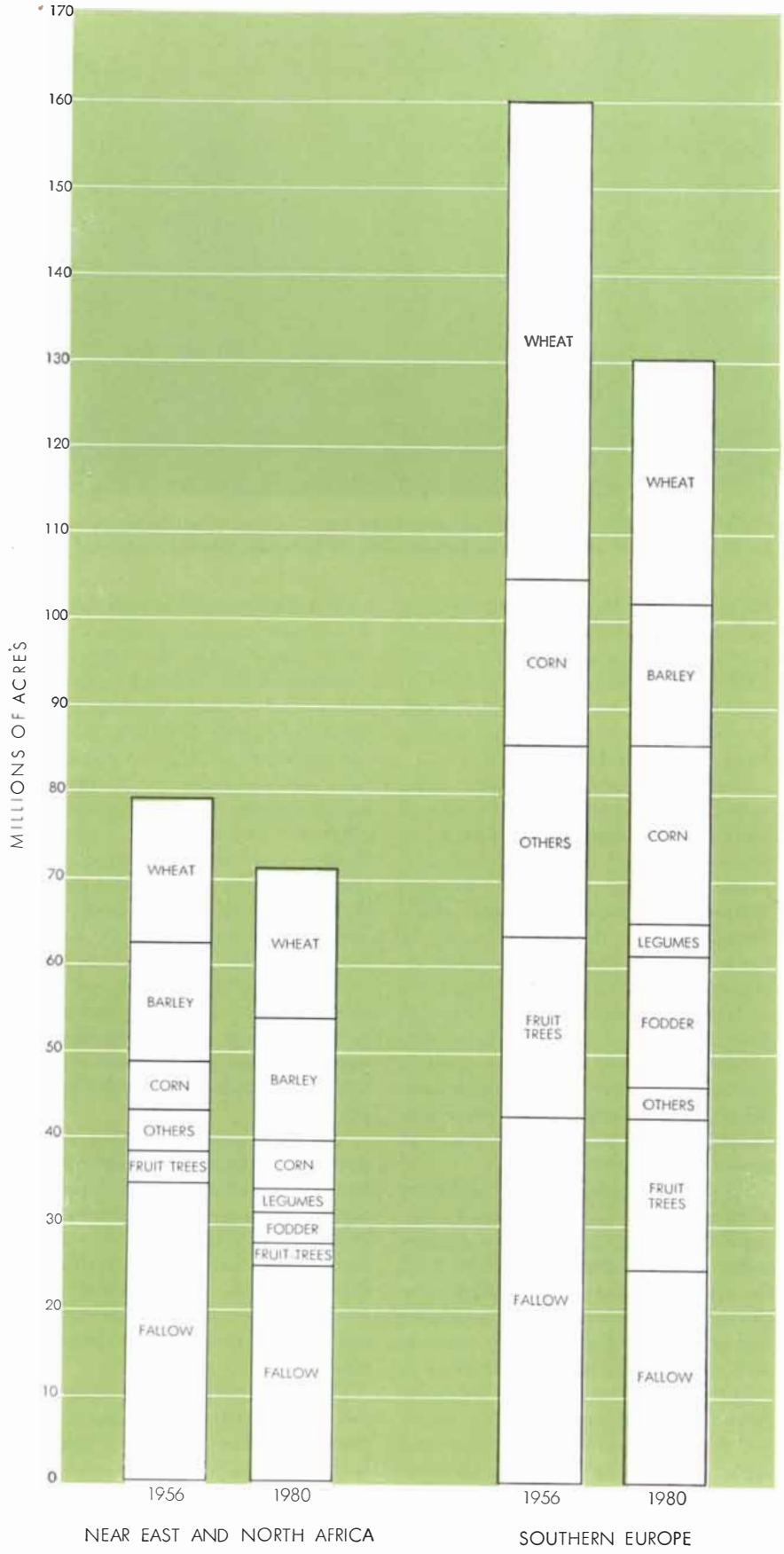
At present seeds, fertilizer and farm implements are largely imported commodities. Expansion of these industries under the collective sponsorship of all the countries of the region could provide products well suited to local conditions and save much duplication of effort as well as foreign exchange. FAO plans to help the Mediterranean countries establish a network of these industries, which will be located in strategic points and aimed at supplying a common Mediterranean market.

Livestock: From Range to Farm

Since well-planned rotation schedules call for the production of forage and fodder crops, the reformation of agriculture in the Mediterranean will lead naturally to its integration with animal husbandry. The present paradoxical situation is that while range lands are overgrazed by enormous flocks, livestock output is far below what it should be. With the quality of their herds dwindling along with the cover on the range, herdsmen have been increasing the size of their herds and prolonging the grazing period in the effort to increase their output. But heavier and more prolonged grazing only reduces the quantity and quality of the herbage and accelerates the decline of both range and animals. The livestock industry is thus devouring itself. This situation must be changed, not only to save the range and forest land but also to improve the diet of Mediterranean man; at present average meat consumption per capita does not reach 25 pounds per year.

The FAO proposes to shift the livestock burden from the upland range and forest lands to the plains. With increased supplies of forage and fodder furnished by the irrigated lands as well as the dryland areas, it will be possible also to initiate systematic improvement of the herds, making them yield more meat and milk instead of a wasteful increase in numbers.

For the farmers the new regime offers the advantages of diversification and more productive utilization of their land. In their present dependence upon single-crop planting (principally wheat) they are exposed to the hazards of weather and the market, and they must let a considerable portion of their land lie fallow from year to year. They will now introduce forage and fodder crops into their rotations and keep all of their land under continuous cultivation. Those who



RAIN-FED LAND is to be reduced in acreage. Mixed farming, with fodder crops rounding out rotations, will reduce fallow acreage and offset retirement of marginal lands.

go the way of mixed farming will grow forage for direct grazing. Others will grow hay or silage for sale to cattle growers when natural or green fodder is available only in limited quantities. Lowland farmers will also undertake the plantation of fodder trees on land not suited for annual cultivation. The most promising species for this purpose appears to be the carob, the cultivated varieties of which produce an edible starchy pod of high nutritive value. Almost half of the present production of this species is exported from the region, a fact that reflects the low standard of the livestock industry. Millions of tons of additional fodder could be obtained from this source, if the livestock were of sufficiently high quality to be able to utilize the fodder economically.

The Nomad in Transition

What role will be left to the steppes and the marginal range lands in this new structure of livestock production in the Mediterranean region? According to FAO, these lands will be used solely as rearing areas for livestock, which will then be fattened on arable lands and on cultivated pastures. The ranges will serve as lamb factories, devoted to supplying the raw material for the livestock industry of the agricultural zones. With the ranges thus relieved of their present overpopulation of livestock, it will be possible to introduce all the refinements of rational management: deferred and rotational grazing, allotment of management units to the various nomadic tribes according to their stock resources, vaccination centers, management and development of watering points, and above all the introduction of animals of higher quality into the Mediterranean herds. There is also the prospect of a radio network to broadcast rain forecasts and hence the location of herbage to the nomads, so that the flocks may be deployed as fishing fleets are. The nomad will thus no longer be either a pirate or a castaway in the vast sea of the steppes, but would follow an orderly cycle of annual migration between the uplands and the agricultural zone. He would once more find a source of cash in the lowlands, this time not as the result of "razzias" (raids) but as the consequence of peaceful economic integration. This transformation of the nomad's habits would probably facilitate still further what has hitherto proved to be a most difficult undertaking: the transition from the nomadic to the sedentary life.

The success of the livestock program

and its integration with other forms of land-use depend heavily, of course, on the sensitive social questions it involves. Between the herdsman and the cultivator, the large sheep owner and the small farmer there has been a long tradition of antipathy. The fact that, especially in southern Europe, livestock raising has been traditionally associated with the population in the mountain areas, confined to the barren hills partly by the fear of disease in the swamplands below and partly by fear of the tax collector, complicates matters even further. With the increase in population density in the plains, the hostility between mountain people and lowlanders has further increased. To secure proper use of the land in the mountains involves resettlement of the mountain populations and the reorganization of the whole system of livestock raising. This means profound change in living habits not only of nomads but of a large section of the population, no less than 40 per cent of the people in Greece. By 1980, however, the plan calls for the production of 5.7 million metric tons of meat and 4.5 million metric tons of milk. By then the livestock industry will be producing 50 pounds of meat and 200 quarts of milk per capita, doubling present supplies.

Restoration of the Forests

At the very foundation of all of these hopeful plans for agriculture and animal husbandry lies the program for the restoration of the forests of the Mediterranean. In any landscape the forest is the anchor that holds the sheet of topsoil in place upon the ground. Trees exercise their beneficial influence on soils, water and climate in many ways. Their roots prevent the attack on the soil of water and wind. Forest soils absorb rain and store the water, thus preventing or limiting floods and equalizing the water supply. As soon as the hills are deprived of their original forest cover, erosion sets in and removes the topsoil at an alarming speed. Erosion also results in the silting of dams. In Turkey a third of the reservoir capacity above the Cubuk Dam has been lost since its completion in 1936. In southern France silting has reduced the capacity of the reservoir behind the water-catchment dam at Gêtre on the Gave River by 85 per cent. Several Algerian dams are already out of service after no more than 40 years.

Not many thousands of years ago forests covered all the mountains and hills of the Mediterranean region, as well as large tracts of land on the plains [*see illustration on pages 90 and 91*]. Altogether the forested area extended to a third or a fourth of the region. Of these 250 to 500 million acres only 50 million can now be classified as true forest. Official statistics, it is true, show more than 100 million acres in forest, but the acreage includes regions of brush and even bare soil.

Given the land needs of the expanding population of the region, no massive reforestation can be contemplated. The FAO proposes, however, that the governments plant during the next 20 years some 18 million acres of forest, primarily for the purpose of protecting soil resources, three million acres in the Near East and North Africa and 15 million acres in southern Europe. The new forests will be of varying density, and frequently will consist of open tree-formations on terraces and slopes, sufficient to protect and stabilize the soils, which will be planted with grass. In many of these hillside forests grazing might be permitted after the trees have reached sufficient height. The program also gives considerable weight to the improvement of degraded forests; some 25 million acres are to be restored, principally in Spain, Turkey, Greece and Algeria. Altogether the region's effective forest area is to be expanded by some 43 million acres, to cover 2 per cent of the total land area, or 5 per cent of the land area excluding deserts. Since the potential forest area is substantially larger, perhaps some 200 million acres, it is reasonable to assume that the forests will be extended further during the rest of the present century until a more satisfactory balance between forests, pastures and cropland is achieved.

Tree Farms

Meanwhile the Mediterranean forests must do what they can to meet the rising demand for forest products. The increase in population, the rising living and housing standards, the gradual eradication of illiteracy and the establishment of industries producing goods to be shipped and distributed, will raise the requirement for structural timbers, printing paper, packaging and wrapping materials and for fuel wood at a substantially faster pace than the increase in gross output. The primarily protective forest plantations on hills and slopes will not contribute much to meet this demand, and the 75 million acres of existing and restored high forest will certainly not be able to supply more than half the prospective needs. In order to save foreign exchange the FAO plan envisages the plantation of four million acres of poplar, eucalyptus and other quick-growing trees on the plains, more than 20 per cent of this acreage to be irrigated land. These species can convert water, air and soil nutrients into wood at the rate of 20 cubic yards per acre per year (as much as 40 cubic yards per acre on irrigated land) and yield timber after 10 years. They can compete commercially with almost any other irrigated crop, and should be assigned land according to the prospective wood needs of the region, not just whatever land is left over as being unsuitable for other uses. Studies carried

BARLEY IS HARVESTED by hand tools on large unirrigated estate in Morocco. Mechanization and organization of large-scale cooperative farms will increase yield on such land.

out in Iraq by FAO experts show that in the upper Tigris valley poplar plantations can produce up to three times as much revenue as the wheat-clover rotation can on the same land. In lower Mesopotamia timber has demonstrated a comparable superiority over irrigated cotton. These striking differences in yield value are due less to high timber prices than to the high rate of growth of timber on irrigated land.

Many of the plantations of quick-growing species will serve as shelter belts and windbreaks for cropland or will give shade along roads and canals. The FAO expects that forestry will play a major role in stopping the encroachment of the desert into the so-called fertile crescent of the Near East, where agriculture had its beginnings some 10,000 years ago. It is not a question of establishing a rigid green bulwark along the desert edge of the fertile crescent, but of planting a dense network of windbreaks and shelter belts all along the borderline between the agricultural zone and the desert. In order to push this band of trees as far into the desert as possible the local supply of ground water may be utilized. Where such water is scarce, it has proved to be more economical to utilize it for starting some kind of perennial vegetation rather than to exhaust it in the watering of agricultural crops that leave nothing behind. In fact on most of the desert fringes irrigation would no longer be necessary after five years, and the tree plantations could rely solely on rainfall.

That portion of the forest program which has been estimated in detail will provide 60 million man-days of additional employment on a seasonal basis during the offseasons in agriculture. To this must be added the jobs provided by the establishment and operation of some 30 pulp and paper factories, sawmills and other forest industries, which will convert $200 million in raw material annually into manufactured forest products.

Goals for 1980

At this stage it is not yet possible to forecast the results that may be achieved by 1980. Detailed studies have so far been completed for 10 of the 15 countries. But the over-all objectives of the Mediterranean project can be stated, and they serve as a guide for the writing and execution of policy. FAO expects the Mediterranean Development Project to achieve an increase of $60 billion per year in the gross output of the region as a whole. Of this total some $20 billion is to be gained in the Near East and North Africa, bringing that region up from its present $10 billion per year to $30 billion, and raising per capita income from $170 to $300 per year. Agricultural output in this subregion is to be increased 110 per cent, by doubling the acreage under irrigation and by more intensive use of rain-fed land. Under the policy of diversification, farmers on rain-fed lands will harvest considerably larger and more secure incomes from such crops as barley, rice and hybrid corn, and will provide pasture and fodder for the herds. The newly irrigated lands will also contribute major increases to the supply of forage and fodder; they will make it possible to double the acreage planted to citrus and other fruits, and they will multiply the truck-garden acreage four times. Since there is little forest left to restore, the principal effort will be the planting of three million acres of new forest, of which 617,000 acres, planted to quick-growing species, will be yielding forest products in eight or 10 years. For southern Europe the objective is an increase in gross output from $26 to about $70 billion in 1980, making it possible almost to double

BEEF CATTLE seek forage in mountain pasture above Isparta in Asiatic Turkey. FAO program calls for restoration of range land to support cattle as well as goats and sheep. This check dam keeps spring torrents from spreading sediments on valley lands.

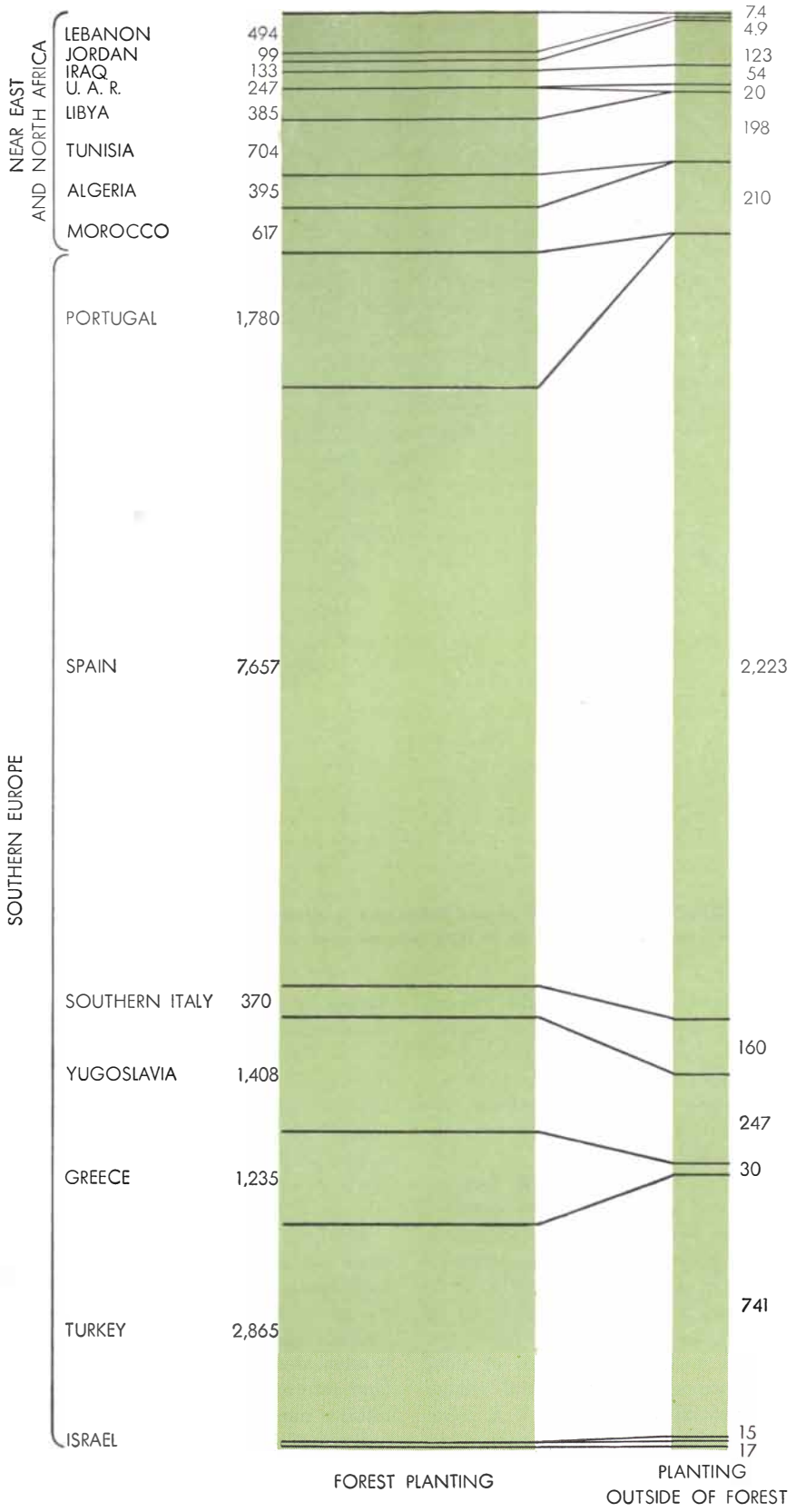
the per capita income, from $250 to $485 per year. Total cropland is to be reduced by some 8 per cent, but the yield will be increased by doubling the land under irrigation and by more intensive, diversified planting on the rain-fed land. Mixed farming, which can be more easily instituted in the European environment, will free more than 10 million acres to plantation of new protective forests, especially in Spain. Forest yields from the thinning of these plantations may be expected in 20 years and, in addition, some four million acres planted to quick-growing species will help to meet the rising demand for wood in all forms.

The Obstacles Are Social

The social obstacles to be overcome in achieving these hopeful objectives are particularly acute. There are three main stumbling blocks in the path of agricultural development in the Mediterranean region: the unbalanced system of land tenure, the excessive fragmentation of land holdings and the primitive structure of rural society.

In nearly all countries well over half the holdings are of less than 10 acres, and they tend to be reduced in size by rental and share-cropping when the seasons are more favorable and the land is more productive. In Egypt nearly 90 per cent of the holdings are of less than 2.5 acres, and minute holdings are also common in southern Europe. Population increase in recent years has tended almost everywhere to reduce holdings to a size that provides the farmer and his family with little more than the food needed for subsistence. No margin is left for investment. Not even irrigation combined with the most modern techniques can extract from 2.5 acres of soil a decent living for a family.

At the other extreme there still exist in most of the countries enormously large estates, mainly in rain-fed areas and sometimes on land too poor to yield a living if worked by traditional peasant methods. The existence of these estates places the tenants in an extremely weak position with respect to their landlords, a position that sometimes smacks of feudal times. Share-cropping is fairly common in these countries, and even when the land is rented for cash, the tenants often have no more than a short-term and insecure lease. Since the peasant has little or no bargaining power, he has to submit to exorbitant demands. Share-croppers may yield up to 50 to 80 per cent of their produce as rent and inter-



REFORESTATION is intended primarily to restore range land, especially in Spain and Turkey (*left*). Quick-growing trees (*right*) will meet rising demand for forest products.

REDISTRIBUTION OF LAND around Salamanca in Spain is designed to assemble small parcels of land into tracts of sufficient size to sustain cultivation by modern methods. The holdings of each farmer were broken up into many small parcels (*left*); the three

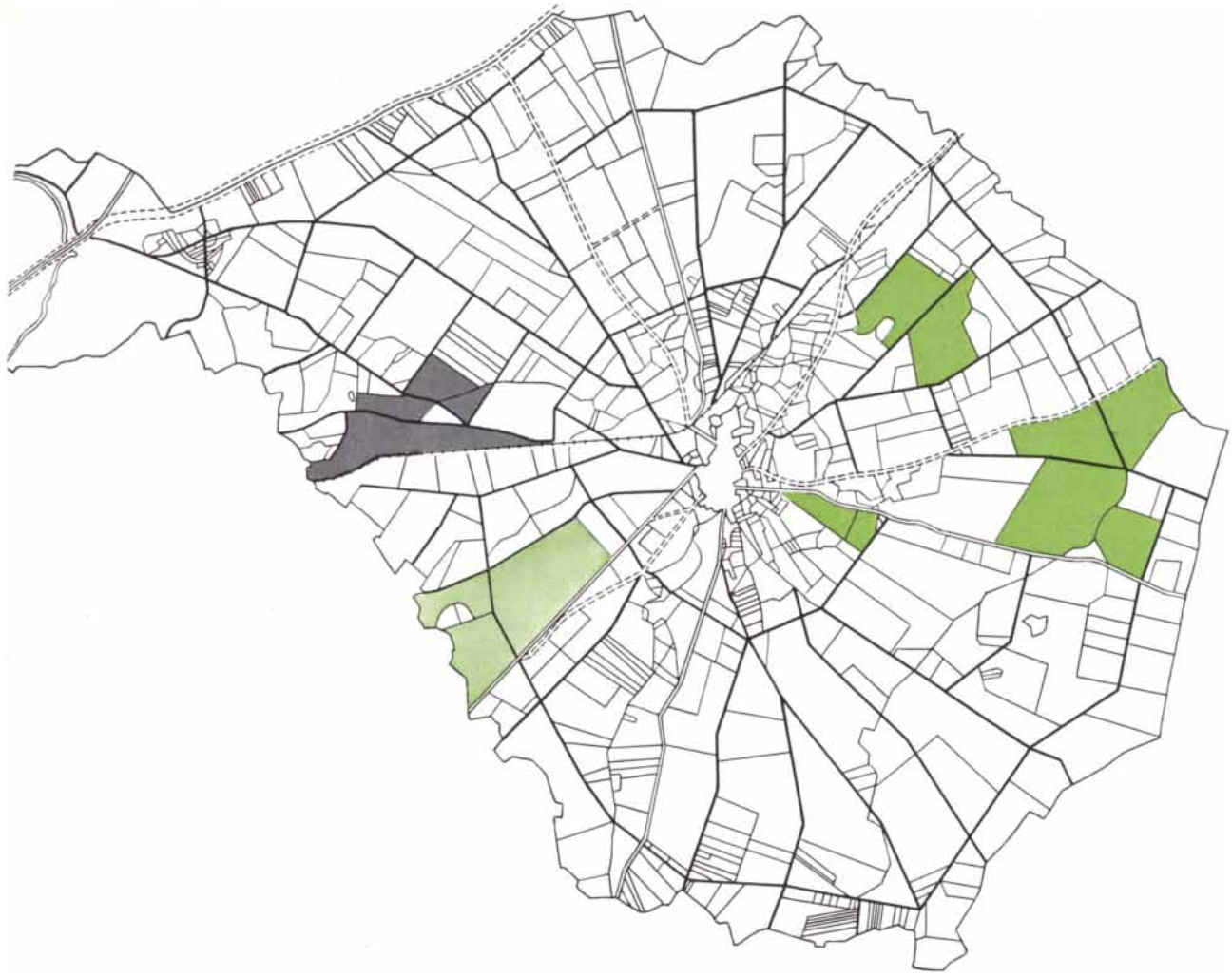
est charges. All too often the tenants' efforts to improve their holdings and increase their output result in demands for higher rent, so that improvements are discouraged. Absentee landlords, for their part, have little interest in the management of their land.

Small as the holdings are, they are fragmented into even smaller scattered plots, so that the southern European peasant cultivates wheat here, gathers in hay there and pastures his cow, if he owns one, in still another plot. An air view of the Mediterranean landscape, with its fine-grained pattern of small plots surrounding the central village, looks very different from the U. S. scene, with its orderly array of rectangular quarter-sections, each commanded by a farmhouse and a capacious barn. A long and tangled history of rights of succession and rigid inheritance-rules lies behind the division and subdivision of land in the old countries of the Mediterranean. In the Peloponnesus, for instance, there are cases of outlying plots located at five to 10 miles from the farm center. The 1950 agricultural census in Greece indicated that about a third of all farms have outlying plots of land in communes other than their own. In northern Portugal plots are counted in square yards instead of in acres. In Yugoslavia peasant holdings consist on the average of 11 different plots.

It is little wonder that production patterns are inflexible or that improved techniques are slow to spread. Insofar as its special position as an intergovernmental organization allows, FAO strongly advocates drastic measures in favor of land reform all over the region. Such reforms must include provisions for the redistribution of large holdings to peasants who are landless or whose holdings are extremely small, and for strengthening the position of the tenants. Redistribution will probably have to affect no less than 50 million acres, that is, a fifth of the cropland throughout the region. The kind of land tenure (that is, whether freehold or leasehold) to be adopted in these reforms is not a question of fundamental importance for which an over-all rule can be established. Perhaps more important is the large expenditure and organizational task that will be involved. Technicians will have to be employed to help organize the co-operative use of such investments as irrigation and machinery. The road system must be remodeled and new buildings constructed in order to provide the economically adequate farm units with the facilities they will need. Since the family must be regarded as the basic unit of the agricultural economy, the real problem in land reform is to combine large-scale organization, designed to get the maximum yield from the land, with small holdings operated by families.

Tribe and Family

In the Mediterranean region custom and deep family loyalty still furnish the social mortar provided by contractual relationships and civic responsibilities



farmers whose holdings are identified by the gray and the two colored tones held 280 to 800 acres divided into parcels of 2.5 to five acres each. After redistribution (*right*) each farmer holds the same number of acres assembled into large contiguous parcels.

in more integrated societies. In southern Europe the links between town and country have strengthened with progress, and there is less resistance to change in traditional ways of life. Yet even here, particularly in the more isolated areas, age-old customs and loyalties persist. In parts of the Near East and North Africa a significant proportion of the rural population is nomadic or seminomadic, and the basic unit is the tribe, which has retained a considerable independence in the administration of its own affairs. In the settled areas the family becomes the basic unit; it provides for the weak and the old, imposes a rigid code of behavior and otherwise carries the responsibilities taken over by the nation at large in more advanced societies.

The breakdown of these institutions can have severe social consequences. This has become obvious in the growing urban areas of the region, where the importance of the family has been declining. The wave of modernization inspired by closer contacts with the outside world and with the more sophisticated members of their own societies has made the conflicts between the younger and the older generations acute. Miserable housing conditions, degrading work in petty and menial trades, the corrupting influence of rackets of various kinds—these combine to erode previously accepted values. Family loyalties have not been replaced by a sense of civic responsibility, and neither public nor private assistance has taken the place of family obligation.

Community Cooperatives

In the planning of agricultural reform FAO has sought ways to mediate the social impact of the new technologies and the economic arrangements that will attend them. The plan banks upon the expectation that the tribal and village spirit will provide a vehicle for economic development. Enthusiasm and leadership must be elicited at the community level for change and progress which, if imposed from without, would probably meet with resistance. The transformation of the community spirit into the cooperative spirit offers the easiest way to modernize these rural societies without an abrupt departure from the old traditions. FAO contemplates setting up a broad network of community-developed experiments, linked to the pilot zones in which the new technologies and patterns of land use are to be demonstrated. The community-development movements in the region have so far been concerned with small-scale civic amenities, such as village roads, sanitation, clinics, schools and recreation facilities. The aim is now to bring the community directly into the productive process. The FAO answer to the almost classic antithesis between the small private properties and the collective farm, whether *kibbutz* or *kolkhoz,* is the agricultural cooperative.

The village cooperatives would have two major roles. On the one hand they would combine the three functions of credit, marketing and purchase. The

provision of credit for farmers in adequate amounts at reasonable cost and at the right time is essential. However anxious the farmer may be to improve his methods, he cannot do so if he has no source of funds to finance his efforts. Private moneylenders are still a common source of agricultural credit; they charge usurious rates of interest and exact otherwise predatory terms. Where public institutions for credit exist, they are frequently reluctant to give credit, since there is no guarantee that the credit will be used for the purpose for which it was granted, or that it will be expended efficiently enough to take the most advantage of it. The cooperatives could provide both technical advice and guaranties to these credit institutions. The farmers would utilize the cooperatives for massive purchase of fertilizers, seeds and other production requirements and would contract through the cooperative for delivery of their crops at market time and at market prices.

On the other hand, the cooperatives would be instrumental in ensuring the success of land reform. They would constitute the necessary link between the farmers for the establishment of large, efficient management units, which are essential to the economic operation of the redistributed lands. Through the cooperatives the state could provide technical guidance to the new settlers, very likely through the agency of extension services modeled on the successful precedent of the U. S. Department of Agriculture. The village cooperatives of Israel have achieved particular success in serving these functions. Systematic colonization under the guidance of the State has also been tried throughout southern Europe, as in the *bonifica* works in southern Italy, and has invariably produced good results. Cooperative movements are also beginning to spread over large parts of North Africa, and the recent land reforms in Egypt and Iraq will provide new opportunities for testing their viability.

The Unemployed and Underemployed

At present it is estimated that the equivalent of 22 million workers in the Mediterranean region are unemployed or underemployed. In 20 years the labor force will have grown from 69 million to 97 million. It is apparent that other employment and another way of life must ultimately be found for the vast surplus rural population. Within the FAO perspective, 33 million new jobs will be created, 10 million in agriculture and 23 million away from the farms in industrial and service occupations associated with the expansion of agricultural output. This objective falls short of full employment, but by 1980 unemployment should be down from 32 per cent to 17 per cent of the labor force. Meanwhile, large-scale public works projects would begin to absorb surplus workers from the farms and start their transition from the country to the town and city. Especially in its early phases the plan emphasizes labor-intensive programs—reforestation, road building, the construction of dams and irrigation works, the foundation of new villages and the provision of such essential services as water and electricity—which absorb more labor than capital-intensive industries. Manpower may be regarded as one of the main resources of the region, available in abundance to help the Mediterranean Development Project achieve its ambitious goals.

The question of whether the Mediterranean labor force is ready to take up and use the tools that modern technology can place in its hands is a troubling one. But the so-called native aptitudes and skills that distinguish the industrially more-advanced nations were acquired by experience and training, and surely the same can be expected for the Mediterranean peoples. Ability to read and write undoubtedly constitutes the first condition. If the peasant cannot read printed instructions and current news about methods and markets, it is unlikely that he will be able to make successful use of fertilizers and tractors. In country after country, therefore, campaigns against illiteracy are already under way, endeavoring to teach the old as well as the young. These efforts go beyond the primary level; Spain, Italy, Israel and a few other countries have established special courses for rural leaders and agricultural extension agents. The governments are recognizing that investment in education yields larger dividends, and in a much shorter time than has generally been expected, even though these dividends do not reduce easily to money terms.

Imported Technology

In regions like the Mediterranean modern development is primarily a foreign product. Some of its vital elements, such as machines, equipment and mon-

WOODEN NAIL-PLOW is still widely employed and is in some ways a better tool for Mediterranean soils than are modern plows.

STEEL DISK-PLOW, drawn by tractor, has not succeeded everywhere in Mediterranean, whose soils must be handled with care.

ey, can be imported. But the failure to take account of the special qualities of the local environment in the introduction of imported techniques can lead to fiasco. For example, sums spent on the importation of certain grasses of the genus *Eragrostis* have been absolutely wasted; although these species have given outstanding results elsewhere, they were a total failure in the Mediterranean. Similarly, imported mold-board plows and disk harrows have done great damage to arid soils in Turkey, making the soils so compact as to prevent the infiltration of rainfall and rendering them more susceptible to erosion. For all their drawbacks the native plows are not nearly so ruinous to the soil. The Mediterranean problem can be solved not so much by importing ready-made solutions as by importing foreign methods for solving problems. An early start on research therefore constitutes a vital step in development. Unfortunately it is typical of underdeveloped countries and their governments that they are quite reluctant to spend the large sums needed.

Inefficient government and underdevelopment are synonyms throughout the world. The establishment of the full range of services provided by the modern state is one of the most urgent needs in the Mediterranean region. The administrative reform will have to be all-embracing. Ministries dealing with economic affairs must be given proper status in relation to ministries responsible for the police, military matters and politics. Departments of agriculture will need to be reorganized. They must be competent to plan production and promote modern techniques, sufficiently decentralized to establish and supervise extension activities, furnished with adequate resources and power and staffed to undertake research and experimentation in all fields. This is a huge task requiring large numbers of well-trained officials who combine competence with faith and devotion. Such men would be difficult to find even if the positions offered to them were really attractive. Instead, they are discouraged by wholly inadequate salaries and status, red tape and frustration.

Unfavorable Balance of Trade

The question of how to finance the projected investment in an expanding agricultural economy is as troublesome for the governments of the region as it is for individual farmers. At present the situation could hardly be gloomier. In recent years the countries have had to rely heavily on loans and foreign grants in order to keep going. In 1956 the region as a whole had a deficit of about $2 billion. Yet the development programs will necessarily impose a heavy additional burden on the balance of payments. Only Iraq, with its oil revenues, can expect to secure from its own resources all of the foreign exchange which a vast development program must involve. In order to improve their credit position, therefore, the Mediterranean countries must seek to redress the unfavorable import-export ratio. The prospects for an increase in their exports are not too bright. Oil will help to ease the situation for Iraq and perhaps also for the North African countries that have claims on the vast new reservoir of the Sahara. Minerals are likely to continue now for those countries that have them. The principal exports of all the countries are agricultural raw materials and foodstuffs, especially wheat. It is uncertain whether these markets will expand and equally uncertain whether, after achieving a rise in consumption, any of the countries will have a considerable wheat surplus to export. Much export revenue comes from specialized products such as dried fruits, cork, olive oil and tobacco, but changes in techniques and taste have contracted the export markets for many of these products as well as for cotton, which is an important new crop in many of the countries. The FAO program therefore aims to diversify output and to promote the export of fruits, vegetables, meat and dairy products. But the countries must coordinate their programs to avoid glutting the export market with an excess output of, say, citrus fruit or tomatoes.

Imports, on the other hand, are bound to rise considerably under the impact of the program. The development of agriculture and of related industries will create heavy needs for agricultural implements, including tractors and fertilizers, and for many other capital goods that the underdeveloped economies of the Mediterranean areas do not produce. At the same time rising employment is bound to generate some increase in demand for imported consumer goods. Reduction of inequalities in income in the Mediterranean region—where the rich are so few and so immensely rich and the poor are so immensely numerous and miserable—will not exert such extreme pressure for imports as it would in more advanced countries. When the income of poor people rises, they go into the market for better food, simple textiles and other goods that are either locally available or can be manufactured by local industries. Conversely, the prospective redistribution of purchasing power is likely to reduce the demand for Cadillacs, high-grade textiles and other manufactured articles that local industries will not be able to produce for many years to come. The achievement of reasonable local self-sufficiency must be one of the guiding objectives of the investment programs. Priority must be given to the production of farm implements, fertilizers and seed and to industries that satisfy simpler consumer demands. Some further relief might be found in the limitation of luxury imports, by subjecting them to heavy import duties.

Nonetheless the import requirements of most countries of the Mediterranean area will for many years exceed their

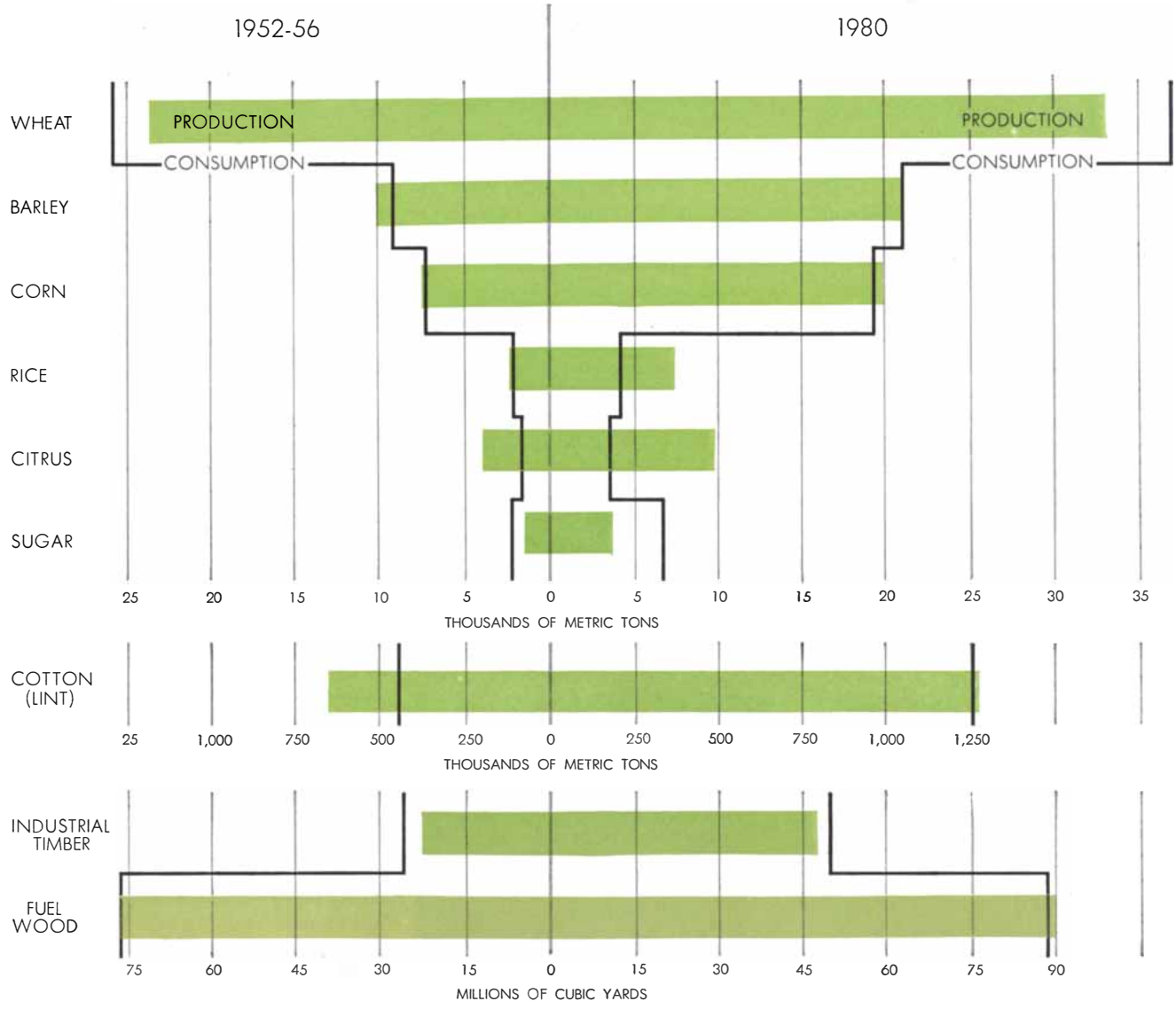
WOODEN WATER-WHEEL, powered by camel, lifts water from main irrigation ditch into feeder ditches to bring water to fields in valley of the Euphrates in northern Syria.

foreign receipts. Given the income targets and the investment requirements, it will still be necessary for the countries in the Near East and North Africa to run a foreign deficit averaging some $1 billion for the period of 1960 to 1980. This deficit will increase as the program develops, and will perhaps reach a peak of some $1.6 billion by 1975, close to the present southern European levels. But it will decline to less than $500 million immediately after the completion of the program. Such a dependence on the external world is not rare even in highly developed countries at the present time. It must also be borne in mind that by 1980 the per capita income of these countries will still be less than half the present French level. In southern Europe, Spain alone will be able to achieve a foreign surplus as early as 1975, mainly as a result of its lower population growth. The deficit for the subregion as a whole will rise to $3.2 billion by 1975 and will decline to about $1 billion, or slightly more than half the 1956 level, by 1980.

Foreign Financial Aid

Despite their deficit position, the Mediterranean countries must find the means to finance a higher rate of capital investment. It is estimated by FAO that the program will require the expenditure of a grand total of $255 billion over the 20-year period to 1980—roughly $117 billion in the Near East and North Africa and $138 billion in southern Europe. Of this total some $50 billion will go directly to agricultural and forestry resources and the rest to industry and services. The total investment thus corresponds to an average of rather more than $12 billion per year. The present rate of investment is no more than $7 billion, and of this figure only 80 per cent is supplied by domestic savings. It is calculated that during the period from 1960 to 1980 total savings will not exceed $225 billion. Some $30 billion, that is, about 11 per cent of the total investment effort, will have to be provided by countries outside the region, at an average rate of about $1.5 billion per year.

Foreign financial aid will therefore constitute one of the indispensable elements of the program. It will not, however, be disproportionately larger than the amount provided at present. From 1980 on it is hoped that this need for foreign aid will taper off and eventually disappear altogether. If the programs are carried out in accordance with the FAO proposals and expectations, the Mediterranean region will have become financially self-supporting and will be able to undertake repayment of the help received.



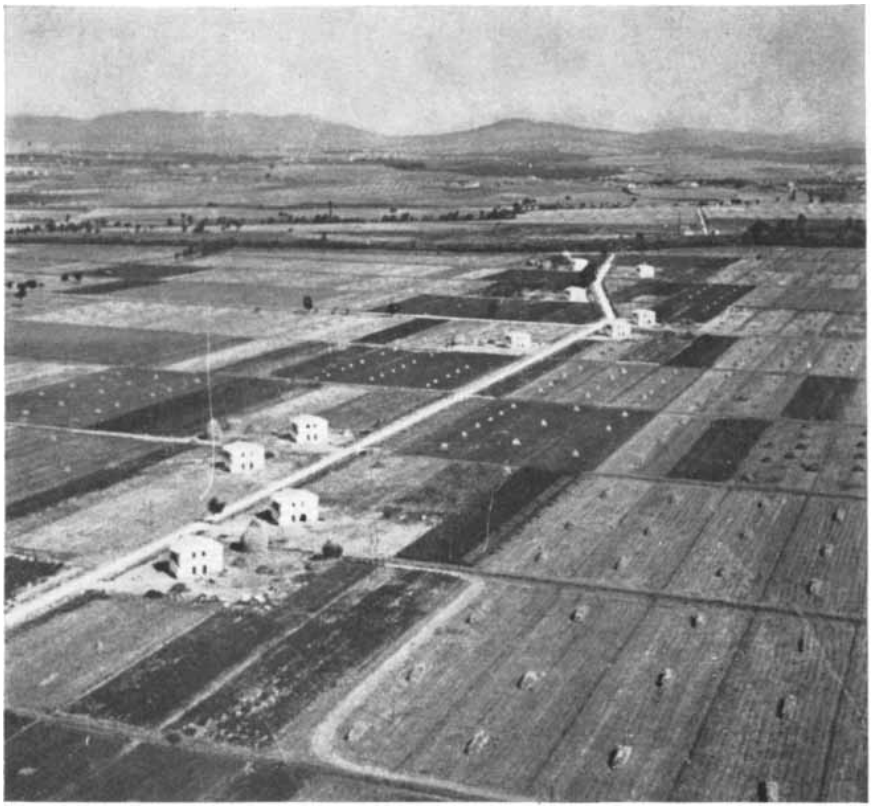
PRODUCTION AND CONSUMPTION goals for agricultural crops are designed to provide for rising standard of living as well as increasing population. The region will still be importing wheat in 1980, but its export-import accounts will be in better balance.

Today any agency that engages in such grand-scale projections as these must reckon with a specter that haunts statesmen and citizens alike—the fear of inflation. The word "inflation" has ceased to be simply a jargon term of economics, and is widely understood to be an evil that must be avoided. This is particularly true in the Mediterranean area, where many countries have experienced recurrent runaway inflation to the point that few of the area's currencies enjoy the respect and the confidence which are needed to attract investors, stimulate entrepreneurs and induce people to save.

Inflation and Expansion

It must, however, be recognized that every period of development is attended by some degree of inflation. This has been true for the monetary systems of advanced countries. For underdeveloped nations the hazard is greater, because a substantial rise in employment usually creates new incomes and demands quicker than it generates additional supplies. In Turkey, Spain and other countries economic expansion in recent years has come up against inflation. Expansion has thereupon been brought to a stop by deflationary measures invoked on the mistaken assumption that the inflation was a monetary disorder, when actually the cause lay in insufficient production which was caused in turn by failure to recognize the restoration of agricultural resources as an essential element in the development program. Despite these difficulties, the rapid expansion of Mediterranean economies is a matter of such urgency that banking institutions and experts at home and abroad must find ways to reduce financial restraint on the process. From this point of view deflation without adequate safeguard is just as great a hazard as is inflation. It is one of the basic policies advocated by FAO that the answer should not be sought by slowing down the process of growth, but by means of outside help. Foreign aid should be granted on a sufficient scale, and related in time, form and size to the proposed development programs.

Thus even though the Mediterranean region will furnish nearly 90 per cent of the needed investment funds, the $1.5 billion in financial aid that must be supplied from outside has a vital bearing on the ultimate outcome of the effort that is proposed by FAO. In addition, the number of foreign experts now working in the region will probably have to be more than doubled. The channeling of foreign aid from different sources—from the UN, the International Bank and bilateral aid arrangements—must be properly co-ordinated in order to avoid waste. But this is not all the outside world can do to help the Mediterranean region. It will also have to provide markets for the substantially increased agricultural output of the region, and to tolerate the protection of the region's infant industries.



"BONIFICA" PROJECT in southern Italy has established farmsteads on redistributed land. This project will serve as a "pilot zone" for test and demonstration of new techniques.

The results to be expected justify this co-operation. The Mediterranean region is admirably suited to demonstrate the possibilities of rational economic development. It is not yet faced with the appalling problems of population growth, illiteracy and low standards of living confronting the Far East, nor with such rudimentary state administrations and shortages of qualified personnel as are found in some of the new African countries. Bold action in the Mediterranean region can give surprising results and set an example for other poor countries.

Capital, Coercion and Surpluses

The only alternative to foreign aid would be to impose drastic measures on the populations of the Mediterranean countries in order to increase the rate of saving and the capital available for investment. It would certainly not be an easy political task to enforce such measures. Adequate foreign aid can upset the unwelcome conclusion, advanced by one school of economists, that coercive power is necessary to the process of capital accumulation, all the more so when the margin of squeezable resources is narrowest. According to this theory someone—whether landlord, industrialist, financial manipulator or people's commissar—has got to be tough. The narrower the squeezable margin for expansion, the tougher he must be. In their determination to get on with the task of improving their lot, the peoples of the underdeveloped countries have even shown a willingness to accept dictatorships that promise and get results. But the need for coercion in the accumulation of capital has now been obviated by the enormous surplus capacity of the industrially advanced nations. The economic function of the dictator can be neutralized by foreign aid.

It is the central challenge of our time to create a partnership between rich and poor countries that will see the latter through into sustained growth on a basis which keeps open the possibility of democratic development. To lay the basis for this partnership FAO has provided a blueprint for economic action in the Mediterranean.

"Mein Herr, jawohl, durch...

$$\psi(x) = \frac{1}{\sigma(2\pi)^{\frac{1}{2}}} \exp\left(-\frac{1}{2}\ \frac{x^2}{\sigma^2}\right)\ldots$$"

"El próximo año

$$P = \frac{A}{A\text{-}B} E_{N,A} - \frac{B}{A\text{-}B} E_{N,B} \ldots$$"

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$$H(x)=\sum_{i}^{n} p_i \log \frac{1}{p_i} = -\sum_{i}^{n} p_i \log p_i \ldots$$"

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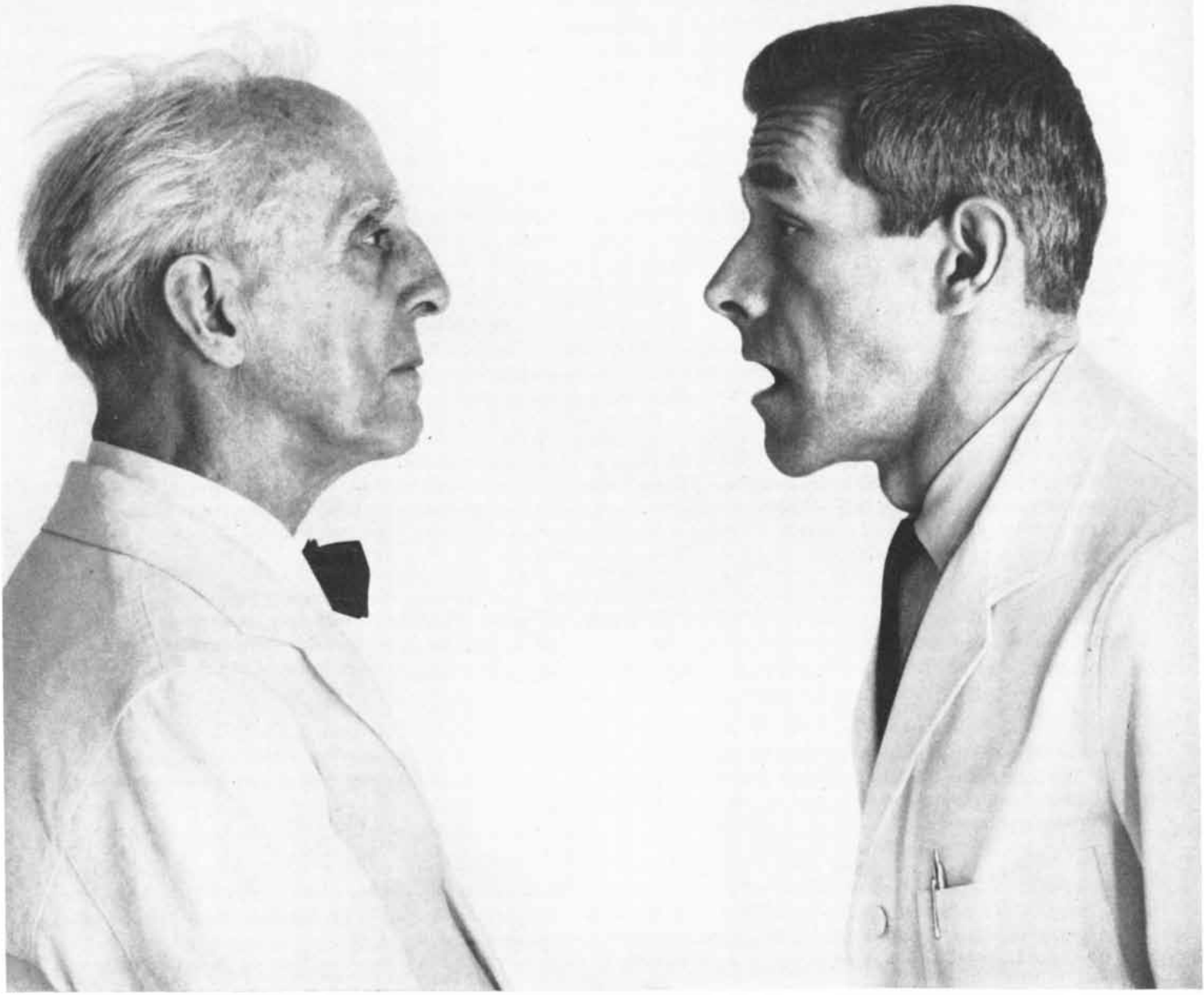

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The Biology of Heavy Water

What happens to experimental organisms that have been raised on water in which the hydrogen is not the common isotope of mass one but the heavy isotope of mass two?

by Joseph J. Katz

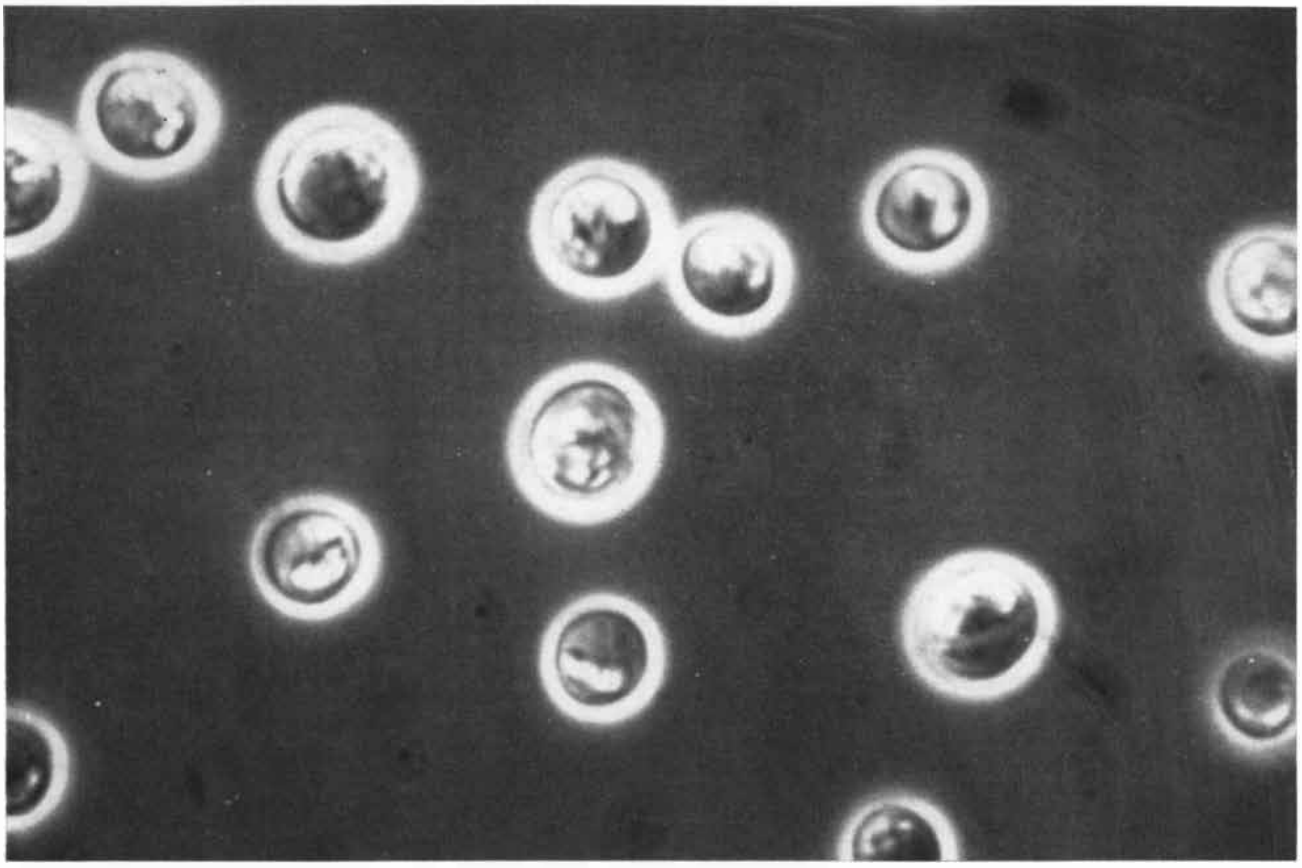
The mnemonic word "CHON" helps the beginner in biology recall that living things are made largely of carbon, hydrogen, oxygen and nitrogen. Strictly speaking, however, the word should read "$C^{12}H^{1}O^{16}N^{14}$." Elements are not simple substances; as they occur in nature each is a mixture of atoms that are related closely enough to share a family name but are distinguishable from one another by differences in the mass of their nuclei. Thus H^1 signifies hydrogen of mass one, by far the most common nuclear species, or isotope, of this element. As it occurs on earth, hydrogen also consists of a small amount (one part in 5,000) of hydrogen of mass two (H^2), a stable isotope that is also called deuterium and is usually designated D. In still smaller ratio to H^1 is hydrogen of mass three (H^3), the radioactive isotope called tritium. The differences in the mass of the isotopes of a given element are accompanied by slight differences in their chemical behavior. Of course in the substances that compose living matter the most common isotopes of the various elements predominate, and they—C^{12}, H^1, O^{16} and N^{14}, rather than their rarer isotopes—determine the character of the chemical reactions of life.

What would happen to a living system if the common isotope of one of these important elements were entirely replaced by the rare isotope? This is a question that has intrigued biologists ever since Harold C. Urey and his associates isolated deuterium at Columbia University in 1932. Living things are so precisely organized that it is difficult, if not impossible, to change their elemental composition without killing them. It seems reasonable, however, to attempt to modify the isotopic composition of living matter. With the rarer isotopes now available in sufficient quantity, a number of investigators are engaged in developing the possibilities of this experimental procedure.

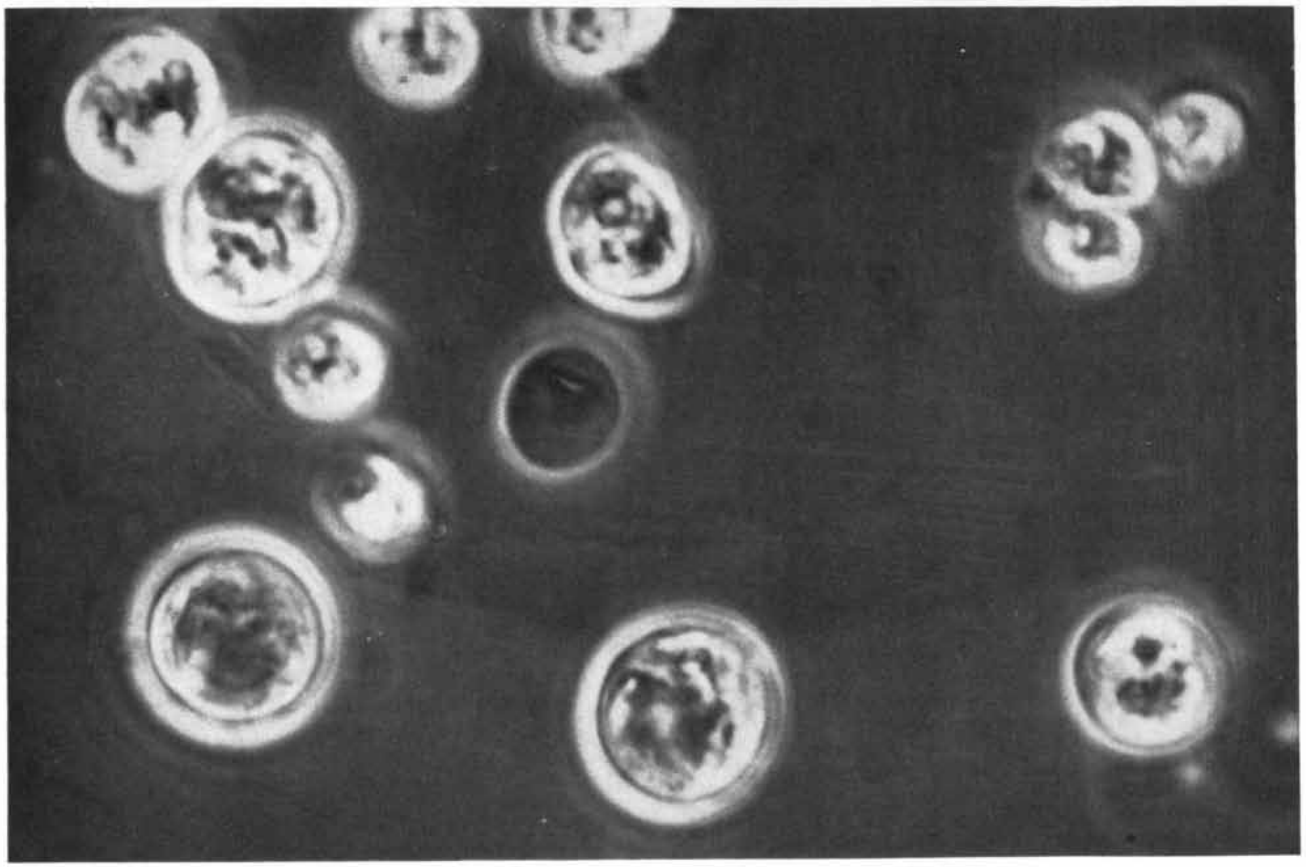
The use of deuterium is especially tempting because hydrogen is the most common element in biological systems, and deuterium, having twice the mass of ordinary hydrogen, differs from its common isotope more sharply than any other rare nonradioactive isotope does. Moreover, in the form of heavy water (D_2O) deuterium has become a relatively abundant substance. A thousand gallons of water, weighing about four tons, contains a pound of heavy water; yet even this small fraction is now extracted in large volume because it is in great demand for the purposes of nuclear technology. As its name implies, heavy water has a 10 per cent higher density than water does and a 25 per cent greater viscosity. Its freezing point (39.2 degrees Fahrenheit) and boiling point (214.5 degrees F.) are both distinctly higher. Many salts and some gases, including carbon dioxide and oxygen, are less soluble in heavy water, and acid solutions of D_2O are distinctly more acid than corresponding solutions of H_2O. In biological systems all of these factors might be expected to produce noticeable effects.

Of such effects perhaps the most significant is the "kinetic isotope effect," that is, the change in the rate of a chemical reaction that results from the substitution of a heavy isotope for a light one. Chemical bonds between deuterium and other atoms are slightly but measurably more stable than the corresponding bonds involving ordinary hydrogen. Calculation indicates that a carbon-deuterium bond may undergo reaction at only a seventh the speed of a carbon-hydrogen bond. Experiments have borne this out, and have shown in general that carbon-deuterium bonds react at a rate one half to one seventh that of bonds involving the common isotope. There is every reason to believe that the perturbation of reaction rate caused by the substitution of deuterium will have critical biological effects, and that such effects will be more drastic in more highly organized biological systems. This is essentially what has been observed.

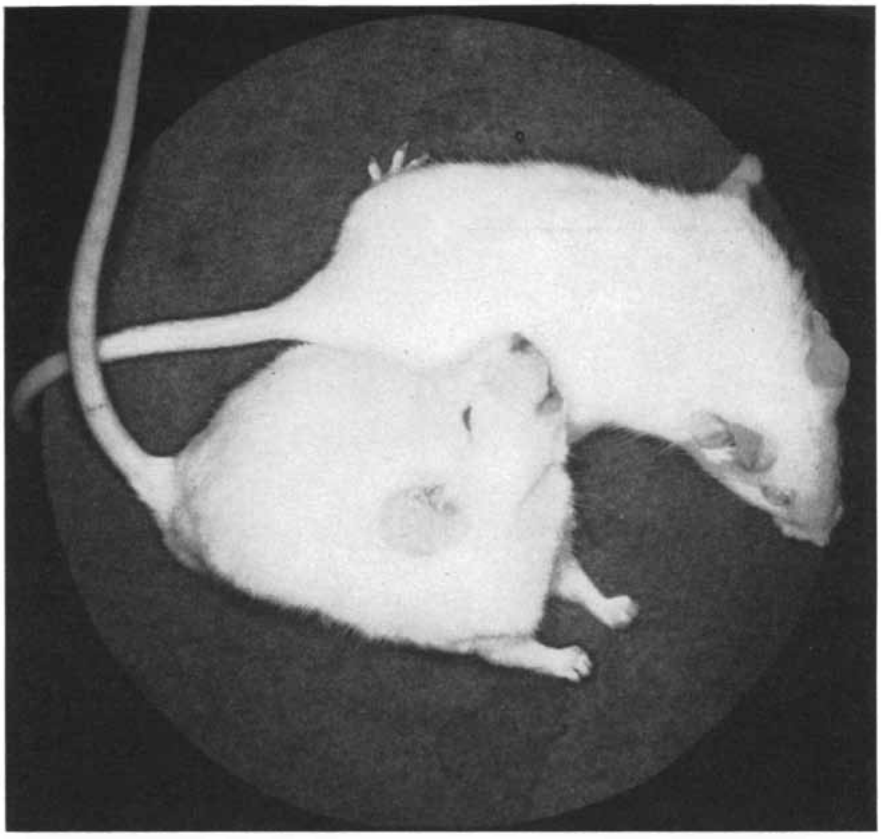
The effect of deuterium on mammals was first observed in 1932 by Gilbert N. Lewis of the University of California, who fed heavy water to mice; between 1934 and 1938 Lewis's investigations were extended by Henry G. Barbour of Yale University. The mouse serves the purpose of such experiments well because it obligingly drinks about 25 per cent of its weight each day; it can be "deuterated" speedily to the extent desired by regulating the concentration of deuterium in its drinking water. The concentration of deuterium in the body fluids of the animal quickly approaches a steady state, determined by the ratio of deuterium ingested in the drinking water to the ordinary-hydrogen content of the food it eats. Mice supplied with water containing 30 per cent deuterium develop a 25 per cent concentration of D_2O in their blood serum or urine within a few days. If a mouse is fed heavy water for an extended period, its tissues and organs will also begin to incorporate deuterium. Apparently no organ in the mouse incorporates deuterium preferentially. The fatty tissues of the brain and nervous system take up the isotope more slowly than do organs such as the kidney, the liver and the spleen, but they incorporate it more permanently. Thus when a mouse is returned to a regime of drinking ordinary water, its brain retains appreciable amounts of deuterium long after the deuterium content of its



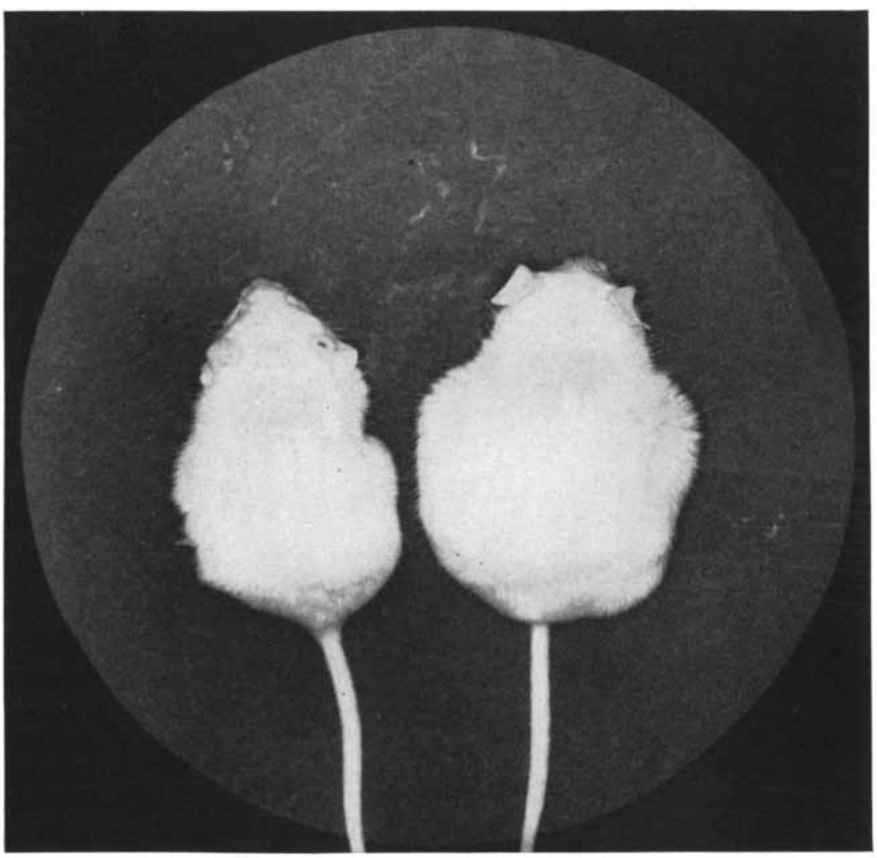
CHLORELLA VULGARIS, A GREEN ALGA, is being used in experiments with heavy water. This photomicrograph, made by phase-contrast microscopy of living cells, shows the normal cells grown in ordinary water. They are enlarged some 3,200 diameters.



CHLORELLA GROWN IN HEAVY WATER has become adapted and contains deuterium in place of ordinary hydrogen in its substance. These cells, shown at the same magnification as those at top of page, resemble the normal ones except for being larger in size.



DEUTERATED MOUSE in the foreground is having a convulsion induced by the photographer's flash. Tendency to have convulsions is one of the symptoms which appear when the level of deuterium in body fluids approaches 30 per cent. The second mouse is untreated.



TUMOR GROWTH is more rapid in an untreated mouse than in a deuterated one. In mouse at left 25 per cent of the hydrogen in the body fluids had been replaced with deuterium. Mouse was then injected with tumor cells and deuterium treatment was continued. Mouse at right was injected with tumor cells at the same time but received no deuterium.

other organs has fallen to a low level.

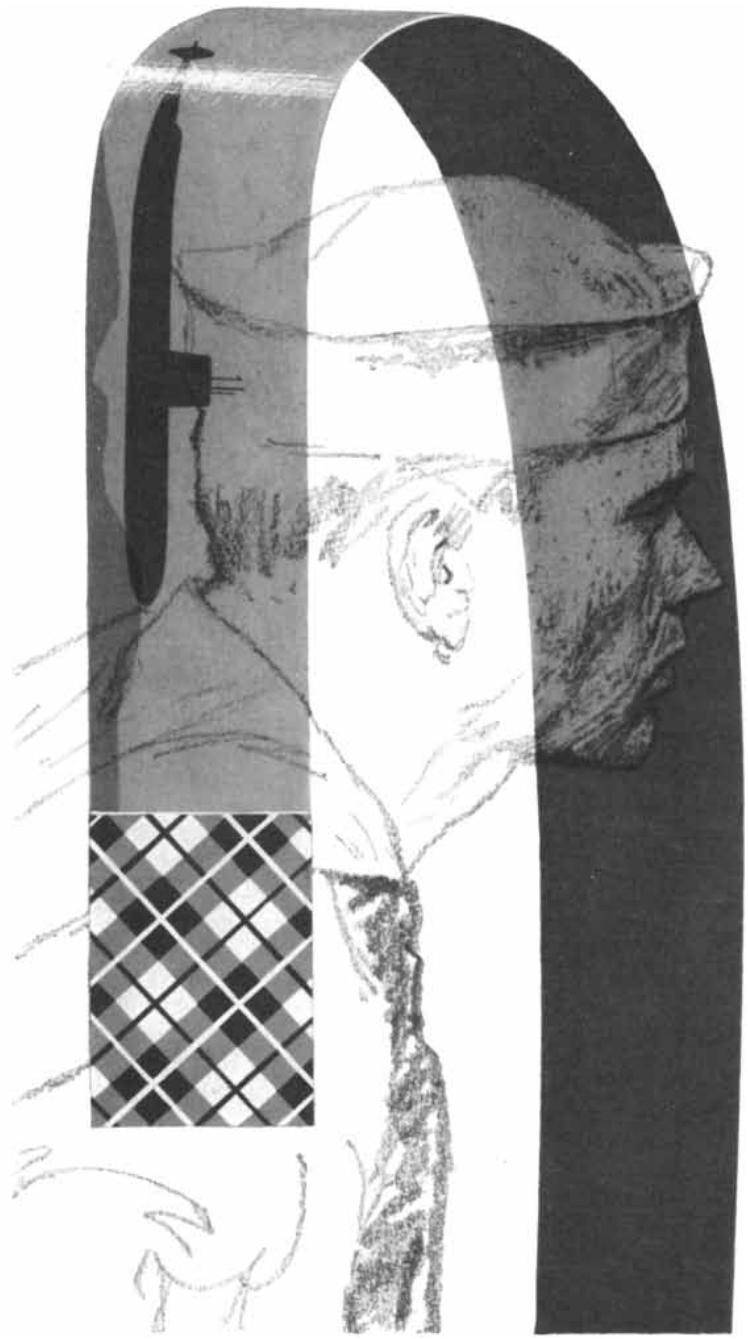
Mice can live in a deuterated condition for long periods. Some have been raised from birth on water containing 30 per cent D_2O, and have been maintained for a year or more with a deuterium level of 25 per cent in their body fluids and 10 per cent in their brain tissue. Such mice are normal except in one important respect—they produce no young. Even a low level of deuterium impairs the ability of the male mouse to produce normal spermatozoa, and in females deuteration during pregnancy interferes with gestation and induces fetal abnormalities.

When the concentration of D_2O in the body fluid of a mouse approaches 30 per cent, the picture changes drastically for the worse. The mouse shows symptoms of weakness, it is easily irritated, its coat roughens, it loses weight rapidly and it is prone to convulsions. When the deuterium level is raised still further, the animal becomes stuporous, its body temperature drops rapidly, all its physiological functions are greatly depressed and within a short time it dies.

Rats react in a similar fashion. At low deuterium-levels they fail to gain weight. When the deuterium content of the blood plasma rises to 20 per cent, they cease to groom themselves and develop skin lesions and necrosis of the tail, as if suffering from a vitamin deficiency. At still higher concentrations they become more excitable and aggressive, as do mice. With 30 per cent D_2O in their blood plasma, some rats actually go into convulsions when handled, resembling in this respect animals poisoned with strychnine. At about 35 per cent the rats become extremely lethargic, lapse into a coma and soon die.

The amount of heavy water required to deuterate larger animals is considerable even by present standards, and such experimentation is necessarily limited. The largest animal that has yet been deuterated is a small dog. Here, too, 30 per cent D_2O in the plasma represents the acute danger level. At about 25 per cent the dog appears quite normal, but closer examination shows that it is not really healthy. Its sugar-metabolism rate is low, its blood cells show a disturbed picture, there are signs of anemia and an electrocardiogram reveals nonspecific heart damage. All the damage appears to be reversible; when the dog is restored to a regime of ordinary water, even the abnormalities in the electrocardiogram disappear; after a few months no defects can be detected. Only a few such experiments have been per-

Sonar student takes his training on a simulated sea— with magnetic tape **SEAPRINTS**



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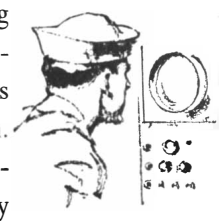
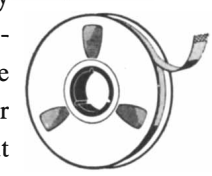
When the master is played into the sonar console at the training center, the signals on it reconstruct the problems just as they occurred at sea. The sonar student thus gains experience in solving actual problems he will encounter at sea—and perfects his skills in the classroom.





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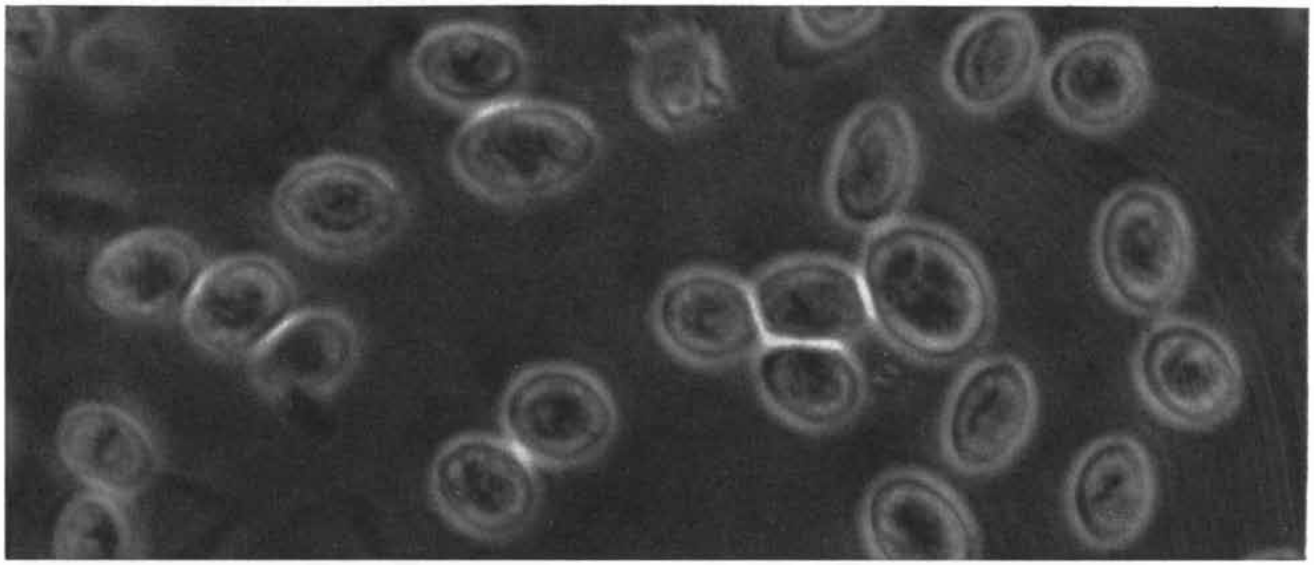
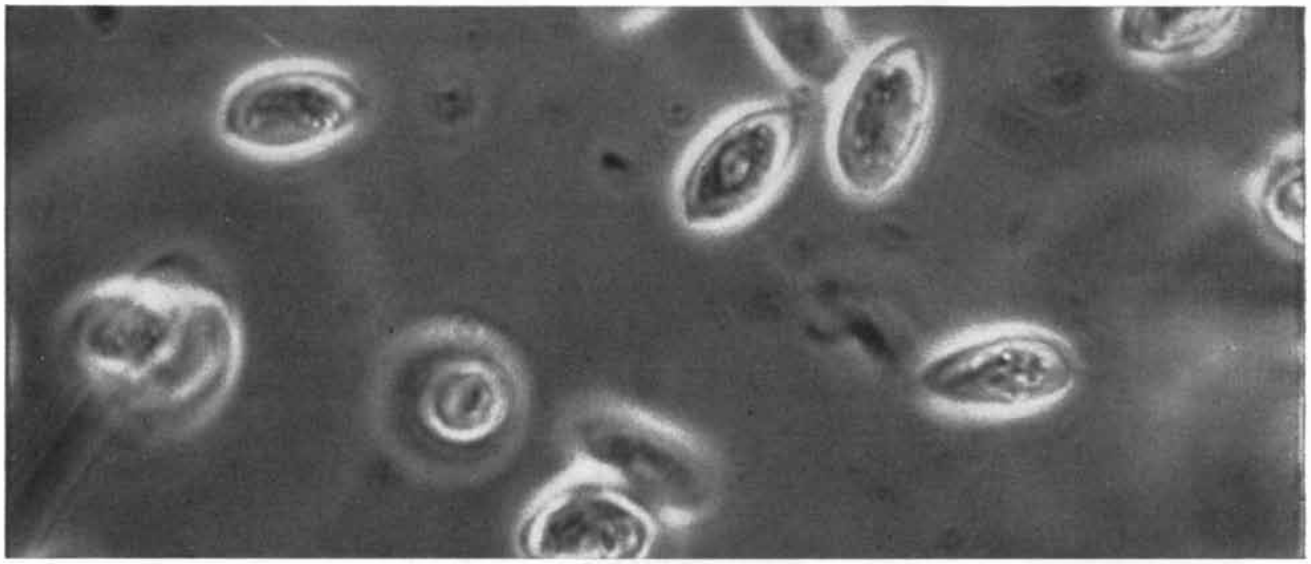
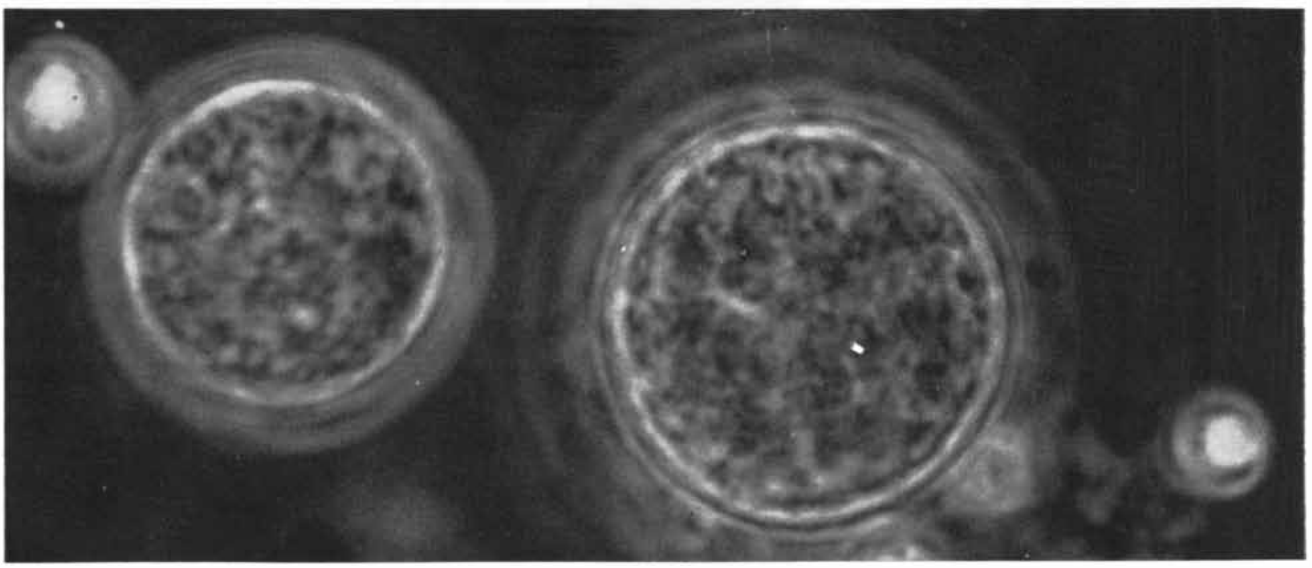


NORMAL CELLS OF SCENEDESMUS, another kind of green alga, are oval when grown in ordinary water. These cells, as well as the others on this page, were photographed by phase-contrast microscopy and are enlarged approximately 2,500 diameters.



DEUTERATED SCENEDESMUS CELLS depicted here have been growing in heavy water for more than a year. The cells have assumed a tear-drop shape and are generally less symmetrical than the ordinary-hydrogen-containing cells of the same strain of alga.



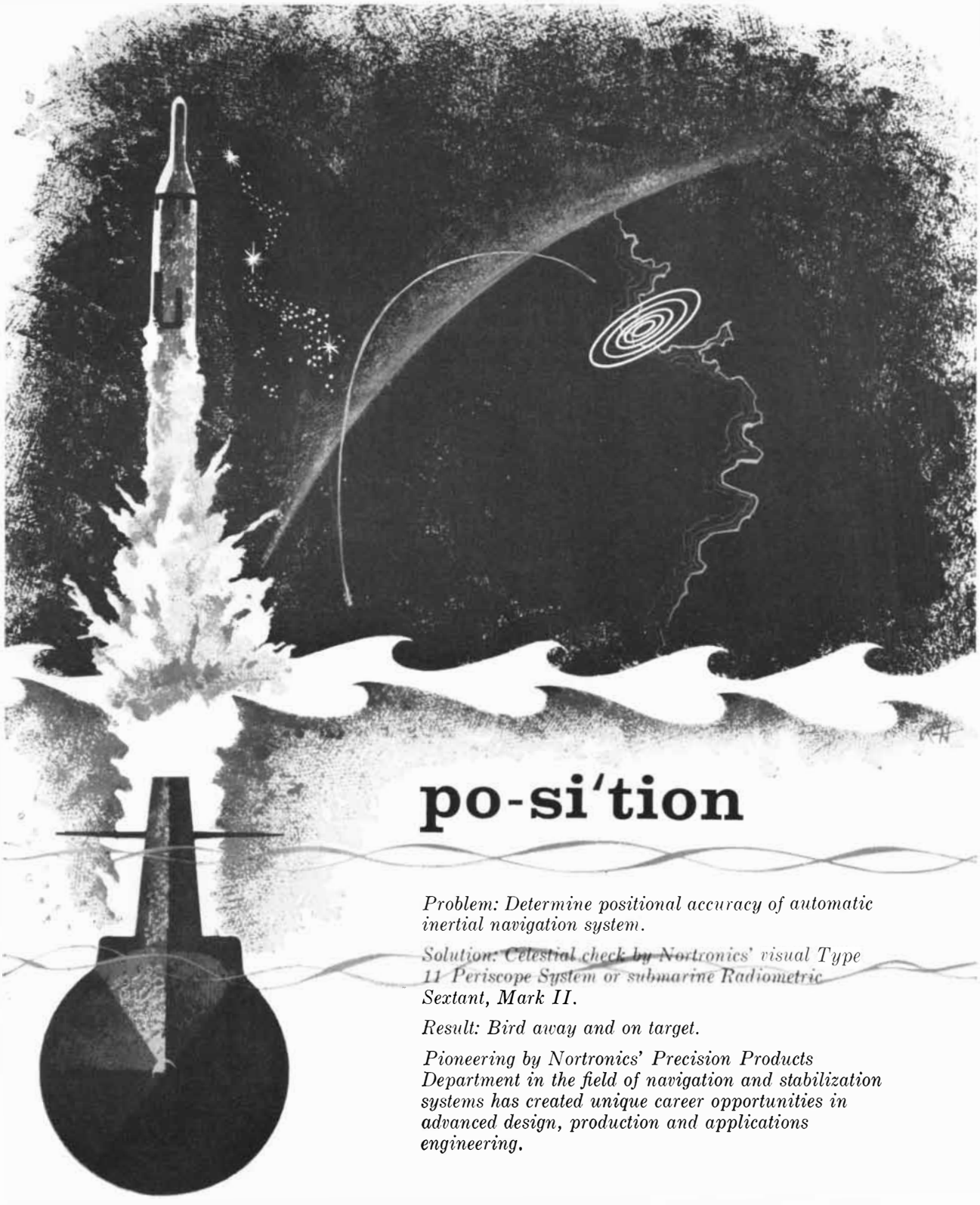
ADAPTING SCENEDESMUS CELLS, observed a few days after the initial transfer from ordinary to heavy water, are distinctly abnormal. Giant cells are especially prominent. It usually takes several weeks to a month for the algal cells to become adapted.

formed; the indications are, however, that large animals will prove essential to the development of certain kinds of experimental evidence.

Since deuteration has marked effects upon the central nervous system and upon embryonic tissue, it appears that organs and tissues with a high rate of metabolism are particularly sensitive to this interference with their chemistry. The observation has suggested that cancerous tissue, which is also characterized by a high metabolic rate, might be more affected by deuterium than corresponding normal tissue is. As early as 1936 Barbour actually observed that deuterium inhibits tumor growth, and more recent studies have supported his findings. In a typical experiment carried out at the Argonne National Laboratory two groups of mice were deuterated to the extent of 15 and 25 per cent respectively, with a nondeuterated group serving as a control. Seven days after the start of deuteration, the mice received abdominal injections of tumor cells. The cells used, from the so-called Krebs 2-A strain, are convenient for experiment because they proliferate separately instead of forming a compact growth; the investigator can follow their multiplication either by noting the weight increase of the animal or by counting the number of tumor cells in samples of fluid taken from its abdomen. In this experiment the tumor grew more slowly in the two groups of deuterated animals than in the controls, and most slowly in the more-deuterated group. Experiments involving the induction of lymphatic leukemia in mice have given similar, though less clear-cut, results, but they, too, indicate that the incorporation of deuterium in the cells slows down their multiplication. At present deuteration is being tried in combination with various chemotherapeutic agents.

It is possible that the selective effect of deuterium upon tumor cells might be amplified to the point of practical interest if the concentration of the isotope in the host animal could be raised to sufficiently high levels, say 50 to 60 per cent. Experiments so far have shown that the tolerance of mammals reaches a ceiling at only about 25 per cent. Attempts to raise that ceiling have so far failed, and one cannot be sure that adaptation to a high level of deuterium is a reasonable request to make of the organism. Investigators have accordingly turned to simpler organisms to learn about the effects of deuterium on growth and metabolism.

Green algae, the familiar green scum of ponds and lakes, had been the



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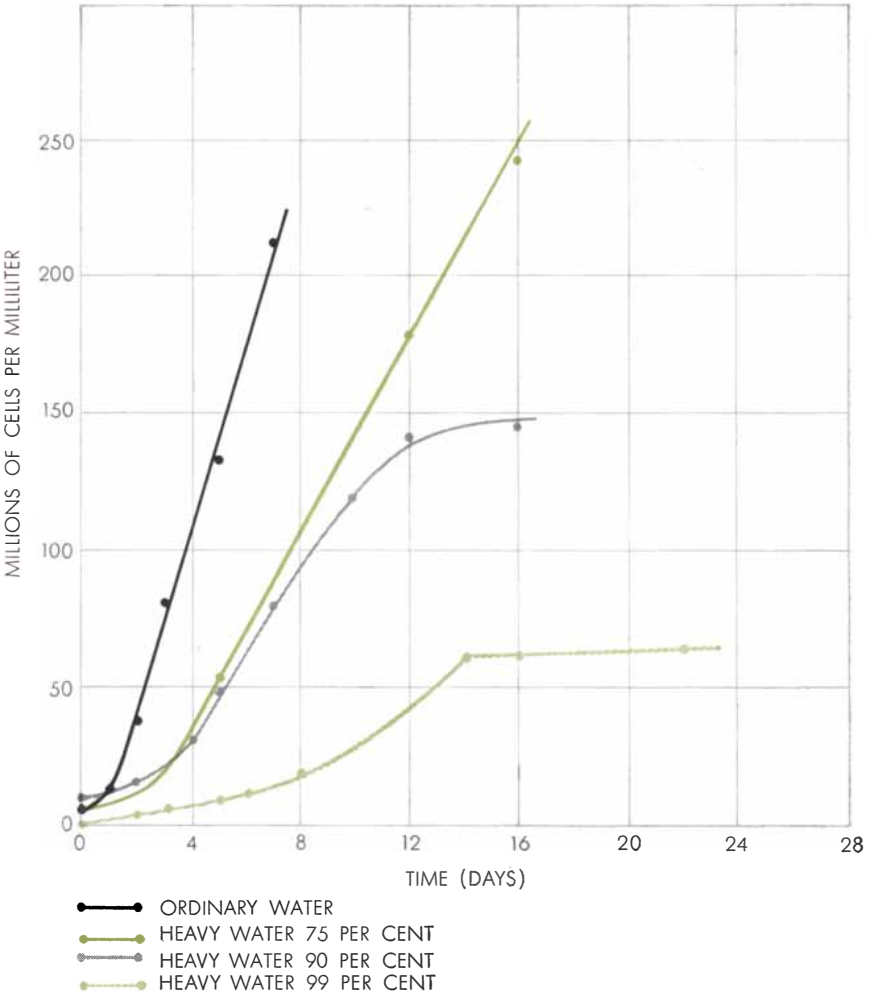
subject of numerous heavy-water experiments during the 1930's. These primitive plants were remarkably tolerant to deuterium, but the evidence indicated that they would grow very little, if at all, in water containing more than about 85 per cent D_2O. It was thus a surprise when we succeeded in growing algae at the Argonne National Laboratory in almost pure (99.6 per cent) D_2O. Earlier workers probably failed to observe growth in such a high concentration of deuterium, because algae require a long period of adaptation before they multiply. Algae transferred from an ordinary-water medium to D_2O show no signs of growth for several weeks. Viewed under the microscope during this period, many cells appear swollen to enormous size, others have distorted shapes and in some the internal structures are fragmented.

If the exposure is continued long enough, however, the cells suddenly begin to multiply. It is almost as if the organisms recognize that no alternative is open, and the sickly looking culture suddenly acquires a healthy green complexion. Growth, once begun, progresses smoothly. The abnormal forms disappear, and the cells assume a more normal appearance. In one variety of green alga, *Scenedesmus obliquus,* the deuterated organism is slightly different in shape and somewhat smaller than the normal one; in the case of *Chlorella vulgaris* the deuterated cells are the larger ones. Otherwise algae growing in D_2O appear normal, at least on superficial examination.

The algae multiply slowly on first becoming adapted to D_2O, but grow more rapidly with time. In our laboratory Scenedesmus eventually grows about half as fast in D_2O as in ordinary water. Organisms transplanted to a fresh heavy-water medium after adaptation usually start to grow immediately, but those



GROWTH RATE of algal cells decreases and the initial period of very slow growth is prolonged as they are transferred from ordinary water to increasingly higher concentrations of heavy water. This graph shows the growth curves of a culture of *Chlorella ellipsoidea* grown in ordinary water and then successively transferred to 75 per cent, 90 per cent and 99 per cent heavy water. End of each curve represents time of transfer to next level.

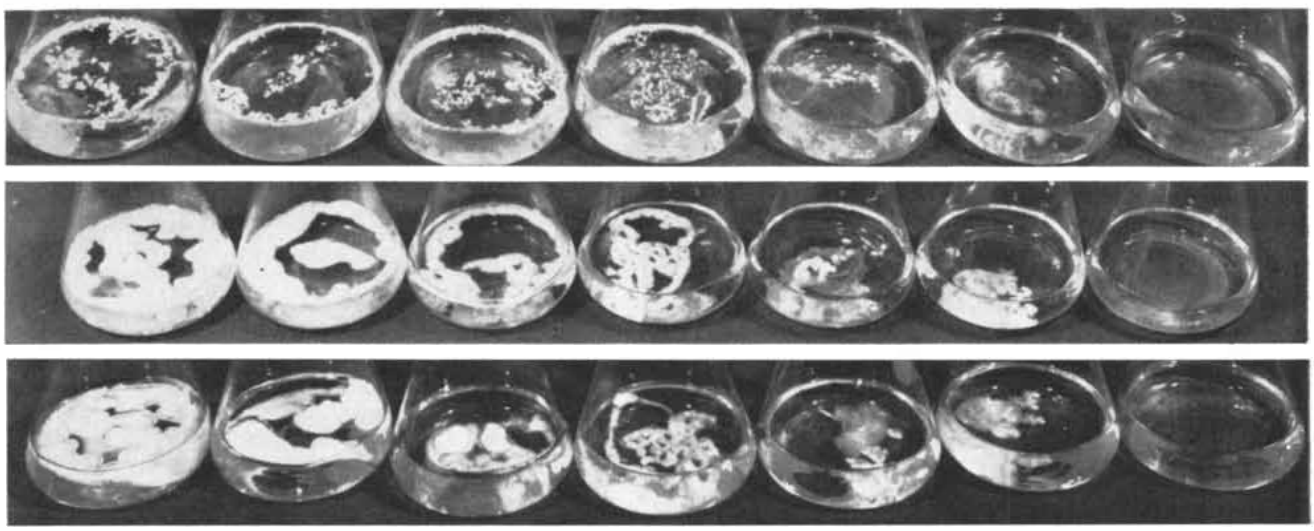
transferred back to an ordinary-water medium again show a lag before resuming growth. The period of readaptation to ordinary water is shorter but may require several days. In addition to green algae at least two species of the related blue-green algae have been grown successfully in heavy water, and probably many other species can also survive in highly concentrated D_2O. The nature of the adaptation process is the focus of our present investigative effort, but the factors involved are almost completely obscure. In fact, though our methods for adapting algae to D_2O are usually successful, they are not completely reliable, and we are looking for a more rational recipe.

Organisms that synthesize their substance from water and carbon dioxide must obviously secure from the water all the hydrogen they build into their various compounds. The compounds synthesized by algae grown in heavy water will therefore have deuterium in all the molecular positions ordinarily occupied by hydrogen. In their enormously versatile capacity for synthesis, algae can produce fully deuterated carbohydrates, amino acids, proteins and a great variety of other compounds, many of which cannot presently be synthesized by the organic chemist.

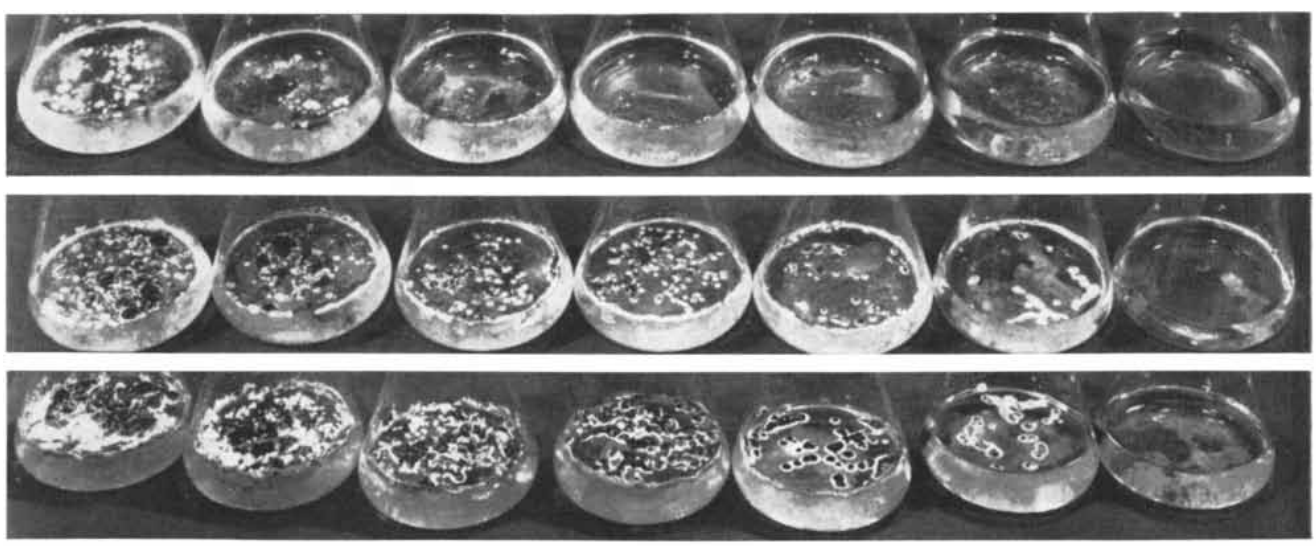
Deuterated algae can thus be employed to manufacture deuterated foodstuffs for the culturing of other microorganisms that require ready-made compounds of carbon and hydrogen. The bacterium *Escherichia coli* and the yeast *Torula* have been cultured in 99.6 per cent D_2O with fully deuterated glucose as their food supply. These organisms, particularly the yeast, are competent producers of complex compounds and can manufacture deuterated substances that cannot be obtained from algae.

Molds are among the organisms that require ready-made carbohydrates. We have grown both Aspergillus and Penicillium on ordinary-hydrogen-containing glucose in heavy-water solutions, and have found that their growth is retarded as the D_2O concentration is increased, the effect being pronounced at a concentration of only 33 per cent. At progressively higher concentrations the molds produce less and less of their pigments and aromatic substances, and at quite high concentrations they lose the capacity to form spores. On fully deuterated glucose in D_2O *Aspergillus niger* grows slowly but remains alabaster-white, unable to form the black spores from which it gets its name.

Another organism that has demon-



PENICILLIUM NOTATUM, the familiar blue-green mold, was grown in nutrient solutions containing (*from left to right*) 0, 10, 25, 33, 50, 66 and 99 per cent heavy water. Growth is shown after three days (*top*), seven days (*middle*) and 10 days (*bottom*).



ASPERGILLUS NIGER, another mold, usually appears black because of its spores, but heavy water inhibits its spore formation as well as its growth. In heavy water it becomes white. It is shown after five days (*top*), nine days (*middle*) and 12 days (*bottom*).

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strated a capacity to adapt to a deuterated environment is the protozoon *Paramecium caudatum*. This animalcule shows unmistakable signs of distress at about the same deuterium level that is toxic to mammals. In 35 per cent D_2O it has great difficulty in dividing; "monster" forms suggestive of those found in adapting algae are prominent. But after a short time the cells begin to grow normally. They can adjust to successively higher deuterium-levels if the heavy water is added in small increments and at intervals that allow time for adaptation. By this procedure they have been induced to grow quite normally in 60 per cent D_2O. How far their adaptation can be carried is still unknown, and it is not apparent whether the mechanism is a true adaptation or merely a selection of mutant strains that have a genetic resistance to the toxic effects of deuterium. The fact that these microscopic animals can adapt to high levels of deuterium offers a small measure of hope that higher animals also will be able to increase their tolerance, though one must draw the analogy with caution.

Instead of deuterating the whole organism, one may compel the organism to utilize essential foodstuffs containing deuterium. Thus glucose, which is ordinarily metabolized to carbon dioxide and water, may be replaced by fully deuterated glucose; the slower reactivity of carbon-deuterium bonds should produce a noticeable effect on the rate of metabolism. It is possible, in principle at least, to vary the relative rates of important cellular reactions to different degrees. This procedure offers a promising way to study the interrelationships of many different reactions which go on in a complex biochemical system.

Not only hydrogen but also the other important elements may be replaced in living matter by their rare nonradioactive isotopes. Ordinary carbon can be replaced by the heavy isotope carbon 13; ordinary nitrogen, by the heavy isotope nitrogen 15; ordinary oxygen by the heavy-oxygen isotopes of mass 17 and 18. Thus it should be possible to create organisms that are in effect living isotopes of those which occur in nature. Already we have produced algae in which deuterium replaces ordinary hydrogen, and nitrogen 15 supplants ordinary nitrogen. Some combinations of isotopes may not result in any appreciable difference, but others may produce organisms with new and valuable characteristics for studying the chemistry of living matter.

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DEEP-SEA SQUID *Heliocranchia pfefferi* hovers head-down. Its buoyancy is imparted by a body fluid that is lighter than water. The fluid comprises two thirds of the squid's volume. Below edge of mantle (*horizontal fold across lower quarter of body*) is squid's head and one of its eyes (*middle*). Bulge to right of eye and below it is siphon through which squid squirts water to propel itself.

THE BUOYANCY OF MARINE ANIMALS

The ability of the creatures of the sea to float is usually taken for granted, but to keep from sinking they must either keep swimming or be equipped with special flotation devices

by Eric Denton

Many fishes, like some people, must keep swimming just to keep from sinking. Bone and muscle are denser than sea water and so tend to drag the animal to the bottom. It is obvious that the ability to float can be advantageous for animals that live in the sea. Accordingly most fishes are equipped with swim bladders which give them neutral buoyancy—that is, an average density equal to that of sea water—and save them the labor of continuous swimming. Two other animals—the cuttlefish and the cranchid squid—have developed quite different kinds of flotation organs. They anticipated man in using the working principles of the submarine and the bathyscaph, the one endowing the cuttlefish with active control of its buoyancy, the other permitting the squid to live at great depths.

The swim bladder, the most familiar of the flotation organs, has a fundamental limitation. It normally occupies about 5 per cent of the volume of the fish; the low density of the gas that inflates the bladder offsets the higher density of muscle and bone, giving the fish an average density close to that of sea water. But the volume of the bladder changes with depth. As a fish swims downward in the sea, the pressure exerted by the water increases by one atmosphere (about 15 pounds per square inch) every 33 feet. Each such change in external pressure reduces the volume of the gas inside the swim bladder in accordance with Boyle's Law; if the fish dives from the surface to 66 feet, for example, the volume of its swim bladder shrinks by a third. With the change in volume the average density of the fish, and its buoyancy, must change. In principle the fish thus resembles the well-known Cartesian diver: a perfectly immobile fish might have neutral buoyancy at one depth, but the slightest change in equilibrium must tend to push it upward or downward with steadily decreasing or increasing buoyancy. This seemed such an impractical arrangement to early investigators that they thought the fish must be able to exert some active muscular control over the volume of its swim bladder, contracting the bladder when it seeks to descend or permitting the bladder to expand when it seeks to rise. In 1876, however, the French physiologist Armand Moreau showed that the fish has no muscular control over its swim bladder.

What the fish can do, as Moreau first discovered, is to change the mass of the gas inside the swim bladder and thus keep its volume constant. It secretes more gas into the swim bladder when it goes deeper and resorbs gas from the swim bladder when it rises. But this is typically a slow process, which occurs in response to long-lasting changes of pressure and takes days rather than minutes to reach completion. The fish thus lives in a state of unstable equilibrium and compensates for transient changes in pressure by swimming.

Most fishes can tolerate some change in the pressure of the surrounding water, provided it is not too large. But if a fish is brought up rapidly from, say, 125 feet, it meets a violent death. With the restraining external pressure reduced fivefold, the swim bladder suddenly expands, crowding and rupturing the fish's internal organs. It is for this reason that whiting, cod and hake that have been trawled almost always arrive at the surface dead. Yet under stable conditions of external pressure, the swim bladder can produce extraordinary internal gas-pressures. Some fishes have been seen from bathyscaphs swimming and hovering, with all the ease of a goldfish in its pond, at a depth of 6,500 feet, where the pressure is 3,000 pounds per square inch. Still other fishes have been caught at depths below 15,000 feet, where the gas in their swim bladders must have exerted a pressure of more than 7,000 pounds per square inch to withstand the pressure of the sea.

The precise nature of the gas in the swim bladder was first determined by the French physicist Jean-Baptiste Biot in 1803. Biot's curiosity was aroused in the course of a survey voyage in the Mediterranean; he noticed that fishes that had been hauled up rapidly from great depths reached the surface with their swim bladders projecting from their mouths and their bodies distended with gas. He introduced a quantity of the gas, together with hydrogen, into the glass tube of a eudiometer, an instrument used for gas analysis. He fired a spark, in accord with the routine of this procedure, and was startled by an explosion that shattered the instrument. Biot realized at once that the swim bladder must have contained a high concentration of oxygen. With a new instrument Biot discovered that although the gas taken from fishes that live near the surface often contains a smaller fraction of oxygen than air does, the gas from fishes that have been brought up from appreciable depths consists largely of oxygen.

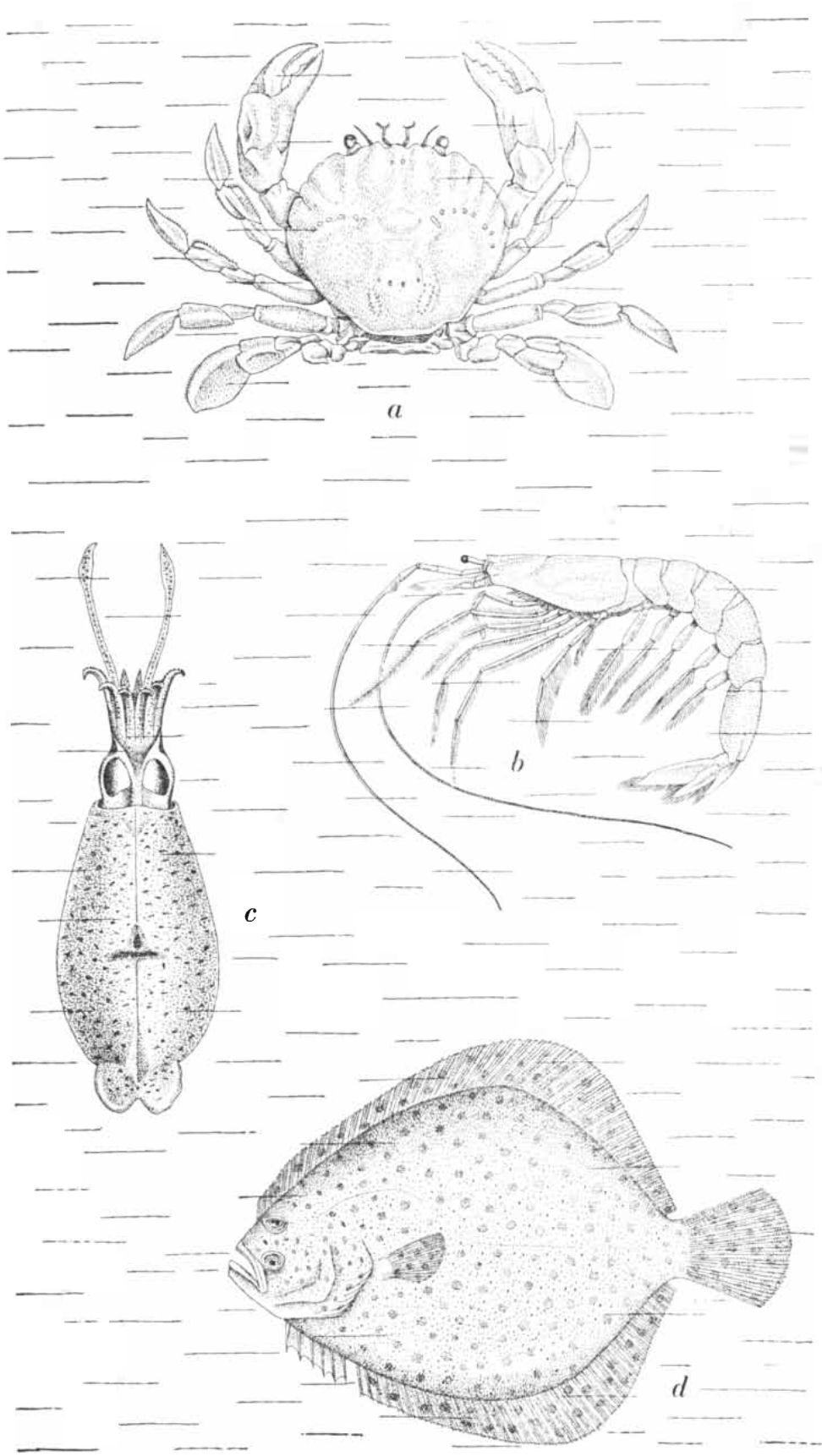
It is, of course, the fish's circulatory system that brings the oxygen to inflate the swim bladder. The remarkable countercurrent mechanism of the "wonderful net" of capillary vessels that establishes the often high gas pressures in the swim bladder has been elucidated by P. F. Scholander, now of the University of California at La Jolla, and Jonathan Wittenberg of the Albert Einstein College of Medicine in New York [see "The Wonderful Net," by P. F. Scholander; SCIENTIFIC AMERICAN, April, 1957]. In

a sense the swim bladder has its human analogue in the air-filled lungs of a skin-diver who carries his air supply in a tank. The diver, however, can adjust the volume of gas in his lungs at will; the fish has no such immediate control of its swim bladder.

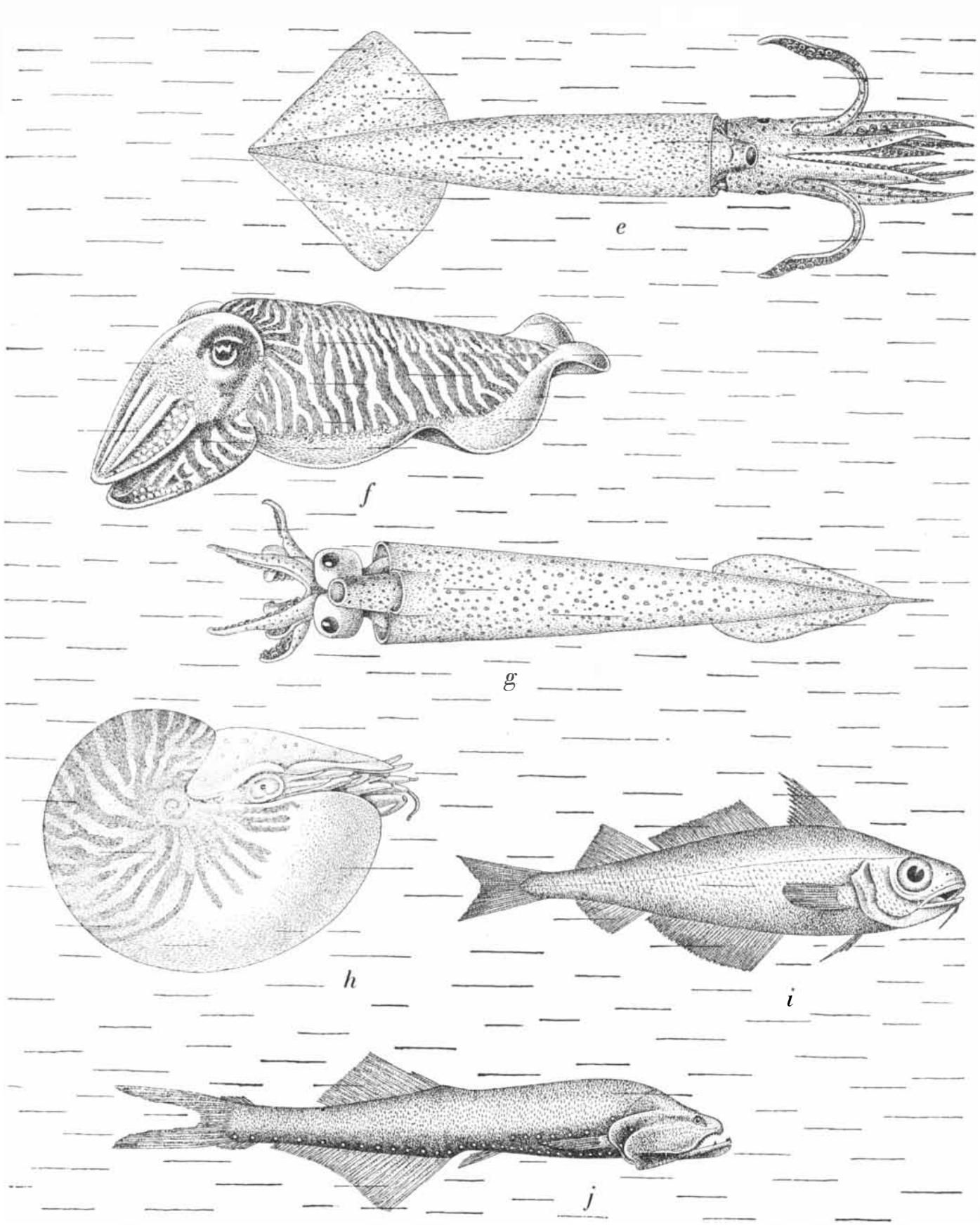
A surprising number of fishes get on successfully without a swim bladder. The turbot, which is about 5 per cent denser than sea water, simply hugs the bottom. The dogfish and the plaice can be seen to swim hard whenever they want to stay off the bottom. More surprising are the mackerel and some tuna, fishes of the open sea that can only maintain their level by steady swimming. Observation of a mackerel in an aquarium shows that whenever it slows down, it sinks. In this sense it is not better off than the prawn and the krill, which must paddle unceasingly to maintain their place in the plankton layer, or the oceanic crab *Polybius,* which can be seen from a ship's side swimming far from shore and with the ocean bed more than two dark miles below it. The lack of a swim bladder, however, gives the mackerel facility in moving up and down in the top layers of the sea. A sudden ascent of 60 feet would increase the volume of a swim bladder three-fold; quite apart from the danger of internal injury, the fish would have to exert a force equal to 10 per cent of its weight to go down again.

In some mid-ocean fishes the swim bladder is invested with fat instead of gas. Fat offers the advantage of maintaining constant volume under varying pressure. But fat has about .9 the density of water, and fish that depend upon it for buoyancy must carry appreciable amounts of it outside the swim bladder. Indeed, it appears from the work of N. B. Marshall of the British Museum that the fat of *Cyclothone,* perhaps the world's most common fish, amounts to about 15 per cent of its volume and gives the animal an over-all density close to that of sea water.

There are yet other bathypelagic, or deep-sea, fishes that have neither swim bladders nor a high fat content, and yet have a density that is within .5 per cent the density of sea water. These fishes embody another solution to the problem of buoyancy. Instead of having special organs to buoy up their heavier parts, those parts have been diminished. Their skeletons, especially in the tail and trunk, are light, and the swimming muscles that pull on the lightened bones are correspondingly attenuated. Such fishes may



SOME BUOYANT AND NONBUOYANT SEA CREATURES are depicted in this drawing. Both the oceanic swimming crab *Polybius henslowi* (*a*) and the deep-sea prawn *Sergestes* (*b*) are denser than water, and so must swim to keep from sinking. The turbot (*d*) is about 5 per cent denser than sea water, but is adapted to life on the ocean floor. Gas in a chamber of its shell gives *Nautilus pompilius* (*h*) buoyancy. A gas- and fluid-filled



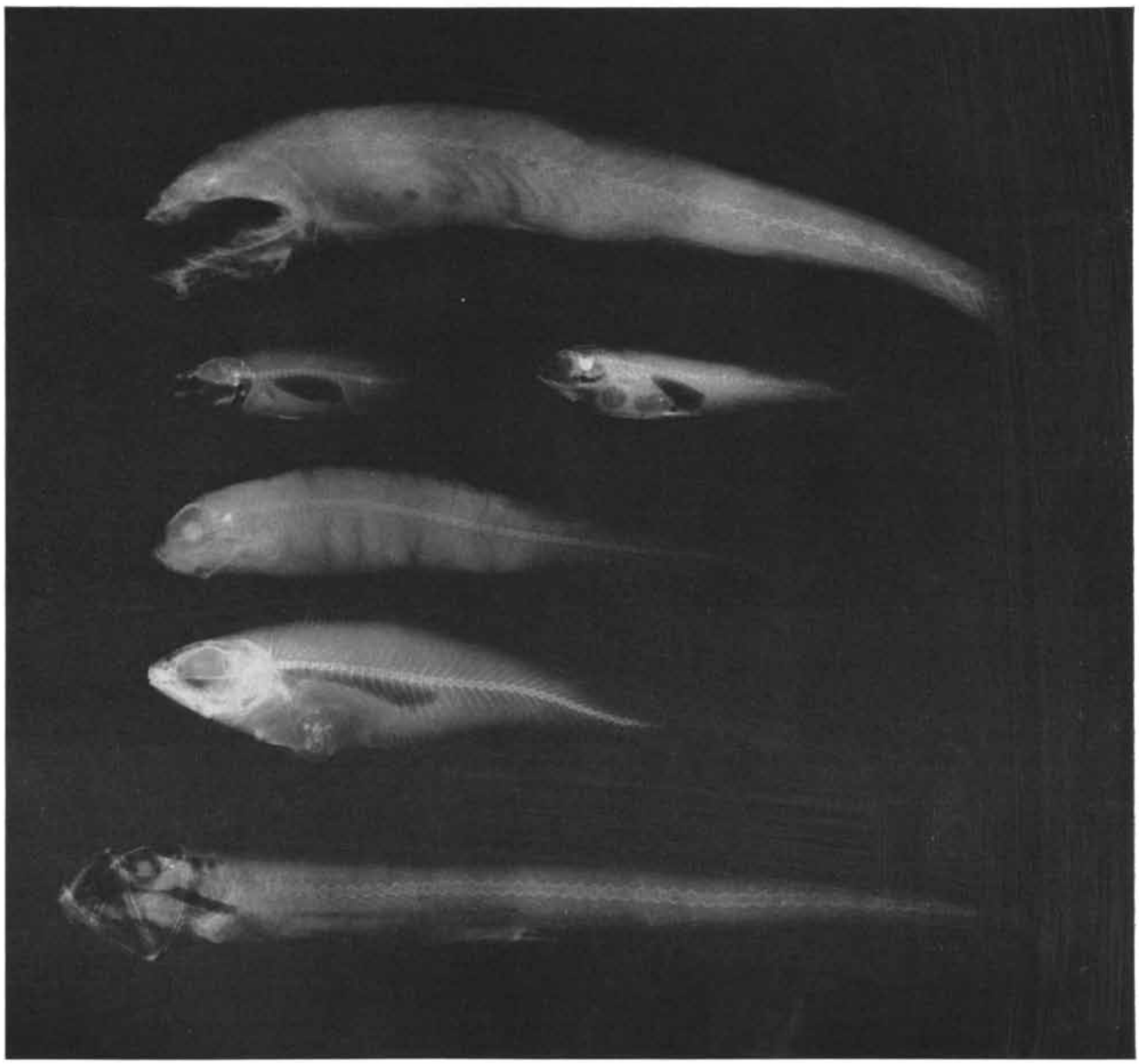
bone that occupies almost 10 per cent of its volume gives the cuttlefish *Sepia officinalis* (*f*) variable buoyancy. *Gadus minutus* (*i*) is representative of a class of fish with buoyant, gas-filled swim bladders. *Cyclothone* (*j*) also has a swim bladder, but the bladder is filled with fat instead of gas. Its fat comprises about 15 per cent of its volume. Squids of the family *Cranchidae* (*c and g*) have a fluid-filled body cavity that lowers their average density and enables them to float. The common ocean squid *Ommastrephes illecebrosa* (*e*), having no such device, must swim to stay afloat. Organisms, seen from various angles, are not drawn to scale.

be less than 5 per cent protein, compared to the 17-per-cent-protein constitution of coastal fishes. The presence of a little fat and of dilute body fluids goes far toward offsetting the net weight in water of scant bone and muscle and brings these fishes close to neutral buoyancy.

In evading or almost evading the buoyancy problem by giving up their swimming muscles, it might seem that these bathypelagic fishes have struck a poor bargain. Yet they manage to catch and eat prey as large as themselves because they are sufficiently equipped with bone and muscle for the peak effort of their mode of predation. Though their trunk and tail are attenuated, their gill arches and main structures for seizing and swallowing prey are the most heavily ossified parts of the skeleton and are well muscled. These fishes are simply floating traps; they lie in the dark of the deep ocean and attract their prey with luminous spots and appendages around their head and mouth. The arrangement has inspired my colleague E. D. S. Corner to liken them to the practitioners of television ("telly" in the United Kingdom):

The use of its luminous lures
An adequate diet ensures
Like people on telly
It fattens its belly
By feeding on gullible viewers

The so-called lower orders of animals have developed other solutions to the problem of buoyancy that are no less elegant than the swim bladder of fishes. One of the great steps in evolution was that by which the ancestor of the modern squid evolved a gas chamber at the apex of its cap-shaped shell. We may imagine that the chamber came to function as a



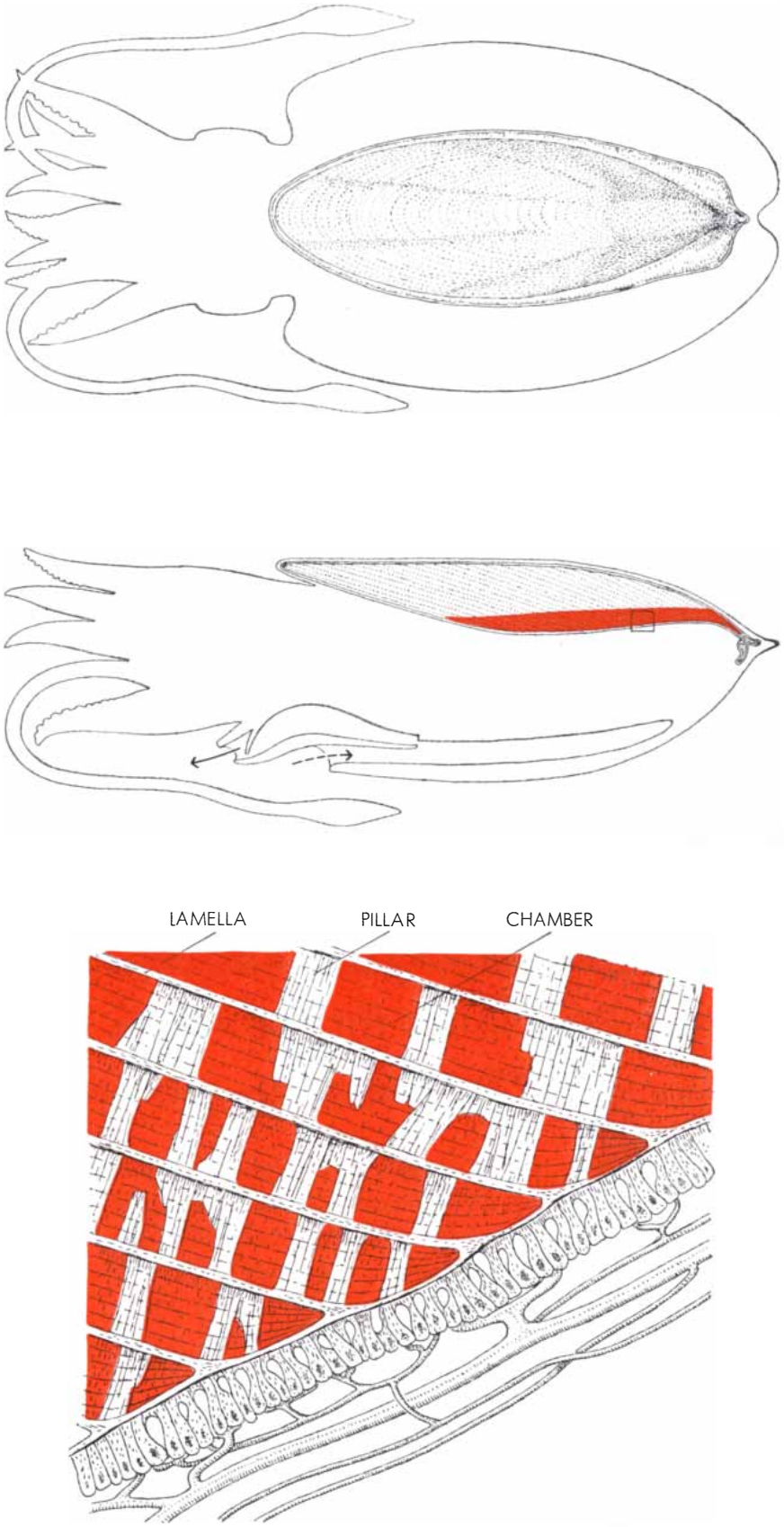
X-RAY PHOTOGRAPH OF FISHES illustrates the fact that a heavy skeleton is usually accompanied by a swim bladder. The buoyancy imparted by the bladder makes the heavier skeleton biologically feasible. Members of the families *Labridae* and *Bathylagidae* (*two fishes below fish at top*) and the family *Gadidae* (*second from bottom*) have both swim bladders and heavy skeletons. The swim bladders appear as dark areas just beneath their spines. Specimens of the families *Chauliodontidae* (*bottom*), *Gonostomatidae* (*top*) and *Alepocephalidae* (*third from bottom*) have no swim bladders, and also have relatively light skeletons.

buoyancy tank, permitting the animal to take off easily from the bottom, propelled by a jet of water. Its foot, freed from the task of crawling, spread forward and surrounded the mouth, its edge becoming a fringe of tentacles. Thus, perhaps, did the distinctive cephalopod form emerge. The chambered, gas-filled shell took many and beautiful forms, and various species of this large family ranged and dominated the Paleozoic and Mesozoic seas. But except for one descendant (the rare Nautilus, the shell of which is one of the most coveted ornaments of the conchologist's cabinet) there are no survivors of these spectacular animals. There is, however, another cephalopod whose buoyancy device clearly derives from the gas-filled shells of the nautiloids. This is the cuttlefish, *Sepia officinalis,* a close relative of the octopus, that thrives off the western shores of Europe.

Beneath the skin along the back of the cuttlefish lies a large bone that serves as the animal's buoyancy tank. The cuttlebone is a soft, chalky structure, as fanciers of canaries and parakeets are well aware. (A piece of it is placed in a cage to provide a surface on which the bird can groom its beak.) The cuttlebone is built up of lamellae, thin plates that, with the pillars which hold them apart, form the walls of independent chambers. The animal lays down lamellae throughout its growth, and by the time it has matured, its cuttlebone is a beautiful structure of about a hundred delicate layers. A thick, calcified outer layer seals most of the bone and extends backward to form a curved, fin-like structure. The back part of the undersurface of the bone is formed by the turned-up ends of the lamellae, and is covered with a yellowish membrane [*see illustration on next page*].

The cuttlebone constitutes about 9.3 per cent of the total volume of the cut tlefish; its density is usually around .6 that of water. In a cuttlefish weighing 1,000 grams, therefore, the bone will give an upthrust of approximately 40 grams, balancing the excess weight in sea water of the rest of the animal.

The first clue that my colleague John B. Gilpin-Brown and I had that the cuttlebone is something more than a static and unchanging organ, passively buoying up the fish, came from the behavior of cuttlefish that we kept in aquariums. They were sometimes so buoyant that they seemed to have difficulty in staying at the bottom of the tank; at other times they settled down and re-



LIQUID-FILLED CUTTLEBONE buoys up the cuttlefish because it is less dense than sea water. Top drawing shows position of cuttlebone from above. Middle drawing is lateral section; color represents bone fluid. Arrows indicate path of water cuttlefish uses to propel itself. Area in small rectangle appears in bottom drawing. Membrane against underside of bone pumps ions from bone fluid (*color*) into blood. Increased osmotic-pressure difference between the two holds out water that sea pressure tends to force in.

mained at the bottom with apparent ease. Cuttlefish can be shepherded into enclosures without being too much disturbed, and we took advantage of their docility to weigh them under water in boxes filled with sea water. We found that the surface specimens were less dense than sea water, and that the bottom specimens were more dense. Upon dissecting the specimens, we found that the difference could be wholly attributed to the varying density of their cuttlebones and that the change in the density of the bones in turn was accounted for by the relative volume of gas and of liquid they contained. In a "heavy" cuttlefish the cuttlebone might have a density as high as .7 and contain about 30 per cent liquid by volume; on the other hand, the cuttlebone of a "floating" specimen might have a density of .5 and contain 10 per cent by volume of liquid.

The response of well-fed cutdefish to light suggested to us that they can effect changes in density quite rapidly. When the light is bright, they usually bury themselves in the gravel at the bottom of their tank; after twilight they emerge and swim about until dawn. We repeated our weighing procedure with animals subjected to rapid alternations of light and dark and found that their density varied as much as 1 per cent within a few hours.

The cuttlefish thus uses its cuttlebone as a submarine commander uses the buoyancy tanks of his craft. When the submarine is to submerge, its buoyancy tanks are filled with water; when it is to surface, compressed air blows the water out of the tanks. The corresponding mechanism in the cuttlefish must meet stern specifications. In the waters off Plymouth, England, the cuttlefish is most frequently found between 100 and 250 feet and is thought to go down as deep as 600 feet. The animal is thus commonly exposed to pressures around eight atmospheres and may occasionally come under a pressure of 20 atmospheres. The pump that empties the cuttlebone must not only be capable of moving water in and out of the bone at the surface of the sea, but also must be capable of balancing the considerable pressure of deep water. Since compressed air works so well in the submarine and even in the swim bladder of fishes, this is the first mechanism that suggests itself.

We soon found that this suggestion is a false one. From cuttlefish that had just been hauled aboard ship from about 230 feet we quickly dissected the cuttlebones, placed the bones under water and punctured them with needles, confident-

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organometallics and inorganics

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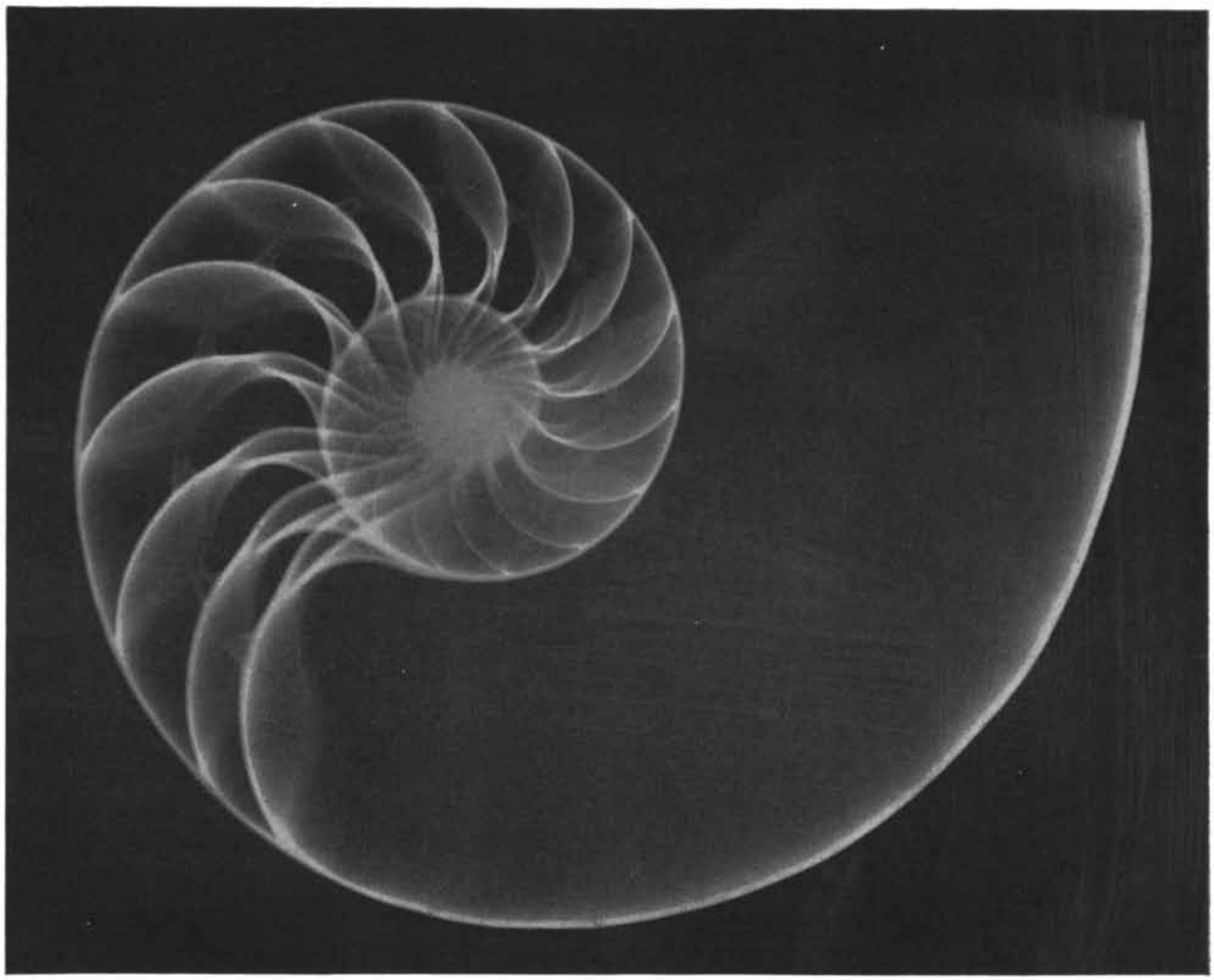
ly expecting to see bubbles stream from the punctures. We found instead that water rapidly entered the holes. Obviously the gas in the cuttlebones was not under pressure. Far from being at the eight atmospheres of pressure we had expected, the gas was in fact closer to .8 atmosphere. Moreover, we found that the gas pressure falls when the cuttlefish pumps water out of its cuttlebone. Clearly it is not the gas that expels the water. It seems rather that the gas, which is mostly nitrogen, plays a completely passive and incidental role in the working of the cuttlebone. It presumably arrives there merely by diffusing into a space created by some other force.

We guessed that this force might be an osmotic one, since osmosis occurs very commonly in biological systems. Our next step was to secure samples of the fluid from active cuttlebones. We immersed a cuttlebone taken from a freshly trawled animal in liquid paraffin in a sealed container. When we lowered the pressure in the container, fluid seeped from the rear undersurface of the cuttlebone. Upon analysis we found that the fluid, which is chiefly a solution of sodium chloride, has a lower concentration of salts than does the animal's blood. The difference in the concentration of salts is enough to provide an osmotic force sufficient to balance the hydrostatic pressure of the sea. Since the fluid issued only from the rear undersurface of the cuttlebone and nowhere else, it was apparent that the yellowish membrane covering that region is active in the osmotic process.

Microscopic examination shows that this is indeed the case. The membrane has not only a copious blood supply but also numerous ampullae, or sacs, close to the bone. Small ducts connect the ampullae to the veins in the membrane, and these constitute a special drainage system. The arrangement apparently enables the membrane to pump salts from the liquid within the cuttlebone into the blood, and so causes fluid to flow from the bone into the bloodstream. The salt pump can thus increase or decrease the osmotic pressure between the animal's blood and the cuttlebone liquid in response to changes in the hydrostatic pressure exerted by the sea, and can keep fluid from diffusing into the bone even when the cuttlefish is exposed to heavy external pressure. It cannot protect the bone from the crushing weight of the sea. But the bone itself is well designed to withstand compression. One bone under test in a pressure tank imploded only after it was exposed to pressure greater than the maximum pressure to which the animal is exposed in life.

In its cuttlebone the cuttlefish thus possesses a buoyancy-regulating device



CHAMBERED SHELL OF NAUTILUS forms a logarithmic spiral in this X-ray photograph. The animal makes a partition after each period of growth. It occupies outer chamber, which has volume equal to all the other chambers. Gas in shell helps animal float.

THOR
MACE
TITAN
HAWK
ATLAS
SNARK
NIKE B
BOMARC
NIKE ZEUS
SPARROW I
SPARROW II
SPARROW III
NIKE HERCULES
SIDEWINDER
REGULUS II
VANGUARD
REDSTONE
JUPITER C
PERSHING
BULL PUP
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of a most ingenious kind. It is true that the bone is bulkier than a swim bladder, but it also serves as a skeleton. As compared to the swim bladder, quick changes of depth affect its buoyancy only slightly, and changes in hydrostatic pressure affect its volume not at all. A very small change in the salinity of the fluid contained in the bone restores the balance between the external hydrostatic pressure and the opposing osmotic pressure. But there is a limit to which this process can go. If the liquid inside the cuttlebone could be completely desalted, the osmotic pressure could withstand the hydrostatic pressure of no more than 800 feet of water.

There is no such limit on the function of the buoyancy organ of the common deep-sea squids, the *Cranchidae*. These are common denizens of the ocean and grow to large size. Perhaps because they live at great depth, the largest have been caught only second-hand, in the stomachs of sperm whales; at least one specimen has been recorded that measured more than 10 feet, not counting the two very long tentacles that are usually included in descriptions of giant squids to make the length seem more impressive. With the facilities of the Plymouth Marine Laboratory ship *Sarsia* at our disposal, my colleagues T. I. Shaw and John B. Gilpin-Brown and I were able to study the nature and function of the buoyancy organ in several varieties of squid kept in shipboard tanks.

A squid propels itself by shooting a jet of water from its siphon, and, to a lesser extent, by means of two small fins at its rear. Confined in tanks of sea water aboard ship, however, our specimens did little but remain still. They hung head-down and almost motionless without any apparent effort. Since the squid possesses neither a swim bladder nor a cuttlebone, it must have some other organ to balance the excess weight of its muscles.

When the outer mantle of the animal is cut open, there appears a large fluid-filled cavity, called the coelomic cavity. If the membrane containing the fluid is punctured and the fluid is drained away, the squid loses its buoyancy and promptly sinks. It is clearly the fluid that gives the animal its buoyancy. From measurements aboard ship and more exact measurements ashore we found that the coelomic fluid of the several varieties studied had a density between 1.01 and 1.012. Since the density of sea water is about 1.026, and since the coelomic fluid comprises fully two thirds of the weight of a squid, this is enough to offset the weight in sea water of the animal's proteins and to give it neutral buoyancy.

What gives the fluid its low density? First inspection did not disclose the answer. The fluid is clear, colorless and bitter-tasting. At first we thought that it might be hypotonic, or less "salty" than sea water, and so have a lower density. A shipboard test of the freezing point of the two liquids showed, however, that this is not the case; the coelomic fluid is isotonic to sea water.

This finding and the bitter taste of the fluid pointed to the one ion that could give a solution isotonic to sea water but with a sufficiently low density, that is, the ammonium ion. Analysis showed ammonia present in the astonishing concentration of nine grams per liter.

The source of the ammonia is the squid's peculiar metabolism. Unlike mammals, the squid excretes the nitrogen from the breakdown of proteins in the form of ammonia instead of urea. It seems to employ a simple chemical stratagem to trap the ammonia in its coelomic cavity. The acidity of the coelomic fluid is high; in consequence the ammonia diffuses from the bloodstream into the cavity and there dissociates into its ions. The ammonium ion does not pass so readily through living tissue, and so remains in the cavity to reduce the density of the fluid and float the squid.

The squid's method of achieving buoyancy has the great merit of being virtually unaffected by external water-pressure. As compared to fishes, the squid need not alter the quantity of its coelomic fluid as it changes depth. As compared to the cuttlefish, the squid can dive much deeper. The great defect of the device is that it is so cumbersome, for while the swim bladder occupies only 5 per cent of the volume of the fish, and the cuttlebone only 10 per cent of the volume of the cuttlefish, the coelomic cavity has a volume equal to 200 per cent of the rest of the cranchid squid.

There is a striking resemblance between the cranchid squid and the bathyscaph designed by Auguste Piccard that has descended into the deeper parts of the ocean. In the bathyscaph a large chamber filled with gasoline plays the role of the coelomic cavity and its fluid; below hangs the observing chamber, which corresponds to the denser working parts of the squid. For this reason, we have described the cranchids as "bathyscaphoid squid." Though the etymology of the term is dubious, it may serve to remind us of an important lesson: Our pride in man's latest discoveries must be tempered by the knowledge that other animals may have been using them from time immemorial.

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Prehistoric Man in Mammoth Cave

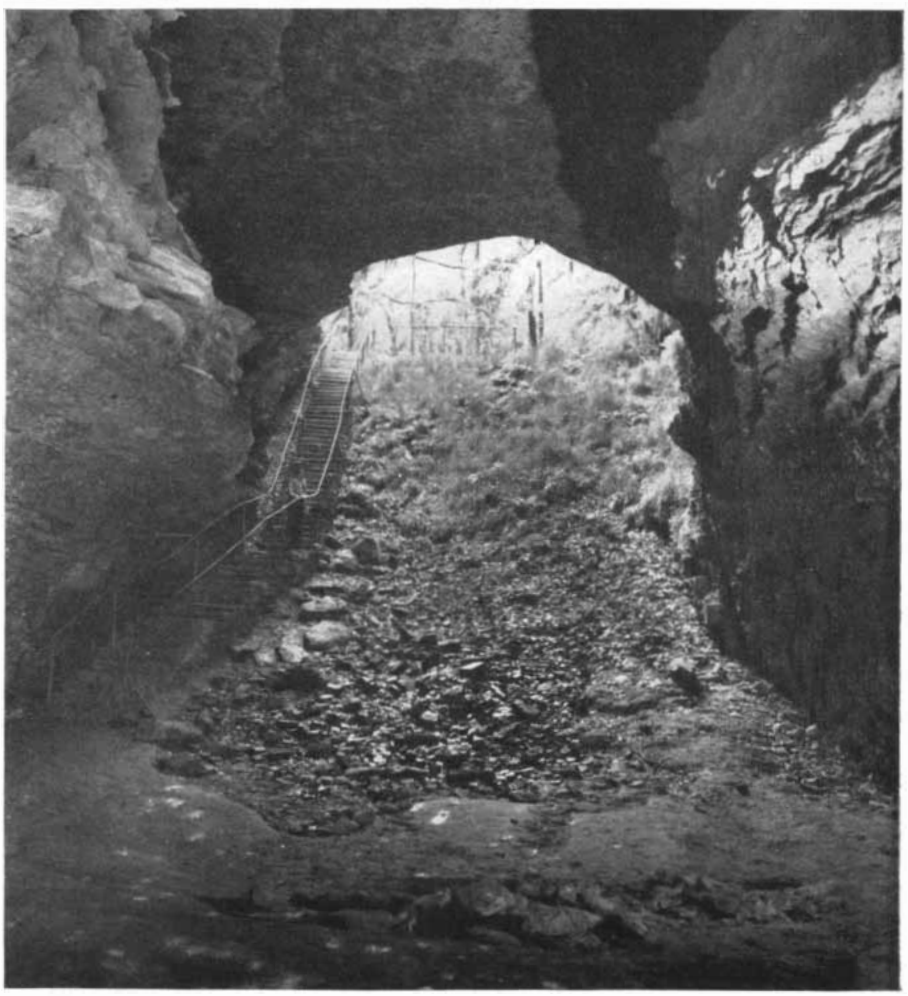
Some 2,000 years ago Indians went deep into the great cavern in Kentucky to mine gypsum, leaving behind them many traces of a society that was just beginning to develop agriculture

by Douglas W. Schwartz

One day some 2,200 years ago a man wearing sandals and a loincloth woven of fibers from the papaw tree descended the steep slope leading to the entrance of the great cavern in Kentucky that is now known as Mammoth Cave. He was going to mine gypsum from the walls of the inner passages of the cave. As he entered the cave, he lit a torch of cane reeds from a slow-burning wick of twisted bark. Then he walked into the darkness. The first half mile was familiar, because he and members of his band and their ancestors had ventured this far so often that they had worn a smooth path through the rock rubble that littered the floor. Doubtless he occasionally shifted his load of reeds, which he would later fashion into new torches when the one he was carrying burned low. He turned a corner and entered a large room where men like him had picked and scraped gypsum from the wall many years before. Now no gypsum remained, but the miner paused to pick up a hand-sized limestone slab that would serve as his mining tool. Deeper in the cave he found the path less smooth and certain. He may have been reassured to note that the way was marked by worn-out sandals abandoned by earlier visitors; he himself was carrying an extra pair.

Entering another large room from a winding passage, he probably sat down to rest and take a drink of water from the gourd he was carrying. Since his first torch was almost gone, he fashioned a new one from a handful of reeds and a strip of bark. Here he also left a cache of reeds to be used for making a torch on his return trip; then he set off into one of the several tunnels leading to the labyrinth beyond. The route was unfamiliar, and he had to take care in the flickering light not to step into a hole or off into space from a sharp underground declivity. Now he began to search the walls for the crystalline flowers and sheets of gypsum that had brought him on his journey. At one time the mineral had been plentiful in the tunnels leading out of the great hall, but now a miner had to go deeper and deeper into the cave to find it. The shell pendant hanging from his neck must have been a source of comfort in the darkness.

At last he saw overhead a rock surface thickly coated with gypsum; he could reach it by climbing several feet to a small ledge. He removed his sandals for surer footing, popped a few sunflower



ENTRANCE OF MAMMOTH CAVE, here seen from just inside, is on a steep slope. Ancient Indians at some seasons lived here while the men went into cave to mine gypsum.

seeds into his mouth and climbed to the sandy ledge. He knelt, stuck his torch upright in the sand, and began to scrape and pick the flaky crystals from the wall, gathering the mineral into a woven bag. He did not realize that a five-ton boulder hung precariously overhead, held in place by a small column of rock. He chipped on that column. The boulder dropped, threw him forward from his kneeling position and crushed him to death.

In the constant temperature and low humidity of the cave his body was preserved, as if it were a well-prepared mummy, and remained undisturbed for 24 centuries until it was found by another race of men in 1935. It now rests in a sealed glass case inside Mammoth Cave, not far from the entrance.

Artifacts discovered in the cave and in its vicinity have provided the information from which the miner's last hours were reconstructed. The same materials have revealed a great deal about the history and daily life of his people. A tantalizing problem is posed, however, by the gypsum. It cannot be said with any assurance what these people did with the mineral, or why it was so valuable to them that they risked long trips into the dark cave. Evidence of gypsum mining occurs for at least two miles into the main passages and for many more miles in side passages. If the gypsum was a salt substitute, a diet additive or a medicine, archaeology may never find the evidence. Some clues indicate that it may have been a paint base. A more interesting possibility is that the gypsum served as fertilizer. These ancient Indians were living through one of the great revolutions of human existence—the change from the hunting, fishing and food-gathering way of life to the settled economy of agriculture.

Mammoth Cave has been known to the descendants of Europeans for a relatively short time. A hunter is said to have discovered the cavern in 1799, when he trailed a bear into the entrance. A few years later white settlers came to the region, and the cave began to be famous. During the War of 1812 another mineral, saltpeter, was mined and processed in Mammoth Cave to make gunpowder. Then in 1813 a nearby cave produced an archaeological find that must have fired the public imagination. According to contemporary accounts, "a scientific man from New York," who was digging for saltpeter, came across an unusual large, flat rock. His workmen raised it and discovered a chamber three feet wide, three feet long and three feet deep. There, seated upright and entirely covered with a blanket, was the body of a tall young woman. A fiber cord held her hands across her chest. She had dark reddish hair cut close to her head except where it hung down at the back. By her side lay two neatly wrapped deerskins, a pair of fabric sandals, a woven knapsack and a net bag. The knapsack and bag contained a cap, seven feather headdresses, a deer-hoof necklace, an eagle-claw pendant, a bear-jaw pendant, two rattlesnake skins, small bunches of deer sinews, seven bone and horn needles and two cane whistles. In 1813 many people

TYPICAL PASSAGEWAY in Mammoth Cave is impressively large. The man is holding a flashgun to light distant part of tunnel. Before the cave became a tourist attraction, floors of passageways were covered with rock rubble that made walking quite difficult.

"MUMMY" OF ANCIENT GYPSUM-MINER today rests in glass case in Mammoth Cave. A five-ton boulder fell upon him some 2,200 years ago, and the dry, cool air in the cave preserved his body. His shell pendant can be seen just to the right of his chin.

GYPSUM CRYSTALS, or "flowers," of the type sought by the ancient Indian miners still hang from many walls in Mammoth Cave. In this photograph the crystals are approximately half natural size. It is not known what use the Indians made of the gypsum.

still thought that one of the lost tribes of Israel had preceded the modern Indian to America; thus anything that looked like a mummy aroused great interest. Of course the body had not been deliberately mummified; this and the other "mummies" found in the Kentucky cave country were simple burials that had been remarkably well preserved by conditions in the caves.

Such spectacular finds and the numerous artifacts that lay at hand for the taking soon attracted sight-seers and souvenir hunters. As early as 1816, Mammoth Cave was being commercially exploited by promoters, who later built a railway to bring visitors from the nearest railhead. Guides carrying smoking torches led large parties through the most accessible passageways. Throughout this period tourists, guides and explorers carried off vast quantities of priceless objects made by Indians. It was only late in the 19th century that a few archaeologists visited the region and made the first useful reports on the materials still to be found in the cave. The early discoveries included black-and-white-striped cloth, feather blankets, fans of turkey tail-feathers, baskets, squash-shell cups, bundles of raw textile materials, fishing nets, basket coffins of cane and bows and arrows—perishable objects that had long since decayed at other sites in the eastern U. S.

In 1916 N. C. Nelson of the American Museum of Natural History came to Mammoth Cave and undertook the first scientific examination of the cave and its environs. He excavated several rock shelters along the Green River, which drains the cave region, and also dug extensively in the mouth of Mammoth Cave itself. Dampness at the entrance had apparently destroyed any impressive objects of cloth, feathers, skins and fiber, and Nelson found only such indestructible archaeological stand-bys as chipped and ground stone, bones and sunflower seeds. Even with this meager material he was able to make the penetrating observation that the culture which had produced the artifacts was more "limited in scope and development, . . . essentially more primitive" than the culture that contemporary archaeologists were then excavating in the mounds to the north and east. Not for two decades would archaeologists define the so-called Archaic period that had preceded the emergence of the primarily agricultural people who built the burial and temple mounds. But in his work at Mammoth Cave, Nelson recognized that earlier period.

For many years Mammoth Cave was

ANCIENT FIBER SANDAL rests today where it was recently discovered on a ledge in Mammoth Cave. Such sandals were woven of fiber from the inner bark of the papaw tree.

CANE REEDS that litter cave in many places were brought in by Indians more than 2,000 years ago. The Indians left caches of reeds within the cave to make emergency torches.

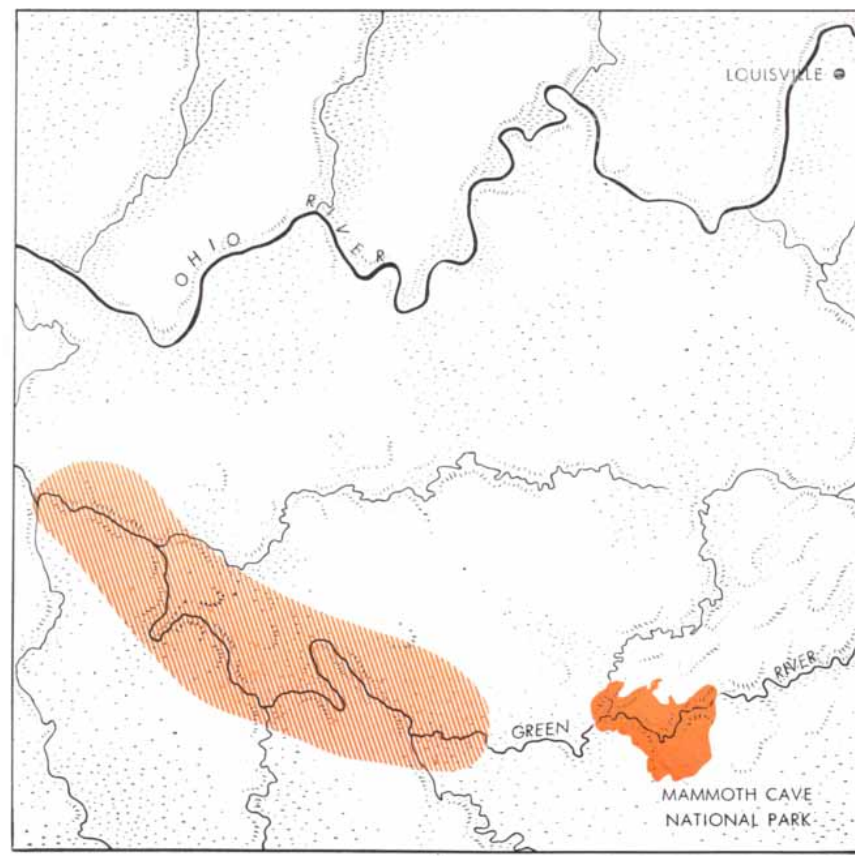
BARK THONGS were dropped in passageway by ancient Indians. This material was used to tie up a bundle of reeds to make a torch. It is preserved by dry air in this part of cave.

WOODLAND CULTURE ARTIFACTS include woven straw bag (*far left*), now in the Peabody Museum of Harvard University. It still exhibits faint vertical stripes from dyed pattern. Large fragment of a gourd bowl (*second photograph*), made from domesti-

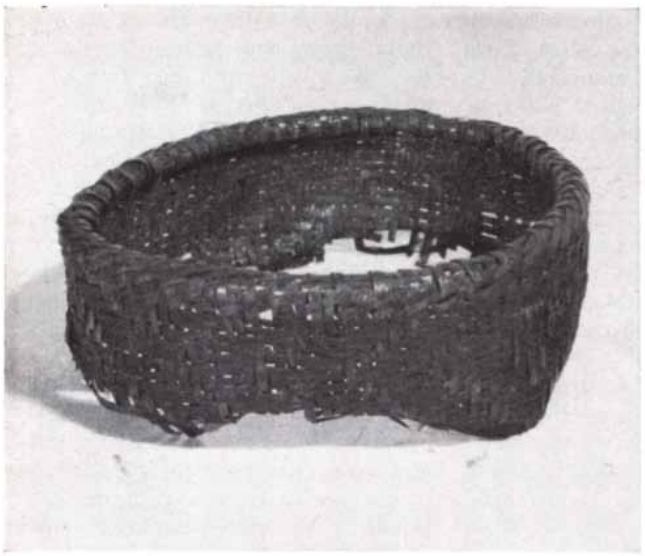
to remain more attractive to tourists than to archaeologists. There was a brief flare of interest in 1935. In June of that year two cave guides, crawling on hands and knees along a sand ledge in the inner reaches of the cave, came upon a skull—"No, a mummy!" It was the body of the prehistoric gypsum miner. The National Park Service was just taking control of the cave, and officials had the good sense to keep the find a secret at first and to call in an archaeologist. A great deal of activity followed: Photographs were made from many angles, the exposed body parts were examined minutely and the ledge was carefully searched for clues to the cultural setting. Finally the Park Service decided that it was safe to tell the press of the discovery. Reporters and photographers swarmed into the passage, bringing lights and heavy motion-picture cameras. All this commotion caused the sand on which the boulder rested to shift, and it became apparent that the rock was about to slide off the ledge onto the passage floor, destroying the preserved body. The Park Service sent telegrams to Washington, seeking permission and the funds needed to lift the stone and to take measures for preservation of the body. At last, after several anxious days of delay, the operation started.

Young men of the Civilian Conservation Corps, who were working in the region, were mobilized to carry in timbers through the two miles of cave passages and build a 30-foot tower for lifting the boulder. They constructed it in the light of gasoline lanterns. Three chain-hoists hanging from the tower were attached to a cradle of wire rope around and under the rock. The workers lifted the rock, slipped a board under the body and slid both out. Then they lowered the boulder and secured it in place.

But the ancient Indian had not completely finished his adventurous career. The archaeologists carried him outside in the sunlight to get a better look at him. They were dismayed when a thick layer of furry fungus began to grow upon the remains. A chemist, called in for consultation, was unable to prescribe a remedy, and the Indian miner was taken back into the dark, dry cave. The



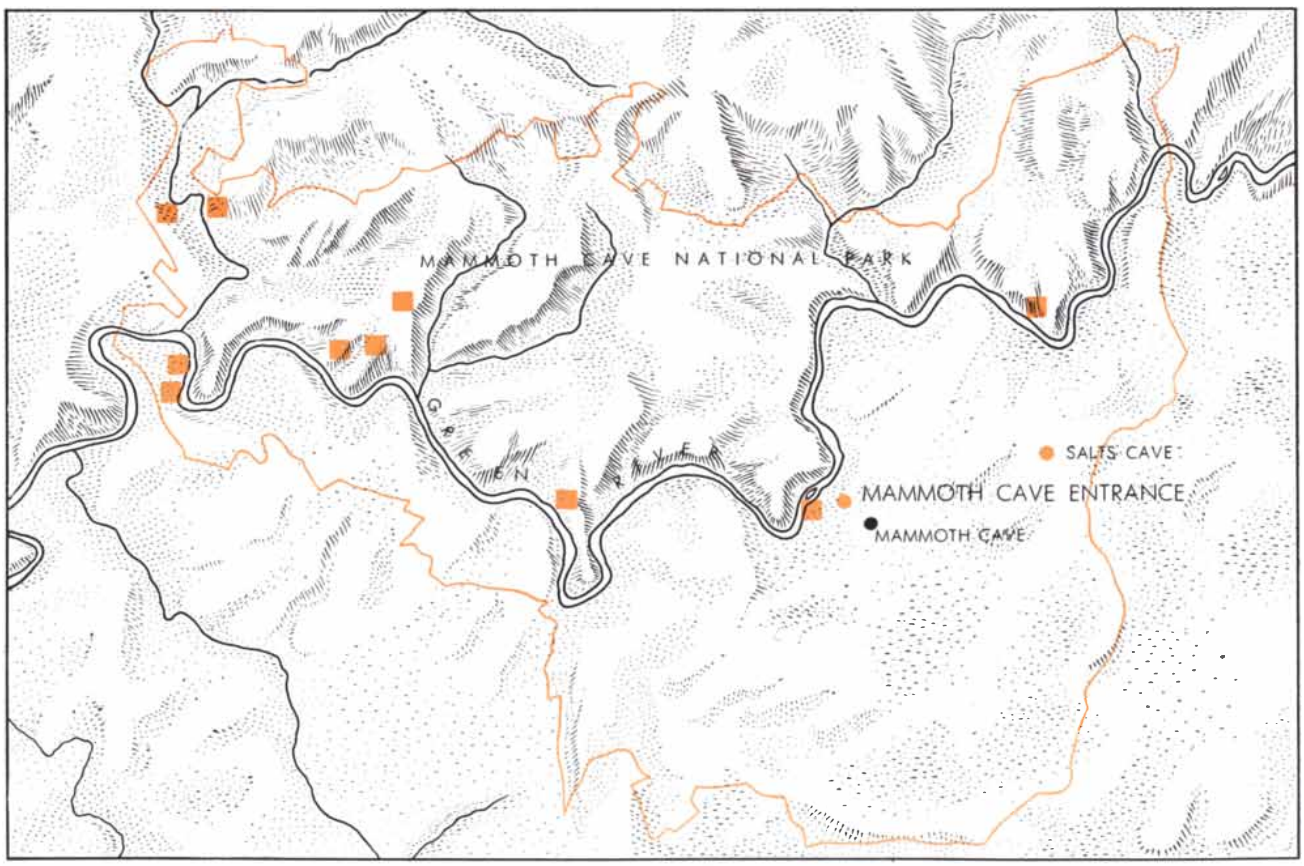
LOCATION OF MAMMOTH CAVE is shown on this map. Colored hatching marks area that contains Archaic shell mounds and villages of much later Mississippian culture.



cated plant, is at Museum of the American Indian in New York, as are the fragment of a basket (*third photograph*) and hanks of fiber from papaw bark (*far right*), probably prepared for weaving sandals. All objects were found in Mammoth and Salts caves.

return to the cave inhibited decay, and the authorities decided to give the body a final resting place within the cave, in a glass case.

The archaeology of Mammoth Cave was neglected for another 20 years. Then the National Park Service launched its ambitious "Mission 66" project, designed to accommodate more visitors in the parks and to enrich their visits with more complete information on the natural and the human history of these areas. The Service built a small museum near the entrance to Mammoth Cave and, in order to present the complete story of the cave in its relation to the life of prehistoric man, instituted a comprehensive program of archaeological research. I was engaged to study all the available artifacts and remains, including materials scattered in several museums, in the

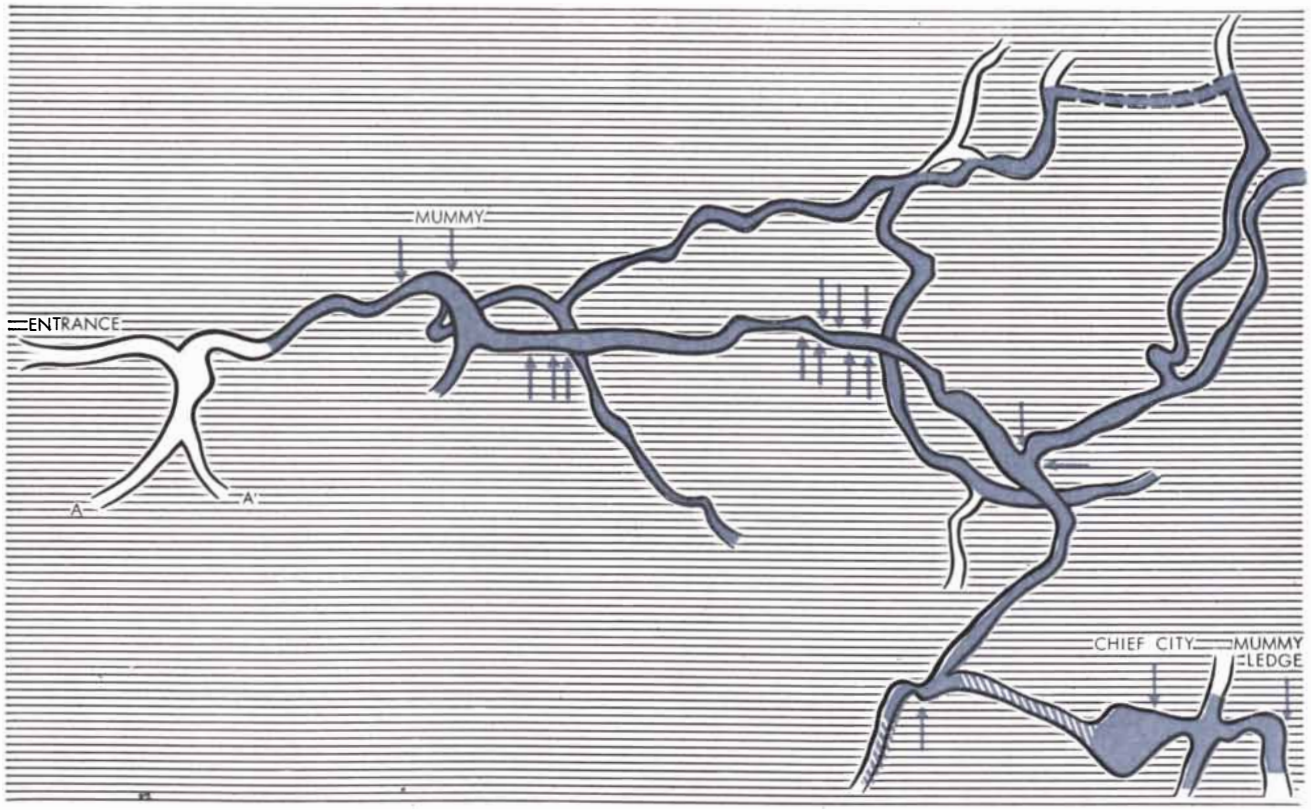


MAMMOTH CAVE NATIONAL PARK has many archaeological sites (*colored squares*) outside the caves. The map shows the entrances of Mammoth and Salts caves, the town of Mammoth Cave and the upper Green River and its major tributaries in park area.

light of the great strides that work in American prehistory has taken in the past 20 years. The program called for radiocarbon-dating of specimens, a thorough study of the remains of the miner, mapping of the location of sandals found in the cave to identify the paths taken by the miner and his fellows, and a surface survey of the sites in Mammoth Cave National Park. A unified picture of the prehistory of the region is now emerging from these studies; it is painted here in broad strokes.

Toward the end of the last Ice Age the cave country near the Green River was visited occasionally by far-wandering bands of mammoth hunters. The large herds of mastodon and mammoth were disappearing, and these people had to adapt to a new way of life. With the change in climate and ecology, the hunters learned to take deer and smaller game and to gather wild fruits, nuts and berries. The population of eastern North America entered a period of rapid increase; the tribes flourished and spread. Where they found a region suited to their ways of obtaining a living, they began to settle down and evolve more complex cultures. The lower valley of the Green River west of the Mammoth Cave country was such a region. The river abounded in fish that the hunters caught with bone hooks and spears; the river shoals supplied mussels in abundance for gathering by hand. Great mounds of midden, shell debris, vegetable material and earth testify to the prosperity of these Archaic people. On the mounds, which probably marked seasonal stops in their migrations, they dug pits in which they buried their dead, sometimes along with tools, weapons and ornaments. The mounds also contain bones of deer, opossum, groundhog, squirrel, fox, beaver, bear, wildcat, rabbit, wild turkey, goose and turtle. In season these people collected wild vegetable foods, adding some variety to their high-protein diet. At some seasons they occupied small camp sites higher up in the valley, as well as the entrances to large caves and other rock shelters. The entrance to Mammoth Cave harbors as evidence of this period a few broken tools and a grass-lined grave, containing most of the skeleton of a young girl.

Shortly after 1500 B.C. a band of these hunters and gatherers moved up the river to take up a more permanent abode in the vicinity of Mammoth Cave. The women had started planting sunflowers and other crops in the open patches of river-bottom land so they would not have to walk so far to collect them in the wild. The idea had probably come from tribes living on the Ohio River, who had learned about the planting of seeds from peoples farther south. This new method of obtaining food may have led to an increase in population that forced some of the people to move up the river valley. Alternatively they may have moved because the land in the cave region was easier to clear for crops. Whatever the reason, the population began to shift from the lower valley. Even after the tribes moved to the cave region, the change in their way of life occurred so gradually that it was hardly noticeable. The men continued to hunt, fish and collect mussels; the women still gathered wild plants along the river banks, and roots and nuts in the forests. By 500 or 400 B.C. agricultural production had increased to such an extent that



MAMMOTH CAVE PASSAGEWAYS used by Woodland Indians more than 2,000 years ago are shown on this map. Color indicates recent finds of vegetable material, mostly cane reeds and bark, brought in by ancient people. Hatching marks areas containing very little ancient material. Arrows denote sites of sandals found by the author of this article in recent survey. The body of the ancient gypsum miner was found at "Mummy Ledge," and now rests at "Mummy." "Chief City" is a great room that served as ancient way station and torch depot for long cave journeys. The major part of Mammoth Cave branches off from A and A′ and the area visited by tourists is in that section. Indians ignored that area because it is damp and gypsum does not crystallize on the walls.

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they were raising sunflowers, squash, gourds, gooseberries and a kind of ragweed whose seeds they presumably ate. The Archaic culture had evolved into the so-called Woodland culture.

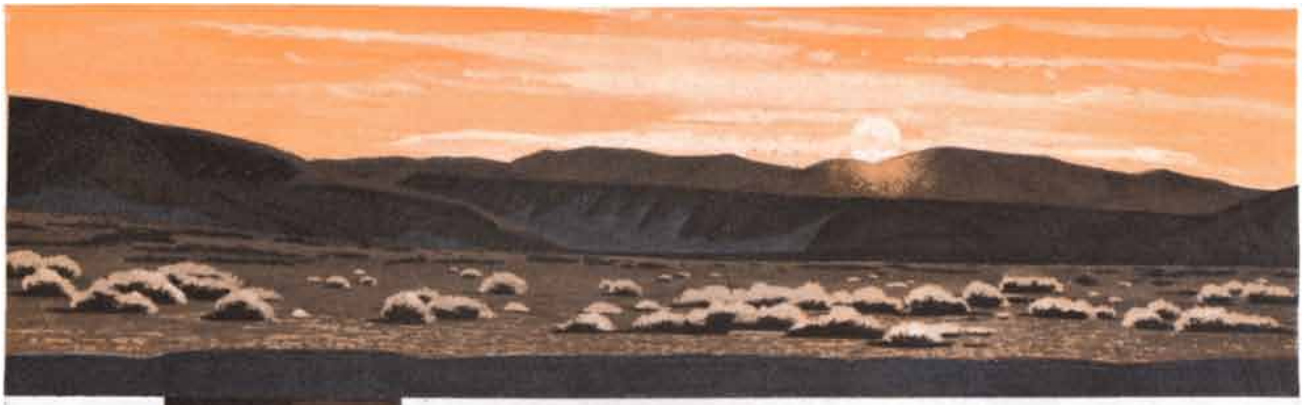
The Indian farmers broke the ground and killed the weeds with flat limestone hoes hafted to short sticks. They also employed digging sticks to make holes for planting and to prod out edible roots. Open glades in the forest usually served as fields, but occasionally they girdled and chopped trees with stone axes and burned the brush to clear larger spaces for planting. The Woodland people collected berries in baskets woven of split cane and gathered nuts in bags made of twine. They skinned and dressed their game with broad flint blades, hung the meat up to age and cooked it on a spit or in a pottery bowl. Dogs, their only domestic animals, undoubtedly enjoyed the scraps. On special occasions a persimmon cake or sunflower bread on a wooden platter would accompany the meat dish. Apparently the people had no alcoholic beverages, but in the spring they made a sweet syrup from the sap of trees. When nuts and seeds were in season, the women ground them in wooden or stone mortars with bell-shaped pestles.

Weaving was a craft these people developed to a high degree, in clothing, bags, sandals and baskets. In their textiles they employed a coarse fiber made from the inner bark of the papaw tree, which they stripped and left to dry for a month or so in the summer. Although the clothing and containers stood up well, the sandals wore out quickly; their heels and toes had to be patched frequently. The quality of the handiwork suggests that young girls, as they learned the craft from their mothers, practiced on the children's sandals but not on those of the men, who had to have the best for hunting. Occasionally the sandals would be too large, and the wearer would stuff grass into their toes to make them fit.

By the time a girl was 12 or 13 she probably knew how to make simple loincloths, although her mother or older sister might have helped her apply the colored designs. The vegetable dyes, which were stored in packages made of large leaves, were dissolved in water in a pot, and the fabric was either dipped or left to soak or boil. Most loincloths were plain, but those for special occasions had bright colors, tassels and fancy fringes. The most beautiful piece of clothing was the chief's feathered cloak; the weaver would drill holes in the shafts

DATE	CULTURAL PERIOD	USE OF CAVES	USE OF SURFACE IN AREA OF CAVES
1200 A.D. TO 1600 A. D.	MISSISSIPPIAN	RARE EXPLORATIONS GOING IN ONLY A SHORT DISTANCE.	SOME BURIALS, PROBABLY HUNTING.
400 B.C. TO 100 A. D.	WOODLAND	INTENSIVE GYPSUM-COLLECTING AS DEEP AS TWO MILES IN MAMMOTH CAVE. PEOPLE LIVING IN ENTRANCE OF CAVE.	OCCUPATION OF ROCK SHELTERS AND RIVER-BANKS. HUNTING, GATHERING, EARLY AGRICULTURE.
3000 B.C. TO 1000 B. C.	ARCHAIC	OCCASIONAL OCCUPATION OF ENTRANCE. NO USE OF CAVE OR EVIDENCE OF ENTRY INTO CAVE.	HUNTING, FISHING, GATHERING, LIVING NEAR RIVERBANKS AND IN ROCK SHELTERS.
8000 B.C.	PALEO-INDIAN	CAVES APPARENTLY NOT KNOWN.	SCATTERED AND INTERMITTENT HUNTING.

HISTORY OF CAVE AREA is summarized. The only intensive use of interior of Mammoth Cave occurred during Woodland period, when Indians sought gypsum. Gaps in dates are explained by fact that no archaeological materials have been found from missing periods.



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INERTIAL NAVIGATION / ARMAMENT AND FLIGHT CONTROL / COMPUTERS AND DATA SYSTEMS

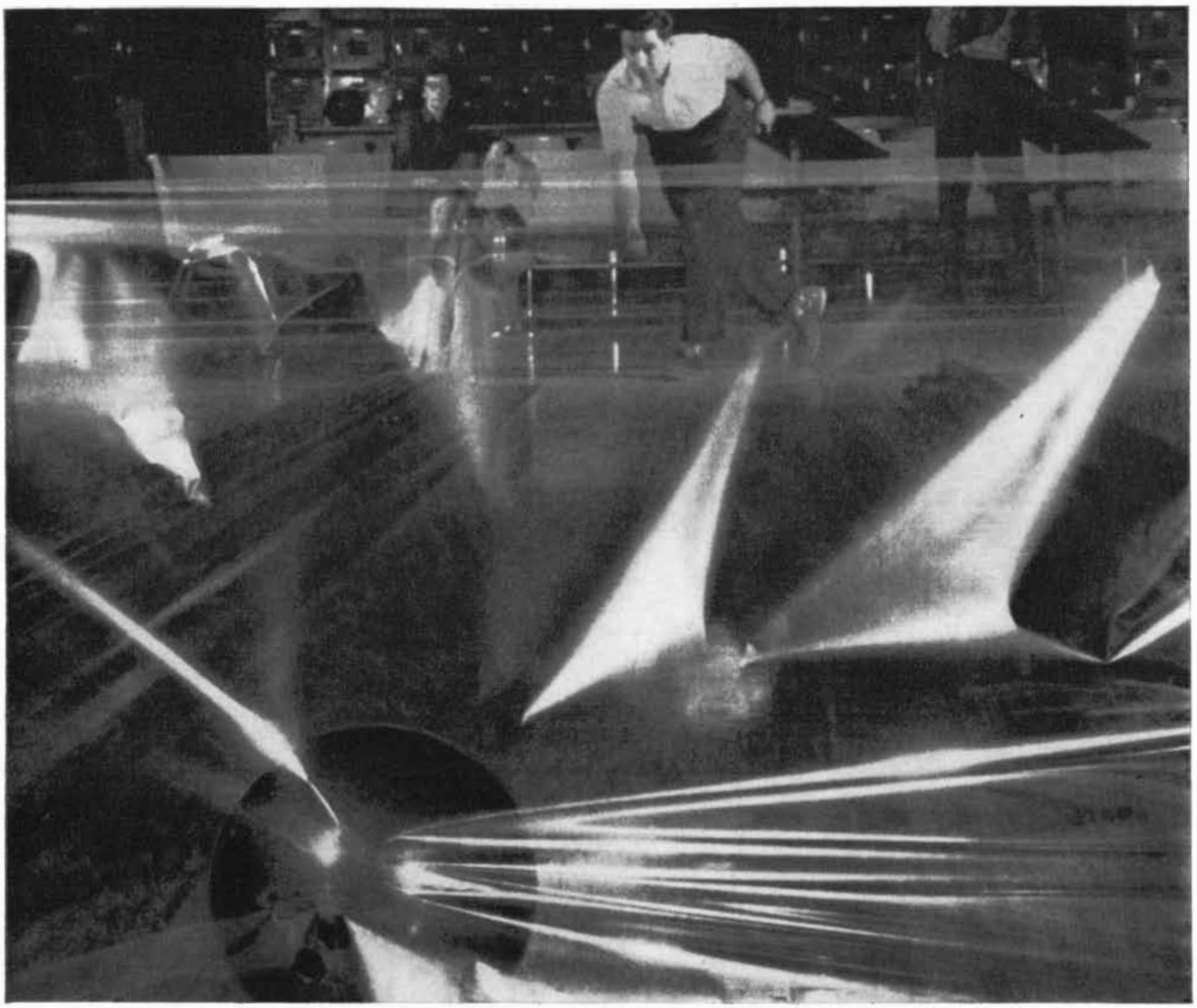
of feathers and suspend them from the twine as she wove it into cloth.

When winter called for warmer clothes, the men supplied animal skins from the hunt. Skins of deer, rabbit, bear, elk or wildcat were tanned and made into blankets or robes. The women used bone awls and deer sinew to fashion these skins into clothing. For adornment they employed fawn hoofs, perforated seeds, stone beads, shells, eagle claws, bear jaws and other materials, which they made into necklaces and pendants.

The many caves in this countryside attracted their interest, especially the two largest caves that are now known as the Mammoth and the Salts. Although they had relatively small entrances, both contained many tremendous rooms and miles of smaller passages, as well as cliffs and rivers, columns of stone and sparkling crystals. Families lived at some seasons in the entrances of the larger cave, while the men went deep into the cave's interior. Occasionally the women would go a short distance into the cave to store bundles of sandals or textile fiber in the constant cool environment. But only the men saw the inner recesses of the caverns, venturing deeper as they exhausted the supply of gypsum nearer to the entrance.

At last, after nearly a millennium, people began to move away from the land of the great caves, settling in the fertile bluegrass country to the north and east. By 400 A.D. the region was abandoned. It remained unoccupied for more than 500 years. Now and then a hunting party would wander through. Sometime after 1300 A.D. a group from the west paddled up the Green River and set up a hunting camp on top of a hill that overlooked the river and the land around it. They found the game plentiful and sometimes even easy to stalk, since it had not been hunted for so long. Every few years they returned for short visits and gradually they learned a little about the region.

One day an Indian hunter—perhaps on the trail of a bear—came upon the entrance of Mammoth Cave. He returned with his tribesmen to explore this opening in the earth, and with cane torches to light the way they crawled and walked through many passages. They found evidence of the earlier cave-explorers and even collected some of the ancient straw sandals to take back to their main village on the lower Green River. Surely one of these Indians must have remarked: "We'll probably never know why those ancient people spent so much time in the cave."



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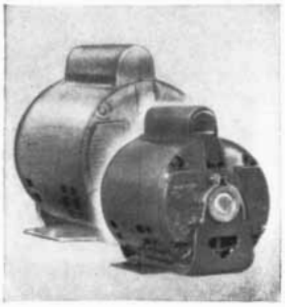

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THINGS THAT GO FASTER THAN LIGHT

Contrary to common opinion, certain physical phenomena move faster than *c* (the speed of light in a vacuum). This speed is a maximum, however, for the transmission of messages, or of mass and energy

by Milton A. Rothman

It is easy to make something travel faster than light. To anyone educated in the 20th century this statement usually comes as something of a shock. Those who know a little about the theory of relativity are apt to protest: "But Einstein proved that nothing can go faster than light." Even many people who really know better find themselves surprised when they come upon one of the several physical phenomena that do propagate faster than the speed of light in a vacuum. So it seems worthwhile to discuss just what can and what cannot travel faster than light, and to find out what Albert Einstein really said.

Let us begin with something as simple as a pair of scissors. If you think about the point where the two blades intersect, you will realize that as the scissors are closed and the blades become more and more nearly parallel, the intersection point moves away from the pivot faster and faster. Eventually, if the scissors are long enough, the velocity of the point must exceed the speed of light.

To be specific, suppose that the blades extend four kilometers past the pivot and that one blade is held fixed while the other is rotated at one revolution per second. If the pivot point is 10 centimeters below the edge of the fixed blade [*see illustration on pages 144 and 145*], then when the point of intersection is about 2.2 kilometers from the pivot, it is traveling at some 300,000 kilometers per second—a little more than the speed of light. From here out the point of intersection will move faster and faster, reaching speeds far greater than that of light.

But this is just a trick, you say. We have not really sent some palpable thing faster than light. We are merely noticing the motion of a geometrical point, a locus of intersection, not a material body. The trick breaks no laws. After all, there are many other ways of performing it. We could, for example, swing the beam of a searchlight across a screen. If the screen is far enough away, the spot where the light hits will move with tremendous velocity. We could move the spot from Mars to Venus in a second, if we had the appropriate apparatus. Similarly, it is possible to move the electron beam in a cathode-ray oscilloscope back and forth so rapidly that the spot on the screen travels faster than light.

In these examples the only objects that actually move are photons and electrons, and they travel along the beams at their usual speed. The appearance of motion across the screen is supplied by our own minds.

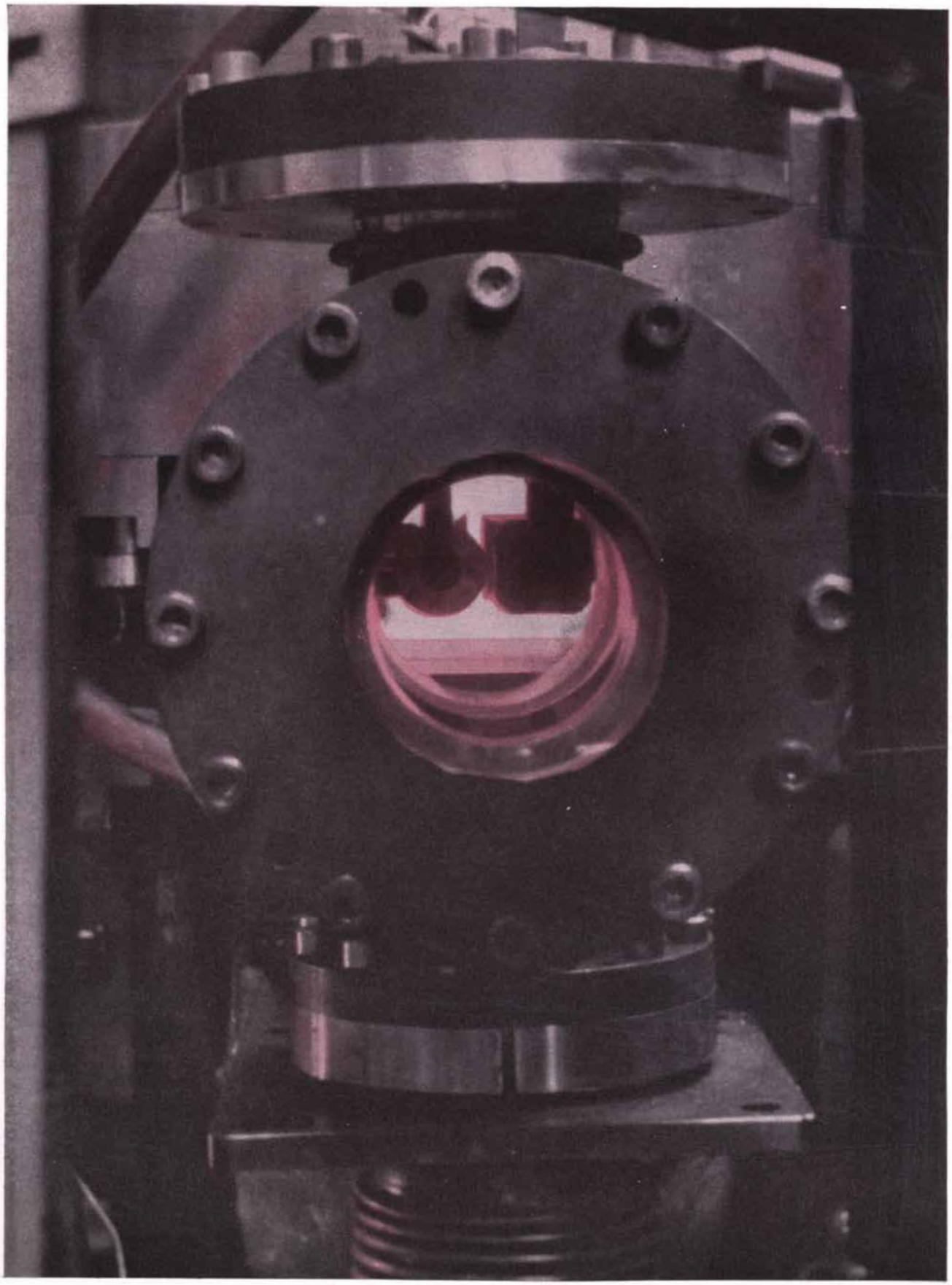
Even granting that the motion is an illusion, something does move faster than light, and we might suppose that we could use it to carry a message. A moment's reflection shows that the searchlight and oscilloscope can be ruled out. Sweeping a light beam from Mars to Venus by means of a projector on the earth is of no help in sending a message from Mars to Venus. However, the scissors seem to offer a possibility. Suppose we gently wiggle the moving arm up and down while it is almost parallel to the fixed arm and thus tap out a code signal. The dots and dashes should then travel out to the far end at a speed faster than that of light.

On closer inspection this superfast telegraph turns out to be based on a false assumption, namely, that the scissor blade is infinitely rigid and that any motion at one end transmits itself throughout the entire length instantaneously. The blade is not rigid, but elastic. When the position of the handle changes, the motion is transmitted along the arm with a velocity that depends upon the arm's elastic properties. In other words, what actually carries the signal is a wave that travels at the speed of sound in this particular blade.

Note that when the arm was rotating at a constant speed, the point of intersection was able to travel faster than light. It was only when we tried to change the motion of the arm that we ran into difficulty. The difficulty is quite general. In order to transmit a message there must be some change of motion. And nature seems to have conspired to make it impossible to send a change faster than light. This is the meaning of the principle of relativity. Einstein never said that nothing could go faster than light. What he said was that no message and no energy (including that contained in the mass of material bodies) could be transmitted faster than light.

The example of the scissors is admittedly farfetched. To find something that really goes faster than light we must look to electromagnetic waves. As a help in visualizing some of their important properties it may be best to talk first about material waves such as water waves.

Imagine you are sitting on a small rock that juts out of an otherwise empty ocean extending in every direction as far as your eye can see. Somewhere over the horizon a huge machine is agitating the water in a regular, rhythmical way and setting up waves. These waves approach you from one side of the horizon, pass by and disappear over the opposite side. We shall suppose that they are ideal waves, with the form of a perfect sine-curve: the crests are all of the same height (that is, the amplitude is constant), and they do not die down as the wave progresses; the spacing between crests does not change



PLASMA, or highly ionized gas, which is producing the rosy glow in this photograph, is a medium in which radio waves have a phase velocity (*see text*) greater than *c* (the speed of light in a vacuum). The plasma is seen through a port in a Stellarator, a device used in thermonuclear research at the James Forrestal Research Center of Princeton University. Dark objects within port are microwave horns, which send waves through the plasma. The increase in velocity is a measure of the density of free electrons.

(the wavelength is constant); the same number of crests passes every second (the frequency is constant).

By keeping your eye on a particular crest and measuring the speed at which it approaches, you can determine the velocity of the wave. What you are actually doing is following the progress of a particular phase in the cycle of vibration of the water particles that make up the wave. Hence the velocity you measure is known as the phase velocity.

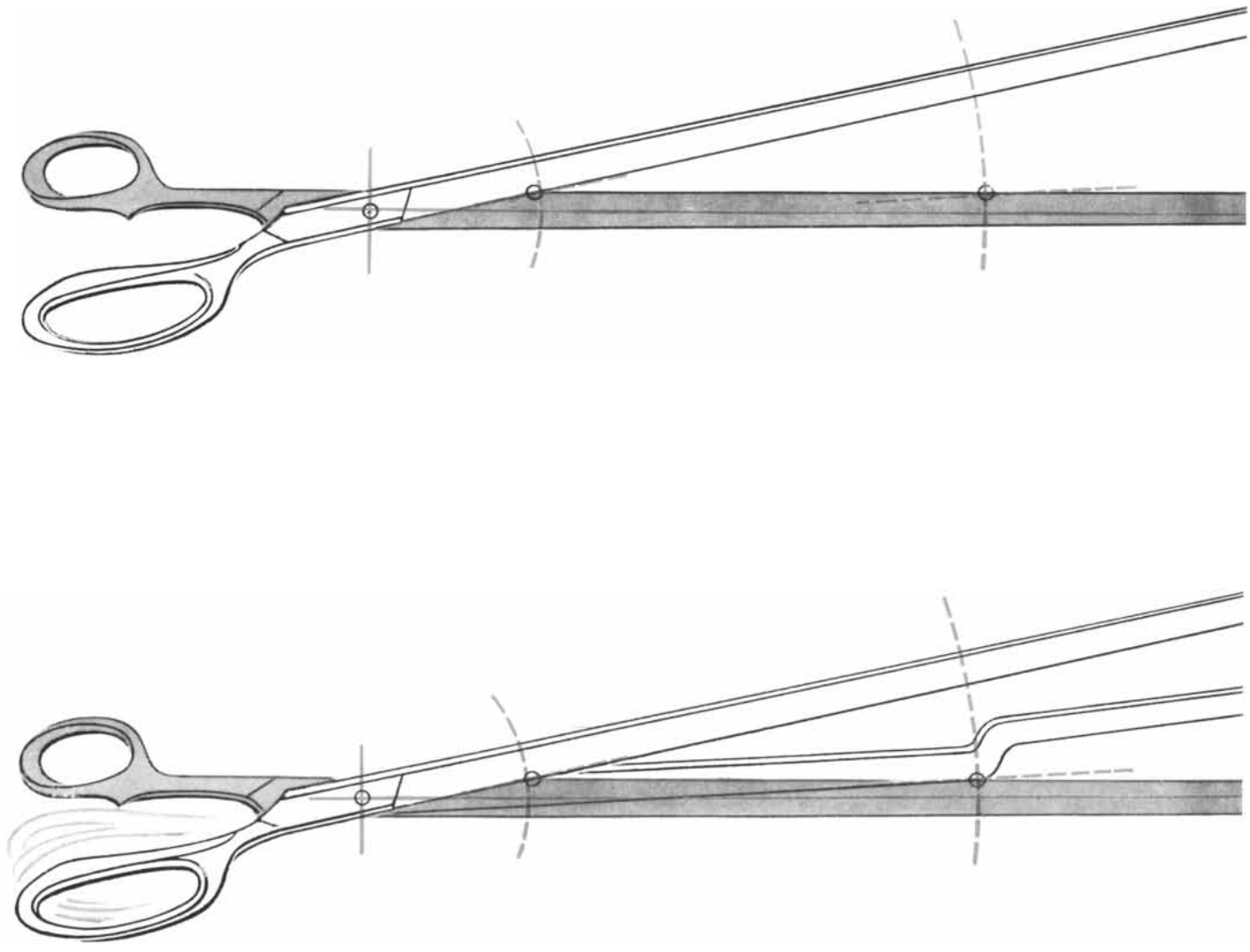
There is another way to find the phase velocity. You can count the number of crests passing in a minute and multiply by the distance between crests. This tells how far the first crest has gone in a minute. In other words, phase velocity equals frequency times wavelength.

What does the wave carry at this velocity? Certainly not a message. The endless, unchanging succession of passing crests can convey no more information than can a still ocean. Nor is energy transmitted. Every point on the surface has exactly the same energy as every other point, and the amount of energy is constant.

Evidently Einstein's restriction should not apply to this wave that carries no message and no energy. In fact it does not; some waves (electromagnetic waves, not water waves) can under certain circumstances have phase velocities greater than the speed of light in a vacuum.

Now consider how a message might be sent by the operator of the water-wave machine to the observer on the rock. Somehow the regular pattern would have to be varied. The variation might take the form of amplitude modulation, for example, where the height of the crests is changed. Another possibility would be to pulse the wave, breaking it up into short, separate packets by alternately starting and stopping the machine.

Whatever stratagem is adopted, it will be found that the significant variations constituting the message progress more slowly than the phase velocity. The pattern of higher and lower crests in the amplitude-modulated wave, or the packets in the pulsed wave, travel



INTERSECTION OF SCISSORS BLADES moves to right at increasing speed as the upper, moving blade rotates at a constant rate. If the blades were long enough, the intersection point could move faster than *c*. In upper drawing the broken straight lines mark the intersection for successive positions of the moving blade after equal angular rotations. In lower drawing the moving blade

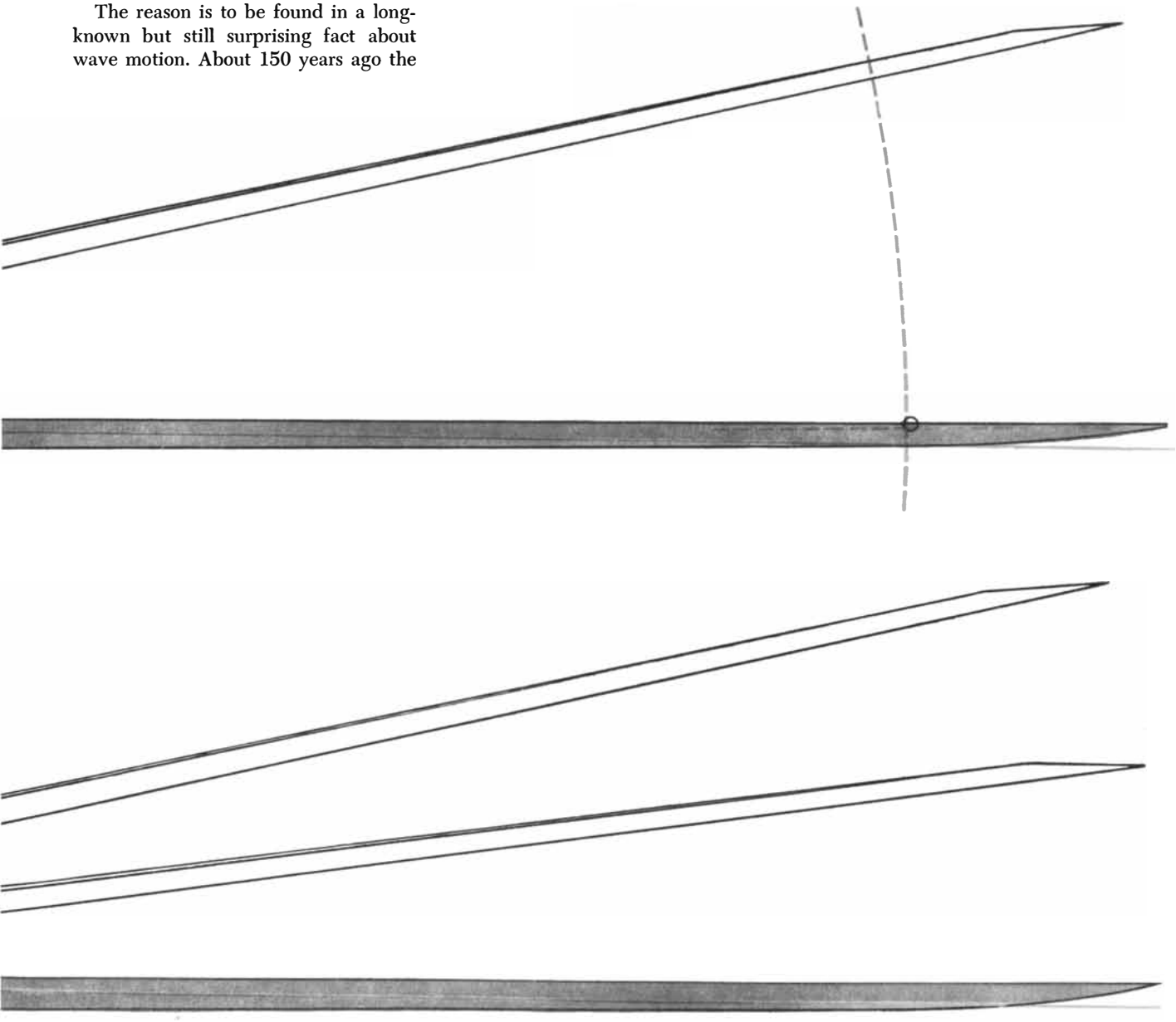
as a group; their speed is called the group velocity.

For waves in general the group velocity can be less than or equal to the phase velocity, and in a few anomalous cases, greater than the phase velocity. Which rule holds depends on the type of wave and the nature of the medium through which it is traveling. For the large gravity water-waves mentioned above, the group velocity is less than the phase velocity. For small capillary surface waves the reverse is true.

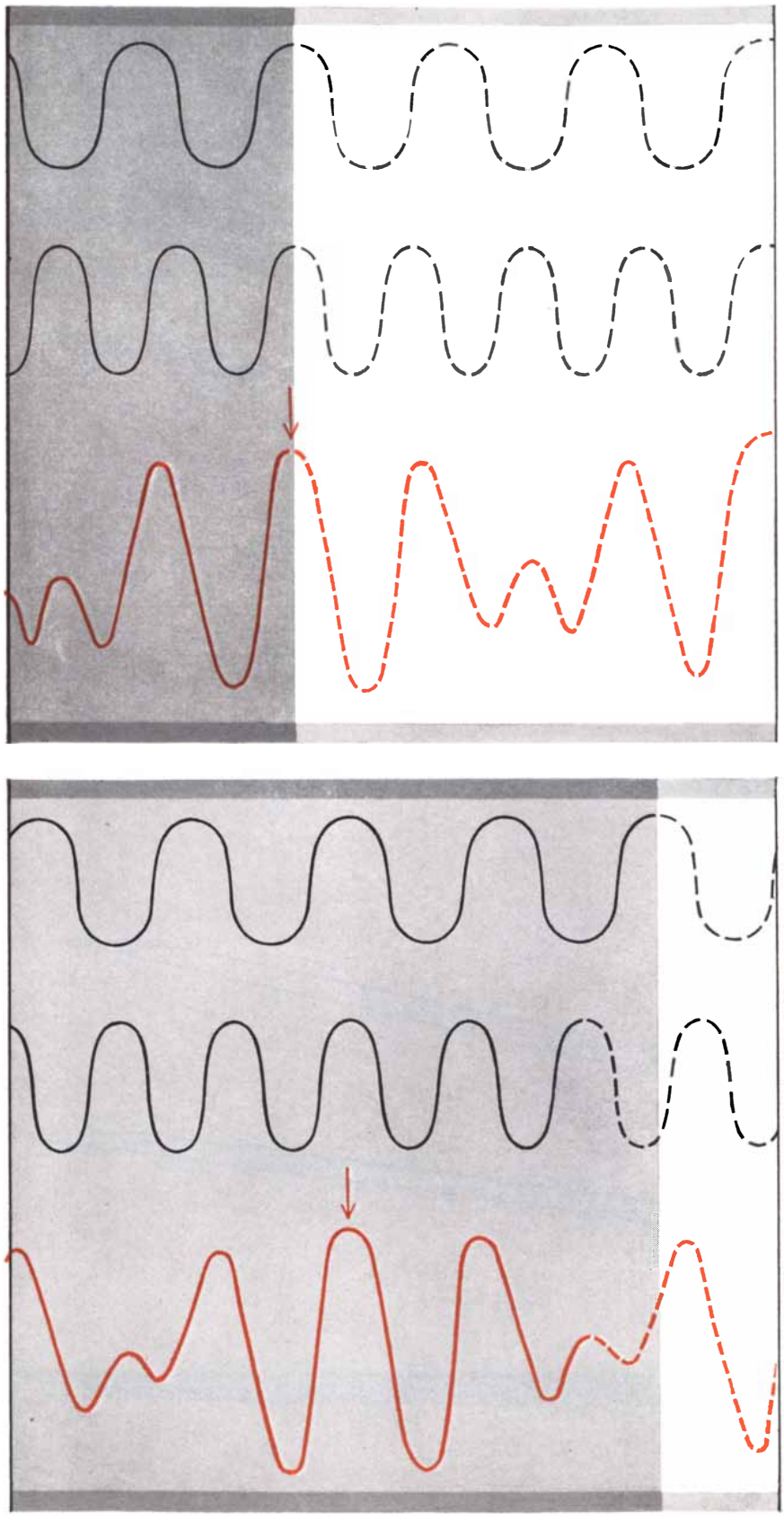
The reason is to be found in a long-known but still surprising fact about wave motion. About 150 years ago the French mathematician Joseph Fourier discovered that every wave group, which means every wave pattern except a perfect sine-wave extending indefinitely in both directions, can be made up by superimposing sine waves of various wavelengths and amplitudes. Not only that, but every wave motion actually contains these pure components; they can be filtered out and detected.

A simple amplitude-modulated signal can be built of just two sine waves [*see illustration on next page*]. Obviously if the two component waves move at the same speed, the pattern obtained by combining them will also travel at that speed. This is the case for light, or for other electromagnetic waves in a vacuum: all the pure sine-waves have the same speed (equal to 299,793 kilometers per second and denoted by c), and the group velocity equals the phase velocity of the component waves.

On the other hand, as a glance at the



is distorted as a result of a sudden closing movement. Now the velocity of the point of intersection depends on the speed at which the jog moves along the blade, and not on the rate at which the handles are pulled together. The progress of the jog depends on the elastic properties of the metal blade, and the motion of the intersection takes place at the speed of sound in the material.



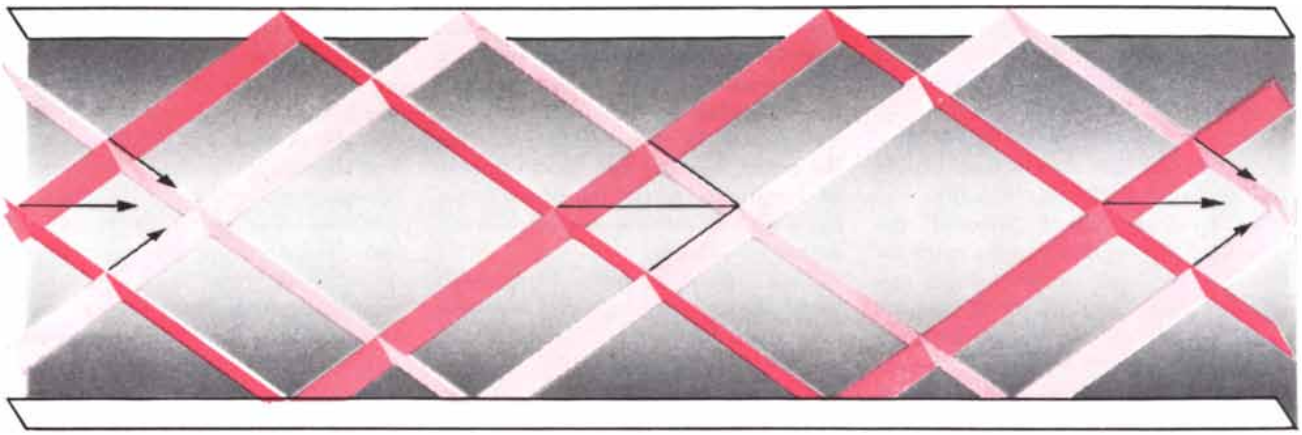
GROUP VELOCITY of a wave form produced by superimposing two sine waves is represented by the advance of the highest crest of the colored curve (*marked with vertical arrow*) from top drawing to bottom one. In the same time interval the upper sine wave, moving at its phase velocity, advanced to point marked by shift of gray area. Lower sine-wave, with a smaller phase velocity, advanced to point at end of solid curve in bottom drawing.

illustration shows, if the component waves move at different speeds, the velocity of the combined wave (the group velocity) is different from that of either component. This is the situation whenever electromagnetic waves travel through a material medium. The velocity of the waves in such media depends on wavelength. Hence different components of a wave have different phase velocities, and in all transparent materials the group velocity is less than any of them.

As a consequence of its change in speed, a light ray passing obliquely from a vacuum to a material medium is bent, or refracted. To check the theoretical relation between velocity and refraction A. A. Michelson in 1885 made accurate measurements of the speed of light in various materials. At first his results seemed to contradict the theory. In carbon disulfide, for example, his velocity measurements yielded an index of refraction of 1.758. But the corresponding figure computed from the observed bending of light rays was 1.635.

The discrepancy was quickly explained when it was realized that the two experiments measured different quantities. The bending of rays depends on phase velocity. Michelson was measuring the speed of short pulses of light; in other words, the group velocity.

In this instance the phase and group velocities, though different from each other, are both less than c. Light travels more slowly through carbon disulfide (and other transparent substances) than through a vacuum. But for other portions of the spectrum, such as the far ultraviolet, the phase velocity in a medium is often greater than c, as can be demonstrated by refraction. The phenomenon of refraction does not provide a direct measure of speed, but rather of wavelength. When light passes through different media, its wavelength changes, and the amount of bending that takes place at the dividing surface depends on the difference in wavelength. Since the frequency of a wave never changes once it has left its transmitter, and since phase velocity equals frequency times wavelength, the phase velocity varies in the same proportion as the wavelength. But phase velocity itself, in the case of electromagnetic waves, is unmeasurable. We cannot see the crests and follow their progress. When we try to measure velocity directly, we always end up as Michelson did, measuring group velocity. And even where the phase velocity

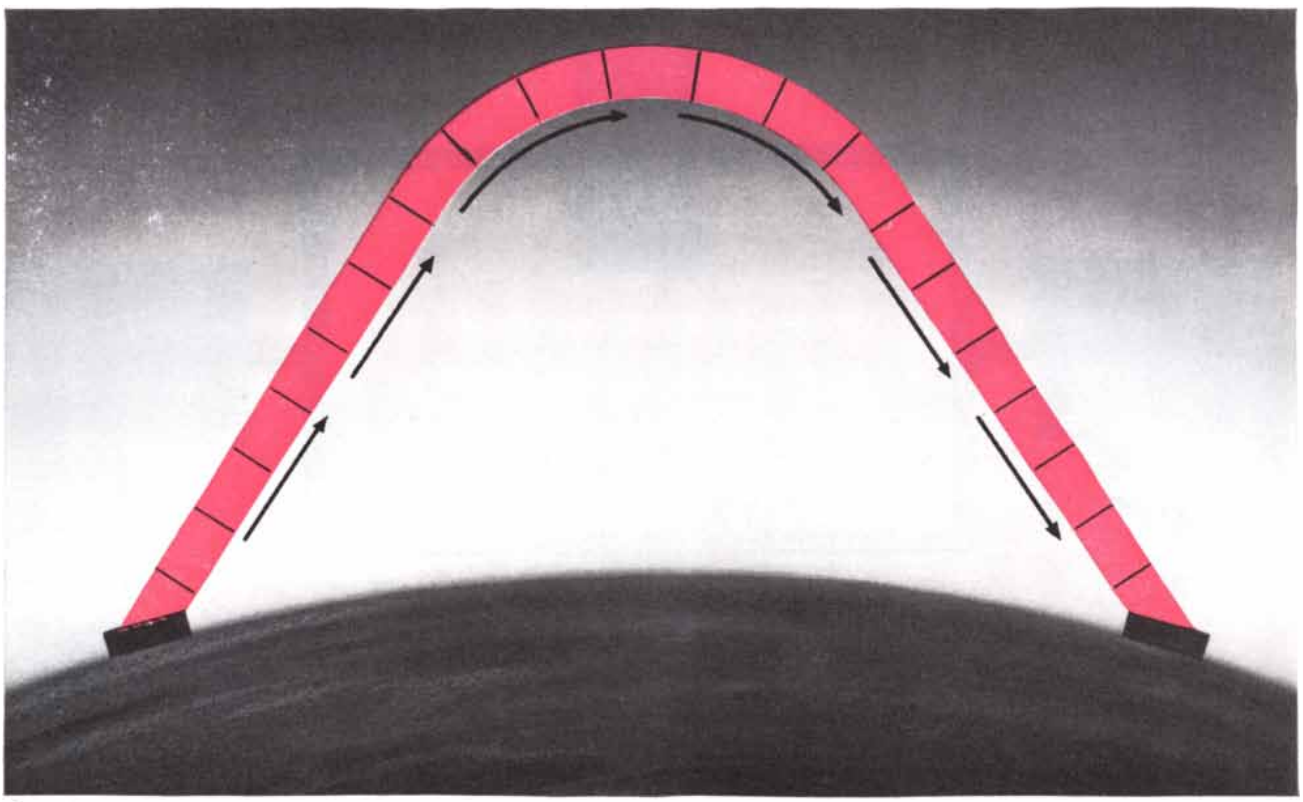


WAVE FRONTS (*colored bands*) advance through a wave guide by shuttling from wall to wall, in direction of slanted arrows, at speed of light. Point where they cross and reinforce moves faster. Pale bands show a position slightly later than that of dark band.

is greater than c, nature has conspired to make the group velocity less.

All this would be but a curiosity—a theoretical concept of an unmeasurable quantity—if it were not for certain rather important consequences in the propagation of radio waves. Electrical engineers are familiar with the fact that when very short radio waves, which move through free space at the speed of light, are sent through a long metal pipe, or wave guide, their wavelength grows longer and their velocity increases. The amount of the change varies with frequency in an interesting way. For very high frequencies, where the wavelength is very small compared with the size of the wave guide, the increase is negligible. This is reasonable, because then the wave is practically traveling through free space. As the frequency decreases, however, and the wavelength becomes comparable with the width of the tube, the waves carom off the walls as they advance [*see illustration above*]. As the wave crests shuttle back and forth between the sides, they cross one another, and combine into a new pattern. It is this pattern, the crest of which occurs where the crests of the individual waves add up, that travels straight down the tube.

It is clear from the illustration that



BENDING OF RADIO WAVE (*colored band*) by ionosphere (*upper gray area*) depends on the fact that the phase velocity is increased in the ionosphere. Wave fronts (*black lines*) tilt forward as upper parts move faster than lower ones, changing direction.

the point of reinforcement travels faster than the individual wave-crests, just as the point of intersection of our scissors traveled faster than each blade. Thus we have a wave that travels faster than light, and is longer than it would be in free space for the same frequency.

As the frequency is reduced, the wavelength and velocity in the guide increase until, at a certain critical frequency (determined by the dimensions of the guide), the wavelength becomes infinite and the wave effectively moves with an infinite velocity. This is called the cutoff frequency, for if we try to pass a wave of a lower frequency through the wave guide, we discover that it will not go. The pipe is actually opaque to the radiation.

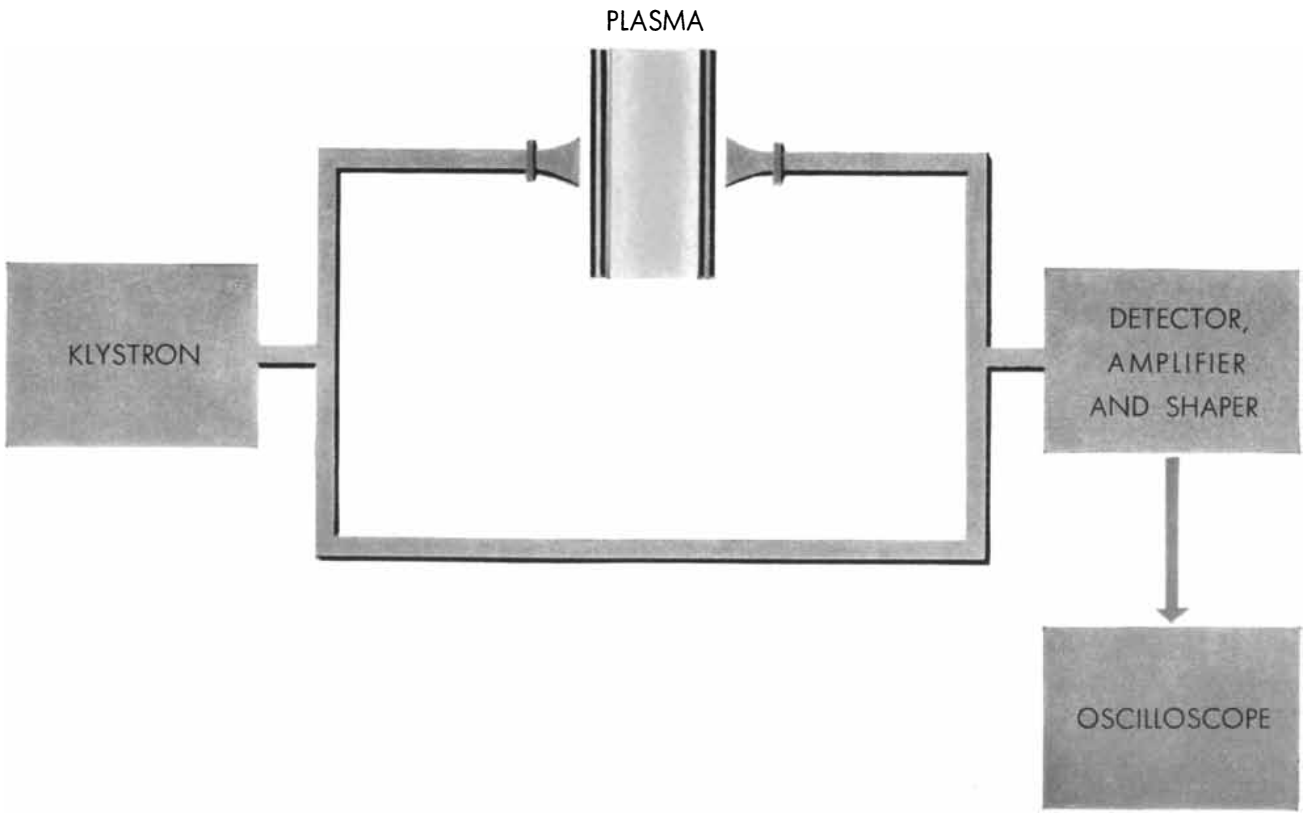
As before, a phase velocity greater than c is nothing to get excited about. The only thing that is moving is an interference pattern between waves. When we start a wave on its way, the resulting change in the conditions within the guide travels with the group velocity. In other words, if we pour energy into the wave guide and wait for it to come out of the far end, the time depends on the group velocity. And the group velocity is less than the speed of light, no matter how great the phase velocity. In fact, it turns out that in a wave guide the group velocity is equal to c^2 divided by the phase velocity. The greater the phase velocity, the less the group velocity; just above the cutoff frequency, where the phase velocity is almost infinite, energy is transmitted very slowly.

Thus although waves undeniably travel through wave guides at speeds faster than light, they produce no detectable result. This, however, is not always true. As a matter of fact, the very existence of long-range radio communication depends on the fact that radio waves in the ionized layers of the upper atmosphere have phase velocities greater than the speed of light. This is what enables them to be reflected by the ionosphere and to connect transmitters with receivers that are over the horizon.

The change in the speed of radio waves in the ionosphere is a result of their interaction with the free electrons there. The greater the concentration of free electrons, the greater the phase velocity. As in the wave guide, the velocity also depends on the frequency.

When a beam of radio waves enters the ionosphere at an angle, the increasing phase velocity and wavelength cause the beam to bend downward [*see bottom illustration on preceding page*]. Furthermore, since the electron concentration grows greater with height, the angle of refraction can increase to the point where the radiation is bent through an arc that brings it back out of the ionosphere and down to the ground again. (More accurately, the angle of refraction increases until the waves can undergo the process known as total internal reflection.)

Waves in the ionosphere behave very much like radiation traveling down a wave guide. There is a cutoff frequency that depends upon the electron concentration. The ionosphere is opaque to frequencies below the cutoff, while it passes the higher frequencies with phase velocities greater than c. As in the wave guide, the higher the frequency, the nearer the phase velocity approaches the normal speed of light, and the less the refraction. That is why waves of very high frequency are not reflected by the ionosphere and so cannot be received much beyond the horizon. They simply pass through the atmosphere without



FREE-ELECTRON DENSITY in a plasma can be determined by measuring increase in speed of radio waves passing through the gas. Microwave output of klystron is split into two parts, one passing through plasma, the other through a length of wave guide. Because of change in speed, waves are out of phase when they recombine in detector. Phase difference is read on oscilloscope.

Latest Analysis,
JULY 1, 1960

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BISMUTH	A-58		2	1		1	2						1*	
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COPPER	A-58	No Impurities Detectable by Spectrographic Analysis												
GOLD	A-59		1*	1*		1*	1*							
INDIUM	A-58		1*			1		1*	1					
LEAD	A-58	1*	1*	1*			1*							
SELENIUM	A-58		1*		1*					1			1*	
SILVER	A-59		1*	1*		1*					1			
SULFUR	A-58											1	1	
TELLURIUM	A-58		1*	1*										
THALLIUM	A-58		3	1		1*	1*					2	1*	
ZINC	A-59		1*	1*		1*								1*

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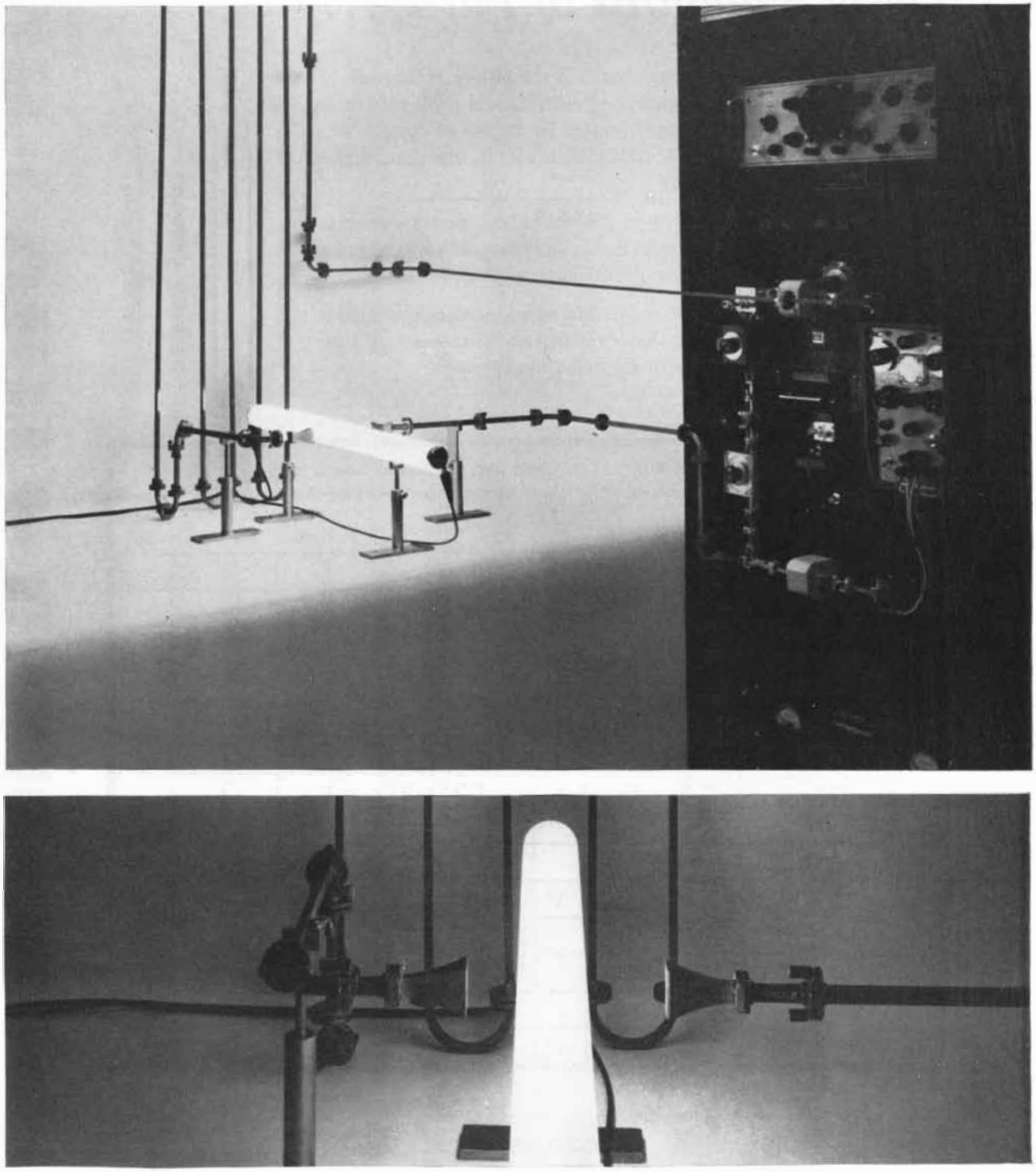
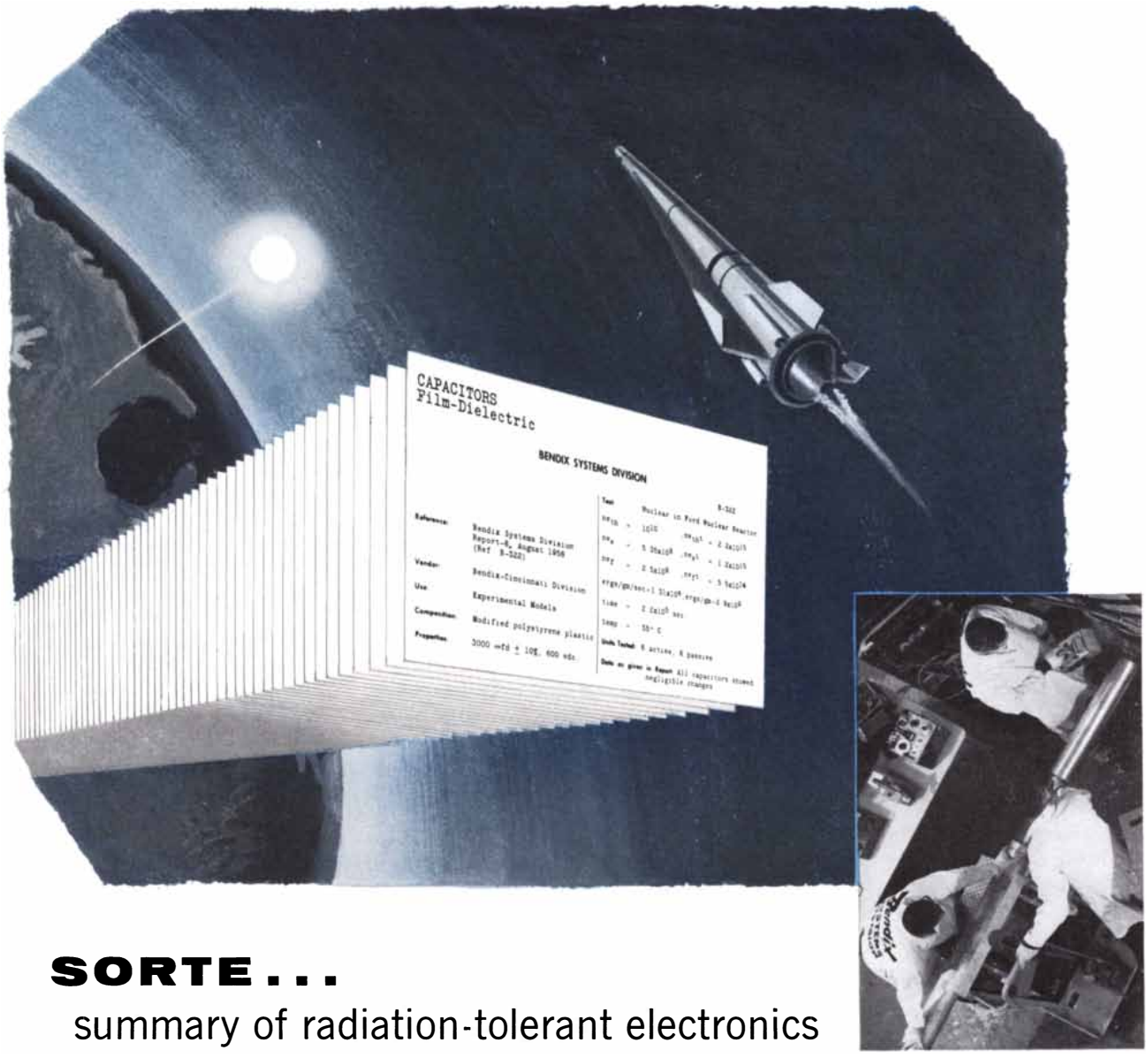
sufficient refraction to return them to the surface.

Radio waves are being used in current studies of the upper atmosphere to determine the electron density of the ionosphere. One way of doing this is to send up a rocket with a transmitter that emits waves of two frequencies, one low enough so that its wavelength is appreciably increased, the other high enough to be relatively unaffected. The two waves are in phase as they leave the transmitter, but the one with lower frequency travels through the ionosphere faster than the other. As a result, when they arrive at a receiver on the ground, they are no longer in phase. By following the difference in phase as the rocket rises, the electron density at various altitudes can be measured.

The ionosphere is an example of a type of fluid that is becoming more and more familiar; it is a plasma, or highly ionized gas, containing a mixture of positive ions and free electrons. In the atmosphere the plasma is produced by the action of the sun's radiation on air



PHASE-COMPARISON CIRCUIT for determining electron density is set up to make a measurement on the gas in a fluorescent lamp. Top photograph shows part of wave-guide sections (*vertical pipes*). Electronic equipment including klystron and detector are mounted on rack at right next to oscilloscope. Bottom photograph shows the microwave horns that send waves through the plasma.



SORTE . . .

summary of radiation-tolerant electronics

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Bendix Engineers use The University of Michigan Reactor to test radiation effects.

Bendix engineers select data on radiation-tolerant components from SORTE file.

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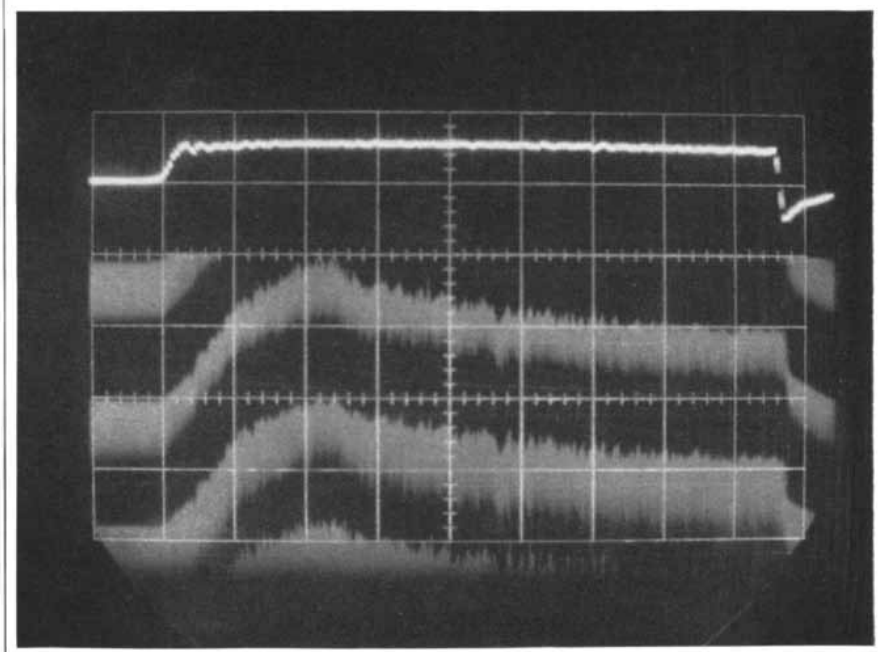
molecules. In earthbound laboratories, particularly those concerned with research in thermonuclear reactions, plasmas are made by passing powerful electrical discharges through gases in various types of device [see "The Stellarator," by Lyman Spitzer, Jr.; SCIENTIFIC AMERICAN, October, 1958].

To learn what happens inside the plasma after it has been produced, we must measure a number of its properties, including its electron density. We proceed in much the same way as in the ionospheric tests, but with one difference. In measurements on the ionosphere ordinary radio waves, with a frequency of a few megacycles per second, can be used, because they traverse thousands of feet of plasma. Within a laboratory device the available path length is generally only a few centimeters, so the probing radiation must have a wavelength that is still shorter, which means a frequency of tens of thousands of megacycles.

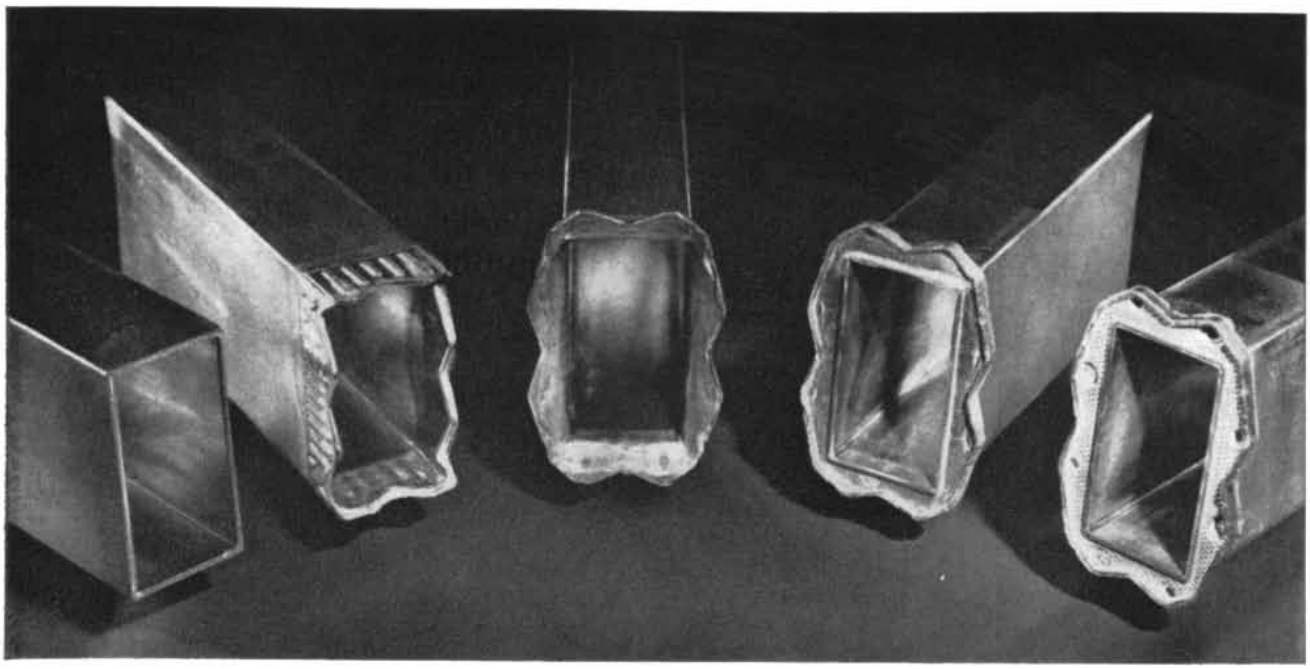
At Project Matterhorn, the thermonuclear project at Princeton University, we use four- and eight-millimeter microwaves in an arrangement similar to that of an optical interferometer [*see illustration on page 148*]. Radiation from a klystron tube is split into two beams, one passing through the plasma and the other through a known length of wave guide. When the beams are recombined, they show a phase shift, the amount of which depends on the electron density of the plasma. By monitoring the phase shift on an oscilloscope, the changes in electron density can be followed through the cycle of a heating pulse. The beauty of the method lies in the fact that it does not require putting a material probe into the hot gas, and so avoids contaminating the gas and otherwise disturbing the very effects under study.

Finally we should mention one other kind of wave that travels faster than light. It is the "particle wave" postulated by the French physicist Louis de Broglie in 1925. The waves that represent atomic particles also have phase velocities greater than c. But particles travel more slowly than light; again the apparent paradox is resolved by distinguishing group velocity from phase velocity. A particle is considered to consist of a packet of waves, which represents a superposition of many frequencies. This packet travels with the group velocity, and, as in the case of electromagnetic waves in a plasma or a wave guide, the group velocity equals the square of the speed of light divided by the phase velocity.

The group velocity is the only quantity that has physical meaning, particularly when we interpret the wave packet to represent the probability of finding a particle at a given point in space. The phase velocity of the de Broglie particle wave is strictly an abstraction, an intellectual invention, and is hardly mentioned in polite society these days.



OSCILLOSCOPE TRACES indicate electron density of plasma in the Stellarator. Narrow trace at top shows pulse of current used to ionize gas. Broad fringes below are formed by output of detector after recombining waves. Maximum vertical deflection of fringes, which occurs near left side, shortly after ionizing pulse starts, measures the electron density.



1 Waveguide cross-section before cold-flanging process.

2 First punch gathers the copper under extreme pressure.

3 The second starts flaring the metal to form eventual flange.

4 The third punch flattens copper into shape of finished flange.

5 The fourth embosses and completes flange. Time: approx. 50 sec.

Making cold copper flow like liquid

Waveguides — the metal tubes which carry microwave signals between an antenna and its transmitter or receiver — are used extensively in military radar and in the transmission of long distance telephone calls by radio relay. They must be manufactured to precise specifications, since a variation of only .003" in their interior dimensions will cause serious microwave distortion.

This problem is complicated by the fact that as many as 100 individual waveguides may be used in connecting radio equipment with its antenna. Thus, not only must the waveguides be precisely engineered, but the connecting points must be constructed so that they offer no interference with the interior dimensions.

Connecting two or more waveguides is accomplished by use of flanges, or rims, on the ends of the tubes. Formerly, these flanges were separately manufactured and manually joined to the waveguides. The process was slow and costly, so Western Electric engineers developed a means of forming the flanges from the ends of the waveguides themselves. In doing so, they accomplished a metallurgical feat never before approached.

As a first step, the possibility of heating the waveguides and molding the ends into flanges was tried. This idea was not pursued since the heated copper annealed and lost its strength. The solution was to make the copper flow without heat — to crush it at such great pressure that the end of the tube would fold back and out in a fluid movement — *and do so without changing the inside dimensions of the tube.*

Development centered around the design of four high-precision forming punches with two complementary forming dies. Each punch was planned to take a step in the redistribution of the copper, with the dies acting as forming molds. To achieve the exact pressure and punching sequence required, it was necessary to design and build a special hydraulic press.

Here's how the process works: A waveguide is held in a fixed position in the press while the punches move in, out, and around, controlled by a revolving index head. The result of each punching stage is illustrated above.

This is believed to be the first time that precision metal tubing has been cold-flanged without distorting its configuration, and the first time that anyone has automatically produced waveguide flanges. The savings in time, labor and materials are substantial.

This break-through in metal-working, with all its many possibilities in other fields, is another example of Western Electric's progress in engineering developments.

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MATHEMATICAL GAMES

Incidental information about the extraordinary number pi

by Martin Gardner

The ratio of a circle's circumference to its diameter, symbolized by the Greek letter pi, pops up in all sorts of places that have nothing to do with circles. The English mathematician Augustus De Morgan once wrote of pi as "this mysterious 3.14159 . . . which comes in at every door and window, and down every chimney." To give one example, if two numbers are picked at random from the set of integers, what is the probability that they will have no common divisor? The surprising answer is six divided by the square of pi. It is pi's connection with the circle, however, that has made it the most familiar member of the infinite class of transcendental numbers.

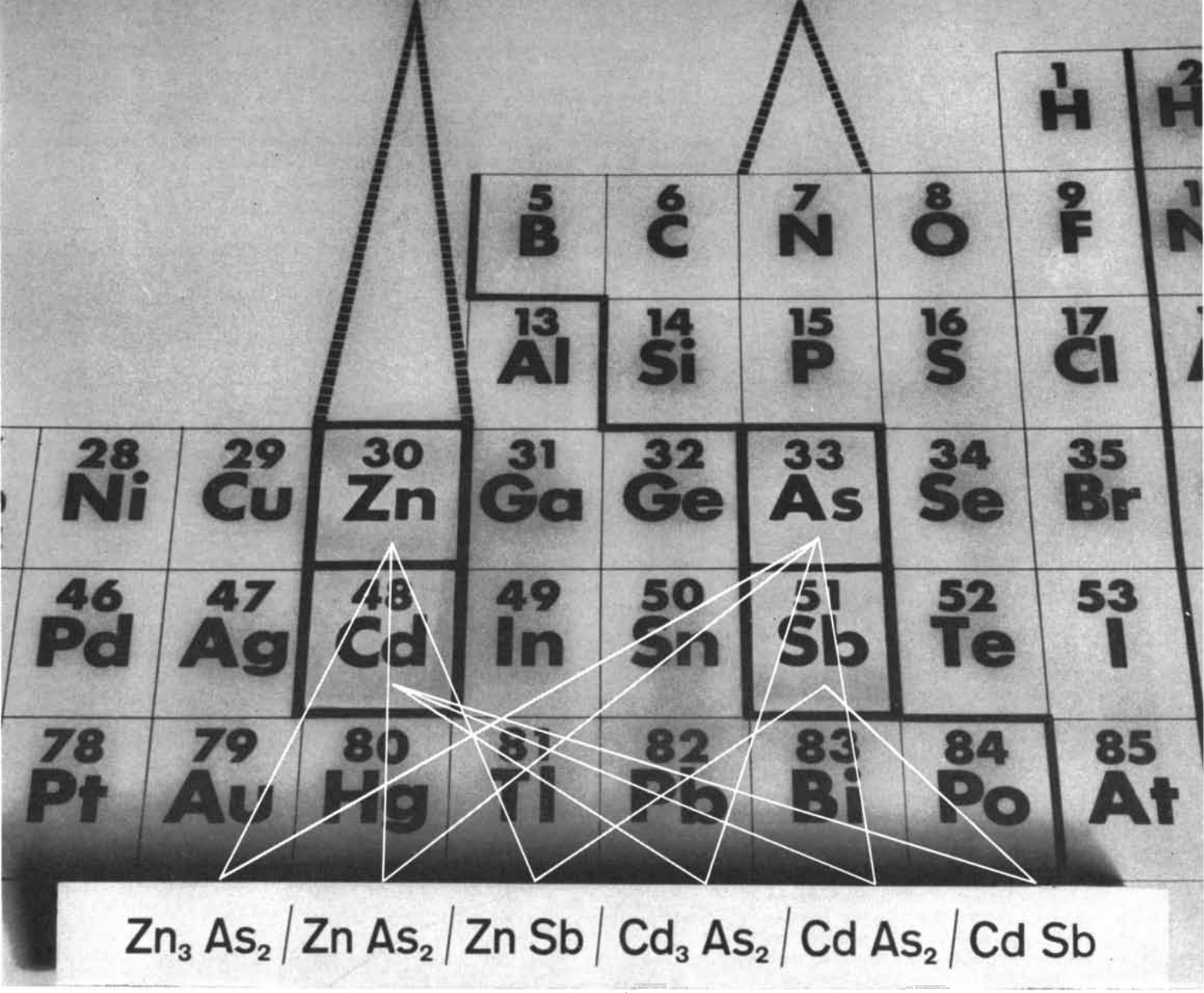
What is a transcendental number? It is described as an irrational number that is not the root of an algebraic equation that has rational coefficients. The square root of two is irrational, but it is an "algebraic irrational" because it is a root of the equation $x^2 = 2$. Pi cannot be expressed as the root of such an equation, but only as the limit of some type of infinite process. The decimal form of pi, like that of all irrational numbers, is endless and nonrepeating.

No fraction, with integers above and below the line, can exactly equal pi, but there are many simple fractions that come amazingly close. The most remarkable was discovered in the fifth century A.D. by Tsu Ch'ung-Chih, a famous Chinese astronomer, and was not discovered in the Occident until 1,000 years later. We can obtain this fraction by a kind of numerological hocus-pocus. Write the first three odd integers in pairs: 1, 1, 3, 3, 5, 5; then put the last three above the first three to make the fraction 355/113. It is hard to believe, but this gives pi to an accuracy of six decimal places. There are also roots that come close to pi. The square root of 10 (3.162 . . .) was widely used for pi in ancient times, but the cube root of 31 (3.1413 . . .) is much closer. (More numerology: 31 comprises the first two digits of pi.) A cube with a volume of 31 cubic inches would have an edge that differed from pi by less than a thousandth of an inch.

Early attempts to find an exact value for pi were closely linked with attempts to solve the classic problem of squaring the circle. Is it possible to construct a square, using only a compass and a straightedge, that is exactly equal in area to the area of a given circle? If pi could be expressed as a rational fraction or as the root of a first- or second-degree equation, then it would be possible, with compass and straightedge, to construct a straight line exactly equal to the circumference of a circle. The squaring of the circle would quickly follow. We have only to construct a rectangle with one side equal to the circle's radius and the other equal to half the circumference. This rectangle has an area equal to that of the circle, and there are simple procedures for converting the rectangle to a square of the same area. Conversely, if the circle could be squared, a means would exist for constructing a line segment exactly equal to pi. However, there are ironclad proofs that pi is transcendental and that no straight line of transcendental length can be constructed with compass and straightedge.

There are hundreds of approximate constructions of pi, of which one of the most accurate is based on the Chinese astronomer's fraction mentioned earlier. In a quadrant of unit radius draw the lines shown in the illustration on page 156 so that *bc* is 7/8 of the radius, *dg* is 1/2, *de* is parallel to *ac*, and *df* is parallel to *be*. The distance *fg* is easily shown to be 16/113 or .1415929+. Since 355/113 is 3 + 16/113, we draw a line that is three times the radius, extend it by the distance *fg*, and we have a line differing from pi by less than a millionth of a unit.

Circle squarers who thought they had discovered an exact value for pi are legion, but none has excelled the English philosopher Thomas Hobbes in combining height of intellect with depth of



The study of these non-cubic compounds provides new insights into semiconductor physics.

Pure Physics Through "Pure" Chemistry

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At IBM Research, chemists have been preparing single crystals of non-cubic Group II-V semiconductors by several methods and studying the physical chemistry, purification, and crystal growth of these compounds.

Another group, solid-state physicists, working in cooperation with the chemists, has been determining the electrical, optical, thermal, and resonance properties of these compounds. Significant in this research has been the observation of the effect of crystalline anisotropy on these fundamental properties.

From this close association of physicists and chemists have come advances in the fundamental knowledge of solid-state science. For example, out of the observations came the prediction that in one of these compounds, $CdAs_2$, cyclotron resonance might be detected. It was. In subsequent studies, cyclotron resonance was also detected in CdSb and ZnSb. Through this work, the number of semiconductors that exhibit cyclotron resonance has been doubled—because the compounds needed to make the observations were made available by IBM Research scientists. Furthermore, the interpretation of the electrical and optical measurements makes it possible to determine quantitatively how changes in preparation affect the quality of the compounds.

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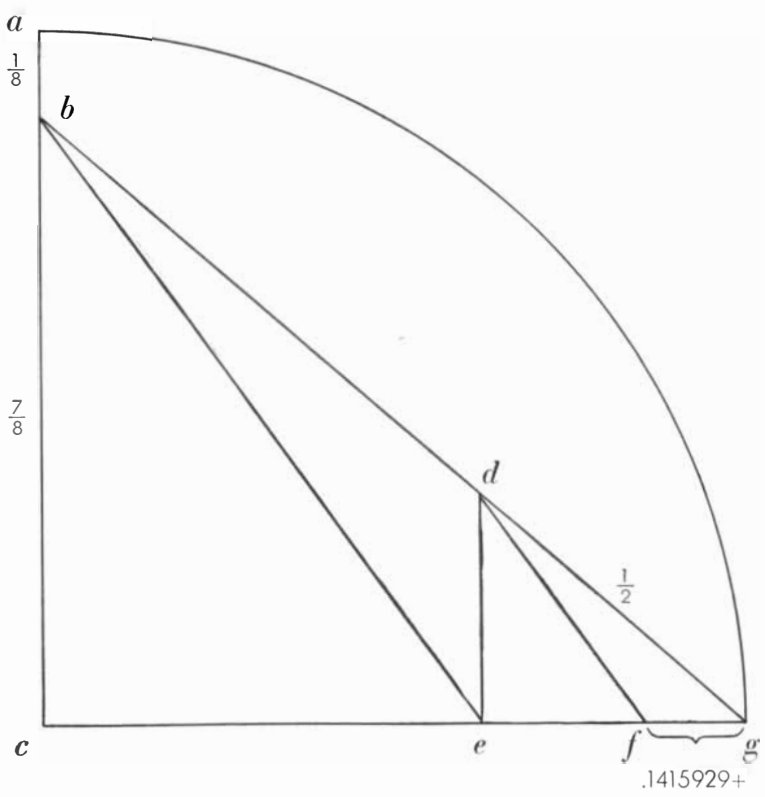
ignorance. Educated Englishmen were not taught mathematics in Hobbes's day, and it was not until he was 40 that he looked into Euclid. When he read a statement of the Pythagorean theorem, he first exclaimed: "By God, this is impossible!" Then he threaded his way backward through the proof until he became convinced. For the rest of his long life Hobbes pursued geometry with all the ardor of a man in love. "Geometry hath in it something like wine," he later wrote, and it is said that he was accustomed, when better surfaces were wanting, to drawing geometrical figures on his thighs and bedsheets.

Had Hobbes been content to remain an amateur mathematician, his later years would have been more tranquil, but his monstrous egotism led him to think himself capable of great mathematical discoveries. In 1655, at the age of 67, he published in Latin a book titled *De corpore* (*Concerning Body*) that included an ingenious method of squaring the circle. The method was unusually accurate, but Hobbes believed that it was exact. John Wallis, a distinguished English mathematician and cryptographer, exposed Hobbes's errors in a pamphlet, and thus began one of the longest, funniest and most profitless verbal duels ever to engage two brilliant minds. It lasted almost a quarter of a century, each man writing with skillful sarcasm and barbed invective. Wallis kept it up partly for his own amusement, but mainly because it was a way of making Hobbes appear ridiculous and thus casting doubt on his religious and political opinions, which Wallis detested.

Hobbes responded to Wallis's first attack by reprinting his book in English with an addition called *Six Lessons to the Professors of Mathematics. . . .* (I trust the reader will forgive me if I shorten the endless 17th-century titles.) Wallis replied with *Due Correction for Mr. Hobbes in School Discipline for not saying his Lessons right.* Hobbes countered with *Marks of the Absurd Geometry, Rural Language, Scottish Church Politics, and Barbarisms of John Wallis;* Wallis fired back with *Hobbiani Puncti Dispunctio! or the Undoing of Mr. Hobbes's Points.* Several pamphlets later (meanwhile Hobbes had anonymously published in Paris an absurd method of duplicating the cube) Hobbes wrote: "I alone am mad, or they [the professors of mathematics] are all out of their senses: so that no third opinion can be taken, unless any will say that we are all mad."

"It needs no refutation," was Wallis's answer. "For if he be mad, he is not likely to be convinced by reason; on the other hand, if we be mad, we are in no position to attempt it."

This is not the place to go into details



How to construct a straight line with a length that differs from pi by less than .0000003

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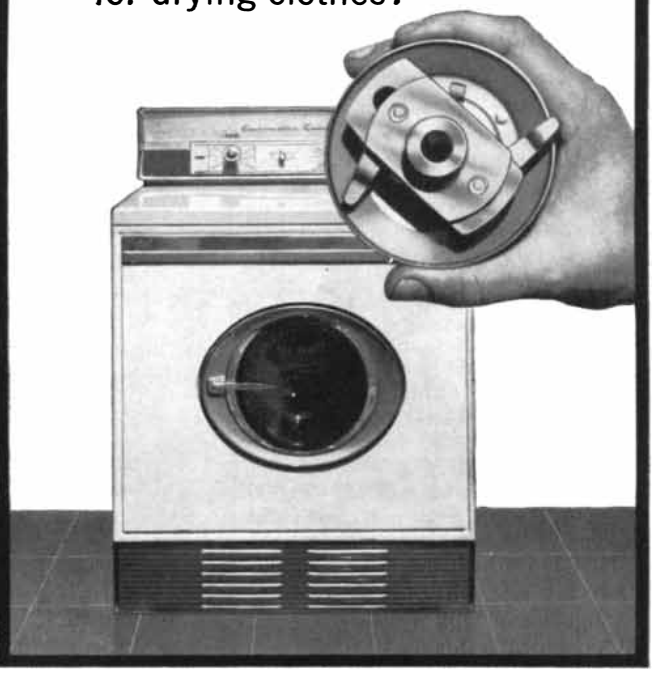

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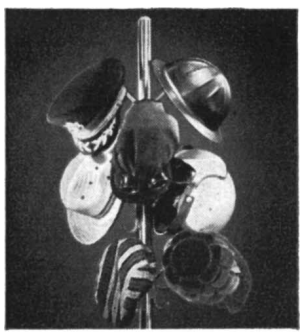

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about Hobbes's curious "incapacity," as Wallis phrased it, "to be taught what he doth not know." One of the philosopher's major difficulties was his refusal to concede that points, lines and surfaces could be regarded in the abstract as having less than three dimensions. "He seems to have gone down to the grave," writes Isaac Disraeli in his *Quarrels of Authors*, "in spite of all the reasonings of the geometricians on this side of it, with a firm conviction that its superficies had both depth and thickness." Hobbes presents a classic case of a man of genius who ventures into a branch of science for which he is ill prepared and dissipates his great energies on pseudo-scientific nonsense.

Although the circle cannot be squared, figures bounded by circular arcs often can be; this fact still arouses false hopes in many a circle squarer. An interesting example is shown in the illustration below. The lower part of this vase is three quarters of the circumference of a circle with a diameter of, say, 10 inches. The upper half is bounded by three quarter-arcs of a circle the same size. How quickly can the reader give, down to the last decimal, the exact length of the side of a square that has the same area as this figure?

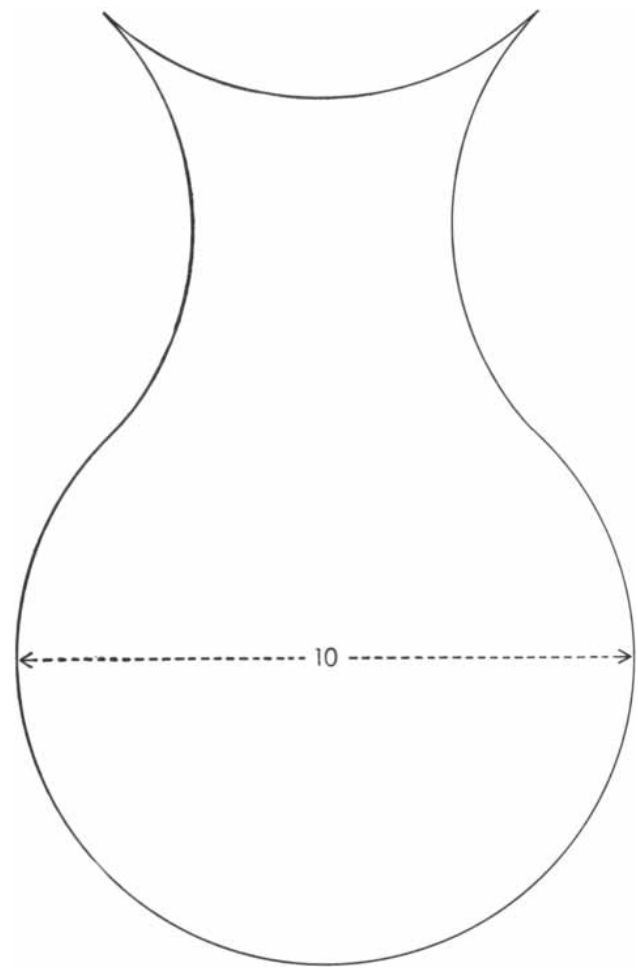
Close cousins to the circle squarers have been the pi computers; men who devoted years to computing by hand the decimals of pi beyond all previous computations. This can be done, of course, by using any infinite expression that converges on pi. Wallis himself discovered one of the simplest:

$$\pi = 2\left(\frac{2}{1}\times\frac{2}{3}\times\frac{4}{3}\times\frac{4}{5}\times\frac{6}{5}\times\frac{6}{7}\times\frac{8}{7}\times\frac{8}{9}\cdots\right)$$

The upper terms of these fractions are even numbers in sequence, taken in pairs. (Note the fortuitous resemblance of the first five lower terms to the digits in the Chinese astronomer's fraction!) A few decades later the German philosopher Gottfried Wilhelm von Leibniz found another beautiful formula:

$$\pi = 4\left(\frac{1}{1}-\frac{1}{3}+\frac{1}{5}-\frac{1}{7}+\frac{1}{9}\cdots\right)$$

The most indefatigable of pi computers was the English mathematician Wil-



How many square units does this figure contain?

DESIGN: ALDCROFTT

WHERE DOES BEYOND BEGIN? Today, the answer changes so fast there is no answer. At Martin-Denver, scientists, physicists, mathematicians in a great many fields are among those pushing beyond in the concepts and vehicles of space. They work in a climate that fosters advancement in the state of the art and professional status. If you would like to join them, write: N. M. Pagan, Director of Technical and Scientific Staffing, Martin-Denver, P.O. Box 179A, Denver, Colorado.

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ANDY DANEFF PUT THE RAINBOW IN A CAN

There are wealthy men today who can credit their first million to men like Andy Daneff. Andy is an Alcoa Specialty Salesman who helped manufacturers formulate a paint for an overlooked source of profit—the fifth side of a building.

By drawing on Alcoa's vast fund of aluminum knowledge, Andy's customers were able to mix color and tiny aluminum flakes to dot the landscape with sparkling rooftops that defy the weather and please the eye.

Andy is one of some 500 Alcoa Specialty Salesmen who scored kindred accomplishments in hundreds of different industries. They helped put buy-appealing foil packages on the grocer's shelf; high-purity alumina ceramic nose cones on today's guided missiles; aluminum electrical transmission lines across the land.

Whatever you make in aluminum, Alcoa trains specialists like Andy Daneff to help you produce it, package it, promote it and sell it. This is still another way we put more than 16 ounces of metal into every pound of Alcoa® Aluminum you buy—an added value that's all yours when you call on your local Alcoa sales office. Aluminum Company of America, 2019-G Alcoa Building, Pittsburgh 19, Pa.

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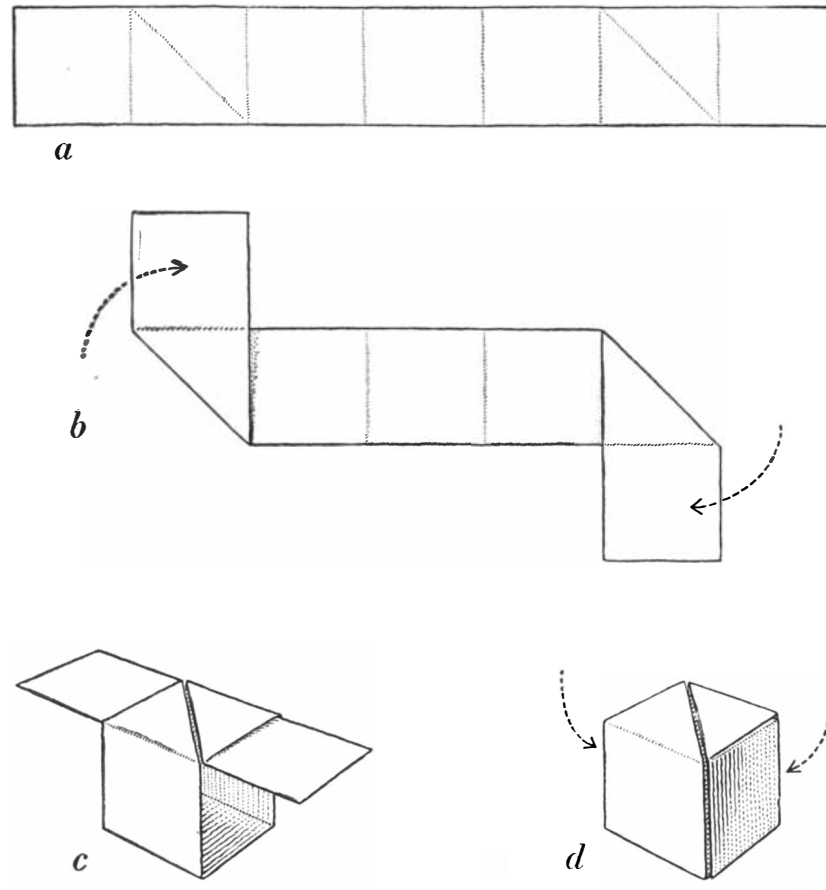
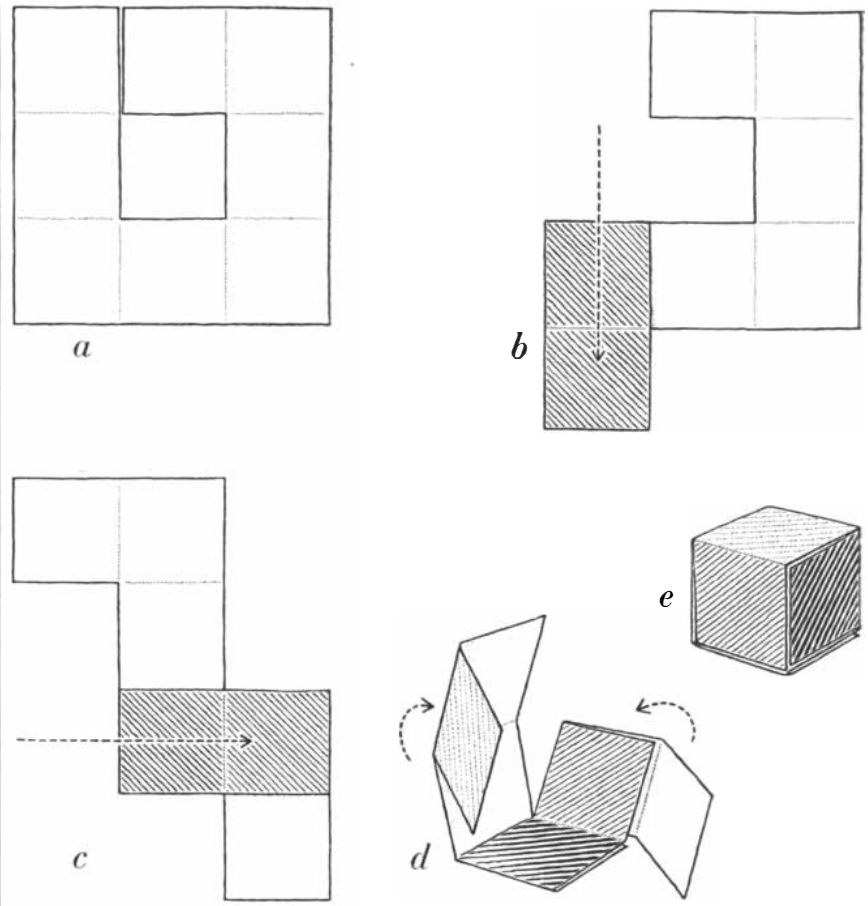


How a one-inch cube can be folded from a strip one inch long and seven inches wide

liam Shanks. Over a 20-year period he managed to calculate pi to 707 decimals. Alas, poor Shanks made an error on his 528th decimal, and all the rest are wrong. (This was not discovered until 1945, so Shanks's 707 decimals are still found in many current books.) In 1949 the electronic computer ENIAC was used for 70 machine hours to calculate pi to more than 2,000 decimals; later another computer carried it to more than 3,000 decimals in 13 minutes. In England a smaller computer calculated pi to 10,000 decimals, but after the figures had been published in 1957, it was discovered that the machine had flubbed on the 7,480th decimal and on all subsequent ones. So many computers are now in operation, working at such furious speed, that it is hard to keep up with them. Perhaps pi has now been carried accurately to the 10,000 mark.

One of the strangest aspects of Shanks's 707 decimals was the fact that they seemed to snub the number seven. Each digit appeared about 70 times in the first 700 decimals, just as it should, except 7, which appeared a mere 51 times. "If the cyclometers and the apocalyptics would lay their heads together," wrote De Morgan, "until they came to a unanimous verdict on this phenomenon, and would publish nothing until they are of one mind, they would earn the gratitude of their race." I hasten to add that the corrected value of pi to 700 places restored the missing sevens. The intuitionist school of mathematics, which maintains that you cannot say of a statement that it is "either true or false" unless there is a known way by which it can be both verified and refuted, has always used as its stock example: "There are three consecutive sevens in pi." This must now be changed to five sevens. The new figures for pi show not only the expected number of triplets for each digit, but also several runs of 7777 (and one unexpected 999999).

So far pi has passed all statistical tests for randomness. This is disconcerting to those who feel that a curve so simple and beautiful as the circle should have a less-disheveled ratio between the way around and the way across, but most mathematicians believe that no pattern or order of any sort will ever be found in pi's decimal expansion. Of course the



An all-black cube can be folded with the pattern at top left. Pattern is black on underside

digits are not random in the sense that they represent pi, but then in this sense neither are the million random digits that have been published by the Rand Corporation of California. They too represent a single number, and an integer at that.

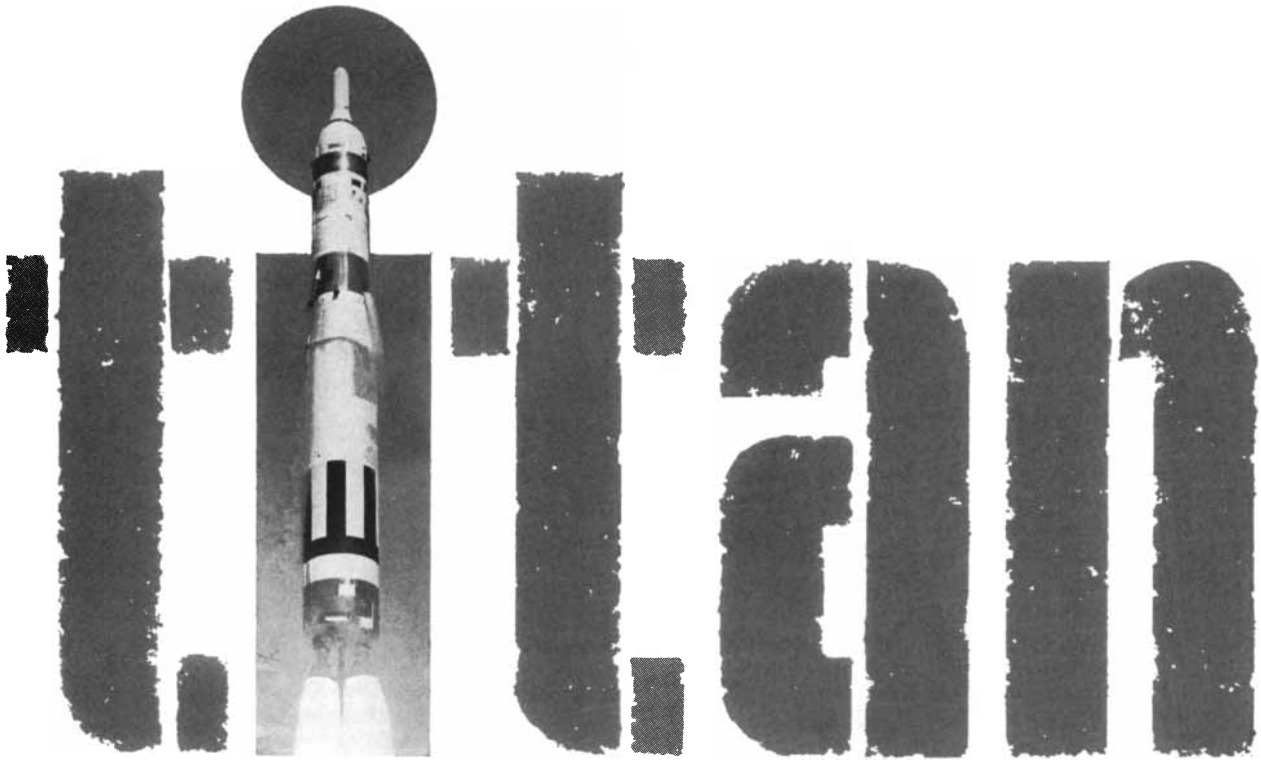
If it is true that the digits in pi are random, perhaps we are justified in stating a paradox somewhat similar to the assertion that if a group of monkeys pound long enough on typewriters, they will eventually type all the plays of Shakespeare. Stephen Barr of Woodstock, N.Y., has pointed out that if you set no limit to the accuracy with which two bars can be constructed and measured, then those two bars, without any markings on them, can communicate the entire *Encyclopaedia Britannica*. One bar is taken as unity. The other differs from unity by a fraction that is expressed as a very long decimal. This decimal codes the *Britannica* by the simple process of assigning a different number (excluding zero as a digit in the number) to every word and mark of punctuation in the language. Zero is used to separate the code numbers. Obviously the entire *Britannica* can now be coded as a single, but almost inconceivably long, number. Put a decimal point in front of this number, add 1, and you have the length of the second of Barr's bars.

Where does pi come in? Well, if the digits in pi are really random, then somewhere in this infinite pie there should be a slice that contains the *Britannica*; or, for that matter, any book that has been written, will be written, or could be written.

The first of last month's problems was to find the shortest length of a strip of paper one inch wide that can be folded into a one-inch cube. The answer is seven inches. A method of folding is depicted on the preceding page.

The second problem was to rule a three-inch square sheet, black on one side only, into nine one-inch squares, then by cutting and folding only on the ruled lines, form an all-black cube. I do not think this can be accomplished with a pattern of less than eight squares, but the missing square inch may be in any position. The illustration on this page shows how a pattern with the missing square in the center can be folded into the black cube.

Another USAF missile
develops from a program
which is in itself a...



Titan, America's two-stage intercontinental ballistic missile, is making giant strides—attaining new goals in U.S. missile technology. It has repeatedly demonstrated its ability to accomplish stage separation and altitude start of the sustainer engine. Equally outstanding successes in guidance and nose cone ejection-recovery are making Titan a significant contribution to our national space potential; a highly sophisticated missile system powerful enough to deliver a warhead accurately at more than 5,500-mile range.

As Titan continues to develop toward a state of operational capability, it provides another demonstration of the remarkable successes of the U.S. Air Force's ballistic missile program. This program, conceived only six years ago, has produced progress beyond expectation in an undertaking never before equalled in complexity.

Space Technology Laboratories is responsible for over-all systems engineering and technical direction for Titan, as it has been for Thor, Atlas, Minuteman and related space programs. Principal associate contractors for Titan include: The Martin Company for airframe and system integration, Avco Manufacturing Corporation for nose cone, Bell Telephone Laboratories and Remington-Rand for guidance, Aerojet-General Corporation for propulsion.

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THE AMATEUR SCIENTIST

How two distinguished amateurs set about refining the accuracy of a pendulum clock

Conducted by C. L. Stong

Elementary textbooks of physics always include an exercise in predicting the rate at which a simple pendulum swings. You divide the length of the pendulum by the acceleration of gravity, take the square root of the quotient and multiply by pi. The result is theoretically the duration of one swing. The exercise is held in somewhat lower esteem by clockmakers than by educators, because real pendulums refuse to swing at the predicted rate. In fact, no one has ever succeeded in building a pendulum that will swing at any constant rate, although scientists and craftsmen have been trying for more than three centuries. Currently, however, a promising attempt is being made by two men who have certain professional qualifications but who are nonetheless amateurs in horology. One is Vannevar Bush, who is now retired but was once professor of electrical engineering at the Massachusetts Institute of Technology, director of the wartime Office of Scientific Research and Development and president of the Carnegie Institute of Washington. The other is John Early Jackson, who is presently director of the Office of Atomic, Biological and Chemical Warfare in the Department of Defense.

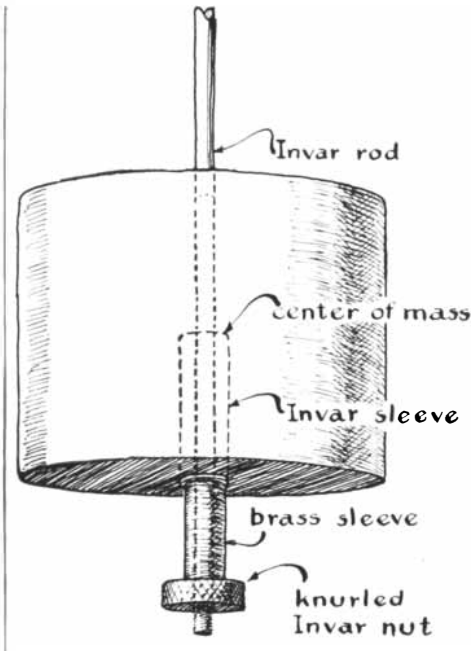
"Our collaboration in pursuing the mysteries of pendulums," writes Jackson, "got under way 10 years ago, when I received a letter from Dr. Bush suggesting that work on pendulum clocks would be 'a delightful hobby, largely because it is now a field where interest, because of modern electrical devices, has to be academic.' If there is any practical use for a really accurate pendulum (one accurate to the order of a millisecond a day), it would be in the field of gravity measurement, or in circumstances where a pendulum clock is more economical to build or to maintain than are electrical oscillators that have equal accuracy.

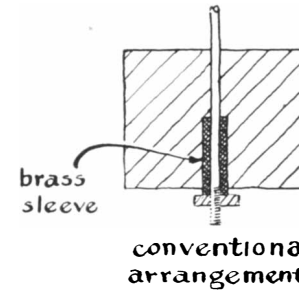
"During the past three centuries considerable progress has been made in the design of pendulums, but many improvements are still possible in the devices used to correct the well-recognized errors arising from changes in temperature and in barometric pressure, from friction in the drive mechanism and from the so-called circular error that makes a pendulum run faster when its amplitude of swing decreases. A much less known, but surprisingly large, error is caused by minute excursions of the pendulum's suspension induced by the motion of the pendulum's weight, or bob. We have investigated this error extensively and have called it support reaction. A number of other minor effects, including those arising from the influence of static electricity and of seismic motions of very small amplitude, prevents a pendulum from running at a uniform rate. Even if all these effects could be reduced to zero, changes in gravity of a tidal nature would produce periodic fluctuations of about .0002 second twice a day.

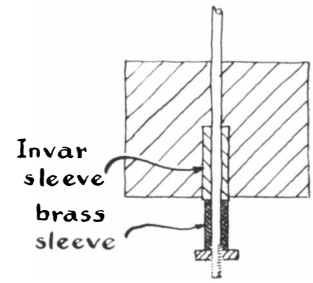
"Most of our recent experiments have been made with the aid of a clock designed by the British engineer W. H. Shortt and used by the National Bureau of Standards until it was retired from service in favor of a clock driven by a crystal-oscillator circuit. The instrument is of the 'master-slave' type and, until superseded by electronic techniques of timekeeping, was perhaps the most accurate mechanical clock available. The pendulum swings in an evacuated housing, has a rod made of an alloy that tends to retain its dimensions despite variations in temperature and is otherwise constructed to minimize the effects of environmental changes on its rate of swing. Our objective was to develop modifications for maximizing the performance of the Shortt clock and ultimately to build a clock of our own that would surpass it. As our standard of comparison we use the time signals broadcast continuously by WWV, the station of the Bureau of Standards. We have not yet built our clock, so the following discussion is in the nature of a progress report.

"Of the many variables that affect the performance of pendulums one of the most serious is temperature fluctuation. If the length of a pendulum rod changes by one part in 40,000, a clock driven by it will gain or lose about a second per day. Nearly all materials expand this much with temperature changes of only a few degrees, so it is essential to compensate in some way for the change in length. John Harrison, the eminent British horologist, made the first major contribution to the solution of the problem 200 years ago by inventing the 'gridiron' pendulum, in which brass rods in compression and expanding upward were alternated with steel rods in tension and expanding downward. The rods were arranged so that the length of the brass times its coefficient of expansion equaled the length of the steel times its coefficient. No net change in the length of the pendulum occurred when both metals expanded or contracted with temperature changes. It was an excellent arrangement, and it was widely used until it was outmoded by the invention of 'Invar' early in the present century. The small expansion-coefficient of this nickel-iron alloy permits a 40-inch pendulum rod to be compensated by only an inch or two of brass. In pendulums made of Invar the pendulum bob is bored oversize from the center down. A sleeve of brass is slipped over the lower end of the pendulum rod and rests on the adjustment nut on the end of the rod. The brass compensator supports the surrounding bob near its center of mass, as shown in the accompanying illustration [*next page*].

"This is the worst possible location for the compensator, because the relatively large thermal capacity of the 10 to 15 pounds of metal in the bob prevents the brass from reaching a new temperature as fast as the rod, which is exposed for most of its length. Consequently if the ambient temperature varies, the rod's length varies, and the clock runs at a different rate until the heavy







Methods of compensating the weight, or bob, of a pendulum for temperature changes

bob and the buried brass compensator reach the new temperature. This means that much greater care must be exercised to maintain a constant temperature than would be the case if the rod and its compensator had more nearly equal thermal masses and exposures, as did the original gridiron construction.

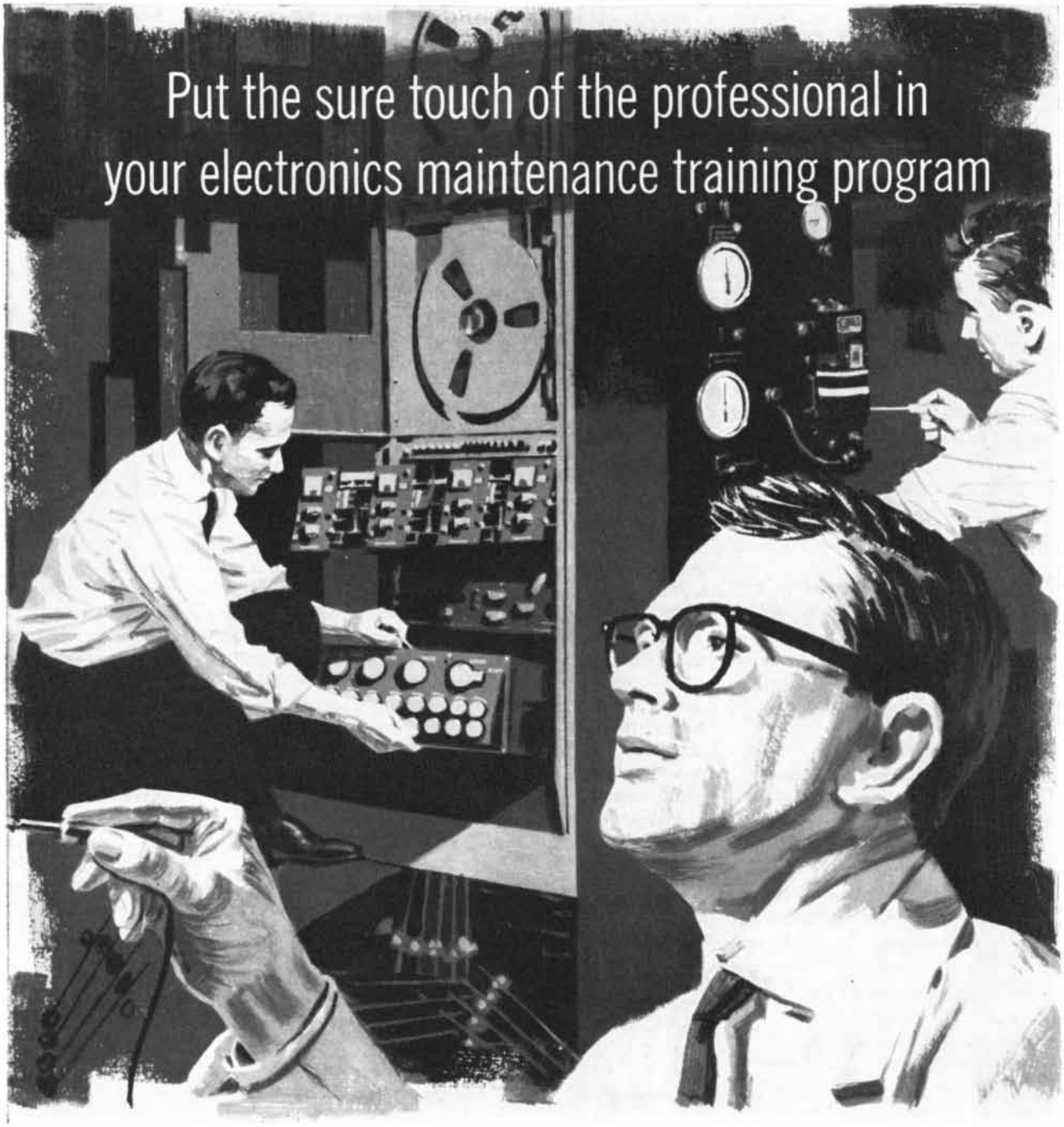
"An easy remedy is to add an Invar sleeve, similar to the brass compensator, to extend up into the bob, thus allowing the brass sleeve to be exposed below. It is still desirable to hold a fairly uniform temperature and particularly to guard against temperature stratification of the air. This can be taken care of relatively easily by constructing a closet of light insulating wallboard around the entire clock, by placing an electric fan inside the closet to provide continuous air movement and also by fitting the closet with a thermostatically controlled electric heater to hold the temperature a few degrees above the highest temperature expected in the room.

"For extreme accuracy it is desirable to compensate different parts of the rod separately. An ordinary brass or aluminum compensator can be placed inside the bob to take care of that portion of the rod which runs through the bob, while the exposed rod and suspension spring are compensated by brass or by aluminum members having thermal capacities similar to the parts they compensate.

"A pendulum rod is usually supported by a thin spring, though all pendulums used to measure gravity are supported by a knife-edge arrangement. Springs are probably better for continuous operation, because they are not subject to wear. Our experiments have shown that even the thinnest practical spring can exert a force equal to a thousandth of the force of gravity acting on the bob. This means that a spring-suspended pendulum is not a pure gravity-controlled device, and that extreme care is needed to keep the force of the spring constant. The stiffness of most spring materials changes with temperature. The coefficient of elasticity of steel changes about 200 parts per million per degree centigrade, and may change the rate of a pendulum clock a 10th of a second or more per day with a one-degree change in temperature. This can be taken care of in the compensation of the rod, but only if the compensator responds at the same rate as the spring. Hence the need for a well-exposed compensator of low thermal capacity, unless a material like 'Elinvar' or 'Ni-Span C' is used for the spring. These materials exhibit little or no change in elasticity with temperature, but their characteristics may change over long periods of time. Further experiments are desirable to determine the best material.

"The spring must also resist side-thrust produced by the inertia of the rod and bob as they oscillate about their common center of mass. A very light rod is desirable if a thin spring is used. In general a given spring will affect the rate of a short pendulum more than a long one, if each pendulum has a bob of equal weight.

"It has frequently been noted that



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clocks do not run at the same rate after they have been stopped and then started again. In many cases the pendulum rod is attached to the spring by means of a hook that hangs on a pin through the spring or its clamp. This facilitates assembly and permits motion at right angles to the plane of oscillation when the pendulum is adjusted. It is most important that the contacting surfaces of such a hook be V-shaped, rather than round, to assure that the length of the pendulum remains constant [*see illustration on this page*].

"Attention should also be given to electrostatic forces that can, under certain circumstances, greatly affect the rate of a pendulum. A beat plate that moves very close to the bottom glass plate, as in the Shortt design, can be strongly attracted by stray static charges on the glass. A remedy for this is small pieces of polonium foil, such as is used in antistatic brushes for photographic work, which can be glued to the inside and outside of the glass near any moving parts of the pendulum system. These brushes can be purchased at most photographic-supply stores, and the polonium foil can be removed from them, though great care must be taken to prevent rupture of the thin protective coating over the polonium. The foil must not be allowed to come in contact with the bare skin. Alpha-particle emission from the polonium ionizes the air sufficiently to prevent any accumulation of electrical charge.

"That electrostatic forces can be a matter of serious concern to pendulum-clock makers is illustrated by our experience with an air-drive escapement that will be described in a later article. It was necessary to provide a moving vane to switch the air from one jet to another to give an impulse in each direction as the pendulum swings from side to side. Various metallic stops were tried, to limit the movement of the vane on each side, but all stuck after a few hours of operation. Tiny glass stops proved satisfactory for several days of operation, but they also stuck eventually. A piece of polonium foil placed near them cured the trouble.

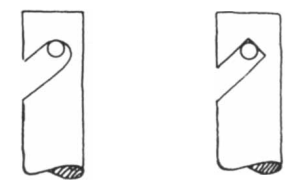
"Of course if the clock case is made entirely of metal, or is properly shielded on the inside, static cannot cause trouble unless there are insulated metal or nonmetallic parts on the moving system. Such nonmetallic parts should be covered with a conducting paint of the type used to ground the outside surface of a television picture-tube. (The paint should make contact with the metal parts of the pendulum.)

"The effect of changes in barometric pressure, which varies the flotation of the bob, and hence its rate of swing, has been handled in all precise pendulum-clocks by the rather clumsy expedient of sealing the pendulum in an airtight case. Aneroid units mounted on the pendulum to raise and lower weights have, in general, been unsatisfactory. Much can be done to improve the design of the case seals, so that the case can be easily opened and closed. We have found, for example, that a fine-threaded metal screw-cap, sealed with an ordinary rubber jar-gasket covered with stopcock grease, is satisfactory for frequent access to the weight pan or other parts during the adjustment period.

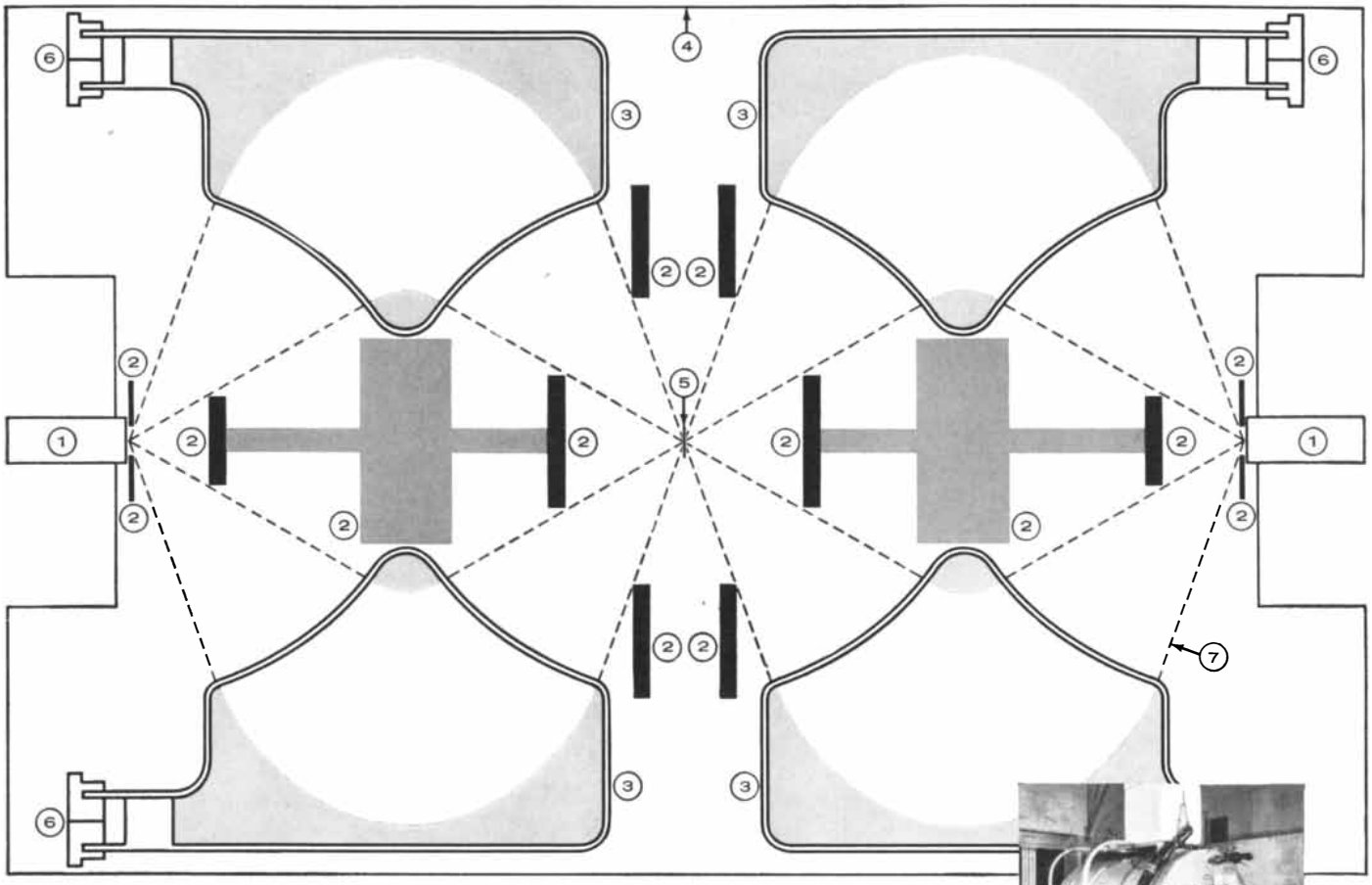
"In addition to flotation of the bob by the air there is a so-called inertia effect caused by the movement of the air as the bob swings. The magnitude of this effect varies with the design of the bob and the case, generally being greater if the case is small and less if the bob is streamlined. Obviously the effect will disappear completely if the pressure of the air is sufficiently reduced. Both the flotation and inertia effects were found to be directly proportional to pressure, producing a uniform increase in rate with reduction in pressure.

"The 'seconds' pendulum of a Shortt clock, fitted with a 14-pound cylindrical bob made of type metal and modified for an electromagnetic drive, runs about 12 seconds a day faster at a pressure of one centimeter of mercury than at 76 centimeters (normal atmospheric pressure), when the arc of swing is held constant at 1.5 degrees. This is about .4 second per day per inch of change in the barometer. If the bob were made of denser material or better streamlined, the change in rate would be less.

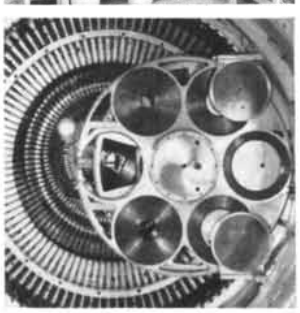
"In general the lower the pressure the better the pendulum will perform, provided that a really good escapement, or drive mechanism, is used. Hermetically sealing the case provides a convenient method of fine rate-adjustment by permitting control of the slight remaining pressure in the case. A sensitive pressure-gauge, or short-tube mercury ba-

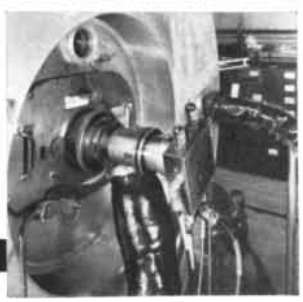


Two designs for a pendulum hook



1 Detector, **2** Baffle, **3** Spectrometer Coil, **4** Vacuum Chamber, **5** Beta Radioactive Source, **6** Cooling Water Supply, **7** Dashed lines represent beta-ray trajectories in the instrument.





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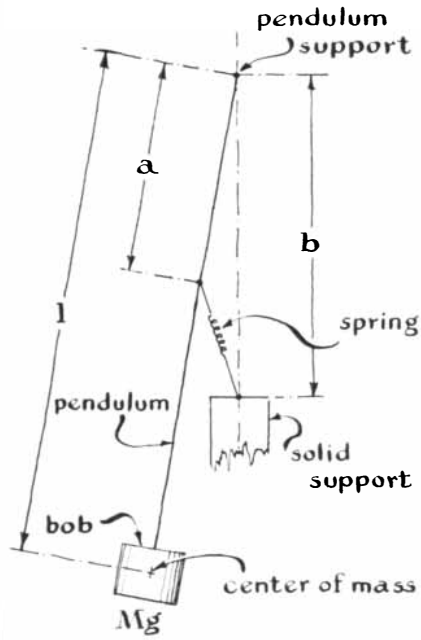
rometer, should be enclosed in the case to aid this adjustment and to indicate any air leakage. At atmospheric pressure, outside barometric changes producing an internal volume-change of one part in 15,000 can cause a one-millisecond-per-day change in rate, but at low internal pressure the rate of change is much less.

"Conventional pendulums swing in a circular arc, the restoring force of gravity varying with the trigonometric sine of the angle from the vertical. This causes the period to increase with the angle of swing, the effect known as circular error. Three hundred years ago Christiaan Huygens suggested a theoretically perfect method of making a pendulum bob swing in a cycloidal arc; he showed that this would result in simple harmonic motion and thus make the period independent of the length of the arc. The proposal required that a cam with a face in the shape of a cycloid be fixed on each side of the flat suspension spring. As the spring bent alternately around each cam, the path of the bob would become cycloidal. Unfortunately the cams cannot be made and installed to the required precision. All attempts to apply Huygens's theoretical solution to a real pendulum have introduced greater errors than the one it is designed to correct. So far as is known, no practical circular-error correction scheme has ever been used by the makers of precision pendulums, and none could be found in the available literature. Accordingly we have concentrated on this problem and have designed and tested what we believe to be the first practical arrangement for correcting circular error.

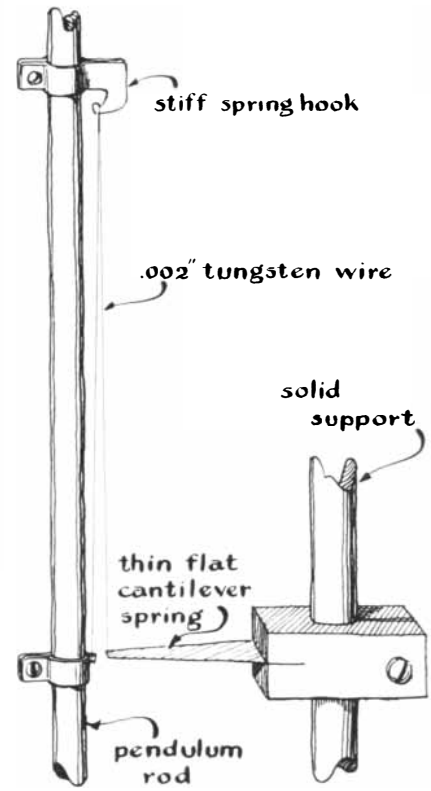
"The device consists of a fine wire connected from a point on the pendulum rod to a very weak fixed spring having a spring constant, K, defined by the equation in the accompanying illustration [*below*]. The spring should be made of Elinvar or a similar material having a negligible temperature-elasticity coeffi-



$$K = \frac{Mgl(b-a)^2}{3a^2b^2}$$

where:

- K = spring constant in lbs per inch deflection
- Mg = weight of bob in lbs
- l = length of pendulum in inches
- b = distance from spring support to pendulum support in inches
- a = distance from spring attachment to pendulum support in inches



A circular-error corrector. Theoretical arrangement is at left; practical arrangement, at right

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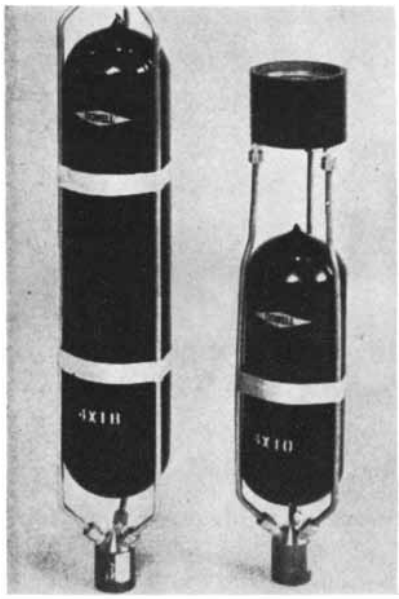

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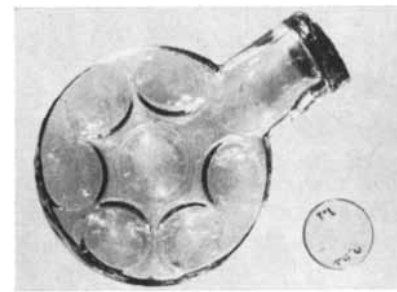

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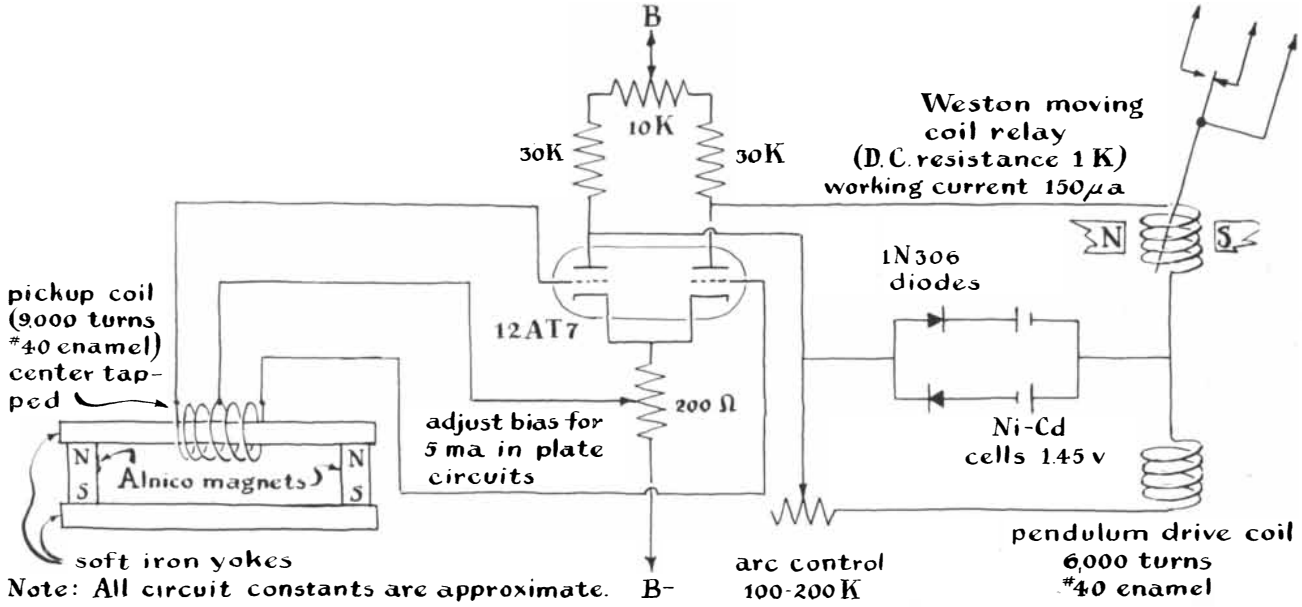


Circuit diagram for an electronic pendulum drive

cient. Tungsten wire .002 inch in diameter provides excellent strength, elasticity and endurance. A cantilever spring, in the form of a horizontal flat strip anchored to the support at one end and fastened to the wire at the other, gives even better correction, and is easier to calibrate than a spiral spring. The spring should be mounted so the tension in the wire will not be affected by temperature changes. This calls for careful temperature compensation of its supporting rod or bracket, as well as of the wire itself.

"Temperature compensation for the wire alone can be provided by fastening the upper end of the wire to a relatively stiff spring on the pendulum rod, and stretching a similar wire of equal length from this spring to a point on the rod opposite the lower end of the first wire, with enough tension to stress the stiff upper spring. The lower end of the first wire will then move the same amount as the pendulum rod does at the point level with the attachment of the second wire. In addition the rod carrying the circular-error spring should be made the same size and of the same material as the pendulum rod, and be attached to the same support. The two expedients in combination give perfect temperature compensation.

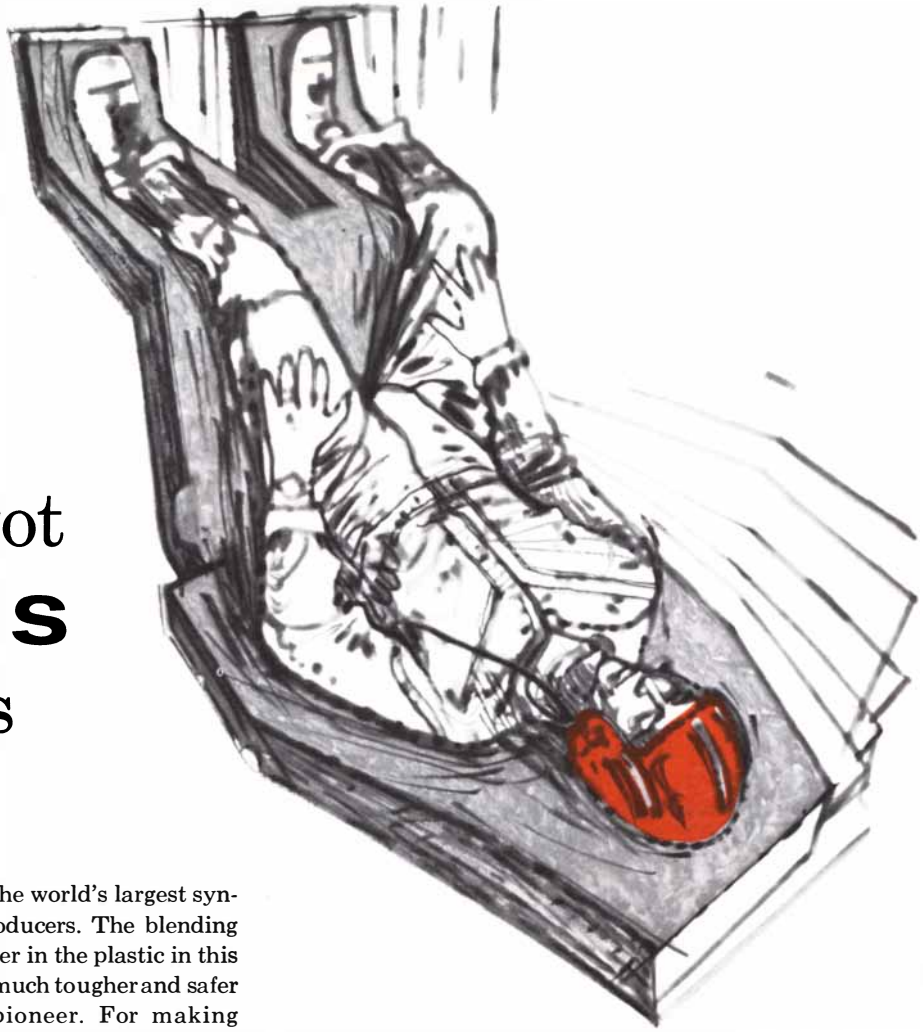
"The system is sensitive to misalignment in the relative positions of the spring and pendulum rod and is therefore subject to malfunction if the mechanism is tilted from the vertical after adjustment. For very precise work a pendulous mounting of both the circular-error spring and the whole pendulum system is required. If the clock is mounted on a reasonably solid wall, however, the spring can be supported on a rod, similar to the pendulum rod, that is steadied at its lower end by attachment to the case. Such a mounting arrangement will considerably improve the performance of most pendulums.

"The spring-and-wire arrangement provides a restoring torque to the pendulum, in addition to that of gravity (but only about a 40,000th as great), which for small angles is very nearly equal to the difference between the angle of swing and the sine of that angle. This causes the pendulum to oscillate in simple harmonic motion, with the total restoring force proportional to displacement, thus freeing it from circular error and making the period of oscillation independent of arc length for angles of practical interest up to three or four degrees.

"Much ingenuity has been exhibited over a period of many years in the design of clock escapements (mechanisms that keep the pendulum going) and several excellent ones have been made. Most have been based of necessity on mechanical methods or simple electromechanical devices that involve the use of make-and-break electrical contacts, limiting the amount by which error can be minimized. It is now possible to apply electronic techniques to the problem of pendulum drive with a high degree of confidence in their long-term constancy and reliability.

"If a pendulum receives a driving impulse before it reaches dead center, the rate of swing is increased; if it receives an impulse after it has passed dead center, the rate is decreased. Conversely, a retarding force applied before the pendulum reaches dead center reduces the rate, while one applied after the pendulum has passed dead center increases it. Most escapement designs therefore attempt to apply a driving force that is symmetrical about the center of swing, so that any effect on rate before dead center is reached is canceled by an equal and opposite effect afterward. In the case of mechanical escapements this is extremely difficult to accomplish. Even with a perfect mechanical design there would be no easy way to adjust the mechanism so that the impulse would split the dead-center position exactly. Assuming that this could be accomplished, any slight shift of the case or support would disturb the adjustment and thereby introduce a change in rate. Any retarding force (such as is needed for unlocking escapements of certain designs) must also be perfectly constant and equal on both sides of the swing and must occur at the same position in the cycle of swing.

"The so-called free pendulum of the Shortt clock gets around the unlocking troubles by using a cleverly synchronized 'slave' pendulum to do this work, together with an electrically tripped and reset weight, or gravity arm, which drops on the rim of a small wheel on the moving pendulum rod to produce the driving impulse. This is perhaps the best escapement heretofore devised, and some Shortt clocks have established rec-



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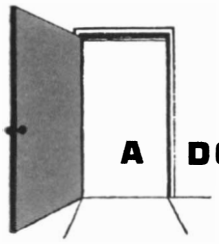
ords of astonishing accuracy. The indirectly tripped gravity-arm escapement also has the advantage of applying an extremely constant driving-force to the pendulum and hence of maintaining the length of the arc at an impressively constant value. Our experience has shown, however, that changes of only a few seconds of arc can produce unacceptable changes in rate unless the Shortt pendulum is compensated for circular error. Even if the driving force and the friction losses in the drive mechanism were to remain absolutely constant, which they seldom do for long, slight changes in support losses (energy spent in moving the structure to which the pendulum is attached, which must be supplied by the clock drive) would result in changes in the length of the arc.

"An escapement that produced a genuinely constant driving-force, or one perfectly symmetrical about the center throughout the entire swing, would have no effect on the rate of a pendulum, because any increase in rate produced during the swing to dead center would be exactly canceled by an equal decrease in rate after dead center. Even if the driving force were not symmetrical about the center, but were duplicated exactly in each direction, any error produced in the full swing one way would be canceled on the return swing.

"An escapement that meets these requirements is now relatively easy to produce by means of an electromagnetic drive, although we found none described in the literature. We have made one and believe that it is unique. It consists of a center-tapped coil of fine wire carried by the pendulum and arranged to swing in a reasonably constant magnetic field. This coil generates a voltage that would be a perfect sine wave if the magnetic field were uniform. But irrespective of its wave form the voltage goes through zero and changes sign precisely at the end of each swing, and the two halves of the full cycle are symmetrical.

"This voltage is fed to the grids of a push-pull amplifier, the output of which goes to another coil mounted on the pendulum. This coil moves in a similar, but not necessarily identical, magnetic field. The reaction between the second coil and its magnetic field drives the pendulum. The magnitude of the driving current can be controlled by a series resistor that regulates the driving force, and hence the length of swing.

"The power output of such an arrangement is unstable. If the arc does change slightly, the magnitude of the voltage generated and the resulting driving current change proportionally, thus



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Answers to such questions make up the contents of a new booklet prepared by Allied Chemical. Entitled "High Polymers," it is offered free to anyone equipped with a company letterhead and a 4¢ stamp.

Importance of polymer research

More and more, as chemists build molecules and arrange them to achieve desired properties, the relationship between properties and molecular structure increases in interest and importance. For there is more implied here than mere addition to the vast array of materials at man's disposal. Here is promise of new light on the life sciences. Polymer chemistry has been aided by the study of natural polymers. Conversely, the study of man-made polymers can be expected to advance our understanding of living matter.

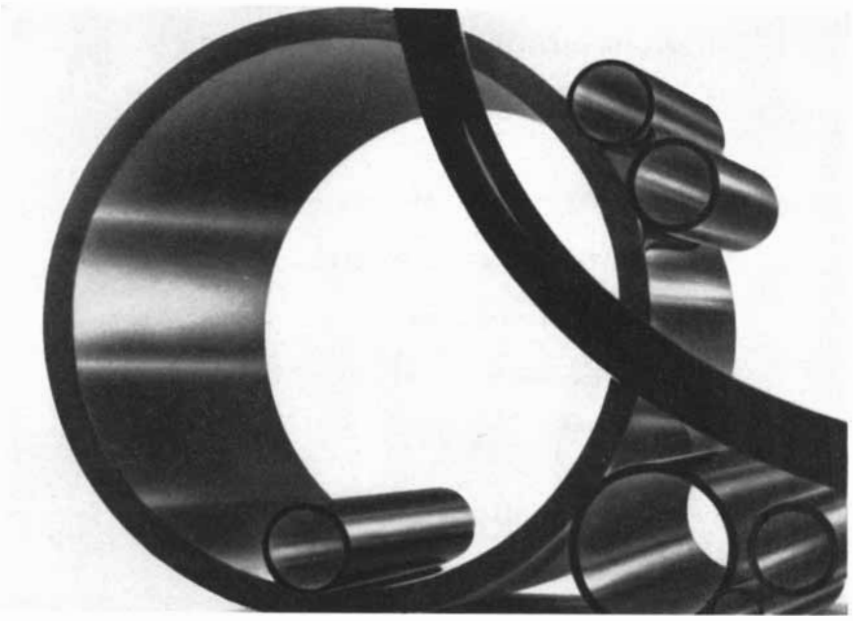
How polymers are made and modified

The booklet points out that there are nearly a dozen methods of creating and modifying polymeric materials. There are "simple" ones, like the blending of rubber into polystyrene to impart impact strength to this highly brittle plastic . . . or incorporating plasticizers into polyvinyl chloride to make it less rigid. Other procedures are highly sophisticated. The use of monomers to carry desired properties directly into the finished polymer—as with the promising new polycarbonate resins—would be a case in point. Then there is the "marriage" method—joining two different polymers in the same molecular chain—resulting in molecules with the properties of both parents. "Grafting"—the tacking of side chains onto the main polymer chain—is another.

Polyethylene—outstanding example

Polyethylene, you will learn from this booklet, is an excellent example of polymer modification, several different methods having been used. It's an "addition" polymer, formed by direct end-to-end linkage of small molecules (monomers) of the simple gas, ethylene. The first plastic to reach an output rate of a billion pounds a year, it is used in the familiar forms of packaging materials, squeeze bottles and unbreakable toys.

Polymer research at Allied Chemical, by the way, has carried polyethylene far beyond these familiar uses. Our Semet-Solvay people have come up with an emulsifiable grade for upgrading water-based products such as textile finishes and washable paints . . . as well as a high-density polyethylene pipe compound with a "life expectancy" of about 50 years.



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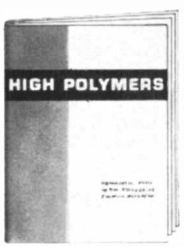
BASIC TO AMERICA'S PROGRESS

Spaghetti—cooked and uncooked

The booklet also covers one of the most fascinating aspects of high polymer structure—namely, that materials formed from giant molecules may occur in either the amorphous or crystalline state. Hence the spaghetti analogy. Amorphous polymers, with molecules in a random tangle, are much like *cooked* spaghetti. Crystalline polymers, with more or less regular structure, can be likened to bundles of *raw* spaghetti. We won't attempt to explain the significance of this phenomenon in the confines of this page—merely suggest you write for your copy of "High Polymers" soon. You may find it somewhat *al dente* in spots, but informative, we're sure.



Anyone interested in the general subject of high polymers or who is working with them will find this booklet of value. *For a free copy,* just write, on company letterhead, to Allied Chemical Corp., Dept. 76-S, 61 Broadway, New York 6, N. Y., or phone HA 2-7300.

maintaining the new arc. This defect can be corrected by connecting a device in the circuit (a so-called nonlinear element) to prevent the output current from changing in direct proportion to the input voltage. A simple diode clipper-circuit, for example, and a couple of small nickel-cadmium storage batteries accomplish this quite satisfactorily. With the proper design, Zener diodes, which require no batteries, might be used. Incidentally, these special diodes, which begin to conduct suddenly when the voltage reaches a certain fixed value, are now replacing standard-voltage cells in electrical measuring instruments.

"The magnetic-field-and-coil arrangement and the electronic circuit that we have used to drive the Shortt clock are shown in the accompanying illustration [*page 172*]. Each half of the voltage pickup coil consists of 4,500 turns of No. 40 enameled wire wound on a spool that moves along a 3/16-inch iron bolt between two Alnico magnets, each about 3/4 inch by 1/2 inch by 1/4 inch. The drive coil has 6,000 turns of No. 40 wire and moves in a similar magnetic field. Both coils are mounted below the bob, and the metal parts of the pendulum are magnetically shielded with stationary sheets of highly permeable material to prevent magnetic attraction or eddy-current effects from changing the rate of the pendulum.

"At full atmospheric pressure the Shortt pendulum requires only about 1.5 microwatts of driving energy; at a pressure of one or two centimeters of mercury it needs only about a fifth of this power. The electromechanical efficiency of the driving system can therefore be quite low. Substantially the full output of the push-pull amplifier is used to keep the batteries charged, to replace the losses due to the series resistor and to operate a relay for counting seconds. Power for the amplifier is provided through a voltage-regulating transformer. The entire electronic circuit is mounted inside the constant-temperature enclosure built around the clock.

"The relay, inserted in series with the clipper, serves to actuate the dial mechanism of the Shortt clock, but the accuracy of its closure is not better than about 10 milliseconds—at least an order of magnitude worse than the pendulum itself. For this reason we installed a photoelectric cell, which is energized by a light beam reflected from a mirror on the pendulum, to generate time pulses. These are compared with WWV signals by means of an oscilloscope. The pulses are also used to operate a relay or chronograph, as desired."

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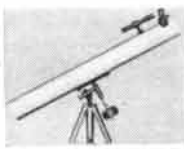

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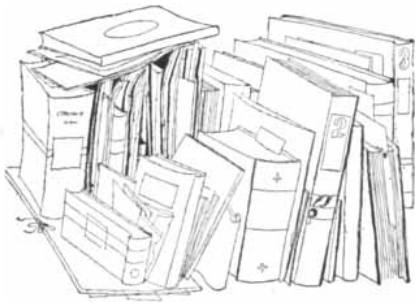

BOOKS

An examination of the history and the present state of science fiction

by James R. Newman

NEW MAPS OF HELL, by Kingsley Amis. Harcourt, Brace and Company ($3.95).

One either likes science fiction or one doesn't; there's no ought about it either way. Not to like it is no proof in itself that one is a cultivated chap, above that sort of thing; nor is being a fan proof that one has a low mind or that one is a great man seeking relaxation and escape in this corner rather than in Westerns or detective stories. I myself am not an addict, and I have never quite understood, I must confess, how one gets hooked. It happens, I have now learned, in adolescence or not at all, like addiction to jazz. It is not unusual, according to my source, for the same person to have contracted both addictions. This is not surprising if one considers how much the two modes have in common. They came to flowering at about the same time—the 1920's—and underwent mutations around 1940; in their present form they are characteristically American products "with a large audience and a growing band of practitioners in Western Europe." Both have a "radical tinge." That is to say, science fiction shows the tinge in its social caricatures; and jazz, though its cacophonies and offbeats may not represent the brand of subversion that literal-minded Congressional investigators can get their teeth into, shows its radicalism in the attitudes of those connected with it. Neither science fiction nor jazz has produced absolutely first-rate artists (I shall doubtless have to take cover on this), but they have turned up gifted and interesting practitioners; both "have arrived at a state of anxious and largely naïve self-consciousness; both, having decisively and for something like half a century separated themselves from the main streams of serious music and serious literature, show signs of bending back towards those streams." Finally, both science fiction and jazz have established themselves so firmly as to attract the attention of the "cultural diagnostician" or "trend hound." Liking science fiction for itself is one thing; coming to it like a microbe hunter, to see where it breeds, who is most susceptible to it and so on, is quite another thing. Not always a bad thing, to be sure, but not necessarily a good thing either, and apt to be pretentious.

The source to which I am indebted for these insights is Kingsley Amis's elegant and entertaining little book, based on a series of lectures he gave in 1959 as one of the Christian Gauss seminars at Princeton University. Amis has written some very funny novels, and he is a wit in the best sense: perceptive, sympathetic and impatient of intellectual heavies. Collegiate seminars on criticism are not often favored with his kind of felicitous impudence; the audience must have been delighted. What he gave them was a thoughtful, wholly unpretentious, amusing and self-amused survey of a branch of writing that deserves just such treatment. The lecturer neither goes overboard nor goes slumming; science fiction, as he makes clear, is not "tomfool sensationalism, but neither is it a massive body of serious art destined any moment to engulf the whole of Anglo-American writing." It is a story form that provides entertainment to many, possesses, at its best, elements of genuine literary quality, and is an interesting social and psychological phenomenon.

How is the form defined? "Science fiction is that class of prose narrative treating of a situation that could not arise in the world we know, but which is hypothesised on the basis of some innovation in science or technology, or pseudo-science or pseudo-technology, whether human or extra-terrestrial in origin." Science fiction, as Amis emphasizes, is to be distinguished from fantasy. To get to the stars in a hurry you apply a "space-warp" (which Bernhard Riemann and Albert Einstein would have found quite natural), or you put your craft into "hyper-drive" (which sounds more reasonable than what is promised for a new Buick). To spend an evening with Madame DuBarry, you turn on your time machine, and zip—there you are. Mr. Midas, who owns a Greek restaurant in the Bronx, saves the life of an extra-terrestrial who is living in New York anonymously as an observer for the Galactic Federation; in gratitude, the extraterrestrial, who is "a master of sciences far beyond ours, makes a machine which alters the molecular vibrations of Mr. Midas's body so his touch will have a transmuting effect upon other objects." Thus the Midas myth in modern garb. All this is science fiction. Fantasy, on the other hand, deals in elves, broomsticks, pixies, cromlechs, occult powers, incantations. Every pretense at a rational explanation is abandoned. (The difference is important, and one might be tempted to say portentous things about it. Amis isn't.) To be sure, there are borderline cases. The vampire, for example, is a staple of 19th-century fantasy; but in his novel *I Am Legend* Richard Matheson makes use of the myth for science-fiction purposes, whereby everything is rationally explained. In our day, in any case, fact is stranger than science fiction. The universe is changing, as is our notion of it; even our tiny environment has queernesses and monstrous possibilities. A nuclear war would produce some strange shapes; maybe not giant ants or "armour-plated, radioactive, supersonic pterodactyls," but can one be absolutely sure? Put it, then, that the borderline between science fiction and fantasy is hard to draw. Still, there is a difference.

Amis sketches the ancestry of the form. The learned dispute the origins. Some point to the Atlantis items in Plato's *Timaeus* and *Critias,* or to Aristophanes' *The Birds;* others prefer the interplanetary voyage recounted by a second-century Greek prose romancer, Lucian of Samosata. On his trip to the moon there is an encounter with some women who are grapevines from the waist down; the men in the moon are of fantastic appearance and habits, but they are not menacing. (The notion of "nasty aliens"—aliens are non-earthlings—is a comparatively recent one.) Jo-

hannes Kepler describes a moon voyage, as does Bishop Godwin in 1638, the latter's craft being drawn by wild swans; Cyrano de Bergerac's traveler gets to the moon in a chariot powered by rockets. The first visit to the earth by an alien is in Voltaire's *Micromégas*. *Gulliver's Travels* clearly has a place in the line, for two reasons. First, Swift was at pains to make the details of his stories rational, that is, non-magical; like Jules Verne he "counterfeited verisimilitude." Second, he invented satirical Utopias, blending ingenious invention and powerful social criticism, which is characteristic of much of contemporary science-fiction. (On this point Thomas More's *Utopia* and Francis Bacon's *New Atlantis* also deserve notice. Bacon's island, particularly, boasts all kinds of technological marvels.)

The paleontologist of science fiction may sniff at many of these earlier examples, but he will concede that Mary Shelley's *Frankenstein* was a major progenitor. His descendants, and those of his monster, are all over the place: mad and malevolent scientists as well as mild eccentrics who mean well but lose control over their creatures. Two big themes are descended from the original book: robots which turn on their master (Karel Capek's *R.U.R.*, published in 1920, was the classic modern treatment of this notion) and "functionalized sermons on the dangers of overgrown technology." Amis also mentions as a *Frankenstein* descendant the stock figure of the "morally irresponsible researcher indifferent to the damage he may cause." I am not sure that the figure is confined to fiction.

Verne, with his technological Utopias and his pessimism about invention overreaching itself, was of course a pioneer of modern science-fiction. The literary quality of his stuff is not high, but some of his yarns are fascinating, and he never ran out of ideas. His foresight was remarkable. In *Five Weeks in a Balloon* (1862) there is the following dialogue:

" 'Besides,' said Kennedy, 'the time when industry gets a grip on everything and uses it to its own advantage may not be particularly amusing. If men go on inventing machinery, they'll end by being swallowed up by their own inventions. I've often thought that the last day will be brought about by some colossal boiler heated to three thousand atmospheres blowing up the world.'

" 'And I bet the Yankees will have a hand in it,' said Joe."

The other major creator of the modern form was H. G. Wells. Wells was much less interested in pseudo-science than Verne was, and he was also an incomparably better writer. For him the story was the thing; scientific verisimilitude, a minor matter. Time machines and Martians (*The War of the Worlds*), monsters (*The Food of the Gods*), invisible men, carnivorous plants—these were used to entrance the reader, to create suspense and excitement rather than to satirize or weave an allegory. Their influence on science fiction, especially of the pre-1940 vintage, was immense. But there were other Wells stories, little mentioned and apparently not influential in shaping modern developments, that forecast the modern satirical Utopia with "fantastic exactness." "A Story of the Days to Come" has such features as advertising bawled out of loud-speakers, phonographs replacing books, vast technological unemployment, with the idle supported by a kind of "international poorhouse called the Labor Company," huge trusts that own everything, children brought up in state crèches, hypnosis as a cure for antisocial traits, dreams that can be obtained to order; and, as an especially edifying touch, men use depilatories instead of shaving.

In 1926 Hugo Gernsback founded *Amazing Stories*, the first magazine entirely dedicated to science fiction. The event was part of a struggle for recognition and existence, because science fiction was still beleaguered by fantasy stories and by space operas, both of which attracted more readers. Space operas, as Amis explains, are like horse operas, with Mars taking the place of Arizona, ray guns replacing six-guns, bad aliens with green skins substituting for outlaws, and bug-eyed monsters, known as Bems, for Indians. (Bems, by the way, which have tentacles and V-shaped mouths, were a Wellsian invention.) Gradually, however, science fiction edged ahead in the competition with Bems, galactic hoodlums and scantily clad virgins.

Around 1940 the present era began. Where there had been five science-fiction magazines in 1938, there were 22 in 1941. There was, of course, no sudden transformation of imbecility into literary excellence. Plenty of mad scientists were still running around; also on the scene were king-sized ants, king-sized sirens in "abbreviated shorts and light cotton sweaters," handsome supermen, and monsters with yellow fangs and massive paws that could rip away a 15-year-old girl's clothing. But the adult was at least "co-present with the stupidly or nastily adolescent."

Amis admits that a science-fiction magazine, even in the new era, does not at first glance look too promising. A title such as *Fantastic Universe* or *Astounding Science Fiction* is not calculated to tempt the fully developed brain. The magazine cover is likely to be either crudely sensational or crudely whimsical; it may picture a multi-armed alien Santa Claus. The inner pages advertise trusses ("Wouldn't trade mine for a farm," says the testimonial of an agricultural user), Rosicrucianism, royal jelly (prolongs life), hand grenades ($1 for an exact replica), "stuffed girls' heads." The contents, however, are at least in part on a somewhat higher level.

Amis samples the October, 1958, issue of *Astounding Science Fiction*. One story, "The Yellow Pill," introduces a psychiatrist in New York who is trying to cure a patient of the delusion that they are both on a space-ship in flight: the psychiatrist takes the yellow pill (an "anti-delusion compound"), presumably to encourage the patient to follow suit, and finds himself aboard a space ship; the patient, taking no pill, imagines himself cured and walks out of the door—leading into empty space instead of the outer office. "Big Sword" is about a small boy who sets up telepathic communication with the tiny aliens of a distant planet and then persuades his earthling elders, who are about to set off on an expedition to destroy the little creatures, that they are friendly and should not be murdered but helped. Another story is about some "amiable visiting aliens" who run out of food; another "shows alien and man agreeing to overlook the differences of appearance and habit that repel or frighten each of them and so coming to an understanding."

Most of this may strike you as moderately dull, but it isn't vicious or incendiary or corrupting. There are no mad scientists, no Bems, giant newts or huge hairy spiders. The alien races are all friendly. There is a moral, however faint, in most of the stories: communication breeds understanding, which breeds tolerance. There is not much science, pseudo-science, technology or sex. This is fairly representative of the content of the other magazines, says Amis, and of the new science fiction as a whole. (The books—the current annual crop is between 150 and 200—are either anthologies of short stories reprinted from magazines, or novels that can be traced back to the magazines, either in serial or in rudimentary form.)

It may be that the trend toward uplift has held down the number of readers; at any rate, science fiction has no mass audience. *Galaxy* sells about 125,000 copies per an issue in the U. S. (there are also foreign editions; the Swedes are special fans); *Astounding* sells

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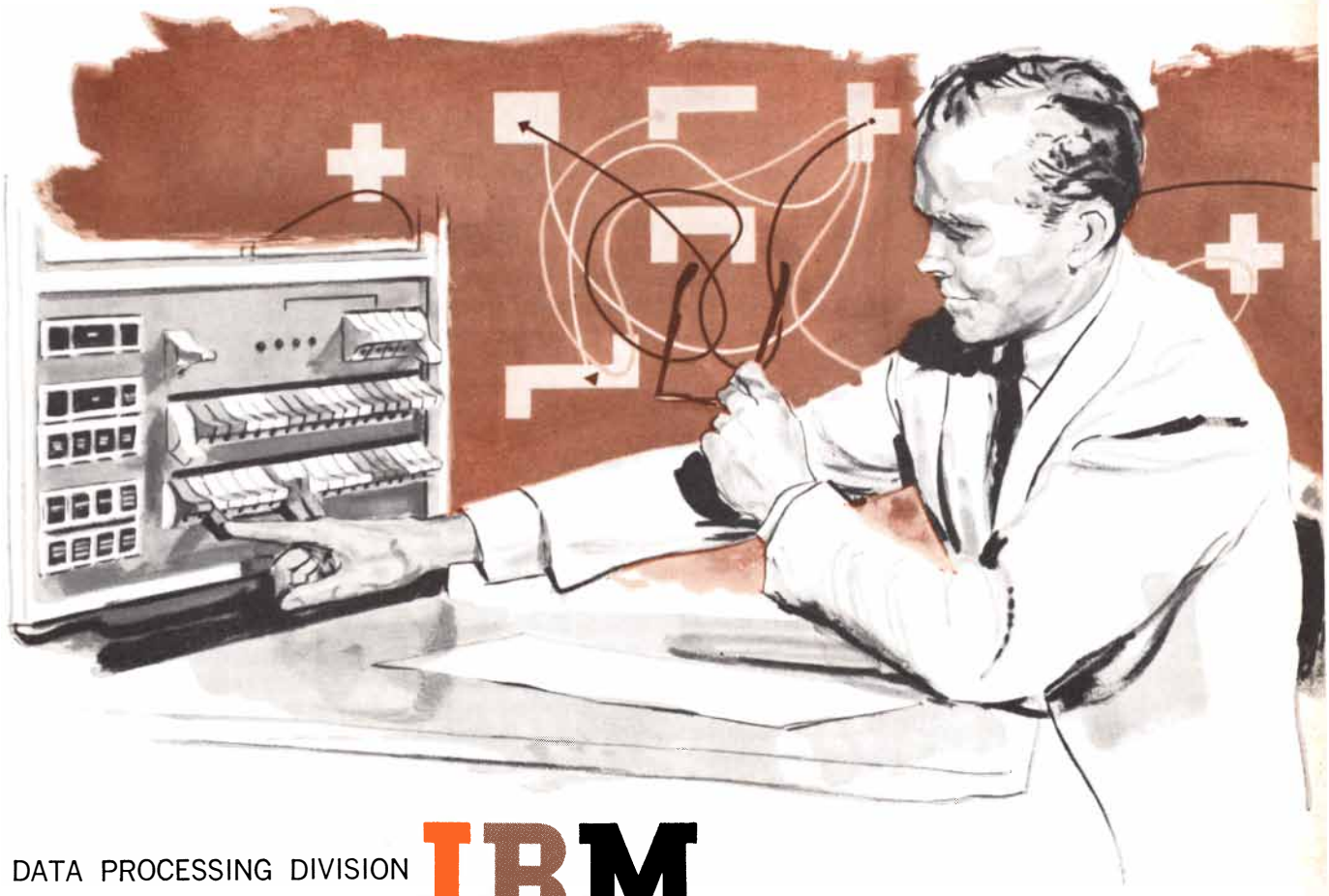

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100,000 copies in this country, 35,000 copies in England, and has subscribers in the U.S.S.R. and China; *Amazing* sells 50,000. The total science-fiction readership, then, comes to around half a million. But it is a faithful audience, given to banding together in fan clubs. These are found all over the U. S., the highest concentration being on the West Coast. They often meet weekly and even print their own fan magazines. They have such names as "The Elves', Gnomes' and Little Men's Science Fiction, Chowder and Marching Society," and "The Little Monsters of America." Every year there are regional conferences and a three-day world convention. The clubs are inclined to be politically liberal, especially on racial questions; once a Communist group from Brooklyn formed an Association for the Political Advancement of Science Fiction.

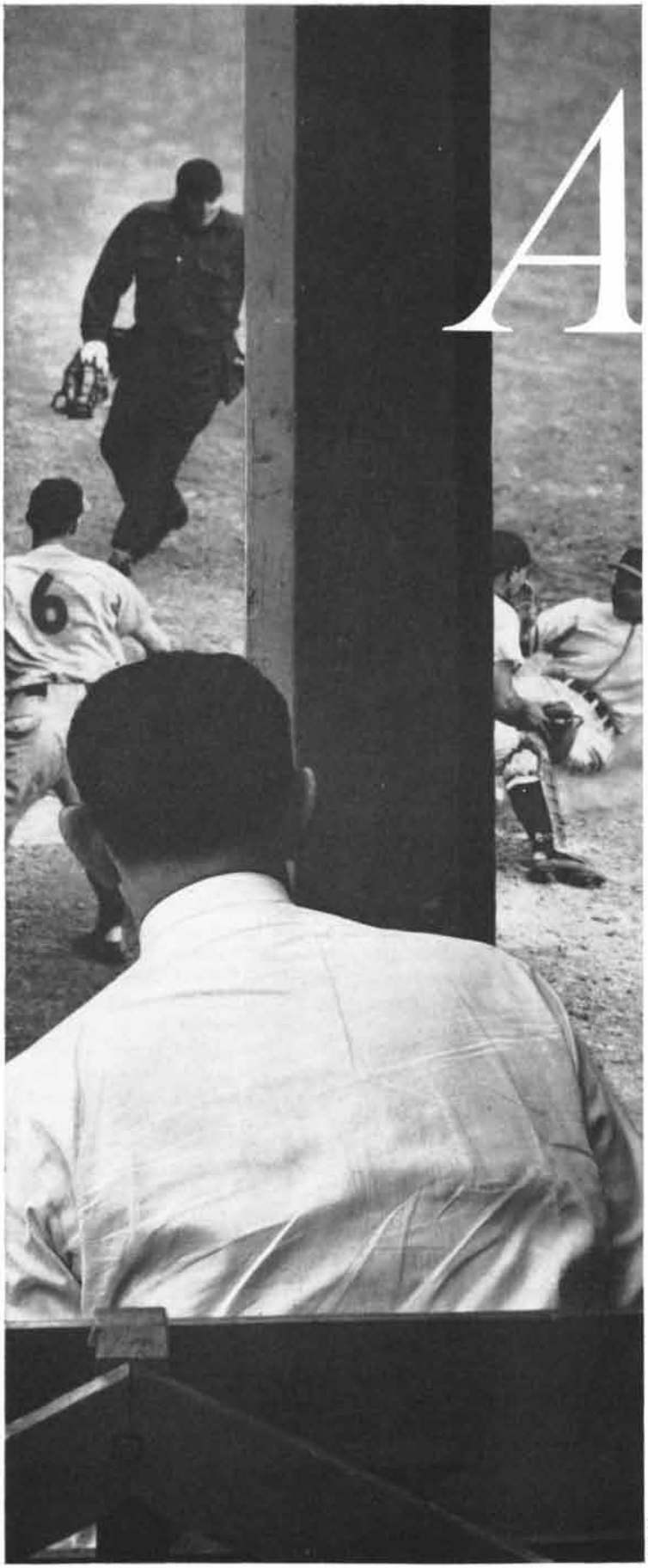
Many more men than women read science fiction, and the audience has a technological or scientific bias. Amis's studies show that engineers and scientists account for perhaps 40 per cent of the readers. That there is a healthy spread in occupational distribution, however, is evidenced by L. Sprague de Camp's anecdote (he has written an authoritative handbook on science fiction) which tells how a science-fiction writer, "happening to visit a New Orleans bordello, found his works so popular with the staff that he was asked to consider himself their guest for the evening."

The anecdote should not be taken as proof of widespread dissoluteness among science-fiction writers. Licentiousness is apt to be expensive, and the financial rewards of science fiction are not high. It is therefore often a secondary occupation of men who teach science or do research. The University of Cambridge astronomer Fred Hoyle is a conspicuous example. Most of the writers and editors, according to Amis, treat their calling with "great, sometimes excessive, seriousness." Their claims include such points as that science fiction is "the last refuge of iconoclasm in American literature," that it exists "to afford objectivity to the reader, for better consideration of himself and his species," that "it helps mankind to be humble." These are respectable views, and even the hyperboles—Robert A. Heinlein, for example, says that science fiction is superior to most modern fiction, is "the most difficult of all prose forms" and is "the only form of fiction which stands even a chance of interpreting the spirit of our times"—are self-respecting. "Few things," says H. L. Gold, the editor of *Galaxy*, "reveal so sharply as science fiction the wishes, hopes, fears, inner stresses and tensions of an era, or define its limitations with such exactness." Perhaps this too is hyperbole, but every kind of literature—even the comic strip—is like a mythology in the sense of embodying man's fears and aspirations.

Amis attempts to distinguish between what the literature reveals of these hopes and fears, and the ideas and morals that it consciously and deliberately sets forth. Sex, as I have already indicated, is no longer an important theme in science fiction, although it strongly persists in the fantasy stories; for that matter, they also continue to celebrate mad scientists, mutilation and such winsome items as jellyfish which, when you step on them, call you by name. The sense of insecurity exhibits itself in many different forms: the race of men is doomed, with or without a nuclear war; men are puppets, at the mercy of the quirks of time, the vagaries of matter and galactic flaws; individuality and free will are an illusion. Robots are still a menace, but less than they used to be. Philip K. Dick has a delightful story, "The Defenders," about robots sent out to fight a war on the surface by a human race now living underground; the robots keep sending down reports about great battles and massive destruction, but when, after several decades, a party of men comes up to see how things are going, they find that the robots made peace almost immediately and, "arguing that mankind could never be trusted not to start things again, have been spending their time faking their reports as interestingly as possible." Nostalgia for the rural way of life is very strong; this is another aspect of the anti-science strain in the new science fiction. Arcadian pleasures, simple things, escape from the world of too much electronics—from what, in short, is called the abundant life—is a heartfelt, recurring emotion. But it must not be supposed that a science-fiction hero is a fellow who simply wants to escape; if he doesn't like things as they are, he means to do something about it, not merely run away. In George Orwell's *1984* O'Brien says to Winston: "If you want a picture of the future, imagine a boot stamping on a human face—forever." No orthodox science-fiction writer, says Amis, would ever concede such abject defeat. In general, then, while no clear-cut, unified picture emerges, the main attitudes are "reassuring": reasonable fears, sensible wishes, admirable hopes. We are not splendid, but neither are we hopelessly degraded; *something* will help us if we help ourselves.

Amis examines the Utopias and the new maps of hell, the sphere of social diagnosis and warning. In William Tenn's story "Null-P" (the P stands for Plato and his notion that political leaders must be men of merit) the U. S., after an atomic war that has produced a zoo of mutations, elects as president George Abnego, the apotheosis of the average man, "median in his flesh and the condition and quantity of the very teeth in his mouth." Mediocrity is enthroned; the non-elite or "unbest" are in charge. Eventually a race of intelligent Newfoundland retrievers domesticate "*Homo abnegus*" and "prize him for his stick-throwing abilities and initiate selective breeding to this end." When a machine is developed that throws a stick better than he can, man disappears "except in the most backward canine communities." The satire is sharp, but general; no recognizable personalities appear, and this seems to be characteristic of science fiction.

Another conformist hell is described in Ray Bradbury's *Fahrenheit 451*. (Reverting to his jazz comparison, Amis calls Bradbury the Louis Armstrong of science fiction, because he is "the one practitioner well known by name to those who know nothing whatever about his field.") The suppression of books—451 degrees Fahrenheit is supposedly the temperature at which book paper ignites—is a major activity of this particular society. A book is considered a "loaded gun in the house next door." Books interfere with sport, pleasure, group spirit, fun; they make men feel unequal because some read and some do not. Books hinder the pursuit of happiness by making us worry; they make us indecisive when we conclude that there are two sides to a question. The cure is obvious. The hero of the story, Montag, is a fireman; when an alarm is turned in, he and his mates charge out of the station on their wagon to burn somebody's house down—one with books in it—under the regulations of the "Firemen of America," "established, 1790, to burn English-influenced books in the Colonies. First Fireman: Benjamin Franklin." While Montag is busy on his rounds ("Monday Millay, Wednesday Whitman, Friday Faulkner"), his wife lies on the bed in her room with the "little Seashells"—thimble radios—plugged into her ears, rapturously oblivious to everything but an "electronic ocean of sound, of music and talk and music and talk coming in, coming in on the shore of her unsleeping mind." I need hardly add that these days we see grown men and women walking down the street carrying little radios that are heard through a tiny



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earpiece. This presumably is what we are fighting for.

Utopias have other desirable features. In Robert Sheckley's "A Ticket to Tranai" wives are put into "stasis" or suspended animation, and are taken out by their husbands only when they are needed. The only rule is that you must take your wife out a few hours a week. The wives' compensation for this deep-freeze celibacy is that they age much more slowly than men, so they have many husbands and gain the financial benefit of multiple widowhood. Disimprovement engineering is another Utopian plus which furthers the commercial aim of built-in obsolescence; so is the new abundance installment economics that permits the citizen with the helicopter and subterranean swimming pool who is $200,000 in debt to have even more playthings by mortgaging the first 30 years of his son's earnings, and by doing the same with his grandchildren.

I should like to give one more choice example, from the writings of the able science-fiction practitioner Frederik Pohl, who is concerned with the sublimities of production and consumption. A new advertising procedure backed by the Establishment consists of driving a van into a residential area playing "at top volume a tape recording of fire engines answering an alarm. Then . . . a harsh, sneering voice, louder than the archangel's trumpet, howled: 'Have you got a freezer? *It stinks!* If it isn't a Feckle Freezer, it stinks! Only this year's Feckle Freezer is any good at all! You know who owns an Ajax Freezer? Fairies own Ajax Freezers! You know who owns a Triplecold Freezer? Commies own Triplecold Freezers! Every freezer but a brand-new Feckle Freezer *stinks!*'

"The voice screamed inarticulately with rage: 'I'm warning you! Get out and buy a Feckle Freezer right away! Hurry up! Hurry for Feckle! Hurry, hurry, hurry, Feckle, Feckle, Feckle, Feckle, Feckle, Feckle!"

The hysteria, the minatory tone, the indecent assaults on privacy are not only fairly close to what advertisers do to us via radio and television every feckling moment of the day, but even closer, as Amis says, to what they would like to do to us if they dared.

Where is science fiction going? Is it marked for higher destinies? There are two things to consider: science fiction simply as readable literature, and science fiction in its concern with political or economic man. From the standpoint of its merit as literature, science fiction has had its ups and downs. It now takes itself very seriously, but this does not mean that its best stories are up to the best of H. G. Wells, say, who himself certainly did not take the form too seriously, at least not in today's sense. No one can pretend that science fiction goes very deep into human personality and motivations. The human heart is a feature only when it is a cavity resonator enclosed by plastics and titanium, and activated by microwaves. The ingenious gadgets are themselves beginning to run out. There are, as I recall from group theory, something like 275 basic patterns of wallpaper; why should science fiction have a larger range? Of course science fiction—the highbrow stuff, at any rate—is getting less scientific. It is still pretty special, so that one has to judge it by its own rules (however difficult these may be to define), just as one judges chess problems not as actual game situations but as esoteric intellectual contrivances bound by peculiar conventions. But the specialness is getting less special, which is to say that a number of science-fiction writers are turning their product in the direction of the mainstream of serious literature, and that certain writers of stature—William Golding, for instance—are invading the science-fiction domain. Each group, as Amis observes, can learn from the other, though admittedly the mainstream group has vastly more to teach its science-fiction counterparts than to learn from them. Their common ground, I should think, is dissent, revulsion, indignation, even bewilderment, over the less lovely aspects of society. Science fiction may run out of scientific ideas, but never out of instances of imbecility and wickedness that can easily be transformed into comic infernos.

It is important not to come to any grand conclusions about what science fiction is or may yet become. It does not exist in isolation, however queer it may seem; it is very much a piece of ourselves; its future is uncertain, but whose is not? It has, I am now convinced from Amis's book, something of value. I hope it prospers.

Short Reviews

THIS SCULPTURED EARTH: THE LANDSCAPE OF AMERICA, by John A. Shimer. Columbia University Press ($7.50). This attractively illustrated, well-written book tells the geologic story of the wonderfully varied landscapes of the U. S. It deals with the meaning of the scenery and the nature of the earth-shaping processes, the formation of capes, bays, dunes and drowned coasts, the action of the sea and wind on the edge of the land, the strange terraces cut

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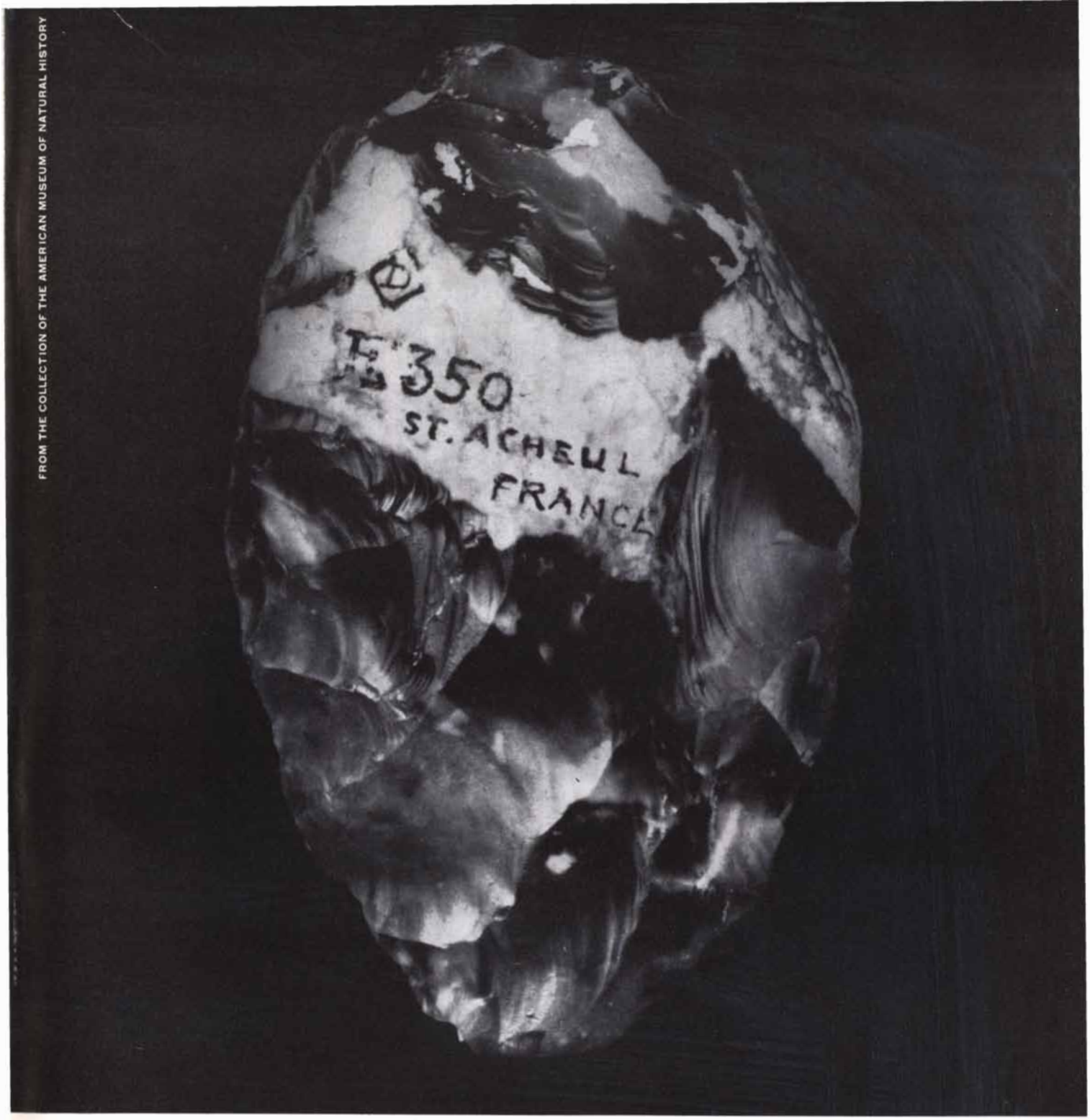
by the waves, the formidable legacy of the glaciers, the effect of earthquakes, the molding of the New England terrain, the erosion and gouging of the mountains of Yosemite, the causes of the jagged topography of the Alaskan ranges, the making of the middle western plains and the Badlands of South Dakota, the history of the Grand Canyon, the birth of huge forests, the spectacular volcanic landscapes, the evolution of caves, the raising of mountains, the work of the rivers, the fossil record and how we read it. From the land as it is at this fleeting moment in the span of geologic time Shimer reconstructs the past and prophesies the future. His book is admirable both as an introduction to geology and as a historical panorama of our continent. Photographs, maps, diagrams and a glossary.

SCHOOLCRAFT'S EXPEDITION TO LAKE ITASCA, edited by Philip P. Mason. Michigan State University Press ($7.50). In 1832 the U. S. Government authorized the 39-year-old Henry Rowe Schoolcraft, mineralogist, geologist, explorer, educator and Indian agent, to make an expedition to the upper Mississippi region to visit the Chippewa tribes and attempt to quell the intermittent but bitter feud between them and the Sioux over boundary lines. A true friend to the Indians and learned in their history, language and customs (his volumes on the American Indian inspired Longfellow to write *Hiawatha*—perhaps a dubious blessing), Schoolcraft had attended other intertribal negotiations in the Northwest Territory and had shown high skill in such matters. He was instructed not only to establish permanent peace among these tribes, but also to collect statistical facts about them, to investigate the conditions of the fur trade and to vaccinate the Indians for smallpox under an act that had just passed Congress. For this grand purpose a budget of $3,200 was allotted his expedition, which the War Department cut to $2,200. Schoolcraft said nothing in his request for the appropriation about exploring the Mississippi River to its source, and his instructions were silent on the point. This was nonetheless his real aim, and this he accomplished. He failed to stop the Indian hostilities, but on July 13, 1832, after a long march across a series of "deluvial sand ridges what had long been sought appeared suddenly. On turning out of a thicket into a small weedy opening, the cheering sight of a transparent body of water burst upon our view. It was Lake Itasca —the source of the Mississippi." Itasca, it is worth remarking, had for many years been known to fur traders as Lac la Biche, or Elk Lake, because of the likeness of its shape to the head of that animal; the Indians called it Omushkos, the Chippewa name for elk. None of these names satisfied Schoolcraft. From the Reverend William Thurston Boutwell, a member of the party, he had learned the Latin term for "true source," *veritas caput*, and out of the last two syllables of *veritas* and the first of *caput* he created the new name. This fact he at first admitted, but later it suited his fancy to pretend that the name came from an Indian legend, a circumstance that led to much controversy. Because of this tendency to embroider, one must read Schoolcraft with caution, as the editor of this scholarly edition of his semi-official report of the expedition observes. The value of the edition is enhanced by extensive appendices containing the journals of three other members of the Schoolcraft party, and by correspondence, reports and other data relating to the condition of the Indians, the organization of the expedition, the mineral finds in the explored area. Regrettably there are no illustrations, and the only map, which is antique and inadequate, appears as end papers.

THE TEMPTER, by Norbert Wiener. Random House ($3.75). This first novel by the mathematician Norbert Wiener is about an upper-middle-class Russian-born engineer who emigrates to the U. S. before the First World War, joins a Boston shipbuilding firm, rises with it and finally lends himself to an elaborate fraudulent scheme in the company's activities as an electronics manufacturer to steal, by means of various patent shenanigans, an important invention of a dedicated, brilliant but impractical British scientist. The scheme succeeds, the company makes huge profits and the engineer himself is well rewarded. However, his conscience never entirely stops eating him, and his personal life, as he reminisces about it in old age in this autobiographical narrative—cast in the form of a letter to his godson—has on the whole been empty, lonely and unfulfilled. Wiener is a fluent writer, but this is not much of a novel. It has some merit as social criticism, it describes ingeniously the technical stuff (control gadgetry) and the patent and corporate chicaneries one can get away with in our society, but the hero is a cold fish, a sort of Armenian trader whom one never gets either to like or to understand; his love affair is canned, the lesser characters are cardboard and the story is writ-



This hand ax was found in the late Pleistocene site at St. Acheul, France. Older than the oldest known fossil of modern man, it may have been made by a prehuman member of the genus *Homo.* Together with other ancient stone tools it suggests that tool-making and tool-using antedate *Homo sapiens.*

ten in a curious, matter-of-fact style that sounds a little like a literate probation-officer's report.

THE OXFORD COMPANION TO FRENCH LITERATURE, compiled and edited by Sir Paul Harvey and J. E. Heseltine. Oxford University Press ($12.50). This new "companion," a worthy cousin to the other volumes (on English, American and classical literature) in an excellent series prized alike by scholars and general readers, contains about 6,000 entries, from brief descriptions to longer articles, dealing mostly with French poets, novelists, dramatists and critics, but also with leading historians, scientists, statesmen and philosophers. In addition to the biographies there are entries on allusions, plays, books, fictional characters, criticism, societies and academies, dictionaries and encyclopedias, literary movements, literary forms and related topics. The period covered is from A.D. 400 to the years immediately preceding the Second World War. There is an appendix on background reading and another containing two maps of France. A most useful compilation.

THE SCIENTIFIC BACKGROUND, edited by A. Norman Jeffares and M. Bryn Davies. Sir Isaac Pitman & Sons, Ltd. (21 shillings). A well-conceived prose anthology whose purpose is to throw yet another bridge over the chasm between the two cultures by providing students of science with examples of literate scientific writing, and by introducing students of art and literature, and the general reader, to the world of scientific ideas. A hundred brief excerpts deal with such matters as the experimental method (Stephen Hales), the chemical history of a candle (Michael Faraday), living cells (Robert Hooke), the structure of bone (D'Arcy Thompson), the astronomer at work (Isaac Newton), radio astronomy (A. C. B. Lovell), physical science (James Clerk Maxwell), mathematics as a language (C. A. Coulson), the sunsets following the eruption of Krakatoa (Gerard Manley Hopkins), natural selection (Charles Darwin), the reproduction of the eel (J. T. Cunningham), the division of labor (Adam Smith), tunnel building (G. L. Groves), relativity (Bertrand Russell), night in Arabia (Charles M. Doughty), convection (Count Rumford), the electric kite (Benjamin Franklin), life on Mars (A. S. Eddington), the Great Barrier Reef (Captain James Cook), the circulation of the blood (William Harvey), the onset of infantile paralysis (Sir Walter Scott), the new cosmology (Fred Hoyle and Herbert Dingle), how to climb the turret of King's College Chapel, Cambridge (Anon.), the hydrogen bomb (Sir George Thomson), advice to a young clergyman on the use of the English language (Jonathan Swift). Many of the excerpts are too short to do more than tease, but this is a very pleasant volume with many excellent things in it, and it is a valuable direction finder in a rich, too-little-known branch of literature.

A TREATISE ON DIFFERENTIAL EQUATIONS, by George Boole. Chelsea Publishing Company ($6); STRING FIGURES AND OTHER MONOGRAPHS. Chelsea Publishing Company ($3.95); RAMANUJAN, by G. H. Hardy. Chelsea Publishing Company ($3.95). A group of well-produced, moderately priced hard-cover reprints of desirable mathematical books. Boole's celebrated 19th-century treatise is presented in its fifth edition, edited by I. Todhunter. Many leading mathematicians sharpened their teeth on this work. *String Figures* is a pleasing miscellany of small monographs combined in a single volume for "purely economic" reasons, as the publisher candidly admits; that is, if any of the books of which it is composed were issued separately, they would cost not much less than the whole volume. It incorporates, besides W. W. Rouse Ball's charming lecture on the various topological figures that can be made from a six-foot piece of string knotted into a closed loop and then twisted or woven on the fingers, Julius Petersen's "Methods and Theories for the Solution of Problems of Geometrical Construction," a Danish essay first published in 1866 which analyzes and classifies geometrical methods of construction; H. S. Carslaw's "Non-Euclidean Plane Geometry and Trigonometry," an excellent introduction to this important branch of mathematical thought; and the late F. J. Cajori's valuable and interesting "History of the Logarithmic Slide Rule." Hardy's book consists of his 12 lectures on the life and work of the extraordinary Indian prodigy Srinivasa Ramanujan, a most romantic and paradoxical figure and in some respects a very great mathematician.

THE CIVIL WAR DICTIONARY, by Mark Mayo Boatner III. David McKay Company, Inc. ($15). An encyclopedic dictionary in which you can find out what happened at the battle of Totopotomoy Creek, the identity of Joseph Roswell Hawley, the record of the XI Corps, the casualties at Irish Bend (also known as Bayou Teche), the names of Grant's

various horses (*e.g.*, "Cincinnati," "Jack," "Fox," "Kangaroo," "Jeff Davis"), the uses of grapeshot, the selfless devotion of Michigan Annie, the date of Price's Raid, the functions of the Freedman's Bureau, the efficiency of the Sharps carbine, the infamous record of Andersonville, the circumstances of the writing of the Battle Hymn of the Republic—and bundles of other information essential to the historian but no less essential to the buff who wants to be in on every detail of the coming centenary.

THE HISTORY OF THE CALCULUS AND ITS CONCEPTUAL DEVELOPMENT, by Carl B. Boyer ($2); A SOURCE BOOK IN MATHEMATICS, by David Eugene Smith ($3.70); MATHEMATICAL PUZZLES OF SAM LOYD, selected and edited by Martin Gardner ($1). Dover Publications, Inc. An inviting assortment of paperbacks, sensibly priced so that any lover of mathematics can add the lot to his library for less than the cost of an orchestra seat at the theater. Boyer's book is a reprint of his *Concepts of the Calculus,* a sound, not-too-hard-to-follow account of the development of this indispensable mathematical tool from antiquity to the present day. Smith is the best source book in the field, with excerpts from the works of the makers. The main divisions are numbers, algebra, geometry, probability, calculus, functions and quaternions; the period covered begins with the Renaissance ("The Treviso Arithmetic") and closes with the end of the 19th century. From Sam Loyd's long-out-of-print *Cyclopedia of Puzzles,* a book that swarms with mistakes and omissions but is the most exciting collection of puzzles ever assembled, Gardner has selected 117 mathematical puzzles for an attractive little reprint. The original illustrations are reproduced, Loyd's own rendering of the puzzles has been preserved (his style was unique), and there are even some fresh errors that escaped the editor, but the volume is vintage Loyd—the highest accolade for the puzzlist.

PRODUCTIVE THINKING, by Max Wertheimer. Harper & Brothers ($6). An enlarged edition of an essay by the late Max Wertheimer, which examines concrete examples of productive thinking—some quite famous, *e.g.*, Einstein's reasoning leading to the special theory of relativity—and attempts to identify the emotional and other surrounding circumstances which appeared to influence the thought processes. The new material consists of three additional chapters dealing with mathematical thinking, and

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half a dozen appendices incorporating notes found among the author's papers. Wertheimer was a leading Gestaltist, and his interpretations are based upon, and intended to promote, this theory of psychology. Lively and intriguing.

FUNDAMENTALS OF ORNITHOLOGY, by Josselyn Van Tyne and Andrew J. Berger. John Wiley & Sons, Inc. ($11.75). A very competent and useful handbook which the senior author, the late Josselyn Van Tyne, a distinguished ornithologist, began as a text to provide the background for his graduate course at the University of Michigan on birds of the world. As completed by Berger, the volume will serve as a reference for information on all families of birds, treating, among other subjects, paleontology, anatomy, plumage and molt, senses and behavior, sound production, distribution, migration, flight, food and feeding habits, breeding, social relations, taxonomy, classification by families.

LOW-LEVEL IRRADIATION, edited by Austin M. Brues. American Association for the Advancement of Science ($3.75). A symposium organized by the A.A.A.S. and presented at the Indianapolis meeting in December, 1957. The papers on radiation background, fallout, genetic and somatic effects, public-health problems and similar topics are of the usual run and are in some respects already out of date. Of more lasting interest is a contribution of C. West Churchman, which raises the question of the scientist's social responsibility and suggests that it is perhaps not a tenable position for a scientist to argue that no limits can properly be imposed on his researches wherever they may lead and whatever use is made of his findings. At the very least, says Churchman, it is the scientist's duty to ensure the continued existence of science itself. Thus science and morality are seen to have a pragmatic connection that must prevail over the easy platitudes about the importance of untrammeled inquiry.

Notes

THEORY OF ELASTICITY, by L. D. Landau and E. M. Lifshitz. Addison-Wesley Publishing Company, Inc. ($6.50). Volume VII, a translation from the Russian, of the Course of Theoretical Physics by two members of the Soviet Academy of Sciences' Institute of Physical Problems.

THE MEDIEVAL SCENE, by G. G. Coulton. Cambridge University Press

(\$1.75). A soft-cover reissue of a famous scholar's informal introduction to the Middle Ages. A delectable book, learned but highly readable, with lovely illustrations. The very model of what a paperback should be.

THE NATURE OF THE CHEMICAL BOND, by Linus Pauling. Cornell University Press (\$8.85). A third, revised edition of a standard introduction to modern structural chemistry. Innovations include the wide application of the electroneutrality principle, a new theory of the structure of electron-deficient substances and a detailed discussion of the valence-bond theory of the electronic structure of metals and intermetallic compounds.

A HISTORY OF BIOLOGY, by Charles Singer. Abelard-Schuman (\$6). A newly revised edition, with many changes, of this critical survey of the historical development of biological problems from Hippocrates and the doctrine of the four humors to Gregor Mendel's experiments on peas and the rediscovery of his theory in 1900. The work of a great student, learned and broad in outlook, this is the best general book on the study of living things. Exceptionally fine illustrations.

ROCKET ENCYCLOPEDIA ILLUSTRATED, edited by John W. Herrick and Eric Burgess. Aero Publishers, Inc. (\$12.50). Information about rocketry—principles, theories, developments—presented in text and pictures drawn from articles and reports published all over the world. A clearly written compendium.

POLAR ATMOSPHERE SYMPOSIUM, PART I, edited by R. C. Sutcliffe; PART II, edited by K. Weeks. Pergamon Press (\$22.50). A symposium, held at Oslo in 1956, treating such topics as arctic geography and climate, winds and temperature of the arctic stratosphere, radiation and visibility in polar regions, sea ice and its forecasting, drift measurements, prediction techniques at high latitudes, polar blackout, turbulence in the ionosphere.

ADVANCES IN AERONAUTICAL SCIENCES, edited by Th. von Kármán and others. Pergamon Press (\$30). Proceedings of the First International Congress in the Aeronautical Sciences, held in Madrid in 1958, containing many survey papers and others dealing with advanced methods and experimental techniques.

HANDBOOK OF AGING AND THE INDIVIDUAL, edited by James E. Birren. University of Chicago Press (\$12.50). Con-

tributions by 28 scientists and scholars on the psychological and biological aspects of aging. The material represents a technical summary of the relevant scientific and professional literature, intended for reference use by graduate students and specialists.

ANALYTIC FUNCTIONS, by R. Nevanlinna, H. Behnke and H. Grauert, L. V. Ahlfors, D. C. Spencer, L. Bers, K. Kodaira, M. Heins, J. A. Jenkins. Princeton University Press ($5). The articles in this book, addresses delivered at a conference held at the Institute for Advanced Study at Princeton in 1957, represent a survey of recent developments in the classical and modern fields of the theory of analytic functions.

THE BACTERIA, edited by I. C. Gunsalus and Roger Y. Stanier. Academic Press Inc. ($13). The first volume of a planned five-volume treatise on the general biological properties of bacteria. Various aspects of structure are treated in this volume; the others will deal with energy-yielding metabolism, biosynthesis, growth and general physiology and heredity.

MATHEMATICS IN ACTION, by O. G. Sutton. Harper Torchbooks ($1.45). Sir Graham Sutton's account of applied mathematics and its influence on physical theory is an outstanding achievement, a book of clear ideas clearly expressed. It now appears as a paperback in the Harper Science Library.

BIOGRAPHICAL MEMOIRS OF FELLOWS OF THE ROYAL SOCIETY, VOLUME V. The Royal Society (30 shillings). Included in this volume are *éloges* of the zoologist and historian of science Francis Joseph Cole, the engineer Alexander Gibb, the animal psychologist Karl Spencer Lashley, the physicist Wolfgang Pauli and the aerodynamicist Ludwig Prandtl.

DOUBT AND CERTAINTY IN SCIENCE, by J. Z. Young. Oxford University Press ($1.50). A "Galaxy Book" reprint of an exceptionally readable and stimulating essay on the working of the brain.

BEACHES AND COASTS, by Cuchlaine A. M. King. St. Martin's Press ($14.50). A summary of theoretical and experimental researches on the evolution of coastal areas in Britain and elsewhere: the effect of wind and waves, the movement of material on the beach, beach profiles, the classification of beaches and coasts, the cycle of marine erosion. A valuable professional monograph.

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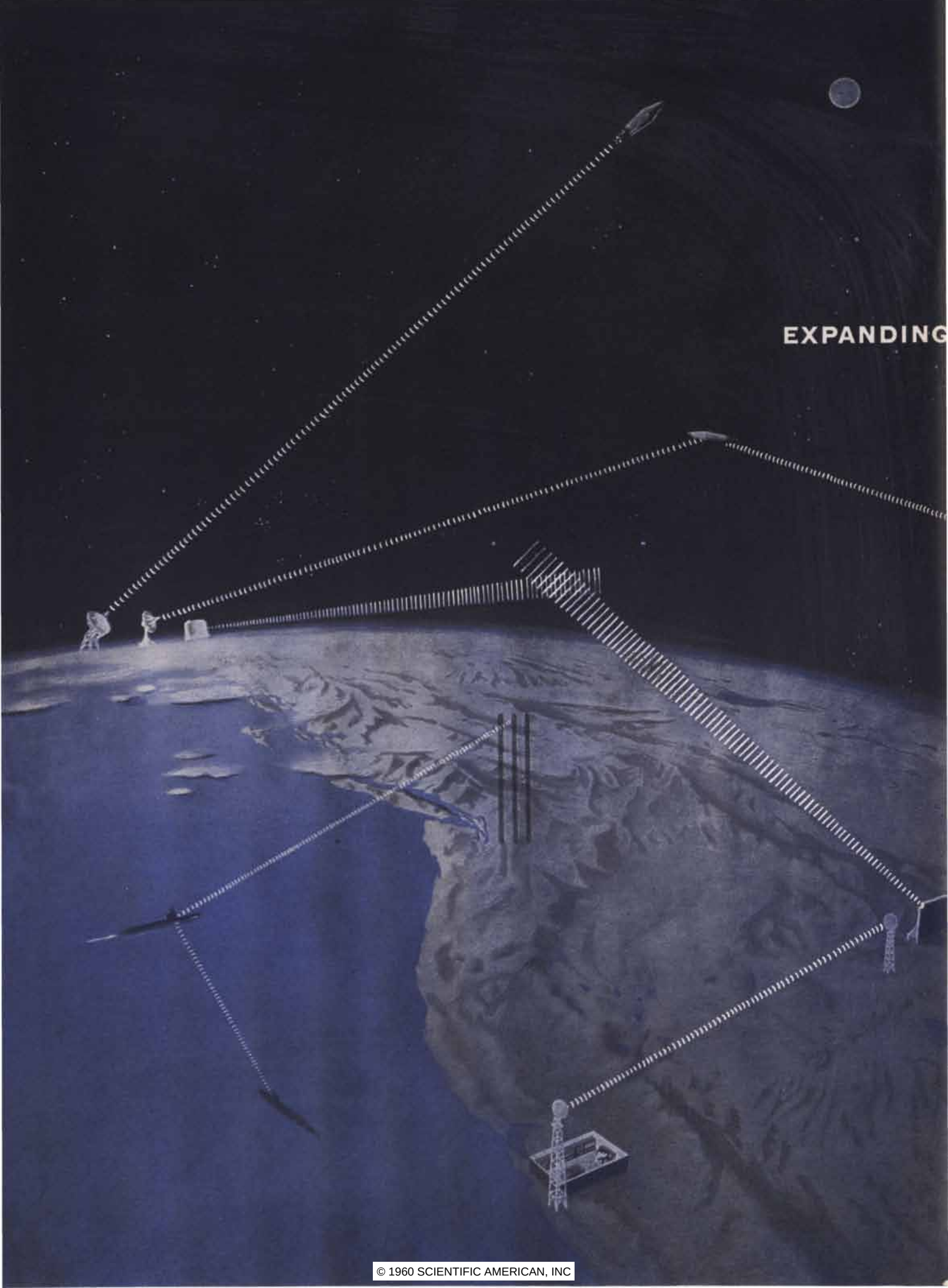

Herodotus, the historian, records (490 B.C.) the use of burnished shields for military signaling. This was the forerunner of the heliograph, invented by Sir Henry C. Mance, which came into wide use centuries later.

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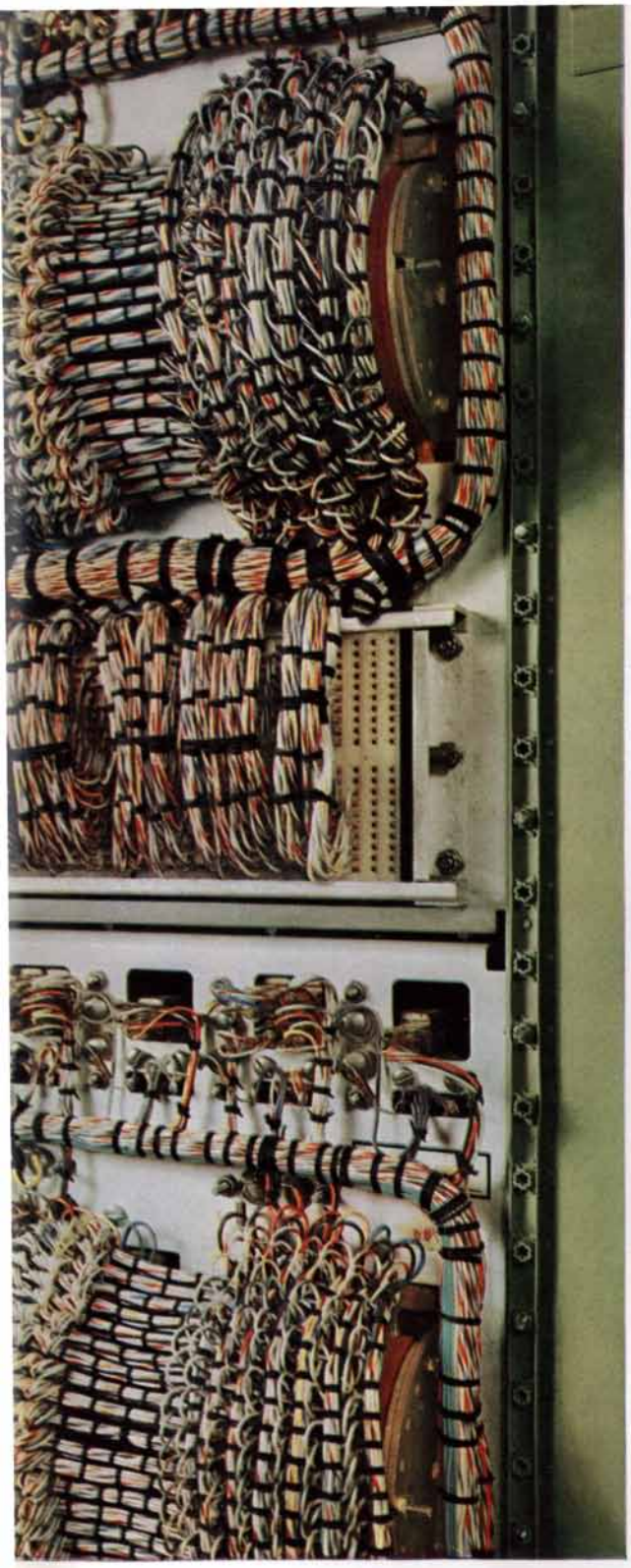

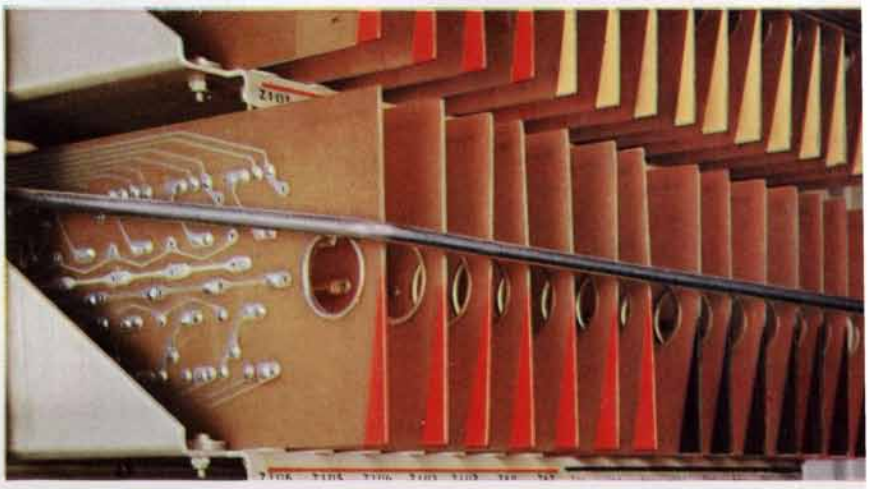

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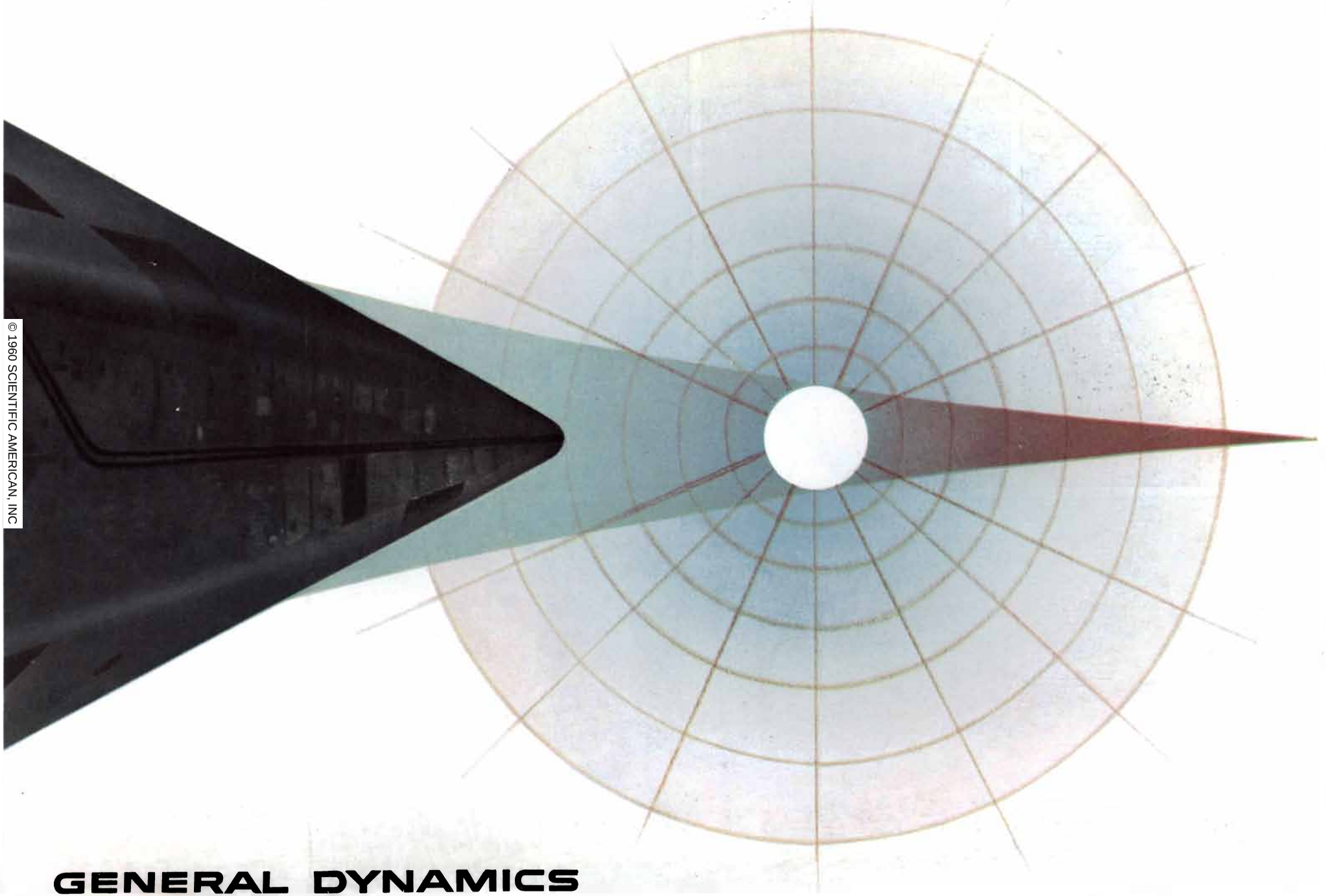

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