SCIENTIFIC AMERICAN

SAND-DUNE WASP

FIFTY CENTS

July 1959

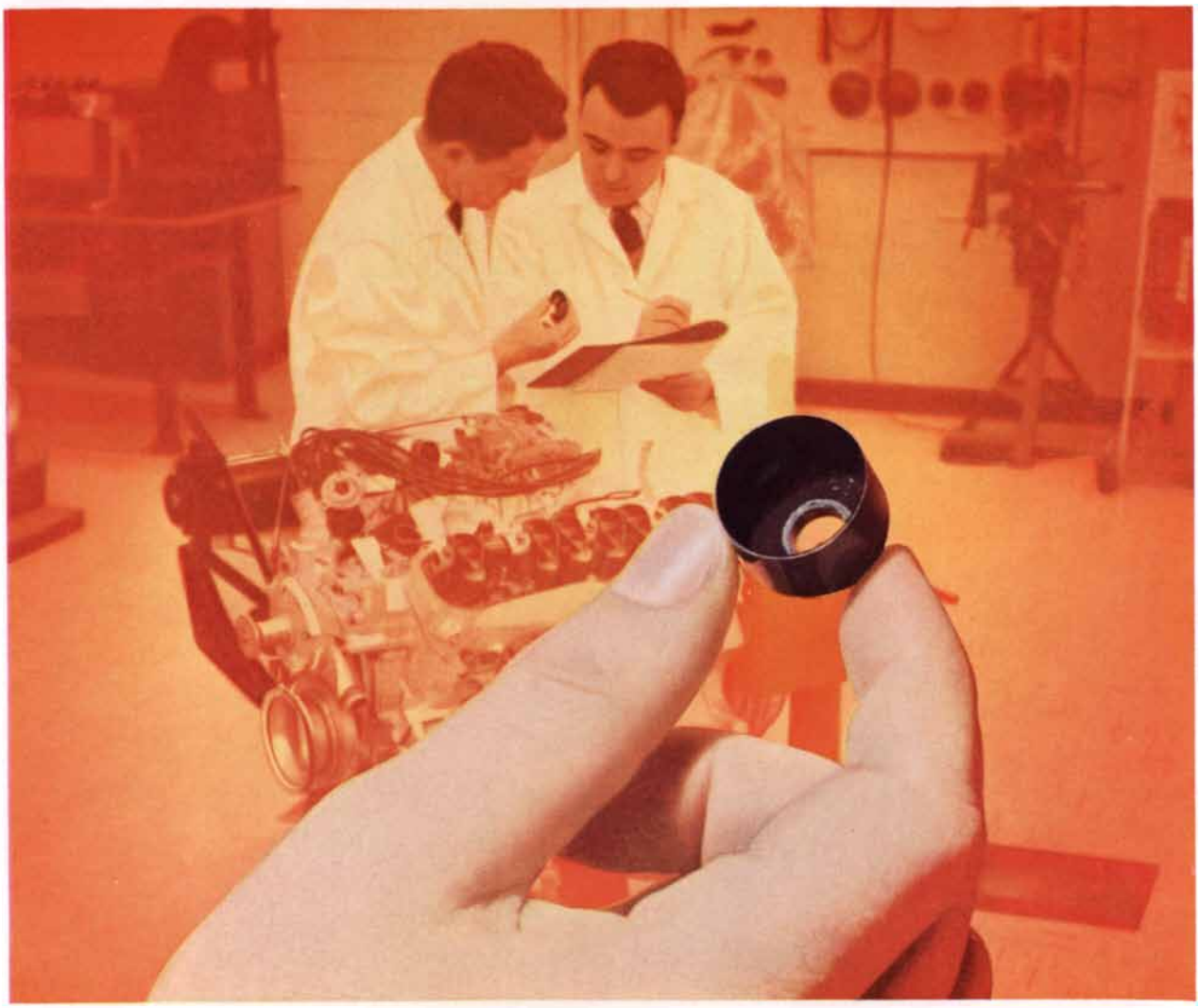

Photo courtesy Ohio Rubber Company, Willoughby, Ohio, a Division of The Eagle-Picher Company.

How's this for a surefire success?

This thimble-size shield works inside an automobile engine. It clings to a pulsing valve stem, prevents excessive loss of engine oil—yet allows enough oil to properly lubricate the stem. Obviously, a tough job for a tiny part.

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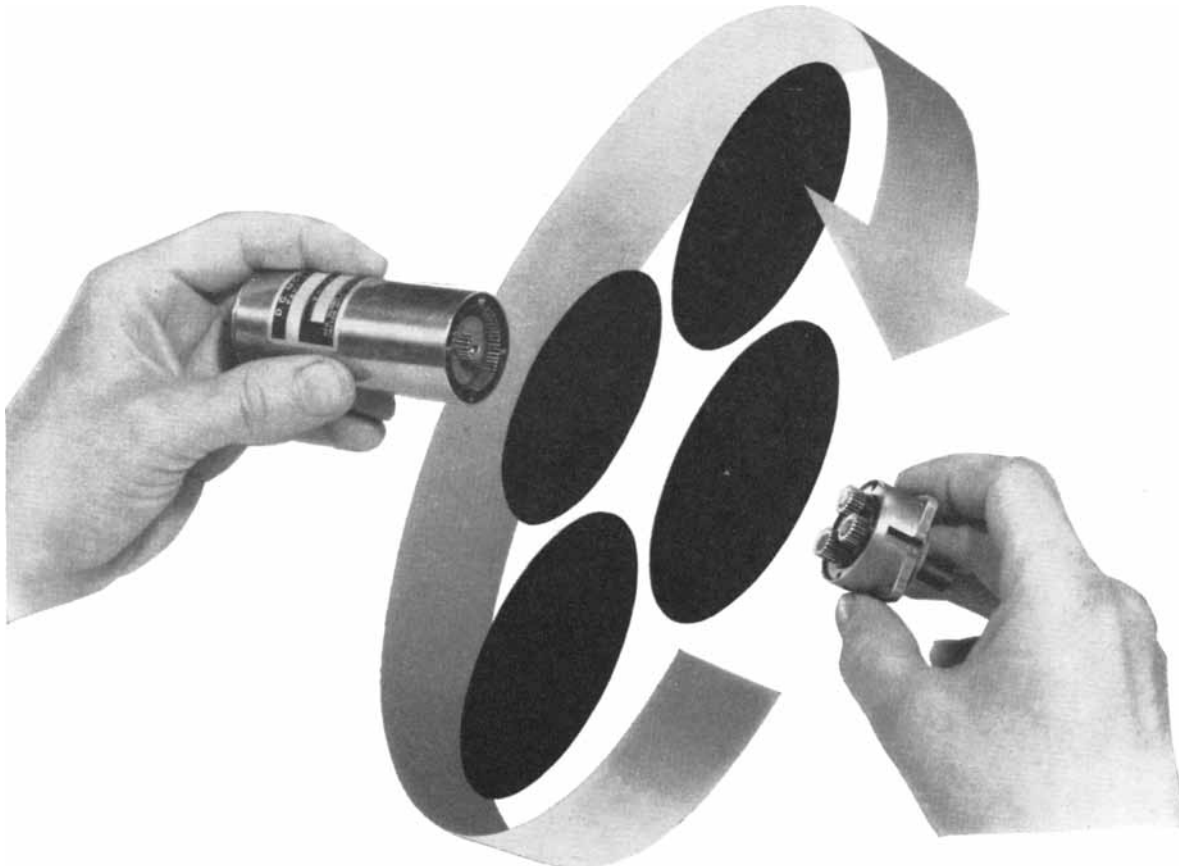

motors for commercial applications

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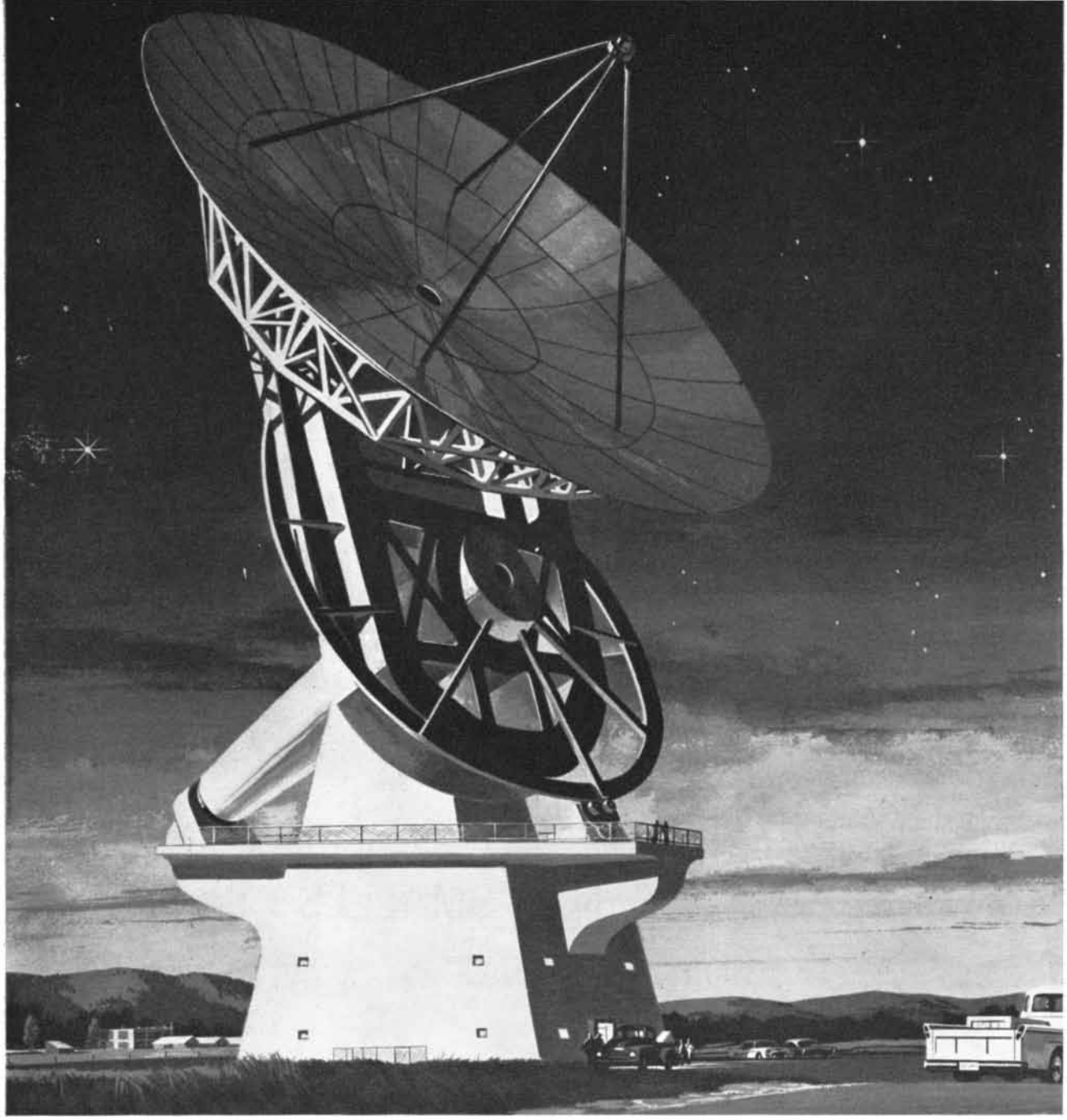

FROM ONE EXTREME TO ANOTHER

Challenging jobs requiring engineering skill as well as metal fabricating experience have a way of coming to Bliss. They may be projects involving massive size, like the 140-foot diameter radio telescope shown above . . . or the precision machining of missile parts similar to the one at the left.

Whatever it is, if it's made of metal, you'll find that Bliss has the skills and facilities to take it from idea to completed project.

These abilities have made Bliss a leading producer of steam catapults for carrier aircraft, overrun barriers, precision machined missile parts, antennas, atomic assemblies and special machinery; everything from small parts with tolerances running to the ten-thousandths to complete turn-key plants.

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ARTICLES

DEPARTMENTS

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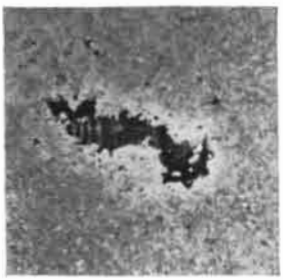

THE COVER

The photograph on the cover is a cutaway view of the burrow of a wasp in a sand dune (see "The Life of a Sand Dune," page 91). The wasp is a member of a group called velvet ants because of a superficial resemblance to ants. The wingless females travel about the unshaded surface of the sand dune, preying upon other insects, at temperatures up to 120 degrees Fahrenheit. Above that temperature they survive by seeking the shade of plants.

THE ILLUSTRATIONS

Cover photograph
by William H. Amos

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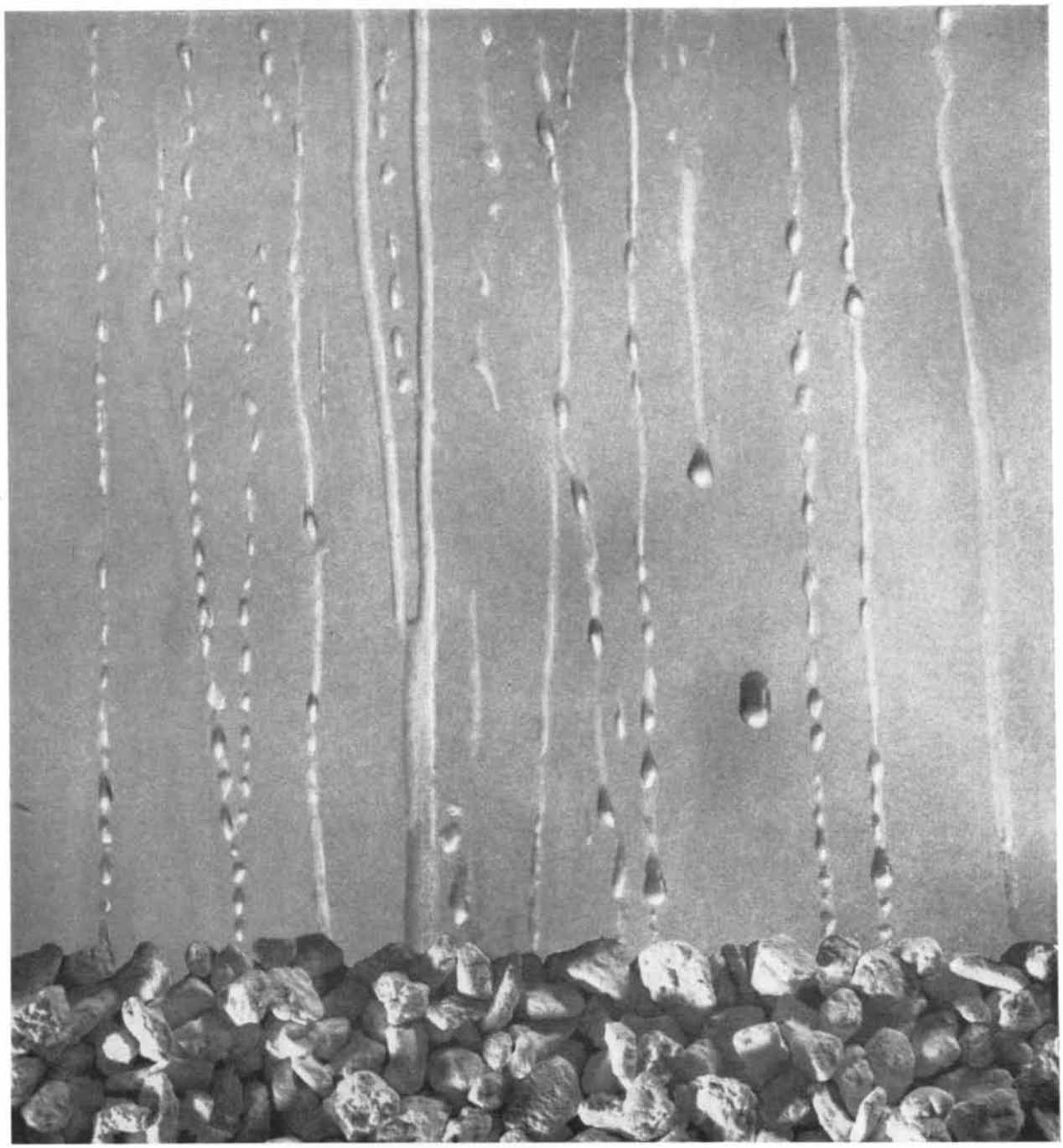

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no. 8 OF A SERIES

THE SOUND . . . AND THE JURY

The quiet, solid feeling inside the 1959 Oldsmobile results from patient testing by a highly specialized "jury"—experts in the field of sound analysis.

Unlike most other phases of automotive engineering, there are no instruments which measure the "annoyance" factor of sounds inside an automobile. Subjective, personal evaluation known as the "jury system" is the most important means of determining how quiet it is inside an Oldsmobile.

With the "jury system", several experienced engineers assemble in an acoustically treated room and listen to binaural tape recordings made inside a test car. Careful editing of the tape recording allows rapid side-by-side comparison between two different test conditions and eliminates reliance on memory since considerable time may elapse between actual tests. By pushing a button, each engineer casts a secret "vote" and then the tabulation of the results determines which test condition is superior.

For the greatest possible accuracy, considerable care is taken making the recordings. Special microphones are placed at points corresponding to the passengers' ears. The recording equipment is in a specially equipped vehicle which follows the test car over a "ride road" that is carefully constructed to excite the vibrations and sounds that occur under normal driving conditions.

Quality, like quietness, is not accidental. It is the deliberate effort by Oldsmobile engineers to *design* quality into every automobile they produce. You'll like the 1959 Oldsmobile—with its solid Body by Fisher—it's the quietest car built! Experience this quality for yourself by visiting your local Authorized Oldsmobile Quality Dealer as soon as possible.

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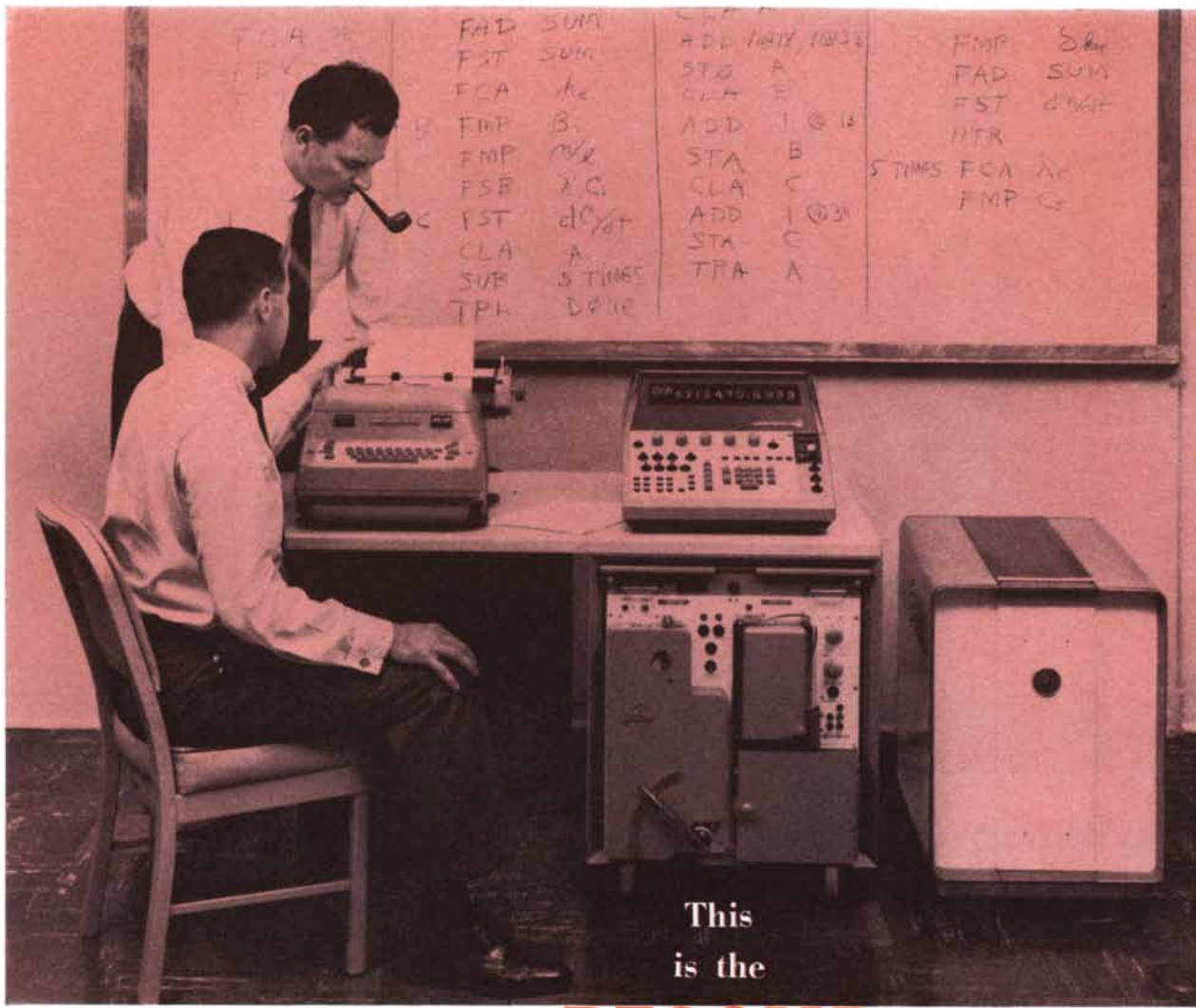

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This engineer learned to program Recomp in two days

Digital computers by Autonetics

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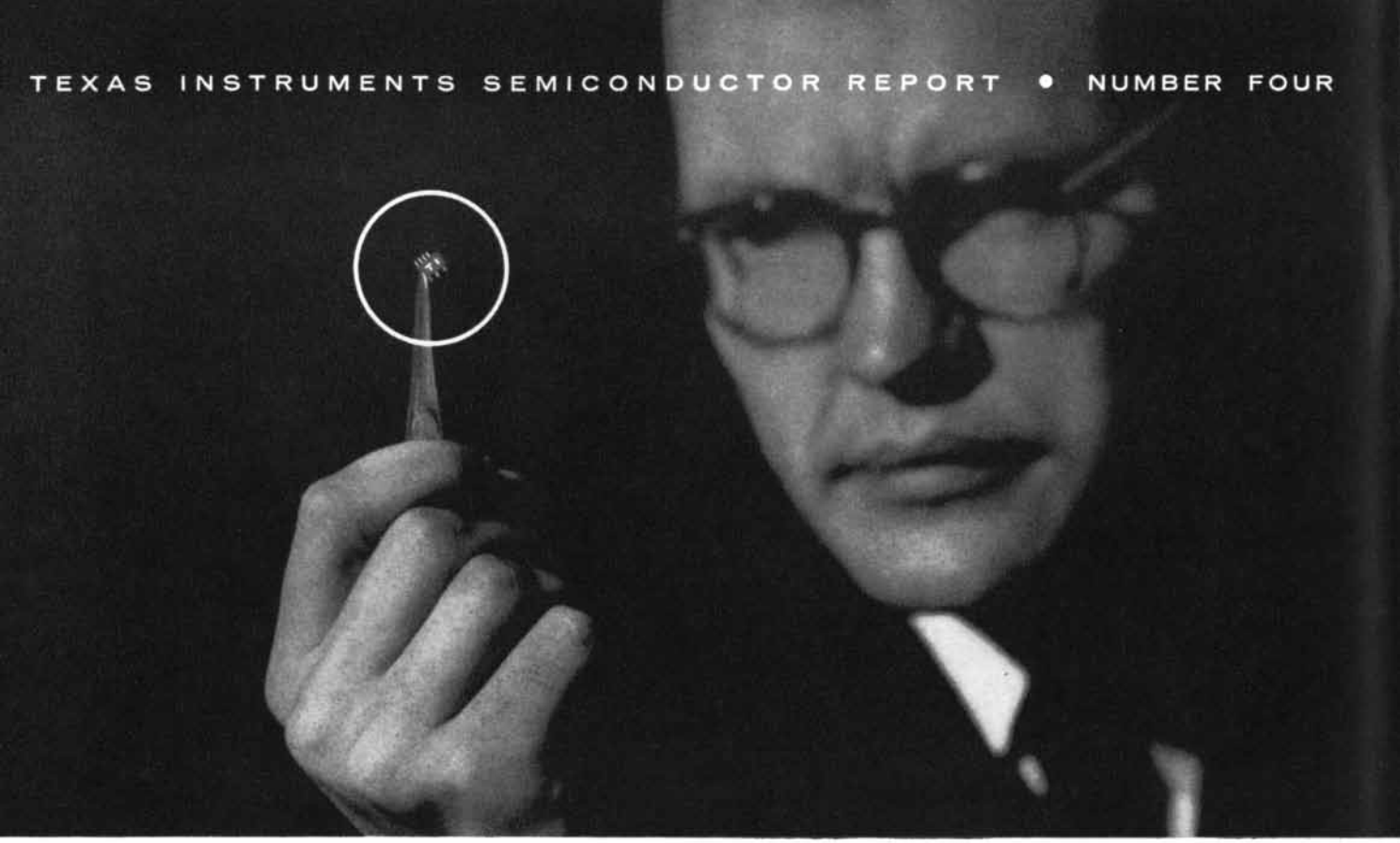
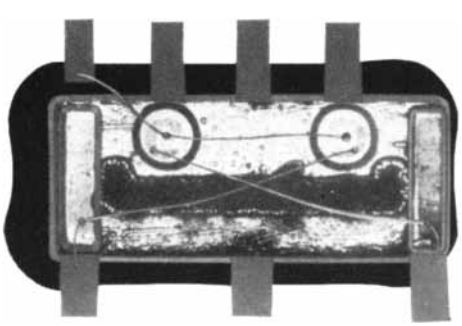


TI Semiconductor Solid Circuitry...
30,000,000 components per cubic foot!

ACTUAL SIZE: 1/4″ x 1/8″ x 1/32″



The Semiconductor Solid Circuit shown above is a complete multivibrator containing two diffused-base transistors, two capacitors, and eight resistors... all formed from a single silicon wafer!

A new order of electronic miniaturization has been achieved with TI Semiconductor Solid Circuits. These new solid circuits will enable missiles, satellites, space vehicles, and computers to be built within a new magnitude of miniaturization, while greatly enhancing systems reliability.

Production of Semiconductor Solid Circuits follows process steps similar to those of diffused-base germanium and silicon transistors now being mass produced by TI for military and commercial users. Through the selection and shaping of conduction paths upon and through single-crystal semiconductor wafers by diffusion, metallic evaporation and similar processes, TI produces basic electronic functions such as amplification, oscillation, counting, and switching.

Only advanced facilities can produce advanced components.

The advancement and realization of the Semiconductor Solid Circuit concept by Texas Instruments evolved from a broad background of semiconductor materials and processes. This trend of developments indicates the bold, forward thinking of TI scientists that brings you semiconductors and other components of unsurpassed performance and reliability.

Write on your company letterhead for new Semiconductor Solid Circuit brochure.

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DALLAS, TEXAS

STEPS IN THE RACE TO OUTER SPACE

Nuclear Rocketship

Despite the sky-high transportation costs, Lunar manufacturing should prove economically viable. With unlimited Solar power, controlled atmospheres and advanced automation, a considerable commerce could be realized in delicate instruments, rare minerals, reactor cores and other items that might be more efficiently processed or produced in the Moon's perfect vacuum.

To supply the Moon colonists, and to carry their production back to Earth, special rocketships will be developed. Nuclear energy is the most promising source of propellant power. The ship shown here utilizes nuclear fission for heat and hydrogen gas as a working fuel. From pressurized tanks, the gas is fed through a heat exchanger, expanded, and expelled for the motive thrust.

When the craft leaves Earth, it carries only enough gas for a one-way trip. For, by extracting hydrogen and oxygen from Lunar rocks, Moon settlers will be able to refuel the rocketship for the return voyage. This will permit smaller fuel tanks on the craft and larger payloads.

Inertial navigation systems will play an increasing role in the exploration of outer space. ***ARMA*** is actively supporting the Air Force's program in long range missiles and is in the vanguard of the race to outer space. ***ARMA***, Garden City, N. Y. A Division of American Bosch Arma Corp.

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LETTERS

Sirs:

In his article "How Water Freezes" [Scientific American, February] Bruce Chalmers asserts that "Water is apparently unique among substances in that it expands in volume during the last few degrees as it approaches freezing." Many men in the printing and the silversmithing industries will be surprised by this statement. Type metal is a special alloy that expands upon freezing, tightly filling every nook and cranny of the mold. The same is true of sterling silver alloys, which are often cast into intricate designs, particularly for the handles of tableware. Perhaps if Dr. Chalmers would clarify the word "substance" my objection could be overruled.

William E. Waters

Electronics Research Laboratory
Stanford University
Stanford, Calif.

Sirs:

In the article "How Water Freezes" [Scientific American, February] the author suggests that the anomalous freezing of ice at the bottom of a lake (rather than at the top) occurs because, on clear nights, "the bottom radiates far more heat than the water" due to the bottom's having a higher emissivity than the water. I had not previously heard of the phenomenon of bottom-freezing, but

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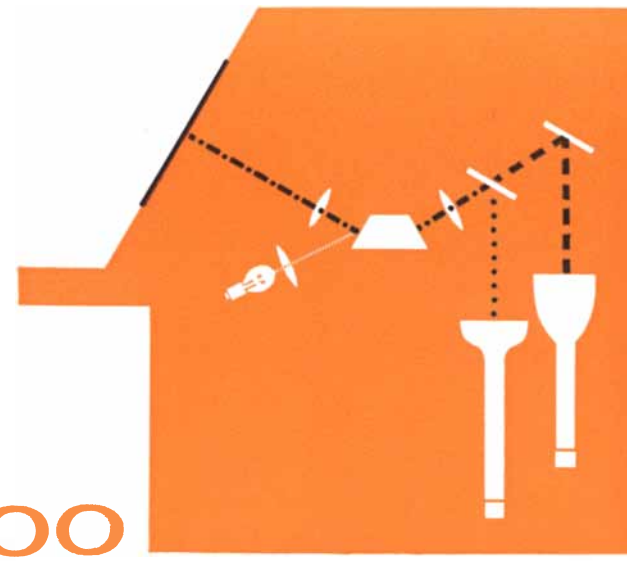

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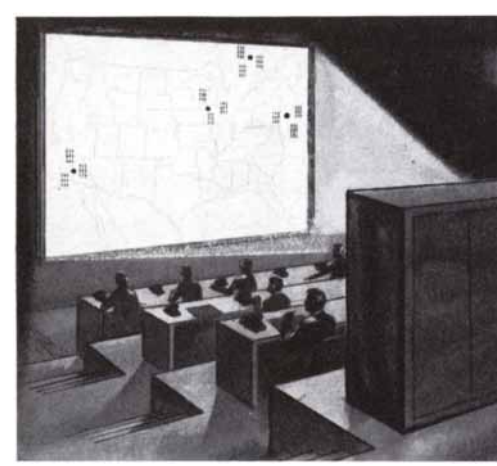
Bright, fail-safe, flicker-free display of alpha-numeric, symbolic and graphic data at high speed . . . simultaneously with PPI-type radar presentations . . . is now provided by S-C 2000 Bright Displays. Displayed data may be viewed in normal ambient light directly on the screen of the S-C 2000 console, or may be projected for group viewing on a large theatre-type screen. For air traffic control and military applications, maps may be displayed concurrently with radar targets and their identifying symbols, assisting the operator in geographic orientation. The fail-safe feature of S-C 2000 Bright Displays results from use of the xerographic process which allows the last frame displayed to be retained permanently, even in event of complete power failure. Send for more complete information concerning SC-2000 Bright Displays. Ask for Bulletin 7-J. Write today: Stromberg-Carlson — San Diego, 1895 Hancock Street, San Diego 12, California.



GENERAL DYNAMICS
STROMBERG-CARLSON DIVISION

if it does occur, it can scarcely be due to the suggested radiative mechanism. In connection with a meteorological problem in infrared transfer, I happen to have computed, just a few weeks ago, the transmission of black-body radiation from sources at atmospheric temperatures through very thin layers of water. The absorption data were taken from recent work by E. K. Plyler and N. Acquista at the National Bureau of Standards. The results indicate that of all the radiation emitted in the wavelength interval from four to 80 microns by an ideal black body (bottom muds would closely approximate this) at zero degrees centigrade, fully 97 per cent is already absorbed by a water layer a mere 50 microns thick, and only .4 per cent is transmitted through a layer .1 millimeter thick. By extrapolation one sees that an ordinary lakeful of water will surely not permit any significant amount of the radiation originating from the bottom muds to escape into the atmosphere. Hence selective chilling of a lake bottom cannot, I believe, take place by the mechanism envisaged by the author.

JAMES E. MCDONALD

University of Arizona
Tucson, Ariz.

Sirs:

In reply to Mr. Waters, it is necessary to distinguish carefully between expansion during the process of freezing and expansion of the liquid before solidification begins. Mr. Waters is quite right in stating that certain alloys expand during freezing. This is also true of silicon and germanium. However, as far as I am aware, these substances do not expand on cooling in the absence of solidification.

Regarding Mr. McDonald's letter, the data he quotes are interesting and, I must confess, new to me. It follows from this data that the explanation I advanced for bottom-freezing cannot be the right one. The only alternative explanation that seems feasible is that nucleation can take place heterogeneously at the bottom with less supercooling than elsewhere. I do not know of any other evidence of nucleation occurring under these conditions.

BRUCE CHALMERS

Division of Engineering and
Applied Physics
Harvard University
Cambridge, Mass.

WASP

THESE MEN DO ALMOST NOTHING BUT THINK

Unique new group helps Westinghouse anticipate and plan for future military needs

It's harder than ever to stay out front in defense.

Weapons systems are now fantastically complex. New innovations—like thermoelectricity and molecular electronics—threaten to make key subsystems obsolete overnight. New developments may suddenly reduce the tactical usefulness of a U. S. weapons system.

Westinghouse, like many other firms, has been concerned about how to meet this problem—and how to organize its many R&D and manufacturing operations to more effectively support America's increasingly complex defense needs. It seemed that the organization which had worked fine in the past simply wasn't adequate for anticipated future demands.

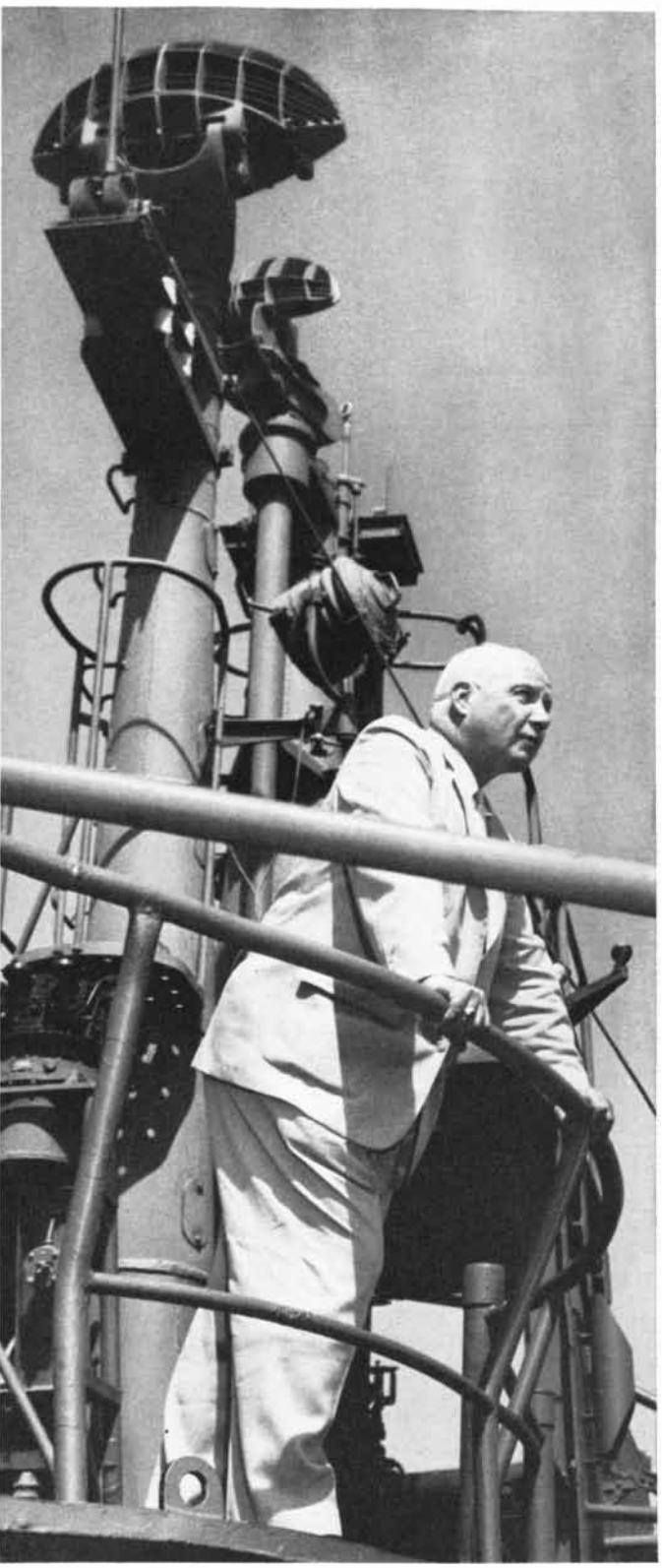
So things were completely reorganized in February, 1958. A new Defense Products Group was established, centralizing control of all defense-oriented activities within the company.

But a most interesting—and promising—part of this new organization, the new Westinghouse Advanced Systems Planning Group (now commonly called WASP), wasn't announced publicly until August.

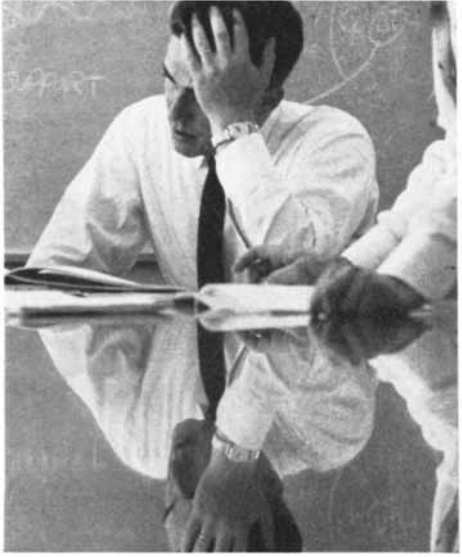
This was a significant development. Since technology is moving faster than ever before, there's a real need to effectively anticipate what will be needed in 5 or 10 years. If this can be done, longer-lived defense systems can be developed more quickly and substantial sums can be saved. WASP should be able to provide the advance thinking needed by Westinghouse to meet this need.

Staffed with hand-picked engineers and scientists—specialists in electronics, outer space, atomic power, ASW, operations research, etc.—and headed by Allan Chilton (top center photo above), WASP operates on a unique charter: to concern itself primarily with

CONTINUED



MATCHING NAVAL REQUIREMENTS with Westinghouse capabilities, Leonard Dow, a professional career specialist in naval strategy, tactics, and weapons systems, is associating advanced technology to future naval systems.



"The idea is sound, but how can we keep it from burning up? Present insulations won't work. How about ablative heat sinks? No—they won't work either in this case."

complete advanced weapons systems, to deal with the "whole" instead of "parts".

This is not just a "blue-sky thinking" assignment. Westinghouse believes future defense needs will be so complex that only a full-time team of specialists—like WASP—will be capable of the kind of conceptual planning and guidance needed.

There's another reason why defense planners will be interested in WASP. This new group gives them a single point of contact within one of America's largest and most versatile industrial firms to which they can take immediate and long-range defense problems. No longer will it be necessary for someone

". . son, it circles the earth at 18,000 miles an hour." Space consultant, K. Satyendra, a Ph.D. from India, keeps WASP and other company scientists abreast of space needs. He is an authority in mission, trajectory, and communication concepts.

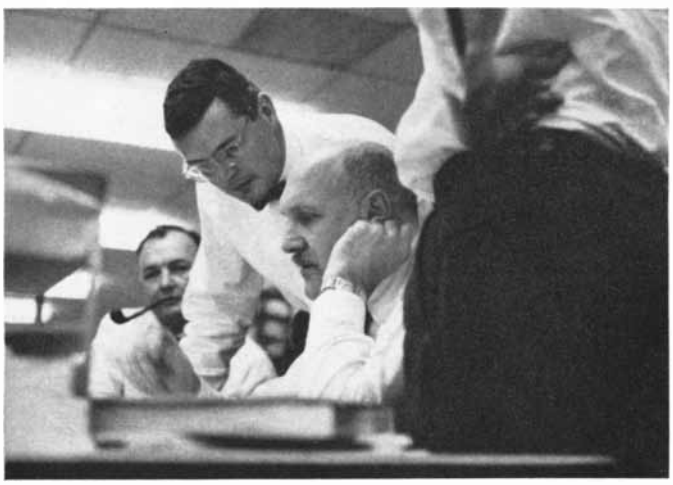
TOP ENGINEER AT WASP, Rein Kroon joined Westinghouse in 1931. Among other accomplishments, he headed the engineering group responsible for the design of the first American turbojet engine for aircraft.

"What's the best way to destroy an enemy reconnaissance satellite? Attack it from earth? Or from another satellite? How would we go about either method?"

to try to guess which Westinghouse division is best equipped to tackle a given job.

This is a bigger advantage than might be apparent. A newly-published capabilities chart*, for example, lists 29 different Westinghouse facilities and, for each, indicates specific study, design, or manufacturing capabilities in 33 different areas (infra-red, rocket powerplants, torpedoes, missile base equipment, etc.). This same chart lists 16 Westinghouse facilities which can handle system analysis and 7 capable of complete system management.

**Available to qualified individuals and firms upon request.*



"Could we deflect enemy ICBM's by sending them false signals at the time of launching? If so, could this be done from distant transmitters? Could this be done automatically from remote un-manned stations?"

MAN ON THE MOVE, Bill Robinson has his sights on tomorrow's systems and provides guidance for WASP in planning for future Department of Defense needs.

Westinghouse

DEFENSE PRODUCTS

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1909: "One of the principal problems considered by the International Meteorological Conference in London last week was the question of wireless marine weather reports. Prof. Willis L. Moore, representing the U. S., urged the necessity of adopting regulations that will compel a ship beyond a certain tonnage to carry wireless instruments and operators and to take at noon Greenwich time a daily observation of the weather. Observations received by a ship would be transmitted to other vessels so that by means of such relays the weather conditions over the entire ocean would in a few minutes reach the central meteorological offices in the U. S., England, France, Germany and other interested nations. Forecasts would then be made and distributed to the vessels by wireless telegraphy."

"There are a great many things to be said in favor of, and a few against, the proposal to advance the clock by one hour during the summer months. Although the suggested change is startling, there is in it nothing of the ludicrous or farcical, as some of its critics have suggested. The principal object of the movement is to apportion a larger part of the period of daylight to evening rest and recreation than is now possible. The proposed arrangement, as advocated by the National Daylight Association in this country is that from and after 2 o'clock in the morning of the first day of May in each year, until 2 o'clock on the morning of the first day of October, the standard time shall be one hour in advance of the standard time now in use."

"The final plans for the locks of the Panama Canal have just been adopted. They are to be constructed wholly of that newest of building mediums, concrete, and it is extremely doubtful whether the great waterway would have been designed upon its present ambitious lines had not concrete gained the powerful prestige as a building material which it now holds. A number of other giant structures, such as the Gatun spill-

"PACKAGING" MICROWAVES FOR MOUNTAIN TOPS

"TJ" radio-relay station at Black Mesa, Arizona

In Arizona, the telephone company faced a problem. How could it supply more telephone service between Phoenix and Flagstaff—through 135 miles of difficult mountain territory?

Radio offered the economical answer: a new microwave radio-relay system recently created at Bell Telephone Laboratories. Operating at 11,000 megacycles, it was just right for the distance, and the number of conversations that had to be carried.

But first other problems had to be solved: how to house the complex electronic equipment; how to assemble and test it at hard-to-reach relay stations way up in the mountains; and how to do it economically.

On-the-spot telephone company engineers had some ideas. They worked them out with engineers at the American Telephone and Telegraph Company and at Bell Telephone Laboratories. The result: a packaged unit.

The electronic equipment was assembled in trailer-like containers at convenient locations and thoroughly checked out. The complete units were then trucked up the mountains and lifted into position.

The system, now operating, keeps a watch on itself. When equipment falters, a relay station switches in standby equipment, then calls for help over its own beam.

The new Phoenix-Flagstaff link illustrates again how Bell System engineers work together to improve telephone service. Back of their efforts is the constant development of new communications systems at Bell Telephone Laboratories.

BELL TELEPHONE LABORATORIES *World center of communications research and development*

way, and various dams, culverts, diversion tunnels, etc., are being carried out in this medium; but the most interesting of all will be the mammoth locks. They will be by far the largest and longest concrete structures of the kind in the world."

"The success of the electrically illuminated baseball grounds in Cincinnati, Ohio, has been so pronounced that it is now proposed to have football games, as well, on the illuminated field. Football is too strenuous to be played under the summer sun, but no such objection can be raised to it in the cool of the evening."

"Prof. Simon Newcomb died on July 11th in Washington at the age of 74. His death has removed not only the most distinguished astronomer that America ever produced, but a man who is honored the world over for his achievements."

"Pipe-line connections have been completed by which it is possible to pipe oil from Oklahoma wells to New York harbor. Oil has been started on the long journey of 1,500 miles. This is the longest pipe line in the world. It is not probable that much oil from the mid-continent district will be brought to the seaboard at present, and the completion of the line seems to be more in the nature of a provision for the future. Oklahoma has the most active oil field in the country at present, moreover its production is increasing, while that of Pennsylvania and West Virginia is decreasing. It may not be long before the western wells will be called upon to supply the seaboard and export demand."

JULY, 1859: "The achievements of our young countryman, Paul Morphy, in vanquishing the most distinguished chess players of Europe, have excited in our people a very pardonable degree of national pride; hence they have exhibited a strong exultant feeling in welcoming him back to his native land as the Chess Champion of the World. He has been received with high demonstrations in several cities, and public testimonials of great value have been presented to him; while at the same time poets have sung and sages have delivered orations in his praise."

"When we consider the vast number of persons who comprise what may be

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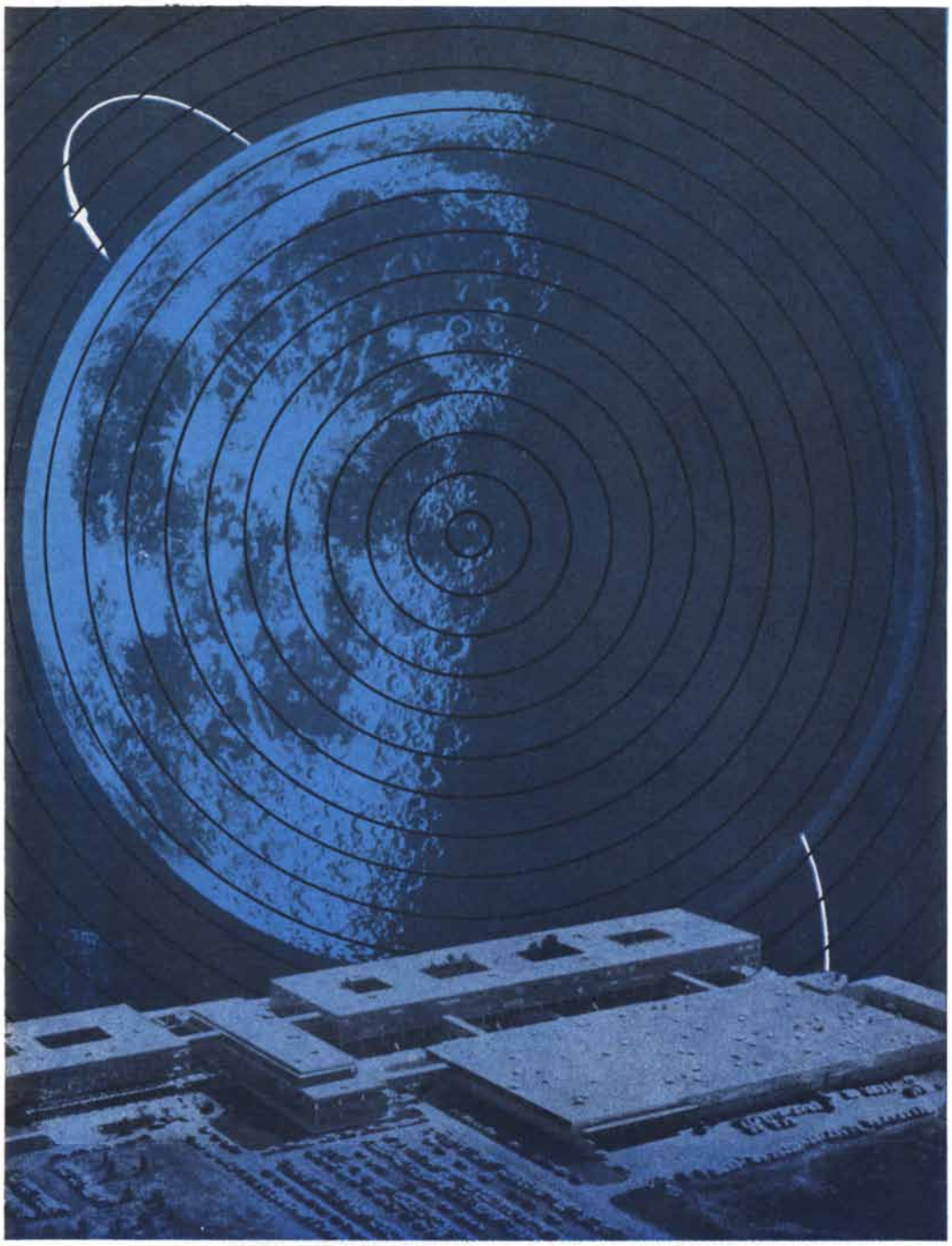
6RV59

called the letter-writing community, we shall at once appreciate the great waste of time which occurs in carrying letters from distant parts of a city, singly or in small bundles, to the central post office. We have the pleasure of calling the public attention to an improvement which has been adopted by the Postal Department in Philadelphia, where they have over 300 letter boxes attached to lamp posts throughout the city, thus bringing the post office to the door."

"The veteran aeronaut, Mr. John Wise, has long entertained the idea that a successful balloon voyage across the Atlantic may be accomplished with a very large balloon. For this purpose the monster balloon, *Atlantic*, was built by Mr. La Mountain, at Lansingburgh, N.Y., and carried to St. Louis in order to make the experimental voyage from that city to New York, prior to making a grand atmospheric journey across the ocean to Europe. On the first instant the balloon was inflated with 60,000 feet of coal gas. At 20 minutes past seven, p.m. Mr. Wise ascended into the basket, and Messrs. La Mountain, Gager and Hyde took their places in the life-boat. The signal was then given for the stay-ropes to be cut, when the mighty mass shot up like a rocket amid the plaudits of the multitude. Having ascended to an elevation where the thermometer fell to 42 degrees, a strong eastward current was met and away they floated toward New York. At five o'clock next morning they were at the upper end of Lake Erie. It was resolved to land at Rochester and let out Messrs. Hyde and Gager, after which, Messrs. Wise and La Mountain were to prosecute the voyage, hoping to reach Boston, knowing they were too far north now to reach New York. In order to carry on this conclusion they gradually descended toward *terra firma,* where they met with a terrific gale of wind which frustrated all their plans and nearly cost them their lives. The balloon went crushing through the tops of the trees, smashing them like pipe-stems, and continued thus for about one mile, until its progress was arrested by a tall oak; and, we are happy to state, although the boat, basket and balloon were much injured, a kind providence preserved the lives of the daring aerial voyagers, who escaped with only a few bruises. Thus ended the longest balloon journey on record: The distance traveled was 1,150 miles; the time occupied, 19 hours; a speed compared with which that of the locomotive is that of a donkey to a deer. The highest point attained was a little over two miles."



Space age research gets a new headquarters—One of the largest and best-equipped research facilities in the nation is the new 16-million-dollar Avco Research Center at Wilmington, Massachusetts. Here, research and development in space age technology is already being conducted in areas ranging from missile re-entry to satellite design. From work such as this—and equally important work at the nearby Avco Research Laboratory—will come further contributions to national security and the conquest of space.

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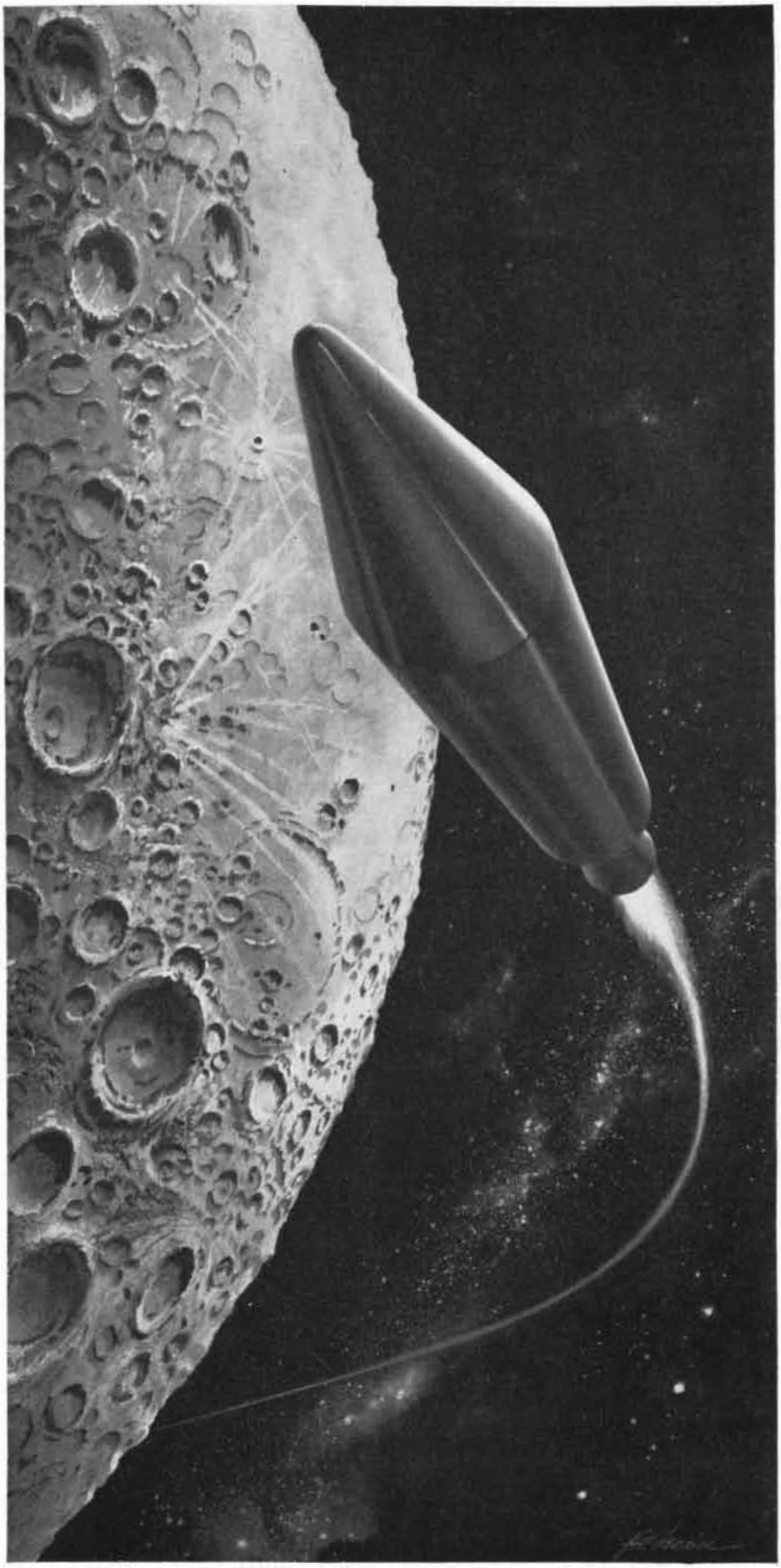

dead center

Kelsey-Hayes thrust vectoring systems give missiles proper directional control.

Kelsey-Hayes is contributing substantially to the design, development and production of new thrust vector control systems for solid fuel propulsion.

For example Kelsey-Hayes, in a recent crash program, designed and fabricated a movable nozzle control that passed static firing tests for one of the newest sophisticated missile systems.

The swivel nozzle control is just one of the latest developments by Kelsey-Hayes as a subcontractor of propulsion subsystems, flight componentry and high performance materials. Spearheading Kelsey-Hayes activities is the Advanced Design Group, a flexible team of experienced design specialists.
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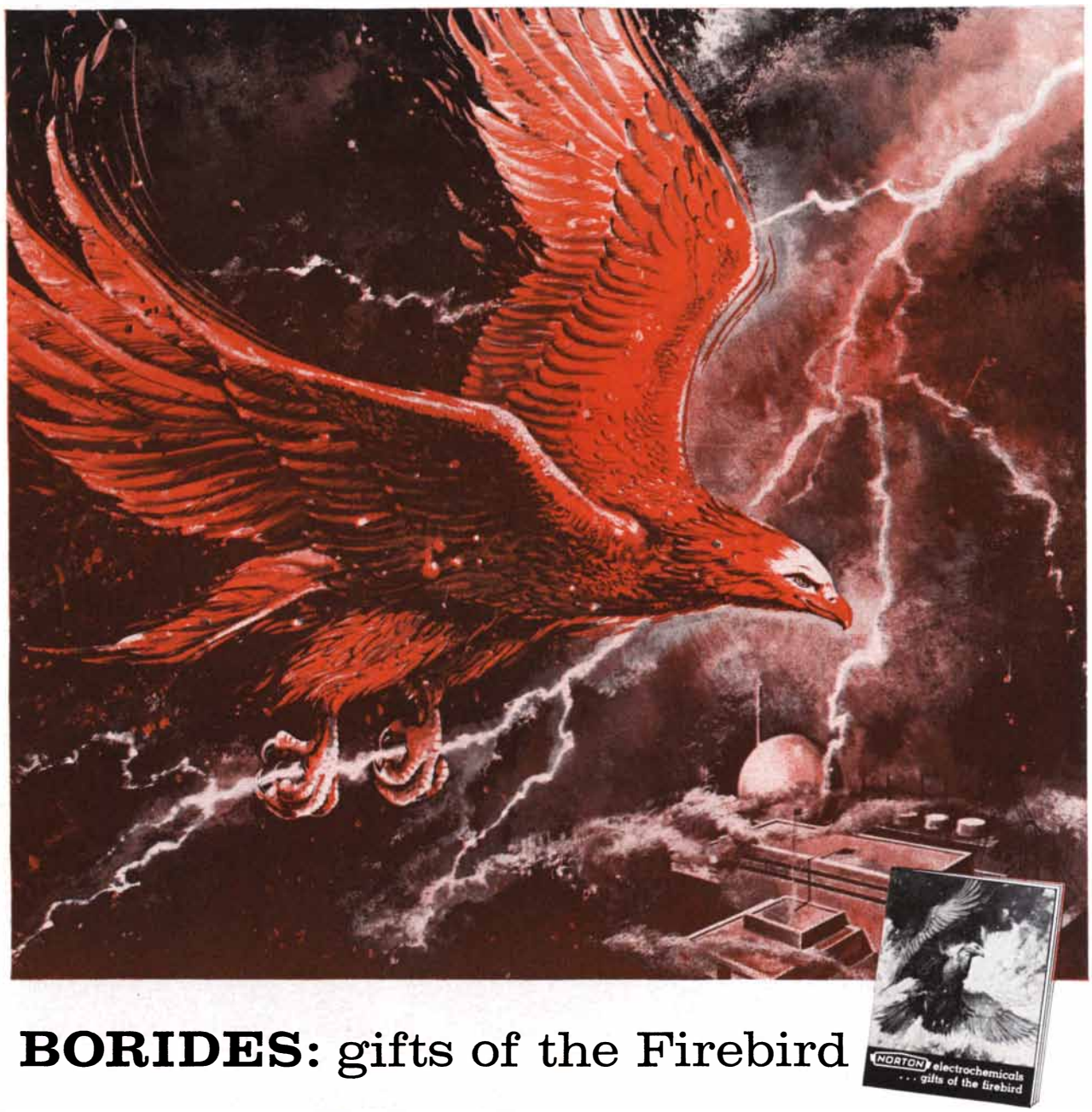

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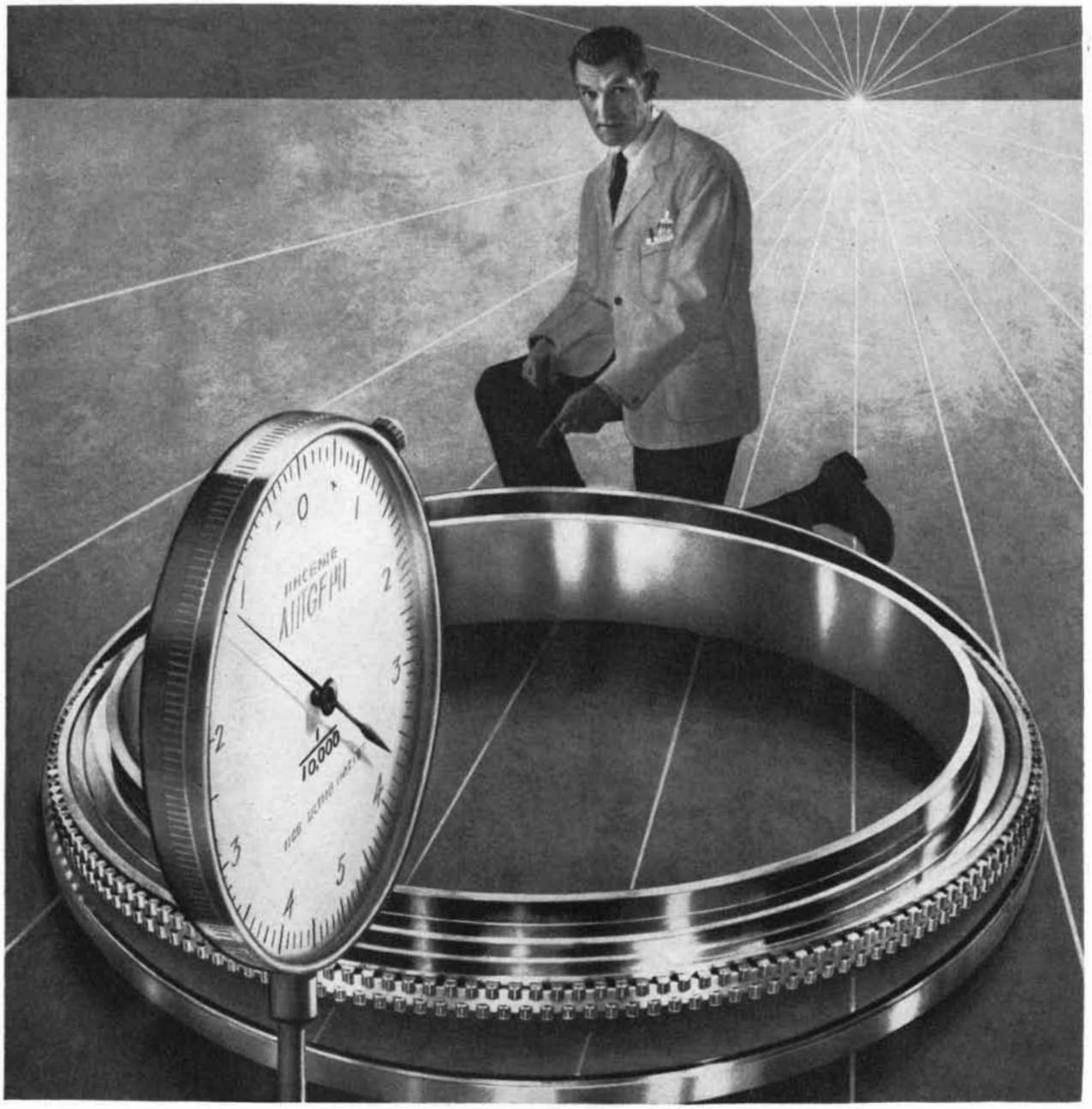

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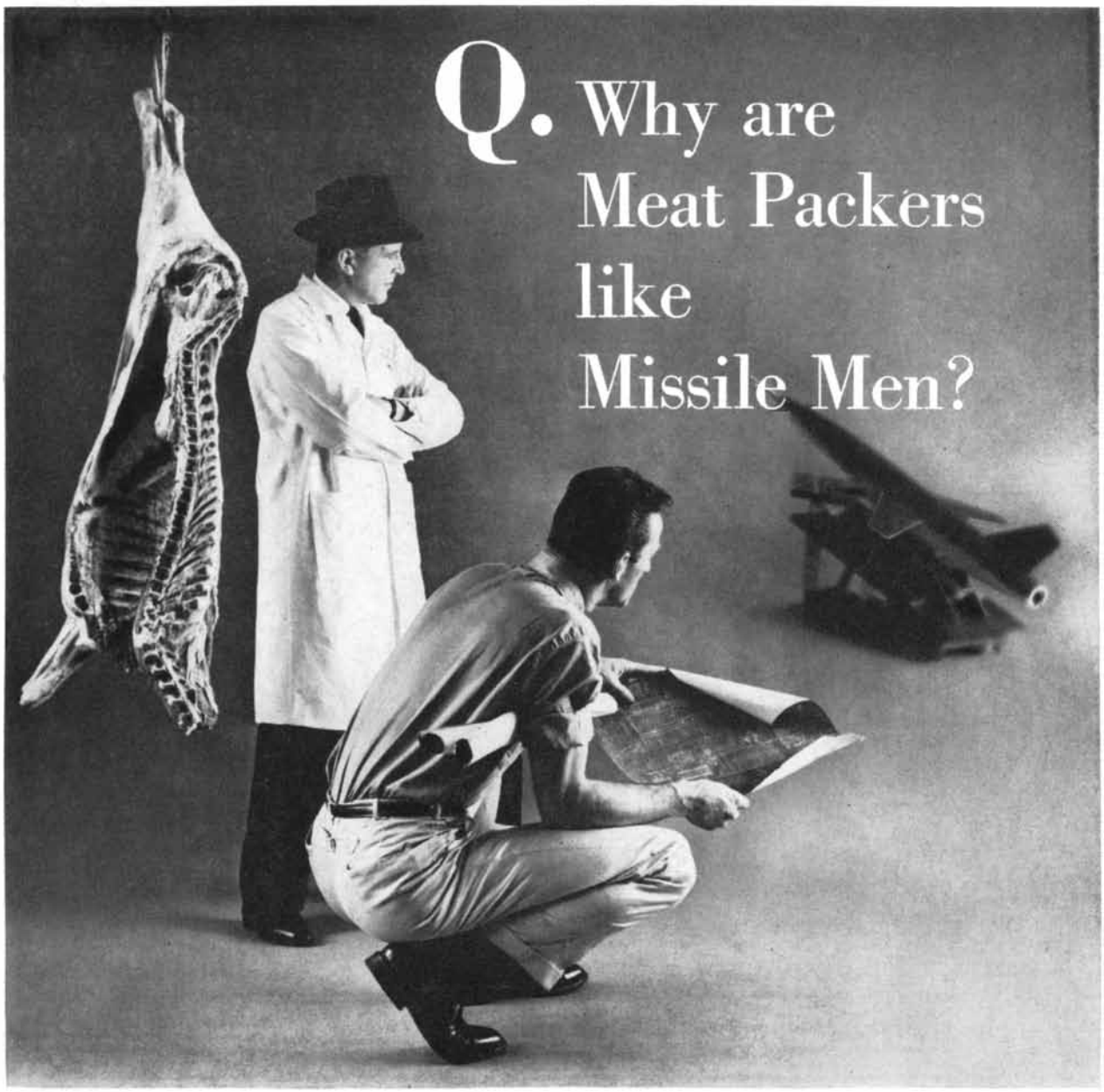

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THE AUTHORS

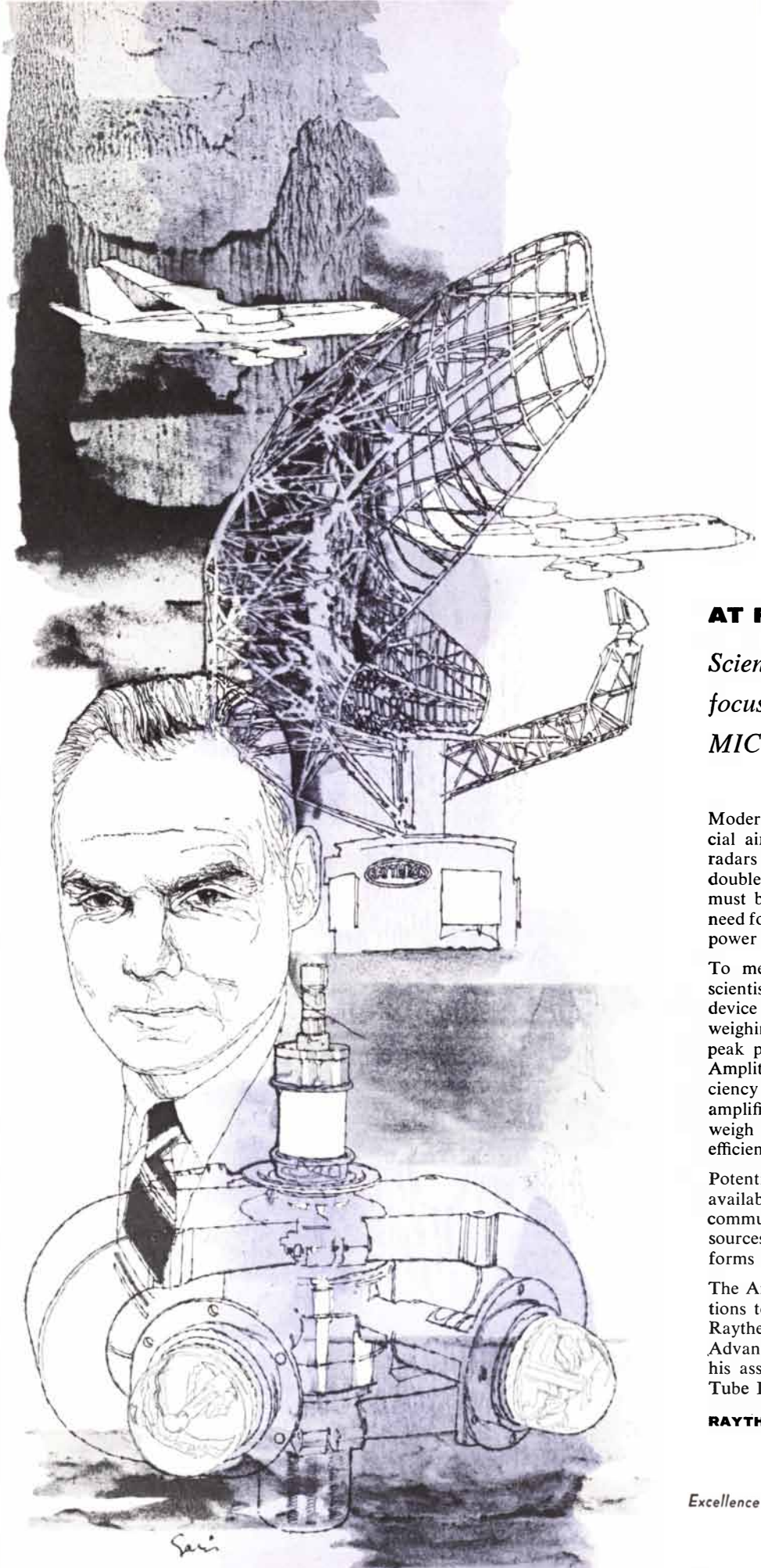
GILBERT N. PLASS ("Carbon Dioxide and Climate") is a senior staff member of the Office of Advanced Research of Aeronutronic Systems, Inc. A physics graduate of Harvard College in 1941, he joined in early studies of nuclear reactors for the Manhattan Project at the University of Chicago's Metallurgical Laboratory during World War II, then acquired a Ph.D. from Princeton University and taught physics at Johns Hopkins University. "I spent several years," he says, "studying the dependence of infrared radiation in the atmosphere upon water vapor, carbon dioxide and ozone. This naturally led me to re-examine the old carbon dioxide theory of climatic change. It soon became evident that the usual textbook objections to this theory were invalid. My long-standing interest in geology, biology and chemistry helped me to synthesize the new carbon dioxide theory from these diverse fields."

ROBERT P. KRAFT ("Pulsating Stars and Cosmic Distances") is currently assistant professor of astronomy at the Yerkes Observatory of the University of Chicago. Next year he will become a staff member of the Mount Wilson and Palomar Observatories. After receiving B.S. and M.S. degrees in mathematics from the University of Washington, Kraft joined the faculty of Whittier College in California. "There are two kinds of astronomers," he remarks: "those who are born to it—who want to do astronomy from the time they are 10 years old and grind their first mirror—and those who come into it later on from some other field, as in my own case. What prompted me was an interest that developed during my stay at Whittier in the philosophy of the physical sciences. This led me to turn from pure mathematics to a truly empirical science, in which theory really meets the test of experience." Aided by National Science Foundation fellowships, Kraft earned a Ph.D. in astronomy from the University of California in 1955 and went on to postdoctoral research at Mount Wilson and Palomar.

HANS WALLACH ("The Perception of Motion") is professor of psychology at Swarthmore College. He writes: "I was born and raised in Berlin. Originally my interest was in physical sciences, and I was starting out in chemistry when I learned about the delights of working in a young science where the unknown territory begins, so to speak, at the doorstep." At the University of Berlin Wallach became a disciple of Wolfgang Köhler, the well-known exponent of Gestalt psychology and author of *The Mentality of Apes.* In 1935 Köhler resigned his Berlin professorship. Wallach, then a newly minted Ph.D., followed Köhler to Swarthmore in 1936 and has remained there ever since, except for three years on leave as a Guggenheim Fellow, as a professor on the graduate faculty of the New School for Social Research, and as a member of the Institute for Advanced Study in Princeton, N. J.

GEORGE GAMOW ("The Exclusion Principle") is professor of physics at the University of Colorado. He was born in Odessa, Russia, in 1904, and studied nuclear physics at the University of Leningrad, where he received his doctoral degree in 1928; at the University of Copenhagen under Niels Bohr; and at the University of Cambridge under Ernest Rutherford. In 1934 Gamow emigrated to the U. S., where he served for over 20 years as professor of physics at George Washington University. During this period Gamow found his interest turning from the atomic nucleus to astrophysics, the theory of the expanding universe and later to fundamental problems of biology, including molecular genetics and the synthesis of proteins. In 1938 he began to write and illustrate a series of popular articles for the British magazine *Discovery* concerning the macro- and microcosmic adventures of "Mr. Tompkins," whose exploits have since appeared in three books (the latest: *Mr. Tompkins Learns the Facts of Life*) and in 19 languages. "The Exclusion Principle" is the 10th article Gamow has written for SCIENTIFIC AMERICAN.

WILLIAM H. AMOS ("The Life of a Sand Dune") is chairman of the science department at St. Andrew's School in Delaware and, in addition, serves as a research associate of the University of Delaware Marine Laboratories. At the Laboratories he edits a publication entitled *Estuarine Bulletin* and heads an ecological survey of the estuary of the Delaware River. In April and May he took leave from both jobs to serve as ecologist with the Smithsonian-Bredin expedition to the West Indies. Amos has engaged in biological research in the Philippine Islands, Japan and Hawaii and has been an associate of the Mount Desert Island Biological Labora-



AT RAYTHEON—

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tory, the Department of Biophotography at Rutgers University, and the New York Zoological Society. "I am fortunate in having published 10 short books in the field of ecology, in addition to a number of papers," he says. "My interest in dunes is continually reinvigorated through the visits of biologists who had been unaware of these inland sand waves. Field ecological studies are often carried on in uncomfortable situations. Certainly a sand dune baking in the midday sun is no exception, but the clarity, the simplicity and the stark nature of biotic relationships on the dunes more than compensate for any discomfort. I am not sure that others will agree with me, but I find it completely refreshing to spend days in these bright, arid sand hills."

MACHTELD J. MELLINK ("The City of Midas") is chairman of the department of classical and Near Eastern archaeology at Bryn Mawr College. Born in the Netherlands, she studied classical languages and archaeology at the universities of Amsterdam and Utrecht, acquiring her doctorate from the latter institution in 1943. Her dissertation, entitled *Hyakinthos,* was a study of survivals in Greece of pre-Greek religion. After World War II Miss Mellink continued her studies at Bryn Mawr and the University of Chicago; from 1947 to 1949 she was a staff member of an expedition, headed by Hetty Goldman of the Institute for Advanced Study, to ancient Tarsus. Since 1950 she has been engaged in the University of Pennsylvania's diggings at Gordion, described in her article.

TREVOR ROBINSON ("Alkaloids") teaches in the department of bacteriology and botany at Syracuse University. "I received my A.B. at Harvard in 1950," he says, "majoring in a hodgepodge field called 'biochemical sciences'—a smattering of courses on a number of scientific subjects. As I intended to be a high-school teacher, I stayed on at Harvard for an A.M. in science education. Despite the supposed need for science teachers nobody wanted to hire me, so I took some more advanced courses at the University of Massachusetts. There I became so interested in biochemical research that I gave up the idea of high-school teaching and took an M.S. in chemistry. Next I went to the department of biochemistry at Cornell University, taking my Ph.D. in 1956. While at Cornell I became entranced by the fantastic array of pe-

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PORT OF EMBARKATION

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culiar compounds found in plants. In addition to alkaloids I have studied plant tannins, another peculiar class of materials. In quite a different vein, I have been carrying on research on the inactivation of dilute enzyme solutions by ionizing radiation."

ROBERT D. ALLEN ("The Moment of Fertilization") is associate professor of biology at Princeton University. He graduated from Brown University and acquired a University of Pennsylvania Ph.D. in 1953. At Pennsylvania Allen was inspired by John Runnström, a visiting professor of zoology from the University of Stockholm, to study fertilization. Allen acquired a U. S. Public Health Service Postdoctoral Fellowship which enabled him to continue his association with Runnström for 15 months in Stockholm, Naples, and at Kristineberg on the west coast of Sweden. "In my early youth I wanted to be a concert cellist," Allen writes, "but I was forced to give up the instrument for a while after an injury to one hand. I still give informal concerts for my friends at the Marine Biological Laboratory in Woods Hole, Mass. In the summers there I also enjoy bike trips and skin diving for edible fish. My wife and I always manage to save about two weeks of the year for hiking and mountaineering—we have climbed in the Swiss and Tirolese Alps, the Apennines and in Lapland."

V. S. PRITCHETT, who reviews Pearl S. Buck's novel *Command the Morning* in this issue, is a British novelist, short-story writer and literary critic. He was born at Ipswich, England, in 1900, attended Alleyn's School in London, and entered the leather trade. Later he became a commercial traveler and shop assistant in France and a newspaper reporter in France, Spain and North Africa. After World War II he was literary editor of the weekly *New Statesman and Nation* for two years. In England he is well known for his talks on the British Broadcasting Corporation's "Third Programme." Pritchett has lived in Ireland and the U. S. as well as in France and the Mediterranean countries. He has reviewed many books for the Sunday edition of *The New York Times* and during 1953-1954 delivered a course of lectures in the Christian Gauss Seminar at Princeton University. His books include *The Spanish Temper*, a character study of Spain; the novels *Dead Man Leading* and *Mr. Beluncle;* and three critical works, entitled *In My Good Books, The Living Novel* and *Books in General.*

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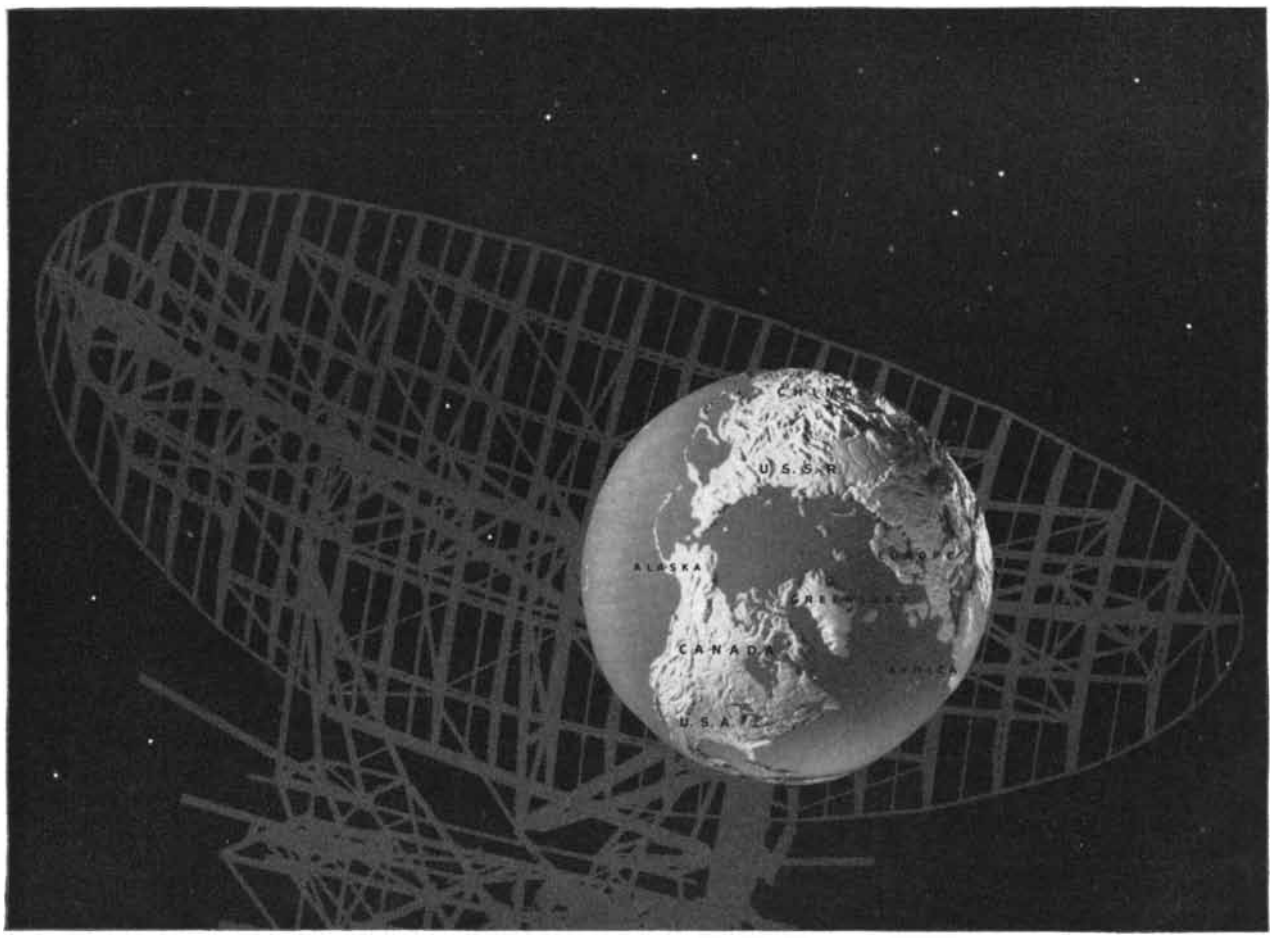

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In addition to military plane radar, we make radar proximity fuses which trigger the warheads of some of our missiles, and radar beacons which help identify the planes or missiles in which they are located.

A new radar system has just been developed for use on military helicopters. This electronic "eye", which can also be installed on liaison and cargo aircraft, is designed for night and bad weather operations and for navigating between mountains and in canyons. It shows the distance to any terrain obstacle and can also be used for ground mapping.

In the marine field, vessels of all types from ocean liners to 35-foot family cruisers use economical Bendix Radar. Leading TV stations, too, now use Bendix Radar to show their audiences the "weather" by actually picturing the size, intensity and exact positions of storm activity.

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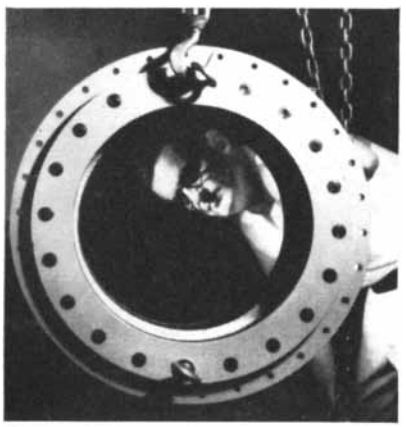
THIS IS GLASS

A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING

NEW PICTURE WINDOWS FOR NAVY'S NUCLEAR REACTORS

In the "older" models of the Navy's nuclear subs, a periscope was used for checking reactor operation.



Not so in today's subs. Now you'll find giant peepholes—windows that let you look directly into nuclear compartments.

These windows are made from a combination of Corning high-lead-content glass and a plastic. The latter shields against neutron bombardment. The high density *glass* (6.2 cc, the equal of iron for shielding) protects against gamma rays.

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The big advantage for you, the user, in all this . . . aside from the fact that you can get any combination of three very special glasses we make for shielding . . . is *simplicity*. You just tell us your energy level, wall thickness, and the viewing area you need. We do the rest . . . ship you a window that's *ready to install*. It's as easy as that.

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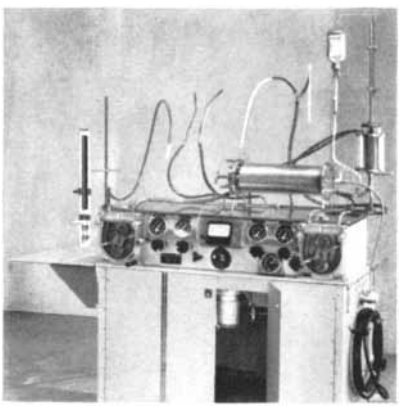
THE HEART OF THE MATTER

During certain operations involving the heart, both the heart and lungs are given a rest.



But the functions of these organs still must go on. So ingenious machines take over. Like the Kay-Cross rotating disc oxygenator that does the work of the lungs, controlling the CO_2 and putting in pure oxygen.

The main component of this oxygenator is a series of discs, so designed that blood spreads out without foaming or bubbling.

Comes the commercial. These metal discs must be enclosed in a container. And the people who make the oxygenator, Pemco, Inc., chose a PYREX brand glass to hold the discs.

For good reasons. First off, this PYREX brand glass lets you keep careful watch over the *color* and *flow* of the blood, both very vital considerations to the medical men who use this machine.

Then, this PYREX brand glass is *inert* chemically. It does not add to or take from the blood in any way. There is no pickup, no side effects.

And, because this glass has a low coefficient of thermal expansion, 32 x 10^{-7}in/in/°C., the entire machine can be steam sterilized *without* any fear of danger from thermal shock.

While this particular application may be far afield from your work, one of the PYREX brand glasses may still turn out to be the answer to one of the tough design problems you are now facing.

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Perhaps the best approach for you is to avail yourself of two well-detailed reference folders, B-83, "Properties of Selected Commercial Glasses," and IZ-1, "Designing with Glass for Industrial, Commercial and Consumer Applications." Use the coupon.

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The pressure can be applied by the fluid or by a small charge attached to the disc. When you want it to go, the glass will shatter instantaneously and homogeneously into small pieces.

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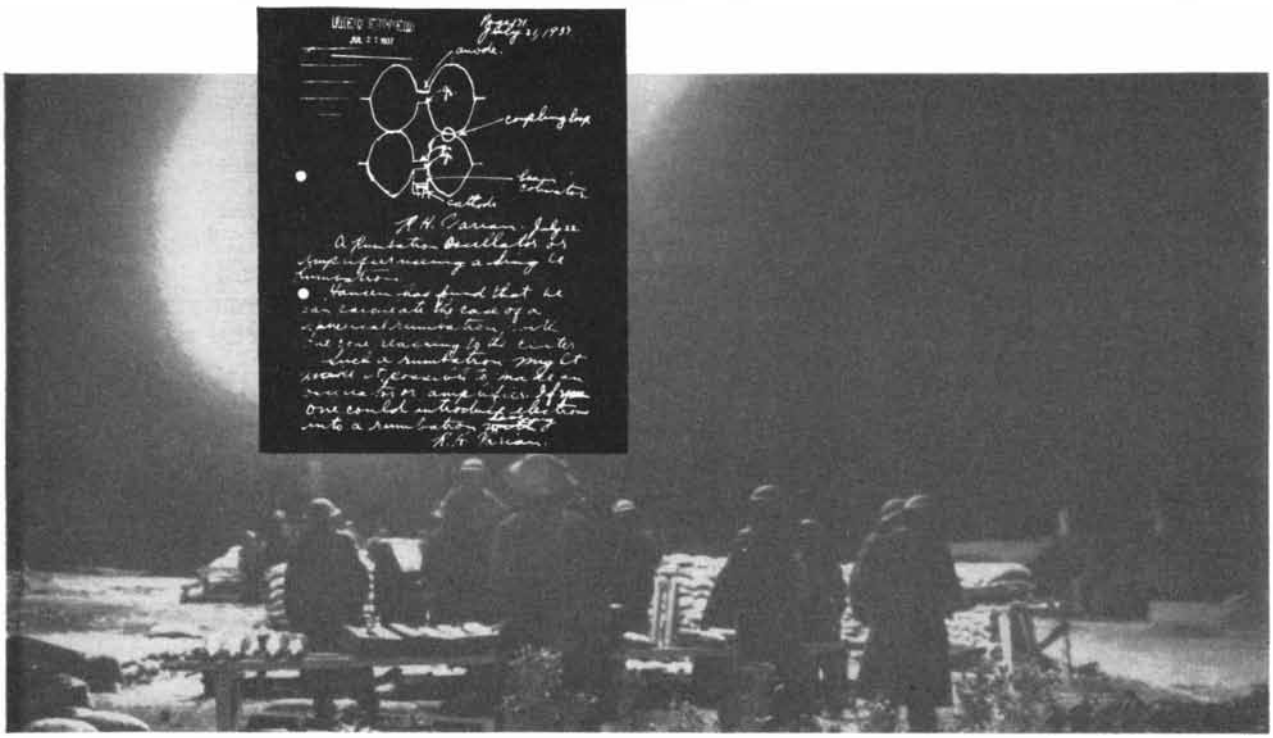
THE SKETCH THAT HELPED WIN A WAR



This sketch, drawn in 1937 by Dr. Russell Varian, Founder and Board Chairman of Varian Associates, led to the development of the klystron — and mobile radar. Dr. Varian's achievement played a vital role in the successful air defense of Great Britain and the ultimate air superiority of the Allies during World War II.

Less than a decade after this historic first practical use of radar, Varian Associates was established to manufacture klystrons and continue the development and improvement of this important new device which is acknowledged to be the foundation of microwave electronics. Today, as the largest manufacturer of klystrons, Varian produces more than 100 types and sizes for a vast variety of commercial and military uses.

The creativity and technical excellence responsible for this accomplishment has found expression in other Varian developments and products, such as NMR and EPR Spectrometers, free-precession magnetometers, graphic recorders, laboratory magnets, Vaclon® High Vacuum Pumps, traveling wave tubes and linear accelerators.

At Varian, the inventive process, creative initiative and the "science of practicality" in volume production combine to produce ever-greater quantities of components, instruments and systems of unexcelled performance and reliability.

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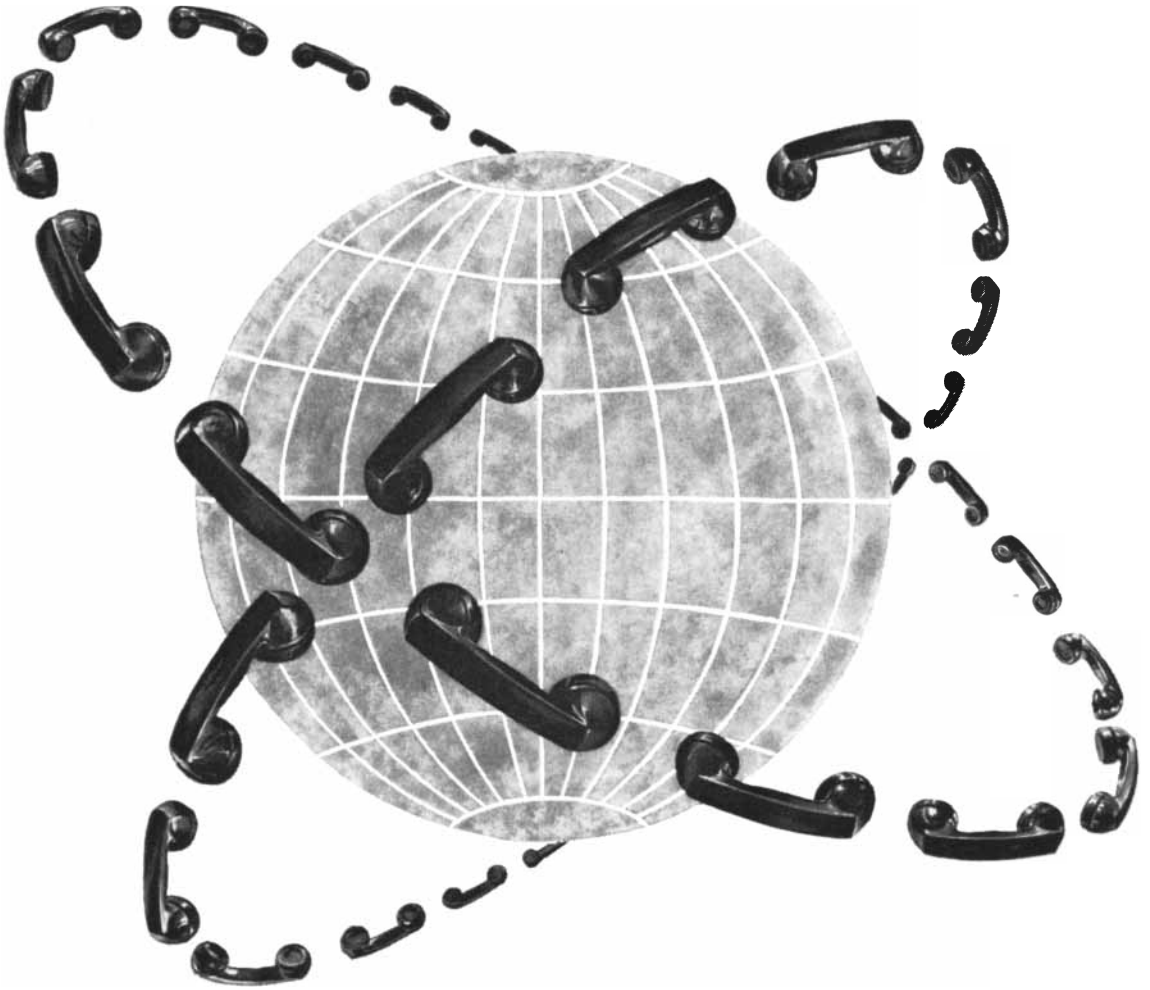

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Pierre Simon Laplace...on the store of higher knowledge

"Astronomy considered in its entirety is the finest monument of the human mind, the noblest essay of its intelligence. Seduced by the illusions of the senses and of self-pride, for a long time man considered himself as the centre of the movement of the stars; his vainglory has been punished by the terrors which its own ideas have inspired. At last the efforts of several centuries brushed aside the veil which concealed the system of the world. We discover ourselves upon a planet, itself almost imperceptible in the vast extent of the solar system, which in its turn is only an insensible point in the immensity of space. The sublime results to which this discovery has led should console us for our extreme littleness, and the rank which it assigns to the earth. Let us treasure with solicitude, let us add to as we may, this store of higher knowledge, the most exquisite treasure of thinking beings."

—Exposition du Système du Monde, 1796.

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Carbon Dioxide and Climate

A current theory postulates that carbon dioxide regulates the temperature of the earth. This raises an interesting question: How do man's activities influence the climate of the future?

by Gilbert N. Plass

The theories that explain world-wide climate change are almost as varied as the weather. The more familiar ones attribute changes of climate to Olympian forces that range from geological upheavals and dust-belching volcanoes to long-term variations in the radiation of the sun and eccentricities in the orbit of the earth. Only the so-called carbon dioxide theory takes account of the possibility that human activities may have some effect on climate. This theory suggests that in the present century man is unwittingly raising the temperature of the earth by his industrial and agricultural activities.

Even the carbon dioxide theory is not new; the basic idea was first precisely stated in 1861 by the noted British physicist John Tyndall. He attributed climatic temperature-changes to variations in the amount of carbon dioxide in the atmosphere. According to the theory, carbon dioxide controls temperature because the carbon dioxide molecules in the air absorb infrared radiation. The carbon dioxide and other gases in the atmosphere are virtually transparent to the visible radiation that delivers the sun's energy to the earth. But the earth in turn reradiates much of the energy in the invisible infrared region of the spectrum. This radiation is most intense at wavelengths very close to the principal absorption band (13 to 17 microns) of the carbon dioxide spectrum. When the carbon dioxide concentration is sufficiently high, even its weaker absorption bands become effective, and a greater amount of infrared radiation is absorbed [*see illustration on next page*]. Because the carbon dioxide blanket prevents its escape into space, the trapped radiation warms up the atmosphere.

A familiar instance of this "greenhouse" effect is the heating-up of a closed automobile when it stands for a while in the summer sun. Like the atmosphere, the car's windows are transparent to the sun's visible radiation, which warms the upholstery and metal inside the car; these materials in turn re-emit some of their heat as infrared radiation. Glass, like carbon dioxide, absorbs some of this radiation and thus traps the heat, and the temperature inside the car rises.

Water vapor and ozone, as well as carbon dioxide, have this effect because they too absorb energy in the infrared region. But the climatic effects due to carbon dioxide are almost entirely independent of the amount of these other two gases. For the most part their absorption bands occur in different regions of the spectrum. In addition, nearly all water vapor remains close to the ground, while carbon dioxide diffuses more evenly through the atmosphere. Thus throughout most of the atmosphere carbon dioxide is the main factor determining changes in the radiation flux.

The 2.3×10^{12} (2,300 billion) tons of carbon dioxide in the earth's present atmosphere constitute some .03 per cent of its total mass. The quantity of carbon dioxide in the atmosphere is determined by the amounts supplied and withdrawn from three other great reservoirs: oceans, rocks and living organisms. The oceans contain some 1.3×10^{14} tons of carbon dioxide—about 50 times as much as the air. Some of the gas is dissolved in the water, but most of it is present in carbonate compounds. The oceans exchange about 200 billion tons of carbon dioxide with the atmosphere each year. When the equilibrium is disturbed, the oceans may engulf or disgorge billions of additional tons of carbon dioxide. This puts a damper on the fluctuations in the carbon dioxide content of the atmosphere: when the atmospheric concentration rises, the oceans tend to absorb much of the excess; when it falls, the oceanic reservoir replenishes it.

Both the atmosphere and the oceans continuously exchange carbon dioxide with rocks and with living organisms. They gain carbon dioxide from the volcanic activity that releases gases from the earth's interior and from the respiration and decay of organisms; they lose carbon dioxide to the weathering of rock and the photosynthesis of plants. As these processes change pace, the content of carbon dioxide in the atmosphere also changes, shifting the radiation balance and raising or lowering the earth's temperature.

Of course during any particular geologic era other factors may influence climate. Nonetheless let us examine some of the known facts of geological history and see how many can be ex-

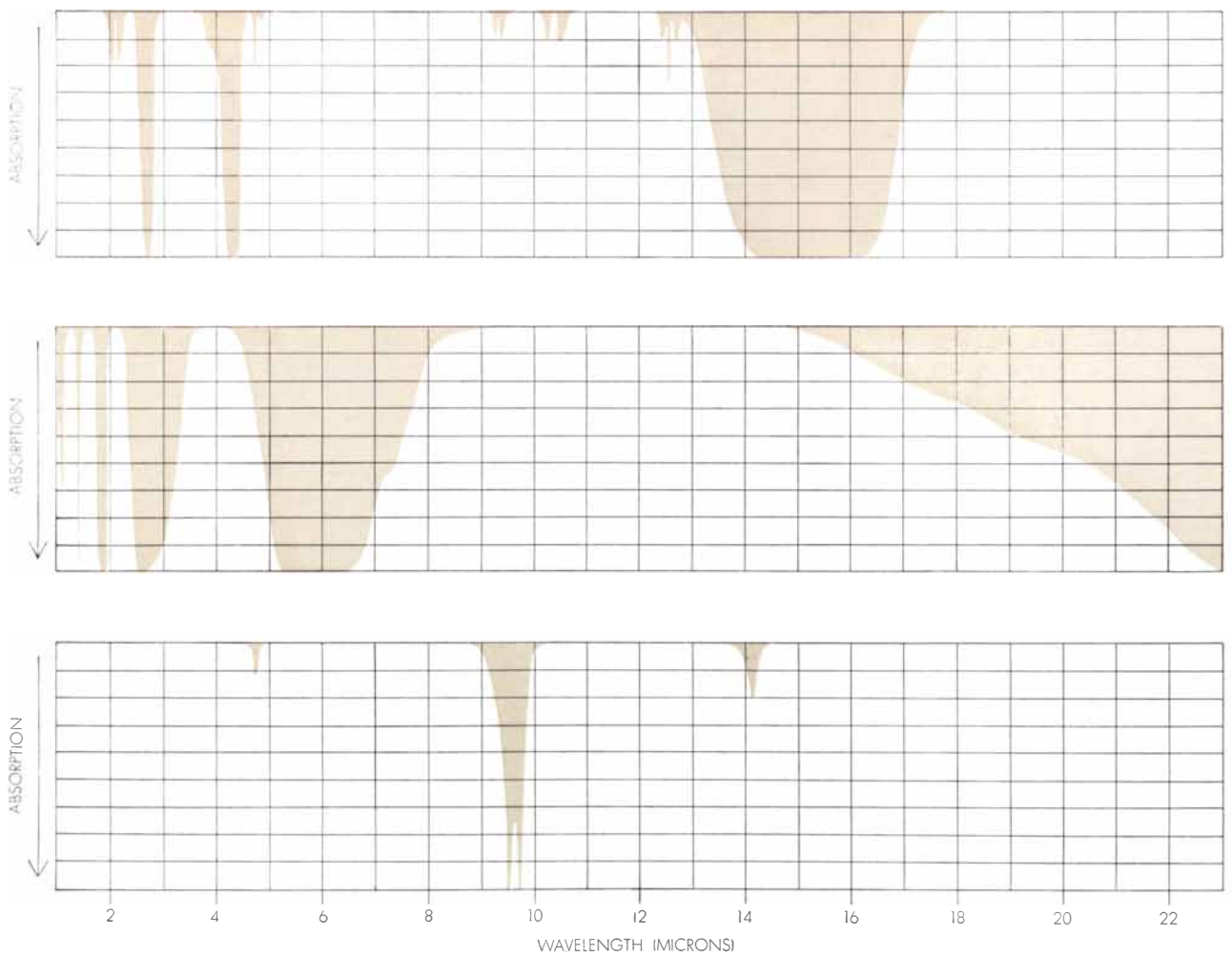
plained in terms of variation in the carbon dioxide content of the atmosphere.

Studies of rock strata reveal that for the past billion years most of the world has had a tropical climate. Every 250 million years or so this tropical spell is broken by relatively short glacial periods which bury a substantial portion of the earth under ice sheets. These cool periods last several million years, during which the glaciers retreat and advance many times as the temperature rises and falls. During the last 620,000 years of the current glacial epoch, for example, deep ocean sediments show 10 distinct temperature cycles. The carbon dioxide theory may well account for these temperature fluctuations.

A decline in the carbon dioxide concentration in the atmosphere-ocean system—and a period of decline in world-wide temperature—may be induced by a number of developments. The rate of volcanic activity could slow down as the rate of rock weathering increased, or an especially flourishing mantle of vegetation could take up huge quantities of carbon dioxide and form new coal beds and other organic deposits in marshy areas. After a geologically short time, the adjustment of the atmosphere-ocean equilibrium to the leaner supply of carbon dioxide could bring the atmospheric concentration down to .015 per cent, half its present value. Calculations show that a 50-per-cent decrease in the amount of carbon dioxide in the air will lower the average temperature of the earth 6.9 degrees Fahrenheit.

We can be reasonably sure that such a sharp drop in temperature would cause glaciers to spread across the earth. As the ice sheets grow, the oceans shrink; at the height of glacial periods ice sheets contain 5 to 10 per cent of the oceans' waters. The glaciers contain little carbon dioxide, however, because ice can hold very small amounts of carbonates compared to the same volume of sea water. The shrunken oceans thus accumulate an excess of carbon dioxide which they must release to the atmosphere in order to return to equilibrium. And so the cycle draws to a close: As carbon dioxide returns to the atmosphere, the earth's temperature rises and the ice melts away. The oceans fill to their former levels, reabsorb the carbon dioxide they had released, and a new glacial epoch begins.

So long as the total amount of carbon dioxide in the atmosphere-ocean system does not change, such a cycle of temperature oscillation will tend to repeat itself. The period of the complete cycle would be determined primarily by the

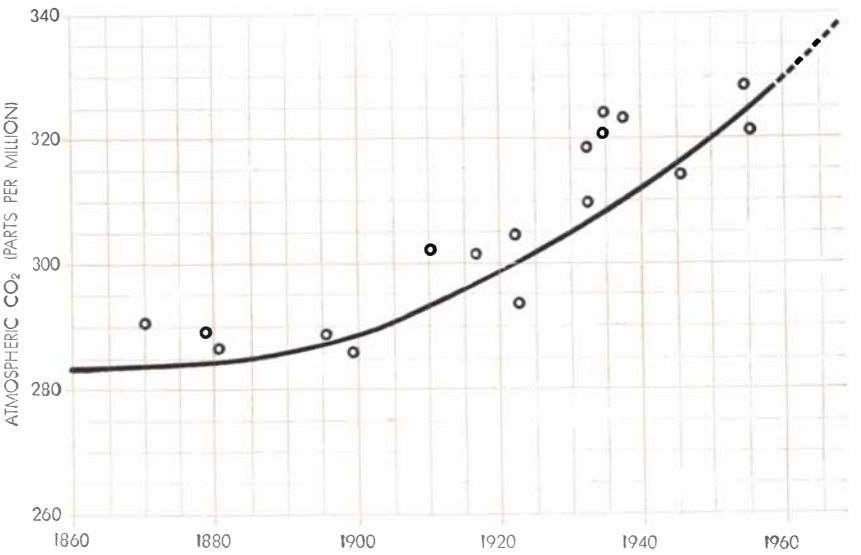


INFRARED ABSORBERS in the earth's atmosphere include carbon dioxide (*top*) water vapor (*center*) and ozone (*bottom*). Spectral charts of their absorption in the infrared region show that these gases warm the earth by preventing its infrared radiation from escaping into space. Carbon dioxide influences climate because it has a broad absorption band at wavelengths (13 to 17 microns) near the wavelengths at which the earth's infrared radiation is most intense. Water vapor and ozone can also influence climate.

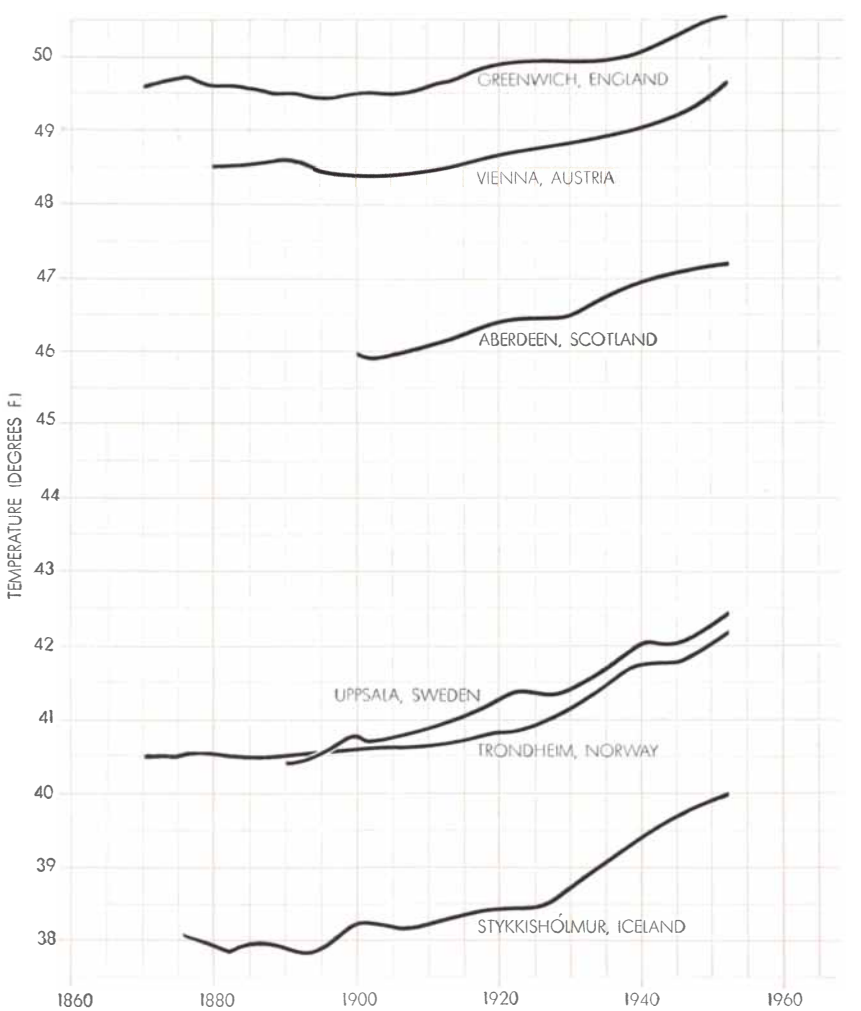
time required for an ice sheet to form, grow to maximum size and melt away. Estimates indicate that this should take about 50,000 years, in agreement with the observed time for the cycle. Other time factors in the cycle, such as the period required for the ocean-atmosphere system to come to equilibrium after a change in its carbon dioxide concentration, are probably much shorter. The system never quite reaches equilibrium, however, because the freezing and melting of glaciers is out of phase with the fluctuation of carbon dioxide in the atmosphere. Glaciers are slow to form and slow to melt, so for thousands of years during the earth's recovery from an ice age the cold winds from melting glaciers continue to chill the earth.

The mechanism here proposed to explain the cycle of glaciation does not depend in any way upon the particular numbers assumed for illustrative purposes. Such oscillations will occur whenever the temperature during one phase of the cycle falls low enough to cause ice sheets to grow and during another phase rises high enough to cause them to melt. A change in the comparatively small volume of carbon dioxide in the atmosphere provides ample leeway to swing the temperature past either extreme. The oscillation is reinforced by the accompanying change in the earth's humidity. A colder atmosphere holds less water vapor, and so further reduces the atmospheric absorption of infrared radiation emitted by the earth's surface. At the same time, however, the earth's cloud cover thickens and precipitation increases despite the reduction in the water-vapor burden of the atmosphere. The top of a cloud is cooled by the radiation of heat into space; when there is less carbon dioxide in the atmosphere, cloud tops lose more heat energy and thus become colder. With a steeper temperature gradient there is increased convection within the cloud. The result is larger clouds and more precipitation. Moreover, since the cloud cover reflects the sun's visible radiation back into space, less solar energy reaches the earth, and the temperature falls still lower.

The geological record indicates that the huge capacity of the biosphere to store and turn over carbon dioxide has also had its effect upon climatic change. We know that plants borrow 60 billion tons of carbon dioxide yearly for photosynthesis. Under present conditions the organic world repays nearly all of this debt each year via respiration and decay. The formation of new fossil fuel



RISING CARBON DIOXIDE CONCENTRATION in the atmosphere during the present century is due to man's increased burning of fossil fuels and greater agricultural activities. The data on which this chart and the one below are based were compiled by G. S. Callendar.



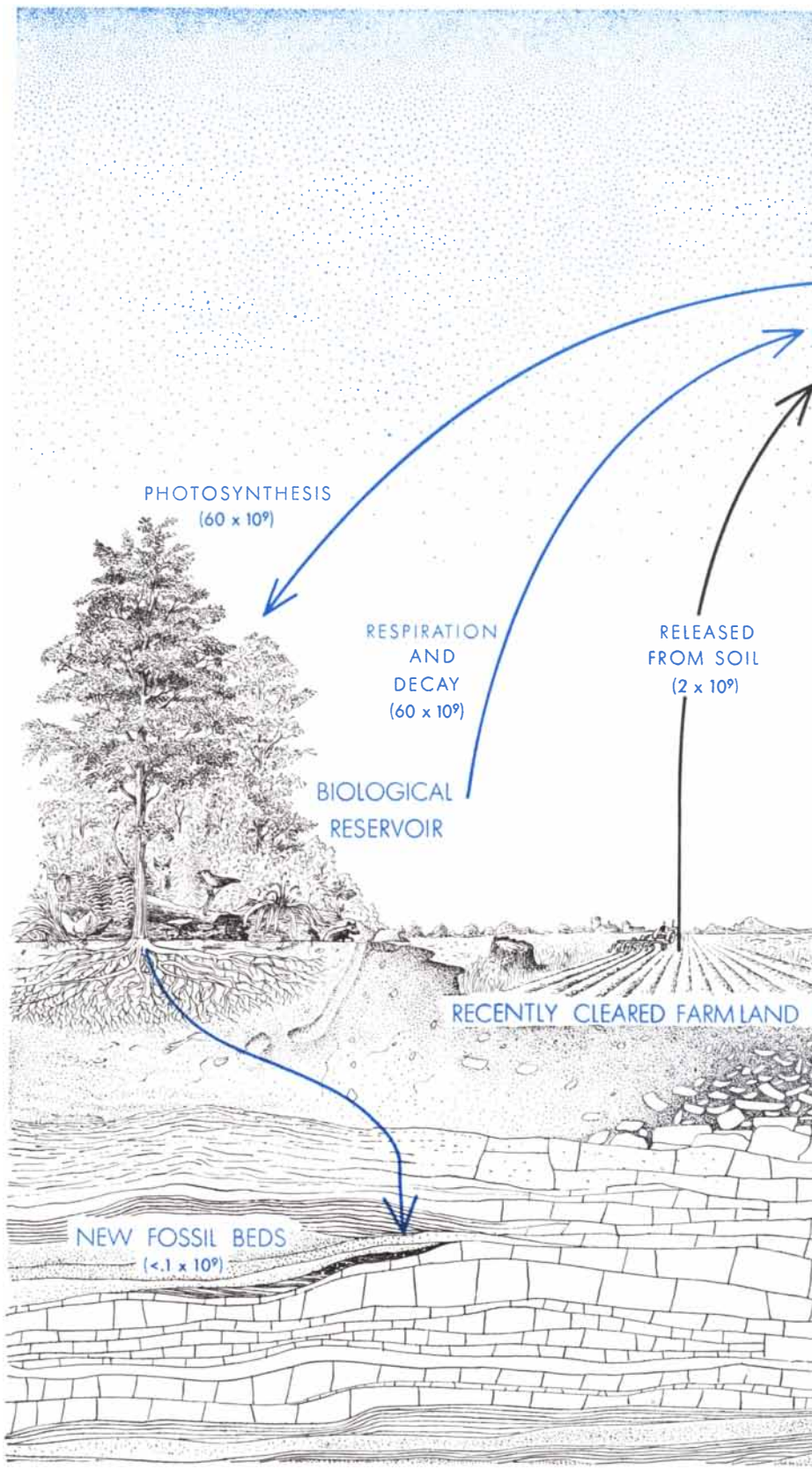
RISING TEMPERATURES recorded at various points on the earth during the past 100 years parallel the increase in atmospheric carbon dioxide plotted in this chart. The yearly mean temperatures shown were averaged over previous 30 years to remove short-term fluctuations.

deposits withholds at most only 100 million tons of carbon dioxide, or less than .2 per cent of the annual amount used for photosynthesis. At one time, however, the withdrawals were much larger. During the Carboniferous period, when most of the coal and oil deposits were formed, about 10^{14} tons of carbon dioxide were withdrawn from the atmosphere-ocean system. This staggering loss must have dropped the earth's temperature to chilly levels indeed; it is not surprising that the gigantic glaciers that moved across the earth after this period were perhaps the most extensive in history.

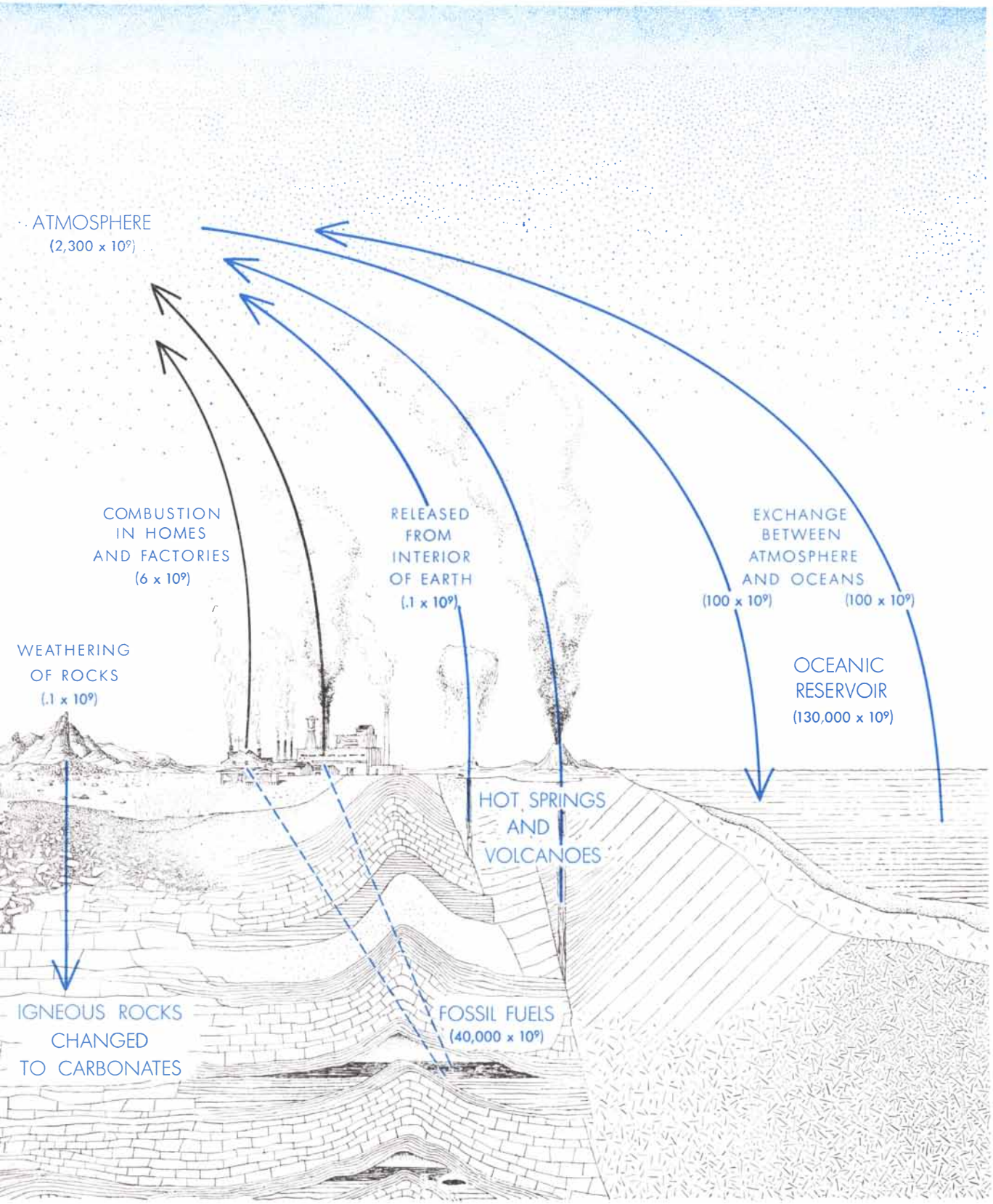
The present capacity of plants to consume carbon dioxide in photosynthesis gives us an interesting clue to the carbon dioxide content of the atmosphere in bygone ages. Plants are almost perfectly adapted to the spectral range and intensity of the light they receive, yet they grow far more rapidly and luxuriantly in an atmosphere that contains five to 10 times the present carbon dioxide concentration; in fact, florists sometimes release tankfuls of carbon dioxide in greenhouses to promote plant growth. The present carbon dioxide concentration in the atmosphere must therefore be unusually low. Apparently plant evolution was keyed to some much higher concentration in the atmosphere of the geologic past. This hypothesis is also supported by the known fact that the earth's climate was warmer during most of geologic time; presumably the atmosphere then contained a much higher percentage of carbon dioxide.

Much of the carbon dioxide in the atmospheres of past geologic epochs now lies buried in the carbon dioxide reservoir of the earth itself. The earth's hot springs and volcanoes pour about 100 million tons of carbon dioxide back into the atmosphere per year. The earth in turn recaptures approximately the same amount each year by the weathering of rocks. But this equilibrium is upset during periods of mountain-building. In fact, the carbon dioxide theory provides an essential link to explain the timing of the last two glacial epochs with respect to the mountain-building periods that preceded them.

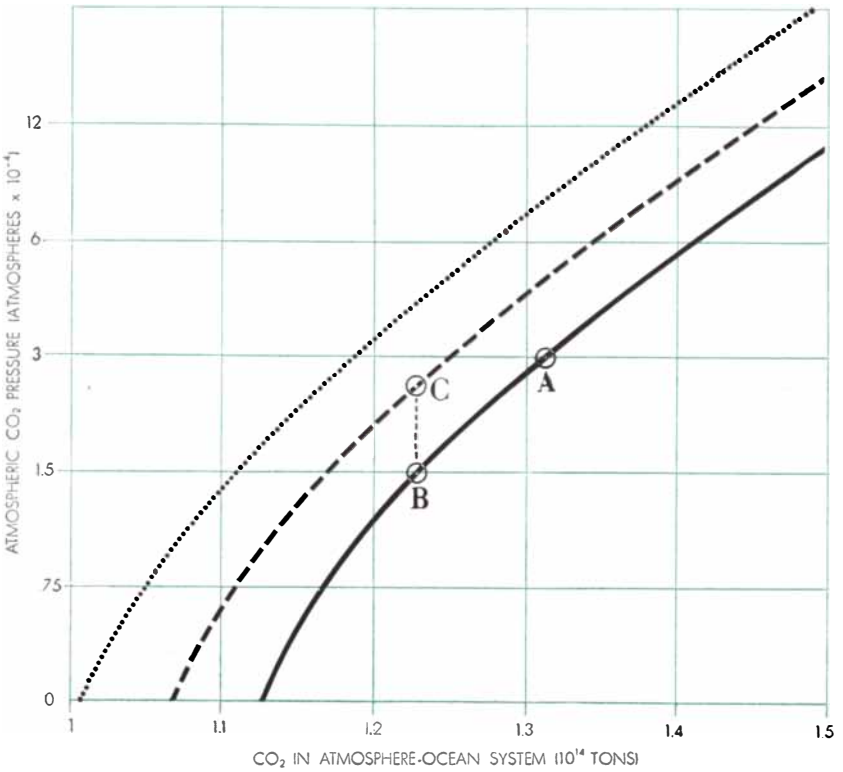
At least several million years intervened between the climax of these mountain-building episodes and the formation of the great ice sheets. If glaciation was brought on only by the elevation of the land or by the slight darkening of the sky with the dust of volcanoes, there should have been no



CARBON DIOXIDE BALANCE results from the equilibrium of natural processes that continuously increase and decrease the atmospheric carbon dioxide concentration. The numbers in parentheses after the name of a process indicate the number of tons of carbon



dioxide being used in that process each year. Vast quantities of carbon dioxide are stored in the three great natural reservoirs: the earth, the oceans and the biosphere. These reservoirs can hoard carbon dioxide or release it to the atmosphere, depending on equilibrium conditions. The black arrows indicate the artificial processes by which man adds carbon dioxide to the atmosphere.



ATMOSPHERE-OCEAN SYSTEM will change the surface temperature of the earth if its equilibrium is disrupted. The three curves here show how this equilibrium shifts when the oceans contain 100 per cent (*solid line*), 95 per cent (*broken line*) and 90 per cent (*dotted line*) of their present volume of water. If the total carbon dioxide content of the system drops only 7 per cent, the equilibrium shifts from point A, its present value, to point B. Such a change would cut the atmospheric carbon dioxide pressure to half its present value, bringing on a possible glacial epoch. As the glaciers grow, the oceans shrink; at the height of a glacial period the ice sheets contain from 5 to 10 per cent of the oceans' waters. With the oceans reduced to 95 per cent of their present volume, the equilibrium would shift to point C, because the shrunken oceans would be forced to release some of their carbon dioxide to the air. Then the temperature rises, glaciers melt and the cycle begins anew.

great time lag before the onset of the glaciers. But these upheavals exposed large quantities of igneous rock to the chemical action of the minute amounts of atmospheric carbon dioxide dissolved in the rain water that washed over them. Over millions of years the weathering of the rock trapped vast quantities of carbon dioxide from the air. With the atmospheric concentration reduced sufficiently, the temperature fell, permitting the young mountains to provide natural birthplaces for the glaciers that then crept across the earth.

Some periods of mountain-building have not produced glaciers. In these periods the output of carbon dioxide from volcanoes, which are especially active during the early stages of mountain-building, might have balanced the carbonate consumption of the newly exposed rocks. In fact, a landscape teeming with active volcanoes could easily release more carbon dioxide than the rocks could possibly absorb, so the temperature of the earth would rise sufficiently to prevent the expansion of glaciers.

The geological effects of volcanic action, coal formation or any other local disturbance of the carbon dioxide concentration are not restricted to the area in which they occur. If the amount of carbon dioxide in one hemisphere of the earth rises or falls sharply, the concentration in the other hemisphere changes rather quickly. In less than a few decades the concentration in both hemispheres becomes identical. According to the carbon dioxide theory, this rapid diffusion helps to explain the fact that glaciers advance and retreat simultaneously in both hemispheres.

During the past century a new geological force has begun to exert its effect upon the carbon dioxide equilibrium of the earth. By burning fossil fuels man dumps approximately six billion tons of carbon dioxide into the atmosphere each year. His agricultural activities release two billion tons more. Grain fields and pastures store much smaller quantities of carbon dioxide than the forests they replace, and the cultivation of the soil permits the vast quantities of carbon dioxide produced by bacteria to escape into the air.

Not all of this eight billion tons of surplus carbon dioxide remains in the atmosphere. Plants remove some of it. When the atmospheric concentration rises, plants use more carbon dioxide for photosynthesis. In a few years, however, the increase in the rate of photosynthesis is balanced by advances in the rate of respiration and decay processes. The net result is only a slight increase in the carbon dioxide content of the biosphere.

Most of the carbon dioxide added to the atmosphere by human activities will ultimately be absorbed by the oceans. To predict the effect of human activities upon climate we must calculate just how rapidly this happens. Recent studies make it appear that the volume of carbon dioxide dissolved in the oceans comes to equilibrium with the carbon dioxide pressure of the atmosphere in about 1,000 years, and that the oceans take up about half of any carbon dioxide added to the air. Over a longer period of time, perhaps several thousand years, the oceans take up much larger additional quantities of carbon dioxide in carbonate compounds before the system again reaches equilibrium. These equilibrium rates are quite significant, because they will govern the temperature of the earth as long as man burns large amounts of fossil fuels.

We have only to extrapolate existing records of temperature and fossil-fuel consumption to predict the climate of the future. Quite accurate records of the amount of fossil fuel consumed in the world each year show that in the past 100 years man has added about 360 billion tons of carbon dioxide to the atmosphere. As a result the atmospheric concentration has increased by about 13 per cent. The carbon dioxide theory predicts that such an increase should raise the average temperature of the earth one degree F. This is almost exactly the average increase recorded all over the world during the past century! If fuel consumption continues to increase at the present rate, we will have sent more than a trillion tons of carbon dioxide into the air by the year 2000. This should raise the earth's average temperature 3.6 degrees.

In less than 1,000 years, if consumption continues to increase at the current

rate, we will have exhausted the currently known reserves of coal and oil. By that time we will have multiplied the carbon dioxide tonnage of the air 18 times. When the ocean-atmosphere system comes back to equilibrium, the concentration of carbon dioxide in the air will be 10 times greater than it is today, and the earth will be 22 degrees warmer. In another few thousand years, when the carbonate content of the oceans has reached equilibrium, the concentration will still be four times greater than it is today. The earth's temperature will then fall to about 12.5 degrees above its present average.

Meanwhile the carbon dioxide content of the oceans will have doubled. This raises an incidental question about the welfare of sea organisms. We know that an increase in carbon dioxide concentration increases the acidity of water, and that many marine animals are extremely sensitive to changes in acidity. However, if the carbon dioxide content of the air were to increase sevenfold, the acidity (pH) of sea water would not rise more than .5 above its present value. Thus changes in carbon dioxide concentration, which have such a profound effect on climate, will probably not disturb future marine life. Perhaps only man will be uncomfortable.

We shall be able to test the carbon dioxide theory against other theories of climatic change quite conclusively during the next half-century. Since we now can measure the sun's energy output independent of the distorting influence of the atmosphere, we shall see whether the earth's temperature trend correlates with measured fluctuations in solar radiation. If volcanic dust is the more important factor, then we may observe the earth's temperature following fluctuations in the number of large volcanic eruptions. But if carbon dioxide is the most important factor, long-term temperature records will rise continuously as long as man consumes the earth's reserves of fossil fuels.

MAN UPSETS THE BALANCE of natural processes by adding billions of tons of carbon dioxide to the atmosphere each year. Most of this carbon dioxide is released by the burning of fossil fuels in homes and factories, such as these plants in Youngstown, Ohio. Like the smoke in the photograph, the carbon dioxide released in this manner diffuses rapidly throughout the atmosphere.

Pulsating Stars and Cosmic Distances

Because the rate at which a cepheid variable star pulsates is related to its luminosity, it serves as an astronomical yardstick. Corrections in the yardstick have again raised estimates of the age of the universe

by Robert P. Kraft

Our present picture of the universe—its structure, size and age—rests to a large extent upon observations of a few pulsating stars. Each of these stars waxes and wanes as much as one full magnitude (2.5 times) in brightness according to a fixed rhythm ranging in period from less than a day to more than 50 days. In general, the longer the period, the greater the luminosity of the star. Such stars are called cepheid variables after their prototype, star delta in the constellation Cepheus; the most familiar of them is Polaris (the pole star), which brightens and fades in a period of 3.97 days. We do not know what causes the pulsation of cepheid variables, nor what it signifies in the biography of a star. Some 40 years ago, however, by a bold stroke of invention, the variable luminosity of these stars was made to furnish a distance scale that gives astronomy its reach into the cosmos beyond the immediate neighborhood of the solar system.

The new distance-scale at once made it possible to locate the center and to measure the dimensions of our galaxy. A few years later the presence of cepheid variables in celestial objects such as the Great Nebula in Andromeda helped establish that these "nebulae" are themselves galaxies—island universes as large as our own located at immense distances out in space. But in recent years the profound usefulness of the cepheid distance-scale has been almost overshadowed by its defects. Corrections in the scale have made it necessary for the dimensions of the observable universe outside our galaxy to be doubled, and still further revisions may be required. Because the age of an expanding and evolving universe can be deduced from its distance scale, cosmologists have concurrently had to revise the age of the universe upward, from two billion to perhaps 10 billion years. These corrections and further refinements still in progress derive from closer study of the cepheids themselves. It now seems safe to say that the cosmic distance-scale will not again expand so radically, and that it is at last ready for secure calibration.

In all likelihood we shall achieve this objective still without understanding why the cepheids pulsate. Among the 15,000 stars listed in the monumental new Soviet *Variable Star Catalogue*, edited by B. V. Kukarkin, P. P. Parenago, Y. Efremov and P. Kholopov, about 3,000 exhibit the regular pulsation of the cepheids. Spectroscopic observation shows that the surface temperature of these stars varies upward and downward in phase with their light. Apparently they also expand as they brighten and contract as they fade. In the 1920's Sir Arthur Eddington was able to show theoretically that the rate of pulsation must be related to the mean density of the cepheid (its mass divided by its volume), much as the period of a pendulum on earth is governed by its length. But we have no mechanism to explain this behavior, and we cannot say why a star becomes a cepheid.

The most important advance in our knowledge of the cepheids—and the most drastic revision of the distance scale—came a decade ago with Walter Baade's discovery that the stars of the universe may be divided into two major populations. To Population I, made up of young, hot, short-lived stars, he assigned the brighter and longer-period cepheids that appear in the arms of spiral galaxies. The fainter and shorter-period cepheids associated with the globular clusters that swarm around the centers of galaxies Baade placed among the older and longer-lived stars of Population II. While astronomers now believe that Baade's two populations represent an oversimplification and that stars are more continuously graded in age, the cepheids seem mostly to belong to the extreme ends of the population spread.

At present we imagine that the young Population I cepheids represent a phase in the life of any star. If we plot the color (that is, the temperature) of stars against their absolute luminosity (their intrinsic brightness corrected for distance), most of them occupy a rather well-defined "main sequence" [*see illustration on page 54*]. To the right of the main sequence is a scattering of other stars, most of them "red giants." Between the main sequence and the red giants is an "instability strip" containing the cepheids. We presently conceive that a star starts out bright and hot, after a very rapid stage of gravitational contraction; then, after the star has consumed a certain amount of its hydrogen fuel, it begins to cool. Thus in terms of the color-luminosity diagram a star spends most of its life on or near the main sequence, but eventually evolves to the right. When it reaches the instability strip, it begins to pulsate. As the star passes through this strip, in the course of a few million years, its pulsa-

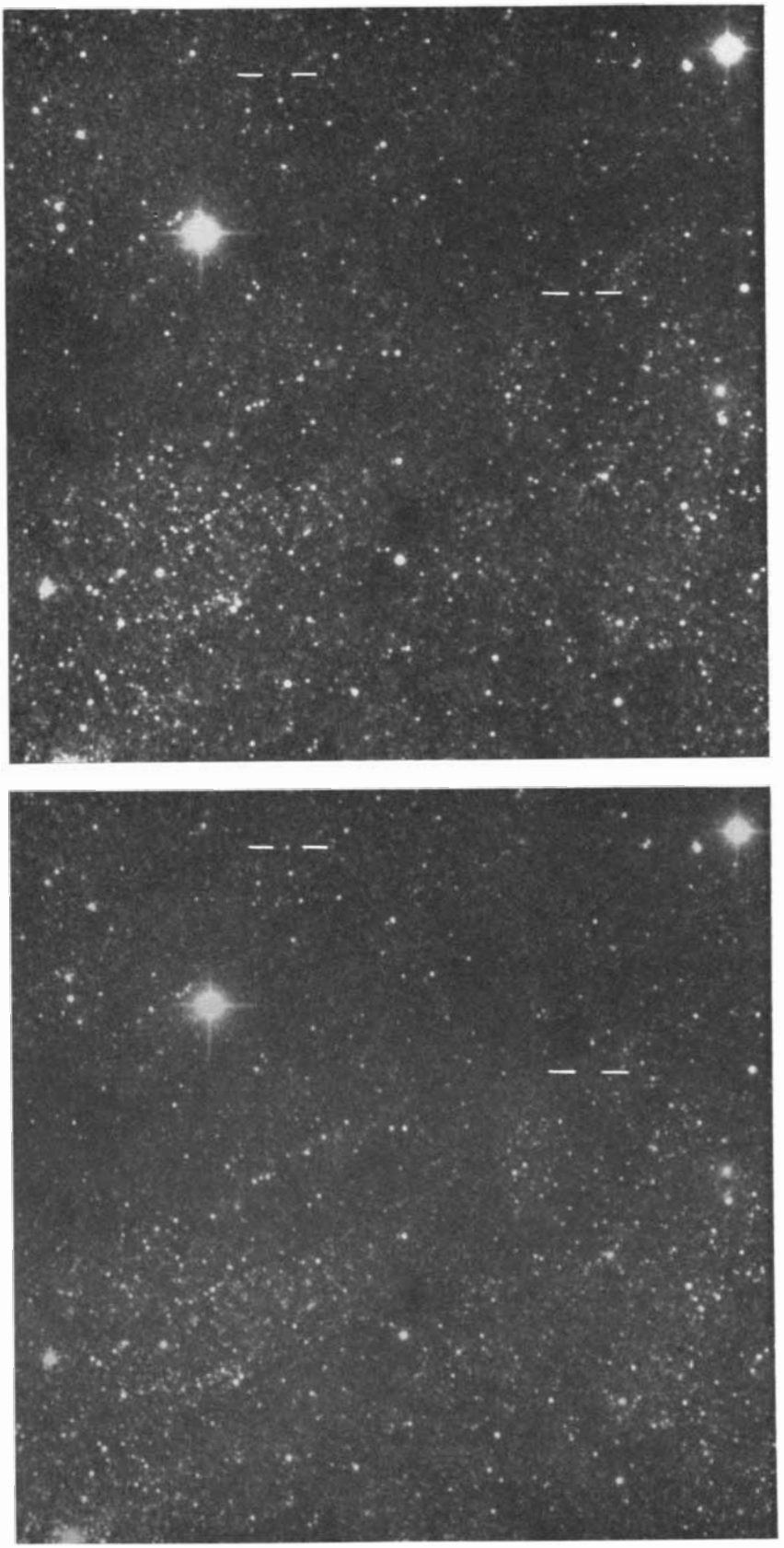
tion slows and lengthens in period. Upon reaching the end of the strip it ceases to pulsate and becomes a red giant. Ultimately it dims into the graveyard of the white-dwarf stars [see "Dying Stars," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, January].

This hypothetical account does not, however, cover the evolution of the old Population II cepheids found in globular clusters. Perhaps these enter the instability strip by evolving "backward" from the red-giant phase instead of from the main sequence. Most of the globular-cluster cepheids have very short periods of less than a day, but even those having longer periods can be clearly distinguished from Population I stars of similar period. Long-period globular-cluster cepheids are on the average 1.5 magnitudes fainter than the younger long-period cepheids, exhibit quite different spectra and have masses only about a fourth as large.

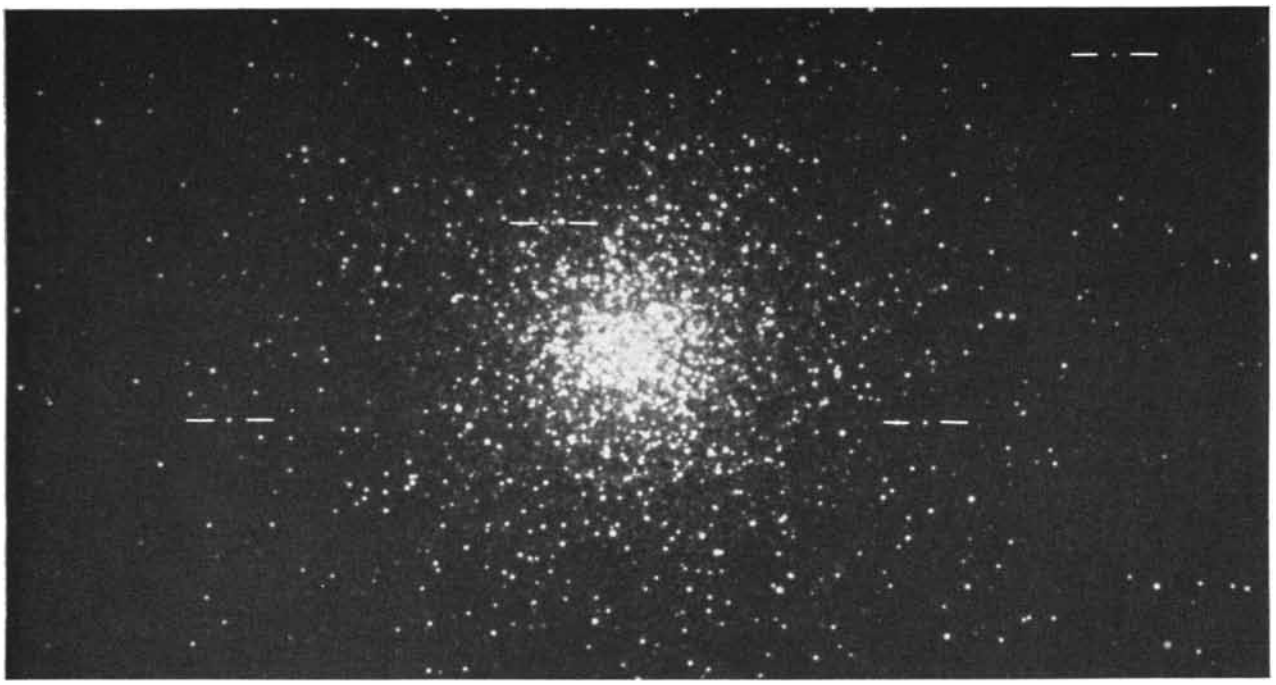
The cepheids are highly luminous stars. Polaris, the nearest of them, is not a particularly bright cepheid, but it is about 600 times brighter than the sun. The brightest Population I cepheids are more than 10,000 times more luminous than the sun! This is a fortunate circumstance so far as the measurement of extragalactic distances is concerned, because it means that such stars make themselves visible at very long range.

In order to understand how pulsating stars can furnish a distance scale, we must go back 50 years to the work of Solon I. Bailey and Henrietta S. Leavitt of the Harvard College Observatory. Bailey carried out an extensive investigation of the cepheids in globular clusters within our own galaxy. He found that almost all had periods of less than a day, except for a few that had periods in the range of 12 to 20 days. Miss Leavitt later studied the cepheid variables that appeared in great numbers in photographs of the Clouds of Magellan, the two small galaxies that are companions of our own; she found that most of these cepheids had periods of more than a day. Even more remarkable was Miss Leavitt's discovery that the average apparent brightness of the Magellanic Cloud cepheids is directly correlated with the length of their respective periods of pulsation. Bailey had found no such dependence of luminosity on period in the globular-cluster cepheids, at least those with a period of less than a day.

Astronomers soon recognized the promise of Miss Leavitt's finding. It was known even then that the Magellanic



LONG-PERIOD CEPHEIDS are found among young Population I stars such as these in the Andromeda Nebula. A small section of one arm of the Nebula was photographed at two different times with the 200-inch telescope on Palomar Mountain. The marked star at upper left is a cepheid variable; the other star (*invisible in bottom picture*) is a nova.



SHORT-PERIOD CEPHEIDS are found in globular clusters of old Population II stars. These photographs of M 3, one of the globular clusters of the Milky Way, were taken 18 hours and 43 minutes apart with the 100-inch telescope on Mount Wilson. Four of the

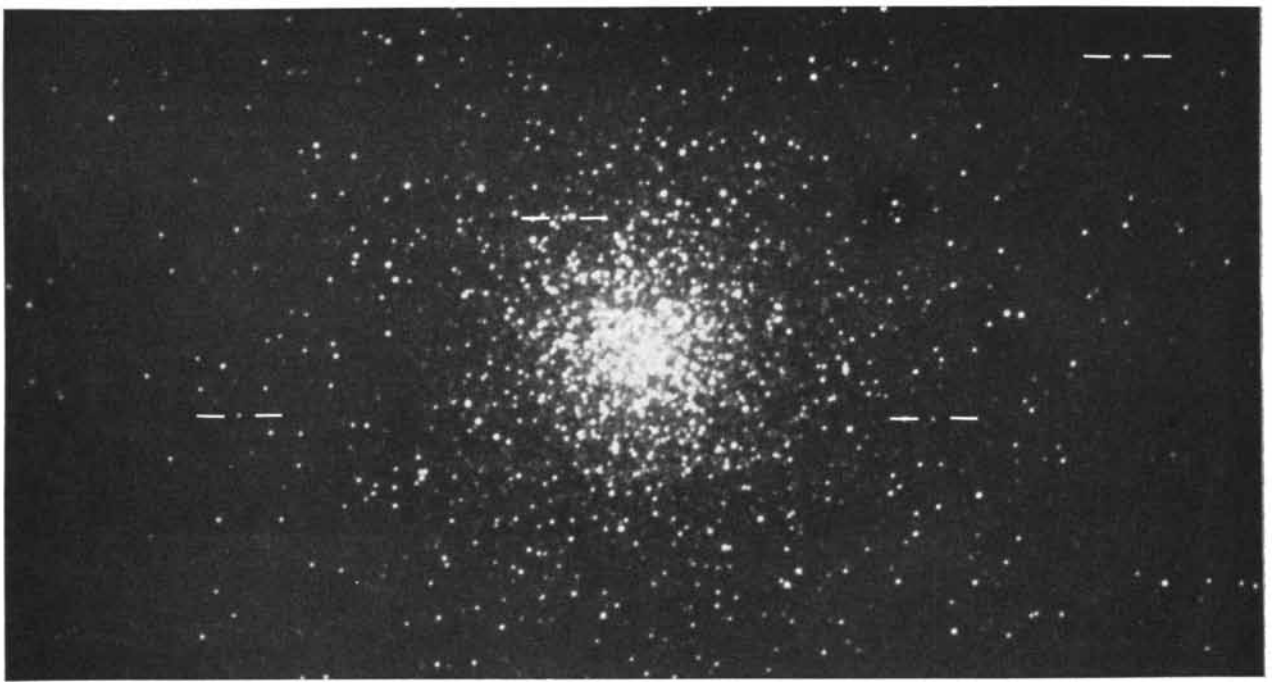
Clouds are distant congregations of stars. Thus the cepheids in the Clouds are all at virtually the same distance from the solar system, and the light of all is attenuated to the same extent by its journey to the earth. Miss Leavitt's measurements of the varied apparent brightness of these stars could therefore be taken as indications of their relative absolute brightness. Here was a potential yardstick for measuring really long distances in the universe!

It was obvious that, if the distance of the Magellanic Clouds could be ascertained, one could determine the absolute brightness of the cepheids. Miss Leavitt's period-luminosity scale could then be used to find the distance to any stellar system or subsystem containing cepheids by turning the problem around: Measure the period of the cepheid, read off its absolute luminosity from the period-luminosity scale, compare this with the observed apparent luminosity of the cepheid and find the star's distance by applying the law that the intensity of light varies inversely with the square of the distance. Of course the accuracy of such a measuring rod depends on the assumption that cepheids in all parts of the universe obey the same period-luminosity law Miss Leavitt had derived from the cepheids in the Magellanic Clouds. This turned out to be a pivotal assumption.

At the time of Miss Leavitt's discovery there was unhappily no way to ascertain the distance of the Magellanic Clouds. Stellar-distance measurement still depended on direct trigonometric parallax, which is effective only for nearby stars. Against the background of stars distributed in the depth of space at all distances from the sun, a nearby star appears to shift its position as the earth travels from one side of the sun to the other. It is thus possible to measure the distances of such stars by simple trigonometry [*see illustration on page 53*]. Even these distances are so large that it is convenient to describe them with a unit called the parsec. We say that a star is at a distance of one parsec if its parallax, that is, half its shift of position, equals one second of arc. But the nearest star has a parallax of slightly less than .8 second of arc. This corresponds to a distance of slightly more than 1.3 parsecs, or 25,000 billion miles. Sirius, the brightest star in the sky, is 2.7 parsecs away, and the parallax of a star at a distance of 100 parsecs is only .01 second. Such small angles cannot be determined very precisely; a distance of about 30 or 40 parsecs is the practical limit for determination by direct trigonometric means.

The cepheids are so rare in space that the nearest of them—Polaris—is 90 parsecs away. It is clear, therefore, that trigonometry could not be used to determine the distance of a single cepheid, and could yield no information on the absolute brightness of even the nearby cepheids.

How, then, could the distance to any cepheid be obtained? Before Miss Leavitt had made her discovery, astronomers had devised a method for measuring what might be called the "middle distances" of our galaxy. With so many stars on our photographic plates we may assume that many stars in any given group have the same absolute brightness. We may also assume that the motions of these stars, either radially in the line of sight or transversely across the sky, will be at random. Now with the spectrograph we can determine the actual radial velocity of any observable star, independent of its distance from us. The spectrum is shifted toward the violet if the star is approaching and toward the red if it is receding, and the extent of shift gives us the velocity of its motion. On the other hand, the apparent transverse motion across the line of sight (called the proper motion) does depend on distance. If the stars of our given group move, on the average, with the same actual velocities independent of distance, then the proper motions of these stars will appear to get smaller with distance. Of course relatively few stars are near enough to the sun to have exhibited any proper motion during the



more than 200 cepheids in the cluster are marked by pairs of horizontal lines. On comparing the marked stars in the two photographs, one can see a small but perceptible change in their luminosity. The star at top right, for example, becomes brighter.

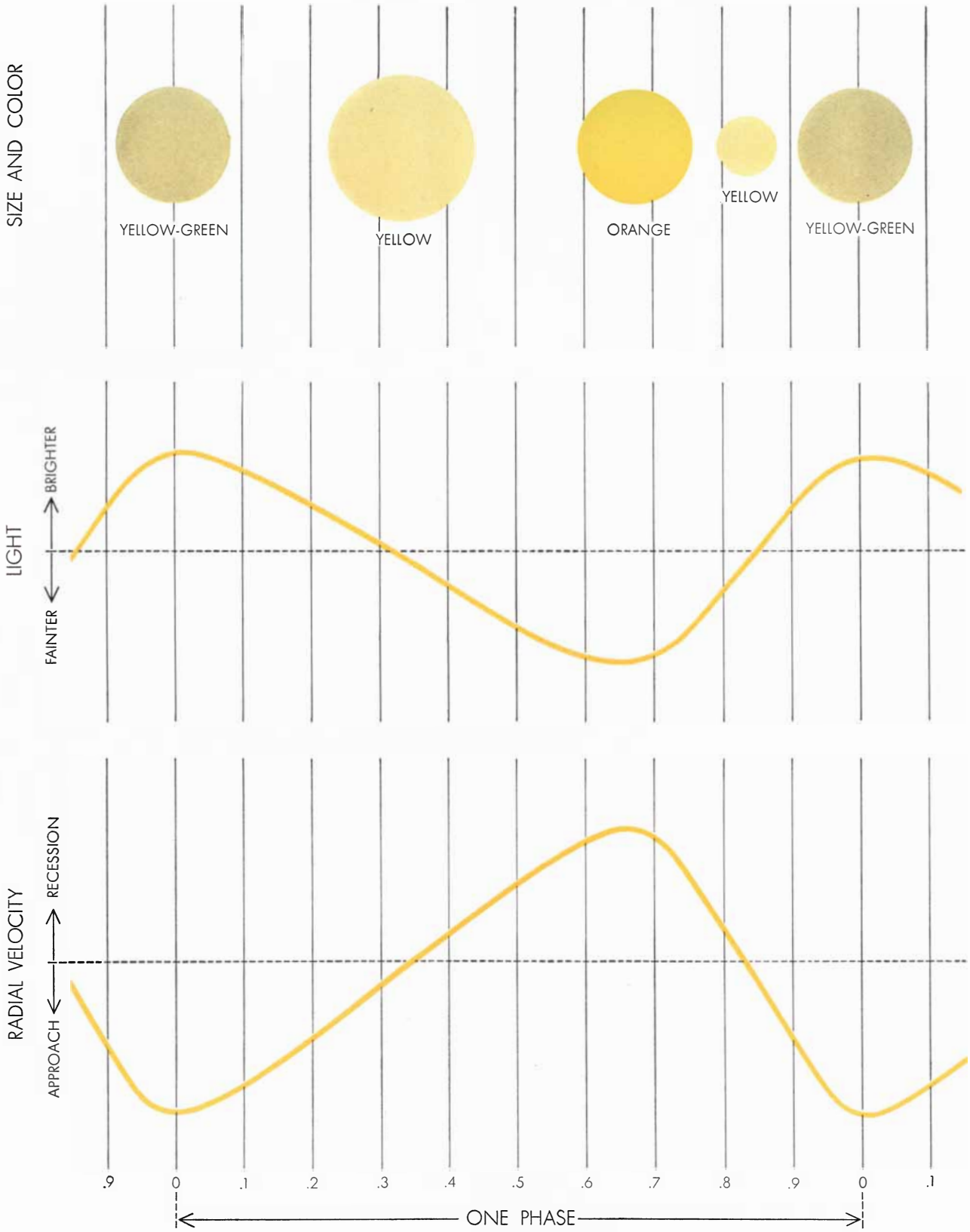
first century of photographic astronomy. But when we have determined the statistical spread of the radial velocities, it is reasonable to suppose that the proper motions vary in the same range. Since the distribution of proper motions does decrease with distance, the identification of the spread in radial velocities with the spread in proper motions indicates the average distance to the group of stars under consideration.

With the mean distance obtained in this way, one can correct the mean apparent magnitude of the stars for the effect of distance and get the average absolute magnitude. From studies of this sort in 1913 Ejnar Hertzsprung of Denmark found an average absolute magnitude of —2.3 for a cepheid with a period of 6.6 days. (On the magnitude scale the lower number refers to the brighter star; stars brighter than the first magnitude have negative magnitudes.) Hertzsprung's result was based on only 13 nearby cepheids for which the proper motions were known. But astronomers now had the absolute luminosity value needed to convert the apparent luminosity of any cepheid to absolute luminosity by reference to Miss Leavitt's period-luminosity scale.

In 1918 Harlow Shapley of the Harvard College Observatory saw how the scale could be applied to determine the distances of the globular clusters in our galaxy. He fitted the long-period cepheids (periods of 12 to 20 days) of the globular clusters to the period-luminosity scale for the cepheids of the Magellanic Clouds. From this he determined the absolute luminosity and hence the distance of the long-period cluster stars. Using this determination of the distance to the clusters, he deduced that the mean absolute magnitude of the numerous fainter cepheids in the clusters with periods of less than a day was a little brighter than zero (*i.e.*, some 100 times brighter than the sun). Shapley then had a scale to measure the distance to the clusters that contain only faint, short-period cepheids. From the globular-cluster distances thus derived, he deduced that the globular-cluster system was centered on a point about 16,000 parsecs from the sun in the direction of the constellation of Sagittarius. It seemed reasonable to identify this point with the center of our galaxy. Shapley had obtained the first good estimate of the size of any galaxy. Later determination of the luminosities of these shorter-period cluster cepheids, obtained by proper-motion and radial-velocity studies, have verified Shapley's deduction and shown his estimate to be of the right order.

The period-luminosity scale could also be used to estimate the distances to any nearby galaxy that contains cepheids. Edwin P. Hubble and his associates at the Mount Wilson Observatory soon ruled off the distance to the Magellanic Clouds and to the Great Nebula in Andromeda. By the comparison of apparent to absolute magnitude thus effected for these and other more distant galaxies, the cepheid distance-scale made it possible to calibrate the spectrographic shift toward the red for the measurement of distances to the throngs of even more distant galaxies so faint and tiny that the cepheids and other stars in their populations cannot be resolved. Cosmologists working from these data were able to estimate the size of the universe and its age from the time of its initial expansion. All this extrapolated from the observation of the peculiar process of cepheid pulsation that we do not yet fully understand!

In the next 25 years, however, astronomers and cosmologists encountered numerous difficulties that cast increasing suspicion on the period-luminosity relationship upon which the whole edifice was built. All other galaxies, as measured by the cepheid distance-scale, were smaller in size than our own, a peculiarly self-aggrandizing result. As nuclear physicists succeeded in calibrating the rate at which uranium and thorium have been decaying to lead in the rocks of the earth, their "clocks" made the earth ap-



CYCLE OF A TYPICAL CEPHEID includes changes in color (*top*), light (*middle*) and radial velocity (*bottom*). Maximum light coincides with the bluest color (*yellow-green*), that is, with the highest surface temperature. The fluctuations in radial velocity are probably the result of changes in the size of the star such that its radius is largest (*large yellow disk*) midway between maximum and minimum light, and smallest (*small yellow disk*) in the opposite part of the cycle when the light is increasing. The relative sizes have been exaggerated in the drawing for purposes of clarity; the change in radius is never more than 20 per cent.

pear considerably more ancient than the universe. There was difficulty also in reconciling Eddington's calculation of the mean density of the cepheids with density estimates derived from the relationship of the observed luminosity of these stars to their rate of pulsation.

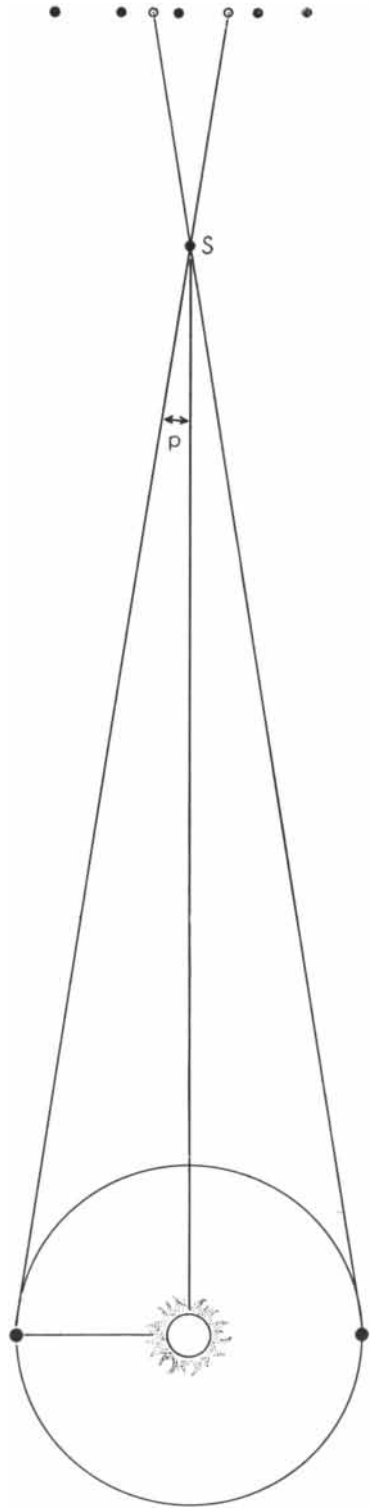
An observation by Hubble and Baade finally opened the way to a test of these suspicions. They pointed out that, if the distance to the Andromeda Nebula had been correctly measured, then the brightest stars of the globular clusters surrounding its central region appeared to be too faint compared to the brightest stars in the globular clusters of our own galaxy. If these bright stars in the Andromeda Nebula were assigned the same absolute brightness as the corresponding stars in our galaxy, then the cepheids visible in the Andromeda Nebula and many of the longer-period cepheids in our own system would also have to be assigned a higher absolute magnitude with respect to the shorter-period cepheids of the globular clusters that had formed the basis of Shapley's scale. Could it be that the globular-cluster cepheids obeyed a period-luminosity law different from that observed for other cepheids?

Such a possibility was foreshadowed in 1940 by an observation made by Alfred H. Joy at the Mount Wilson Observatory. He found a marked difference between the spectrum of a 15-day cepheid in the vicinity of the solar system and a 15-day cepheid in a globular cluster. Then, during the war years, Baade was able to devote the 100-inch telescope on Mount Wilson almost full time to his study of the stellar populations in the Andromeda Nebula. In dividing all stars into two populations he also found a basis for classifying the cepheids into two species.

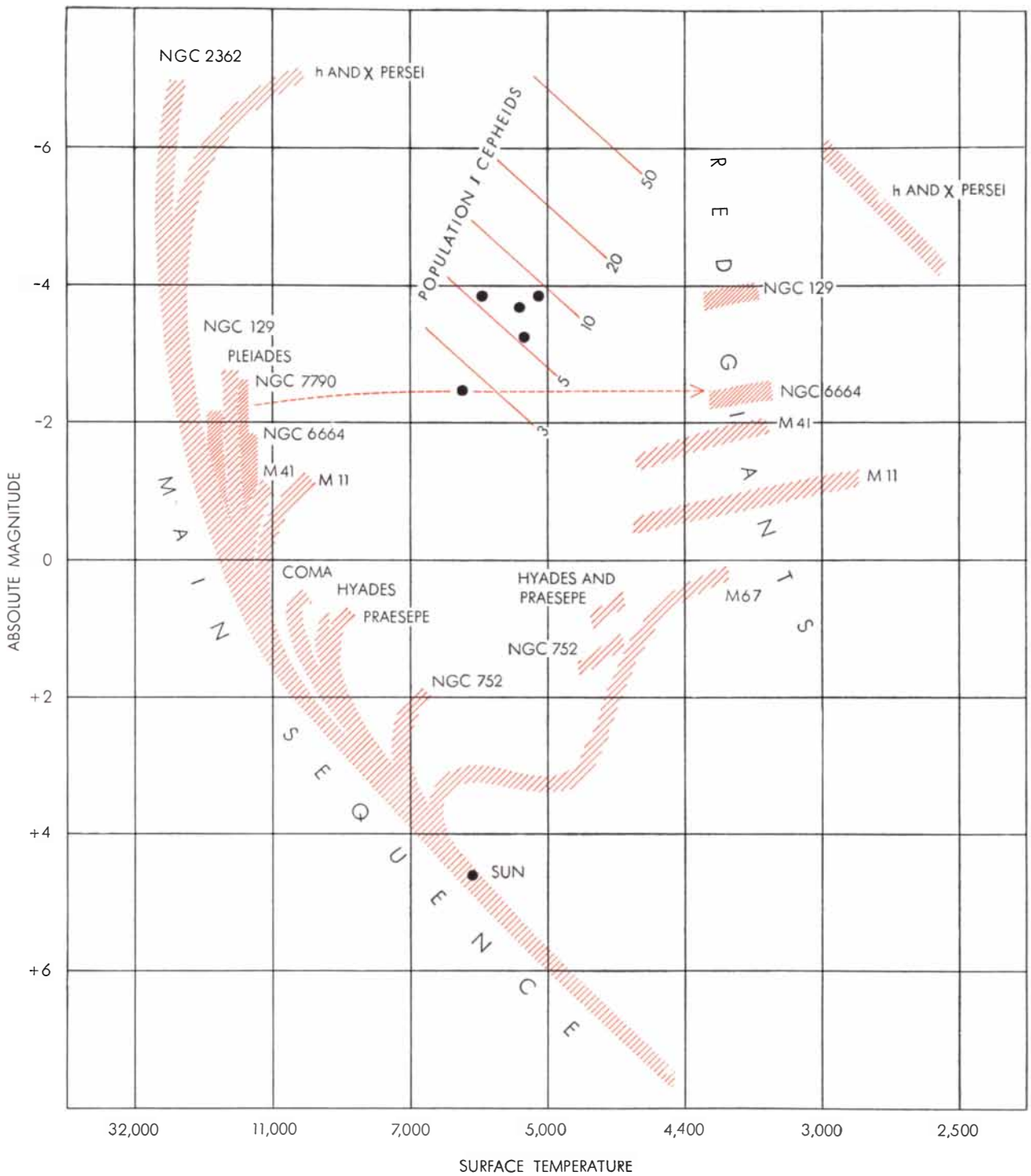
With the 200-inch telescope in operation on Palomar Mountain shortly after the end of the war, Baade set out to observe the two types of stars "side by side," that is, at the same distance. Unfortunately not even the 200-inch telescope can resolve the faint short-period cepheids in the globular clusters of the Andromeda Nebula. But Baade was able to measure the Population I cepheids of that galaxy with great accuracy against the brightest globular-cluster stars, for which absolute magnitude had been established with the help of the Population II cepheids in our galaxy. Shapley had set the absolute magnitude of these stars at —1.5, based upon his determination that the shorter-period cluster cepheids have an absolute magnitude of zero. The distance to the Andromeda Nebula, calculated from its Population I cepheids in accord with the established period-luminosity scale, predicted that the bright globular-cluster stars should have an apparent magnitude of 20.9. Baade found that these stars were actually magnitude 22.4. In other words, they were 1.5 magnitudes fainter.

This demonstrated that the estimate of the distance to Andromeda was too small by a factor of about two. It also showed that the absolute brightness of the Population I cepheids in the Andromeda Nebula was 1.5 magnitudes brighter than had been indicated by the period-luminosity scale. They have a lower apparent magnitude because they are farther away than had been supposed. With distance to the Andromeda Nebula doubled, its size also doubled, bringing it into line with the size of our own galaxy. These results were dramatically confirmed when A. D. Thackeray and A. J. Wesselink of the Radcliffe Observatory in South Africa discovered short-period cepheids in the Large Magellanic Cloud at exactly the magnitude predicted by Baade.

Hindsight now fully explains the discrepancy in the period-luminosity scale. With the Population I cepheids advanced 1.5 magnitudes in luminosity, there is a discontinuity in the scale that clearly divides the cepheids into two types. We also understand why this distinction was missed in the early part of this century. The young Population I stars in the arms of our spiral galaxy lie close to its central plane; the brighter light of these stars is accordingly dimmed by the clouds of dust and gas in which stars are formed. The older Population II stars, which resemble the stars in globular clusters, have had time to drift above and below the galactic plane, so their dimmer light reaches us without obscuration. By a remarkable coincidence the interstellar absorption of the light from the Population I cepheids almost exactly equals the difference in the actual brightness of Population I and Population II cepheids, that is, 1.5 magnitudes. No such obscuration dims the light of Population I cepheids in the Andromeda Nebula or the Magellanic Clouds; their lower apparent magnitude is now correctly attributed to their greater distance. Thanks to this combination of circumstances Shapley was able to fit the long-period cepheids in globular clusters to Miss Leavitt's period-luminosity curve for the cepheids in the Magellanic Clouds. He could not



PARALLAX is used to measure the distance of nearby stars. As the earth moves around the sun (*bottom*) a nearby star (S) appears to change its position (*open circles*) in relation to stars much farther away. When the parallactic angle *p* is one second of arc, the star's distance from the sun is 19,000 billion miles, or 3.26 light-years, or one parsec. Here the change in the apparent position is much exaggerated.

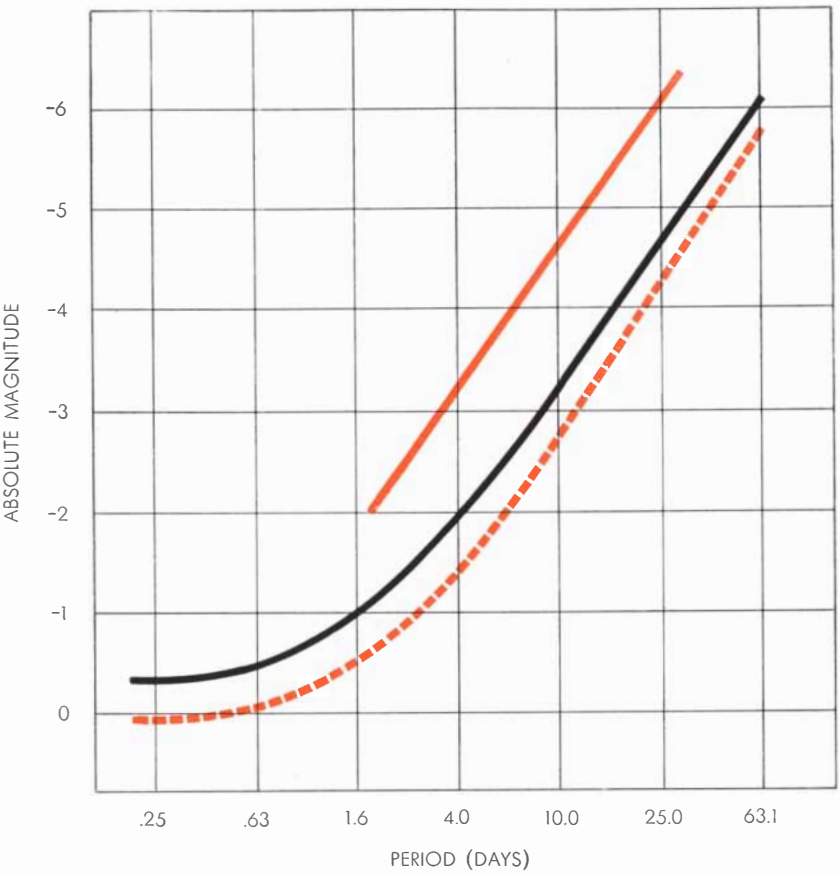


GALACTIC CLUSTERS OF THE MILKY WAY are plotted by determining the absolute magnitude and the intrinsic color of their stars. In this diagram the colors have been converted to approximately equivalent surface temperatures in degrees Kelvin. Galactic clusters are identified by their names or numbers; fine hatching marks those that contain long-period Population I cepheids. Five cepheids of the galactic clusters are shown in the "cepheid domain" which is marked off according to the length of the period in days. The broken line is the evolutionary track of a cepheid of NGC 6664. Originally the star was located among NGC 6664 stars on the main sequence, but about 100 million years ago it increased in luminosity about one magnitude and began to decrease in surface temperature, so that it moved horizontally across the diagram toward the cepheid "instability strip." Later it will become a red giant with a very large radius and a surface temperature of about 4,000 degrees K., like the present NGC 6664 red-giant stars.

have known that the two types of stars are quite different objects.

From the time of Miss Leavitt's first observations the distinction between the two species of cepheids had also been obscured by a scatter of about one magnitude in the positions of the stars along the mean line of the period-luminosity curve. For many years this was attributed to observational error and possibly to internal absorption within the Magellanic Clouds. But the scatter could also result from a bona fide physical departure of a given star from the mean line. This is a point of more than academic interest; such uncertainty in the magnitude of a particular star corresponds to a factor of 50 per cent in the computation of its distance. The range of error is too great if the objective is to measure the distance to a galaxy in which only one or two cepheids are available. Accurate determination of distances to individual cepheids has also assumed new importance in the study of our own galaxy. Population I cepheids might be expected to outline the spiral arms of our galaxy and, being very luminous, to carry our knowledge of the spiral structure to considerable distances from the sun.

We are now certain that the scatter is real. Highly accurate photoelectric measurements of cepheids in the Small Magellanic Cloud by Halton C. Arp of the Mount Wilson and Palomar Observatories have established that the scatter is very much larger than the errors of observation. Allan R. Sandage of the same observatories has offered an explanation. Sandage predicts from the theoretical period-density relation that the period-luminosity law must be amended to take account of a third variable. This variable is the surface temperature of the star.



PERIOD-LUMINOSITY RELATION used by Harlow Shapley fitted all cepheids into one curve (*black*), with the short-period cluster variables at the lower end. The period-luminosity relation of Walter Baade divides the cepheids into Population I (*solid color*) and Population II (*broken line*). The latter stars are fainter than Population I stars of the same period. On magnitude scale, brightness increases by a factor of 2.5 from –1 to –2, and so on.

Observations of certain cepheids for which highly accurate surface temperatures and absolute magnitudes can be derived seem to confirm Sandage's theory. These stars are members of loose clusterings of very young Population I stars in our galaxy called open or galactic clusters. The first two were found by John B. Irwin in 1955 at the Radcliffe Observatory. Others were located by Sydney van den Bergh and myself, and the number of such cepheids is now about 10. Their colors (hence surface temperatures) and absolute luminosities are obtained by yet another method for determining distances to stars. We may expect stars that are close together on the color-luminosity diagram, and thus are similar in color and spectral characteristics, to have the same absolute brightness. By matching some of the stars of a cluster to similar stars for which the distance is known, we can derive the distance to the cluster. We can then determine the luminosity of the other stars in the cluster. Unfortunately most of the galactic clusters are obscured by interstellar material. This material not only absorbs light, but also reddens it, making the surface temperature of a star seem lower. By observing these stars in several colors, however, it is possible to derive intrinsic colors and surface temperatures.

With Sandage's period-luminosity-surface temperature relationship apparently well sustained, we can now determine the distance of a single cepheid if we know its surface temperature and period. The procedure may be demonstrated by reference to the color-luminosity diagram on the opposite page. On this diagram the cepheid variables occupy a band that, at a given position, reaches horizontally across a temperature range of about 1,000 degrees absolute and vertically over a factor of about six in absolute magnitude. Sandage has computed the lines of constant period, which slope down diagonally to the right on the diagram. To use the diagram, we locate a given cepheid (not necessarily from a galactic cluster) on its appropriate period line. We then draw a vertical line from the base of the diagram corresponding to the temperature of the star. The intersection of this line with the period line gives us the luminosity with high precision. We can then obtain the distance to the star with what is hoped to be an error of less than 10 per cent.

The final result of these studies of cepheids in galactic clusters should be a useful and accurate period-luminosity-surface temperature chart for the cepheid variables. Astronomers may expect soon to have a much more reliable scale for measurement of long distances inside our own galaxy and beyond.

THE PERCEPTION OF MOTION

Relativity of motion furnishes the chief clues to the perception of it, yet we ascribe motion to objects as if they had acquired an absolute quality. This way of perceiving plays strange tricks

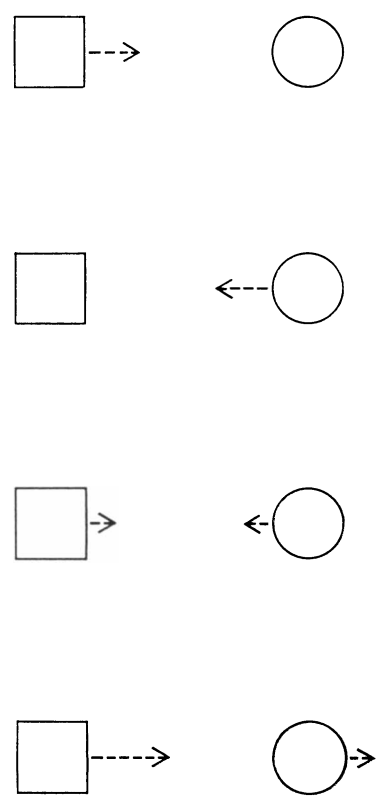
by Hans Wallach

Most of us have had the experience of staring from a waiting train at a train on an adjacent track and sensing momentarily and mistakenly that it was our train that had started to move forward. Alternatively we have idly gazed at a branch reaching upward from a running stream and have seen the branch apparently drift upstream. Or we have looked at the moon through wind-swept, broken clouds, framed in treetops, and have wondered as the moon appeared to sail through the sky against the motion of the clouds.

These are familiar instances of a peculiar aspect of our visual perception of motion. As strictly defined by the physicist, motion is the displacement of one object relative to other objects. But the physicist does not help us to clarify our perception of motion, for he will add that motion is a matter of definition. Which object is displaced and which serves as the frame of reference is an arbitrary choice. Visually perceived, however, motion has no such relative aspect; it is an attribute of the moving object, even if only a temporary one. We say that an object is at rest when this property is absent. Thus, in experience, motion and rest are absolutes, inherent in the object perceived. We sense this absolute quality of motion especially when we must correct a first impression. Though we can certainly make ourselves aware of the displacement of a moving object in relation to other objects in our field of vision, this awareness is by no means a genuine part of the perceived motion, which remains entirely an affair of the moving object.

It is tempting to ascribe this absolute, nonrelativistic aspect of experienced motion to the manner in which the experience is caused. Is not motion perceived when an object changes its position in relation to the observer, causing the eyes to pursue it? The perception of motion would thus seem to accord with the conditions of stimulation, quite independent of the presence of other objects in the visual field. But matters are not quite so simple. We also experience motion when it is caused by the displacement of one object relative to another. At first glance it might seem impossible to distinguish between these two modes of perception, for the displacement of one object in relation to another must always involve the displacement of at least one object in relation to the observer. The distinction may be proved, however, by experiment. As everyone who has watched the hour hand of a clock knows, motion may be too slow to be perceived; one may notice change of position, but not motion. With a luminous dot in a homogeneous dark field, we can measure the threshold of velocity at which motion is perceived. But if we now light up a second, stationary dot near the moving one, we discover that the threshold is lowered considerably. Motion at a lower velocity will be seen so long as the two dots do not move too far apart. We may thus distinguish between motion perceived on the basis of an "angular displacement" of an object relative to the observer and of an "object-relative displacement" of one object in relation to another.

This experiment reveals a further interesting fact. When the moving dot moves too slowly to excite perception of motion by virtue of its angular displacement, object-relative displacement will lead the viewer to experience the motion of one dot or of the other or of both in various patterns, as shown in the illustration on this page. The results reported by observers are as varied as the ambiguity of the situation would suggest. We may now ask a useful question: How do perceived motion and rest in such a situation distribute themselves among the objects that are being displaced relative to one another? The



OBJECT-RELATIVE MOTION may give a viewer perceptions of motion quite different from the objective motion. Relative dis-

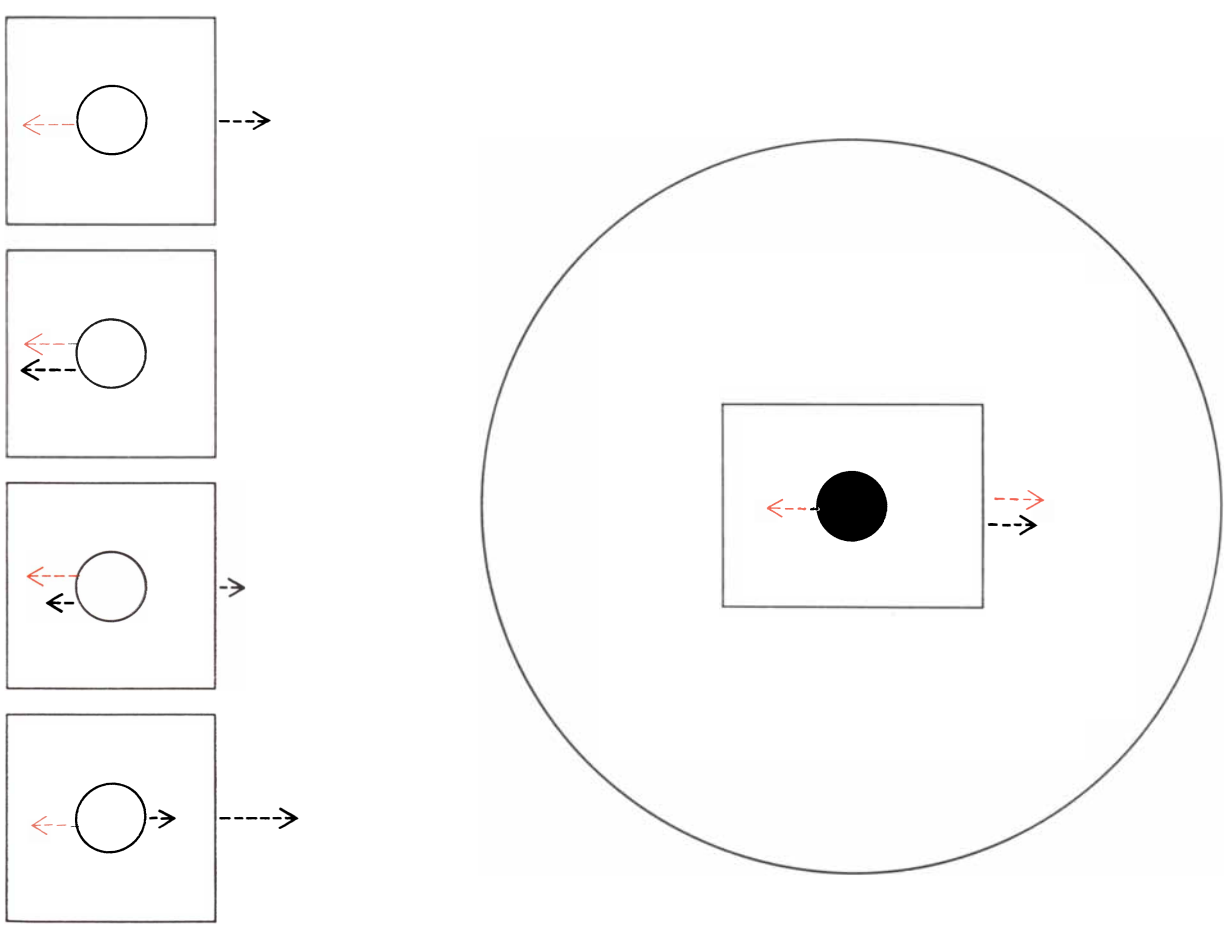
question suggests further experiments which reveal some significant principles that rule the visual assignment of the properties of motion and rest to the objects perceived.

Consider what happens when one of the two objects surrounds the other, the first object in effect forming the background of the second. For example, the viewer is presented with a dot surrounded by a circle. No matter which object is moved by the experimenter, the result is invariably the same: the viewer sees the dot move and sees the circle remain at rest.

This rule is rather strict and pervasive. It even holds under conditions in which it gives rise to experiences that are at variance with the objective situation. For example, the viewer is presented with a dot surrounded by a rectangle which is in turn surrounded by a ring. If the rectangle is now moved, the viewer perceives motion in both the dot and the rectangle and sees the ring remain stationary. The perceived motion of the rectangle is in the direction of its objective motion, while the motion of the dot is in the opposite direction. But this distribution of motion and rest among the objects is quite inappropriate. That the dot appears to move and the ring does not is inconsistent with the fact that there is no objective displacement between the dot and the ring. The nature of this discrepancy is clarified by removing the ring from the picture. Without the ring only the dot is seen to move. The addition of the ring adds the motion of the rectangle to that of the dot, for the rectangle is now a surrounded object. Thus the two motions perceived arise from the two different relative displacements.

The rule that the surrounded object appears to move holds even when the surrounding object is moved at a velocity above the threshold for perception of angular displacement. In the ring, rectangle and dot experiment, the stationary dot still appears to move in the direction opposite that of the objectively moving rectangle. The ring, however, is no longer a necessary part of the situation, because the motion of the rectangle can now be perceived in the absence of the ring. We have here, in fact, the scheme of the illusion of the sailing moon or of the drifting branch. The moon corresponds to the dot, and the clouds represent the rectangle. The trees or rooftops in our line of vision may serve as the ring, but their presence is not essential because the clouds are moving above the angular-displacement threshold. Similarly the objectively stationary branch in the stream is the surrounded object, and leaves or other debris on the sliding surface of the stream are analogous to the moving rectangle.

This illusion is usually called "induced" movement. The term has been in use a long time; it has been commonly assumed that the induced movement is caused merely by the perceived movement in the environment, and that it is always in the opposite direction. But as

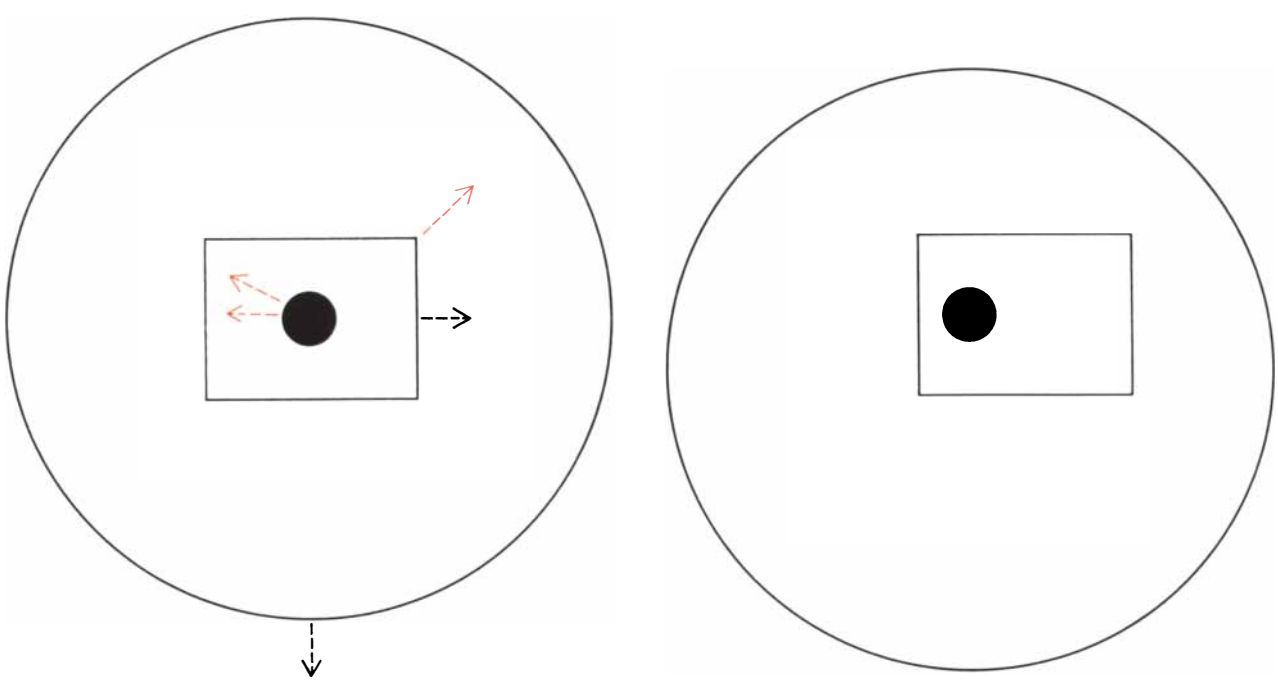


placement of the circle and square at left, produced in four different ways, may be experienced as any of the three upper combinations of motion. A surrounded object, as in center panel, takes on uniform perceived motion (*colored arrows*) despite varying combinations of objective motion (*black arrows*). If surrounded object is itself surrounded (*right*), it too acquires perceived motion.

our experiments have already suggested, this simple view of the matter is inadequate. The crucial element in the picture is the relationship of the surrounded object to the surrounding object. We can, in fact, contrive an experiment in which induced movement is not opposite to the perceived movement of the surrounding object. The dot, rectangle and ring again provide the elements of the picture, but this time the ring is moved downward as the rectangle is moved to the right (in each case at a velocity below the threshold for perception of angular displacement). These objective movements produce a displacement of the rectangle upward and to the right in relation to the ring, and a displacement of the dot horizontally leftward in relation to the rectangle [*see illustration below*]. As in the previous experiments, the perceived motions correspond to these relative displacements: the rectangle is seen to move obliquely upward to the right and the dot horizontally to the left. Under certain conditions the leftward motion of the dot may be slightly oblique in the upward direction. But what has become of the induced motion of the dot relative to the perceived motion of the rectangle? In accord with the original notion of induced motion, the dot should move obliquely downward and to the left, since the perceived motion of the rectangle carried it upward and to the right. But the dot is never seen to do so. Its induced motion relative to the rectangle is fundamentally determined by the fact that the rectangle surrounds it. The displacement of the surrounded object relative to its surrounding remains unaffected by the secondary displacement of the surrounding object relative to a third object or to the observer.

Once we recognize the effectiveness of the object-relative condition of stimulation, we find it playing an ascendant role, even in situations that might otherwise seem to be dominated by perception of angular displacement. Consider, for example, our judgment of speed, taking this term to stand for the perceptual counterpart of objectively measured velocity. A crucial discovery was made in 1927 by J. F. Brown, then working at the University of Berlin. He had his subjects, in a darkened room, observe the speed of a small black disk moving up or down in a lighted aperture. They were to match the speed of the disk by adjusting the speed of a smaller disk moving up or down in a lighted aperture half the size of the first. The experiment yielded a result that at the time was quite unexpected. It turned out that, in order to match the speeds of the two disks, the velocity of the disk in the smaller aperture had to be set at a little more than half that of the larger disk. This transposition of velocity in accord with the relative size of the two fields held over a wide range of velocities, from as little as two inches per second to as much as 10 inches per second. It also held over larger contrasts of field size, although the ratio of matching velocities tended to depart from the ratio of field sizes when the difference in size became very large. When the room was fully lighted, however, and common frames of reference became visible to the experimental subjects, the transposition of velocity became a good deal less exact.

We can explain these results quite readily in terms of the object-relative mode of motion perception. With no general frame of reference available, the judgment of speed in this experiment depends upon the size of the field in which it is observed. Speeds in two different fields are seen to be



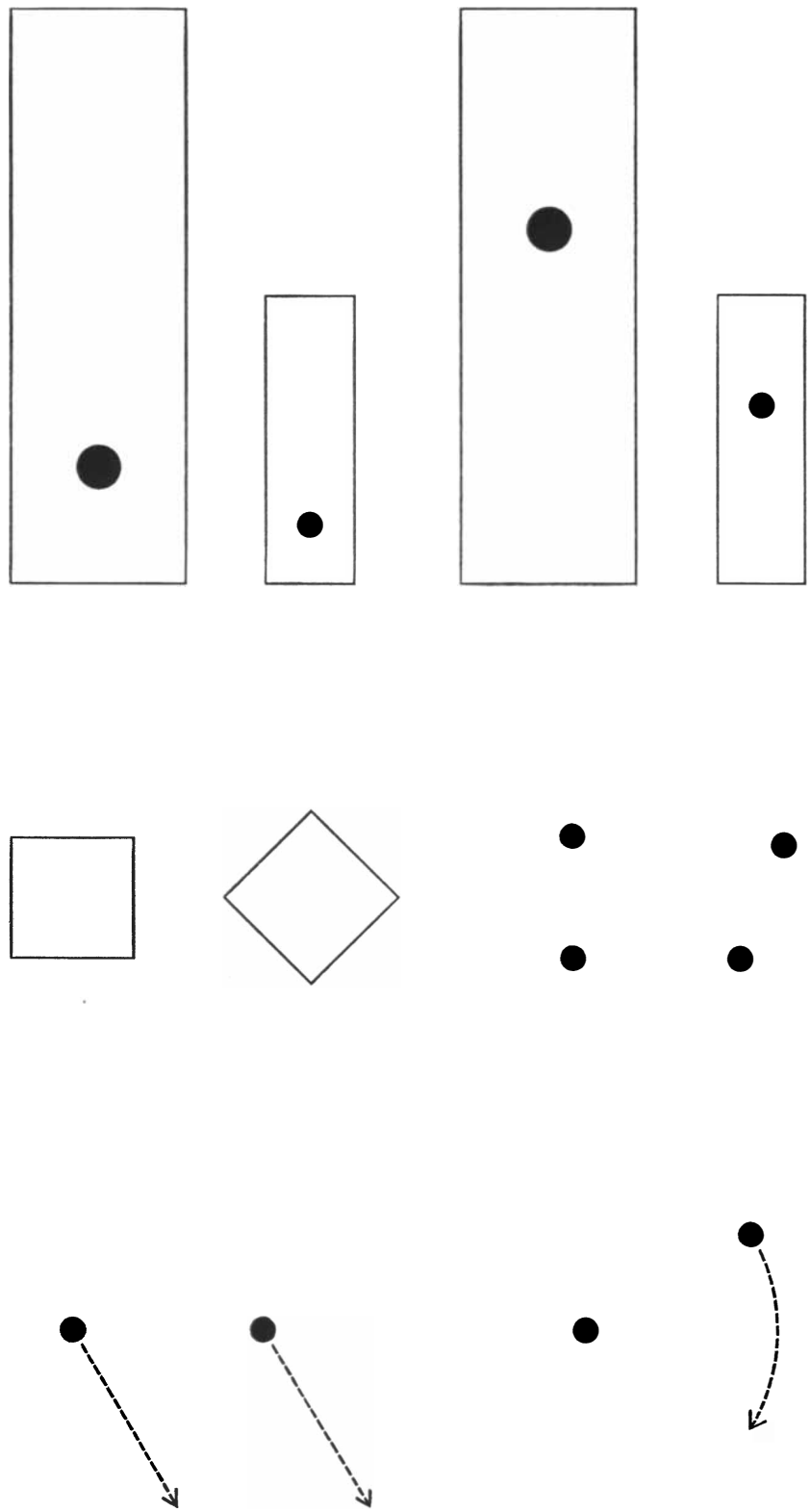
SURROUNDING OBJECT plays the decisive role in determining what motion is perceived and in allocating perceived motion to various objects in the visual field. Here the ring and rectangle at left are moved (*black arrows*) to new positions (*right*). The perceived motion of the rectangle (*colored arrow*) is the outcome of these two motions. The central spot, objectively motionless, acquires perceived motion in either one of two directions: with reference to the rectangle alone or with reference to the circle as well.

the same when the moving disks traverse equal fractions of the apertures in the same unit time. The transpositions are not, of course, 100 per cent perfect. This is because the perception of angular displacement also plays some role in our estimate of speed. But the close match of velocity ratios with the ratios of aperture sizes indicates the preponderant role of the object-relative mode of motion perception.

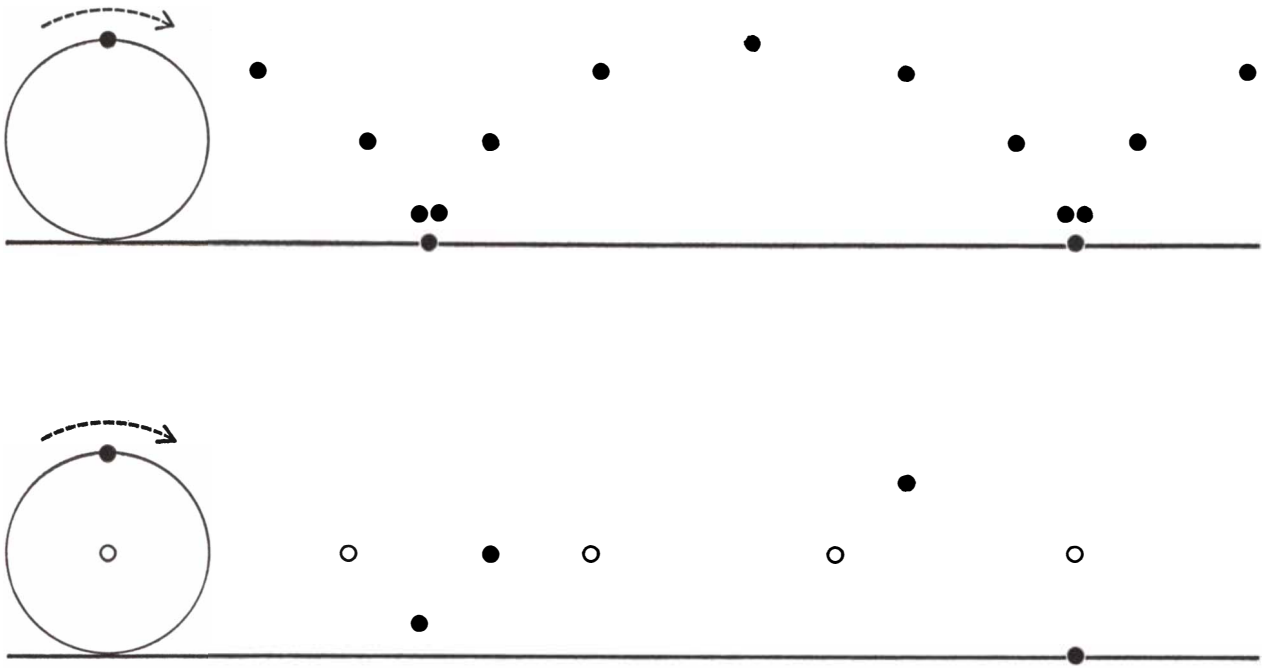
The important factor of form enters the discussion at this point; it plays a critical role in perception of object-relative motion. A pattern of visual stimulation may be transformed in a number of ways without changing the form. The most familiar, and the one relevant here, is the transformation of size. Two apertures of different size, each with moving disks at the same relative point, present identical forms to the observer. As the disks move at matched speeds, the two forms go through identical changes.

Whereas a change in size does not affect perceived form, another simple transformation produces surprisingly impressive changes in our perception of form. A pattern may change its form entirely when its orientation to the upright is altered. Turn a square through 45 degrees and it looks so different that it commands a different word in our language. The same is true of such a simple configuration as a pair of dots, because the dots produce, in their perceptual relationship to each other, an impression of direction [*see middle illustrations at right*]. Our perception of motion reflects this quality of form perception. For example, if two dots are moved in the same direction at the same velocity below the threshold for perception of angular displacement, they do not appear to move at all. There being no change in the distance between them, there is no object-relative displacement. On the other hand, if one dot is held stationary and the other is moved around it in a circular path, one or the other or both dots are seen in motion. Although the change in form here does not involve change in distance, it acts exactly like object-relative displacement and produces perceived motion.

Our perceptual dependence upon object-relative displacement and form change accounts for a number of engaging phenomena. Frequently the movement of an object along a given path gives rise to the experience of two simultaneous movements. We produce an impressive experience of this kind if we place a light source on the rim of a wheel



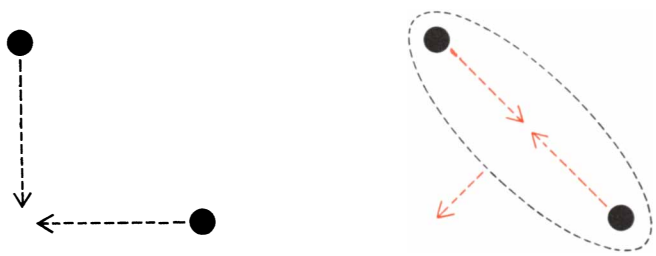
FORM PERCEPTION plays an important role in the perception of motion. At top the motion of the spots in the two similar rectangles appears to be at the same speed because the patterns are identical (*as at right*) at each stage of motion. Rotating a square through 45 degrees makes it into a "diamond." Similarly a change in the position of two dots (*right middle*) conveys quite a different sense of form. If two dots move slowly in the same direction (*bottom left*), no motion is perceived. However, circular motion of one dot (*bottom right*) causes a change of form and excites definite perception of motion (which may involve both dots).



DIFFERENT EXPERIENCES in the observer are caused by the same objective motion of light on the rim of a rolling wheel. At top, the perceived motion (*on a cycloidal curve*) fits the objective motion. However, if the hub is lighted (*bottom*), this perceived motion gives way to a compound motion: the light on the rim now seems to rotate about the hub as the wheel rolls from left to right.

and another at its hub and observe the wheel rolling in the dark. The light on the wheel is seen to move in a circle around the hub and to travel forward along with the light at the hub. If we turn out the light at the hub, both of these motions disappear entirely. The perceived movement of the light at the rim now resembles its objective path, moving along through successive arches of a cycloidal curve [*see illustration at top of this page*].

The experience of two simultaneous movements of a single object can be obtained under even simpler conditions. In an experiment, first performed by Gunnar Johansson, then at the Psychological Institute of the Stockholm Högskola, two round spots are moved along the legs of a right angle toward its apex, and then back to their starting position [*see illustration below*]. Observers invariably see the two spots moving straight toward each other as they travel a slanting path together, and then moving apart as they retrace the same slanting path. Each spot appears to be going through two simultaneous motions. One motion is in the direction of the other spot; the other motion is at right angles to the first and parallel to the slanting path on which the two spots converge. It is as if the true objective motion of the spot were the resultant of the vectors of these two motions. Observers usually find the movement of the spots toward and away from each other to be much the more conspicuous of the two simultaneous motions. About 35 per cent must be prompted before they perceive the second motion and "confirm its presence without hesitation."

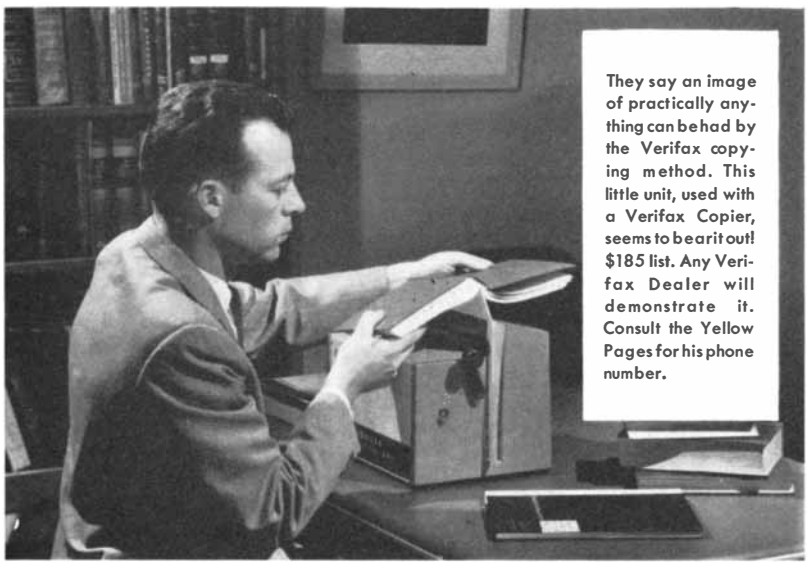


COMPOUND MOTION is perceived in two dots which objectively move (*black arrows*) along straight lines at right angles (*left*). To an observer, however, the dots seem to move (*colored arrows*) toward one another and simultaneously to move as a unit obliquely downward. Observers often fail to note the second component of this compound motion.

To the extent that one's awareness of one's own motion is mediated by visual perception, it may be subject to the vagaries illustrated in these experiments. The illusion of motion experienced when the train on the neighboring track pulls out is an example of induced motion in the perceiver. If the scene that fills the observer's field of vision is in some manner displaced with respect to him, he will feel himself in motion and perceive his environment at rest, even when some large objects in the foreground are not displaced. The visually induced sensation of locomotion seems quite indistinguishable from that which arises from kinesthetic stimuli and on these occasions overwhelms them. This is another instance of our paradoxical tendency to experience motion as an absolute rather than a relative process, even though its perception depends upon relative displacement. In allocating the qualities of motion and of rest to ourselves and to our environment, visual perception follows the rule that keeps the surrounding at rest and bestows motion upon the object surrounded.

Kodak reports on:

copying as you go . . . adjusting at the lab instead of in the sky . . . before and after yogurt



They say an image of practically anything can be had by the Verifax copying method. This little unit, used with a Verifax Copier, seems to be a ri t out! $185 list. Any Verifax Dealer will demonstrate it. Consult the Yellow Pages for his phone number.

Film to view a planet by

Speaking of fresh approaches to old problems, let's get rid of complex and heavy equipment that an airborne (or better) vehicle on photographic duty must carry to adjust exposures as it moves into different illumination conditions. Let's expose the whole roll of film at the same settings and forget the light level. Let's make the adjustment during processing at the lab, not zipping through the sky.

We now sell a film you can treat that way—*Kodak Plus-X Aerographic Film.**

First thing after it comes back from the ride is to put it through a certain developer for 7 minutes. Inspect. Cut off the part of the roll that shows printable image and put the rest through *Kodak Developer D-19* for 2 more minutes. Inspect. Cut off whatever part of the roll still shows no printable image and put that part back in the *D-19* for another 10 minutes. Whatever you don't have by then, you just don't have. If there are regrets, you can sadly conclude that standard aerial emulsion speed, even with spectral sensitivity extended to 710mμ as it has been in the new *Plus-X*, is inadequate for what you were trying to do.

*Down, boy! You can't have this emulsion yet on 16mm, 35mm, or sheet film. There are honest technical reasons for this, but you have to work in a film factory to appreciate them.

We do have one, *Kodak Tri-X Aerecon Film*, that's quite a lot faster. It doesn't offer as big a definition boost as has been built into *Plus-X*, nor does it tolerate fishing in the developer for the proper effective emulsion speed.

On the contrary, we sort of feel that the brightest prospects for the future of photography to see a planet by lie in films *slower* than the new *Plus-X*. Trading in film speed for film definition strikes us as a good bargain. We suspect that with recent advances in lenses, image movement compensators, and vibration control, the customers don't need as much film speed as they have been used to. We know where we can lay hands on some slow aerial films of astounding definition. The exposure index-by-development technique works very well on them.

In youth you learned to develop paper prints by inspection. This is a different principle, and the inspection is by infrared. You'll need plenty of advice. Write to Eastman Kodak Company, Government Sales Division, Rochester 4, N. Y., for encouragement.

Acido orotico

Around the turn of the century it was brought to the world's attention that the inhabitants of certain Bulgarian villages were a) living to ripe old ages and b) consuming vast quantities of the ripe old fermentation products of the local dairying. Echoes of this coincidence have rumbled forth at intervals since.

In the twenties a certain elderly biochemist who had seen much importance in the correlation was a celebrated figure of Paris. In the thirties American milk wagons were bedizened with signs advertising a certain brand of fermented milk. In the forties the word "yogurt" entered the vocabulary of the American intelligentsia. With the dawn of the fifties, the Journal of the American Chemical Society (*72*, 2312) reported that certain strains of *Lactobacillus bulgaricus* throve when supplied with 6-carboxyuracil, a substance first synthesized in 1897 for academic exercise and later shown to be identical with orotic acid. This name was derived from ορος, whey, by two Italians who had encountered the substance while making lactose from milk whey liquors.

The flowering of biochemical sophistication in the mid-fifties has excited a deeper curiosity about orotic acid. To some it looks like a significant intermediate in the process by which living organisms fabricate nucleotides for their DNA—the stuff of genes—out of the amino acids at their disposal. This is big talk.

In Italy interest in *acido orotico* has been rekindled to a small-scale frenzy. At the University of Urbino last June a colloquium on pyrimidines (*Acta Vitaminologica*, *12*, 195-328) devoted much of its attention to the compound. One man claimed his evidence showed that a dietary deficiency of orotic acid affects pregnancy, lactation, and growth in the rat, that it is a vitamin-like factor essential for the survival of the newborn. One senses the closing of a circle.

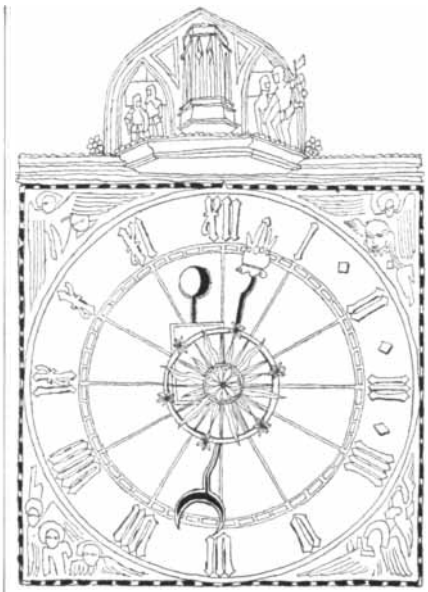
If we had not been invited to quote on 100 kilos of Orotic Acid *recently, we might not have looked up all this lore. We didn't get the order, but in trying we made enough of it to stock as Eastman 7784 (along with* 2-Thioorotic Acid, *Eastman 7783) for the convenience of biochemical investigators. Anybody who wants to sell it from milk trucks is strictly on his own.*

Price is subject to change without notice.

Kodak
TRADE MARK

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



Education in an Age of Science

The President's Science Advisory Committee has recommended that the nation double its current $15 billion annual expenditure on education. In a report entitled "Education for the Age of Science" the Committee proposed that the added funds be used to raise the pay of teachers, to aid all gifted students in need of financial assistance, to enlarge the number and improve the quality of graduate engineering schools and university science departments, to bring up to date outmoded science and engineering curricula, equipment, textbooks and teaching aids, to set up technical institutes, to operate adult-education programs in science, to establish mobile science museums, and generally to improve education in all fields.

The Committee also addressed itself to the national attitude toward education. States the report: "An enhancement of the nation's desire to learn and an increase in its respect for intellectual excellence have become essential to national progress, and even to survival. . . . In school or in college, learning to think must take precedence over learning to run or swim or drive a car."

The Committee was critical of personal-adjustment courses and of teacher-training programs that stress educational techniques at the expense of subject-matter courses. "We deplore," the report states, "those rules which exclude from secondary teaching first-class scholars solely because they lack the proper number of credits in 'education.'"

The Committee recommended that secondary-school students who plan to study science in college should take four years of English, three or four of mathematics, two or three of science, three of a modern language and two of social science, including history. College students who do not major in science should spend at least 15 per cent of their time studying science, and should take at least two full-year science courses before earning a baccalaureate degree in any field. Courses for such students should help them think their way through and appreciate fundamental scientific concepts such as organic evolution.

The Committee report suggested that the U. S. is wasting half of its human resources in underestimating the potential of women in science and technology. Other resources are wasted when gifted students are required to follow an inflexible curriculum for a fixed number of years.

The Committee pointed out that vital national decisions are made primarily on the basis of scientific and technological knowledge, and that citizens who have no interest in this knowledge can take no intelligent part in such decisions. "There is, therefore, no escape from the urgency of providing high-grade and plentiful adult education in science now, planned for those who are unprepared even in the fundamentals. . . . This is primarily a challenge to the scientists themselves. It is they who must determine what science the citizen most needs to know; it is they who must suppress the notion that 'popularizing' is evil or impossible."

Shortly after the report was issued, the chairman of the Science Advisory Committee, James R. Killian, Jr., announced his resignation as President Eisenhower's special assistant for science and technology. Killian leaves "for compelling personal reasons," and to take up his position as chairman of the Massachusetts Institute of Technology Corporation. He was president of M.I.T. when the President named him special assistant in 1957. He is credited with having exerted a great influence on the nation's scientific policies and activities in the intervening period.

To succeed Killian, President Eisenhower appointed George Bogdan Kistiakowsky, Russian-born professor of chemistry at Harvard University who has been a member of the Science Advisory Com-

THE CITIZEN

mittee. Killian will remain a member of the Committee.

Two-Mile Accelerator

The Atomic Energy Commission has announced plans to build a two-mile-long linear accelerator as a national research facility at Stanford University. The machine will initially accelerate electrons to an energy of 10 to 15 billion electron volts; ultimately, it is hoped, it will produce particles of 45 bev. Development of the accelerator will cost $18 million; construction, $100 million; annual operation, $15 million. Construction will take about six years.

The accelerator will occupy two parallel tunnels separated by several feet of earth and buried at a depth of 35 feet. One tunnel will house the operating equipment; the other will hold the two-mile-long evacuated tube through which the electrons will be propelled in a straight line by a traveling radio-frequency wave. The largest linear accelerator in existence at present is also at Stanford. A midget by comparison with the projected machine, it is 220 feet long and produces electrons of 700 million electron volts.

The new linear machine will eventually be in the same class as the 25- to 30-bev circular synchrotrons now being built at Brookhaven National Laboratory and in Geneva. The U.S.S.R. plans to build a 50-bev synchrotron. All of these circular machines will produce protons.

In accelerating electrons the great linear machine will make possible studies in the nature of matter that cannot be undertaken with protons. Although electrons can also be accelerated by a synchrotron, it is much more efficient to do so in a linear machine. The reason is that electrons accelerated to huge energies in a straight line radiate away much less of their energy than those accelerated on a curved path.

Blood and Genes

Research on that least manageable of all animals, man, is overtaking studies of molds, viruses, bacteria and fruit flies as a source of knowledge of how genes control the processes of life. A recent example is found in a paper in *Nature* on the way in which the hereditary ma-

terial controls the synthesis of a protein. Investigations by John A. Hunt at the University of Cambridge and others indicate that two genes direct the production of the protein hemoglobin in man. Each of the genes seems responsible for synthesizing one of the two chains of amino acid units in the hemoglobin molecule. Until recently one gene was thought to account for the production of one kind of protein.

In his studies Hunt used blood drawn from the umbilical cord of newborn infants. Babies have two kinds of hemoglobin, one characteristic of adults and one of fetuses. The fetal hemoglobin tends to predominate at birth, but after a few months a normal infant has only the adult hemoglobin. The two hemoglobins differ in the quantities of several amino acids each contains and in other respects.

In both types of hemoglobin Hunt separated the two linked series of amino acid units, which are called the alpha and beta chains. Then he used the enzyme trypsin to break the chains into fragments, and separated the fragments by electrophoresis and chromatography. He verified suggestions by others that the alpha chains of adult and fetal hemoglobin are identical, and he found further that differences in the adult and fetal beta-chains fully account for the known variations between the two kinds of hemoglobin.

As Hunt points out, others have suggested that the synthesis of the two-chain molecule may be controlled by two genes. He believes that the synthesis of the alpha chain of both fetal and adult hemoglobin may be controlled by the same gene, and, if this is true, identical abnormalities should be found in the alpha chain of both adult and fetal hemoglobin taken from the same individual.

On the other hand, if the beta chain in adult and fetal hemoglobin is controlled by different genes, then an abnormality on an individual's fetal beta-chain should not appear on his adult beta-chain. Conversely, an abnormality on the adult beta-chain should not be found on the fetal beta-chain. Some experiments, Hunt reports, have already confirmed this in part.

Recent discoveries by Hunt's Cambridge colleague, Vernon M. Ingram, provide an opportunity to investigate the matter further. Ingram has found that four abnormalities, including the well-known sickle-cell anemia, are associated with the beta chain of adult hemoglobin, while two are found only on the alpha chain. Using this information, Hunt

plans further studies of the hypothesis that different genes control the two chains of amino acid units in human hemoglobin.

Plutonium for Reactors

A new plutonium-fabricating plant at the Argonne National Laboratory has already started work on its first project—the development of plutonium fuel-elements for reactors. The work can be regarded as a technological precaution against the inevitable exhaustion of the earth's supply of uranium 235. Plutonium, the fissionable element used in nuclear weapons, is potentially much more abundant than uranium 235 because it can be made from uranium 238, which is 140 times more plentiful than uranium 235. By capturing a neutron, nonfissionable uranium 238 becomes fissionable plutonium 239.

This reaction is turned to advantage in fast breeder-reactors, which produce (or "breed") more fuel than they consume. Uranium 238 elements blanket the core of a breeder reactor, and become plutonium by capturing some of the reactor's surplus neutrons. The plutonium can be separated and made into fuel elements that yield even more power per kilogram than those made with uranium 235.

Between the idea and the reality lies a no-man's-land of technical problems. The development of satisfactory plutonium fuel-elements presents difficulties that seem formidable, even in an industry accustomed to the tricky metallurgy of exotic materials [see "Reactor Fuel Elements," by James F. Schumar; SCIENTIFIC AMERICAN, February]. Plutonium is a metal subject to such drastic changes that one physicist waggishly suggested that it should have been named "proteum," after the Greek sea demon who changed himself into a lion, a serpent or a fire to avoid capture. Plutonium assumes at least six crystal forms and passes through five solid-state transformations between room temperature and its melting point (640 degrees centigrade). These transformations are accompanied by changes in volume and physical properties. Plutonium fuel-elements would tend to buckle and twist on being heated or cooled.

Plutonium is also extremely dangerous to work with. Plutonium dust and turnings (as well as its hydrides, some alloys and impure residues) are pyrophoric—they burst into flame spontaneously, giving off deadly radioactive plutonium-oxide smoke. Since plutonium is an intense emitter of alpha particles, neither

the smoke nor any form of plutonium dust can be allowed to escape into the air, where it might be inhaled or ingested by humans.

Such problems have already been solved in the new Argonne plant. The plant contains a miniature rolling-mill designed to handle plutonium ingots the size of a bar of soap. The mill machinery is completely encased in glass, and operates in an inert atmosphere of helium. More than 100 fume hoods filter plutonium dust from the system and more than 1,500 sealed portholes fitted with sleeve-length neoprene gloves permit human intervention at various stages in the milling and fabricating process. Most of the operations are performed either remotely or automatically, however, to reduce the need for handling the material.

The $4-million plant will operate in conjunction with Argonne's $10-million Fuel Technology Center, a research installation scheduled for completion early next year. The joint goal of these establishments will be to manufacture prototype plutonium fuel-elements for testing in Argonne's experimental reactors, such as the second Experimental Breeder Reactor (EBR II), located at the National Reactor Testing Station in Idaho. Plutonium's potential as a reactor fuel seems to justify the trouble required to develop it, for not only will it multiply the world's supply of fissionable reactor fuel, but it will also eventually permit the construction of lighter, more compact power reactors that will operate more economically than those in existence today.

The Replacement of Bone Marrow

Investigators have recently shown that it is possible to repopulate bones with healthy marrow after high-energy radiation has destroyed this tissue. In laboratory animals the deliberate destruction and replacement of bone marrow provides a way to tinker with the immunological mechanism. In human beings bone-marrow grafts have been employed with apparent success to treat victims of accidental radiation exposure, and the radical combination of X-rays and self-donated tissue has been suggested as a therapy for leukemia.

Mice irradiated with lethal doses of X-rays can be made to survive by transplanting marrow from unexposed mice into their bones. The fresh marrow takes hold and functions normally. The mice do not react against the foreign marrow because the radiation has virtually destroyed their immunological mechanism.

Two years ago research teams in Bri-

tain and the Netherlands carried this experiment a step further. Into the bones of irradiated mice they grafted rat marrow. A few of the animals lived and became synthetic hybrids. Some of their blood cells were ratlike, others mouselike, and rat skin grafted onto their bodies remained in place and even sprouted rat hair [see "Science and the Citizen"; SCIENTIFIC AMERICAN, October, 1957].

Workers at the Pasteur Institute in Paris have adapted this experiment to human therapy. They transplanted bone marrow from donors to six Yugoslav physicists who had been exposed to radiation in a laboratory accident. All but one survived.

Recently four workers at the Massachusetts General Hospital and Harvard Medical School have used a more elaborate procedure to treat three children in the last stages of leukemia. In this disease the marrow produces a malignant excess of white cells. The scientists first employed drugs to bring about a temporary remission, then removed some of the patients' marrow and stored it under refrigeration. A few weeks later, when the disease had resumed its course and was approaching the terminal phase, the patients were given X-ray doses massive enough to kill their leukemic marrow. Then their own stored marrow was regrafted into their bones. All three children died, but one of them lived long enough to justify further trials. The work was reported in *The New England Journal of Medicine* by Joseph McGovern, Paul Russell, Leonard Atkins and Edward Webster.

Were it not for previous irradiation, such transplants would be unsuccessful; the body would react against foreign marrow with fatal consequences, as it would to transfusions of unlike blood or grafts of foreign skin. But Ray Owen of the California Institute of Technology has found exceptions. Newborn animals generally do not react to marrow transplants from other animals of the same species, presumably because the immunological mechanism is not firmly established at birth. Owen started by transplanting marrow from one young chick to another. He found that the chick that received the marrow would then tolerate skin grafted from all the donors into the receptor chick. The chick that had received the marrow shared the immunological reactions of all the donors.

If this technique could be applied to human infants, a child might be made to tolerate grafts of skin, bone and other organs from many other people. While

being immunized *against* various diseases, a baby might then be said to have been immunized *for* other people.

How Cells Drink

How can an animal without a mouth drink water? The microscopic amoeba, a one-celled bag of protoplasm, is an animal in just such a predicament. According to recent experiments by Ronold C. Rustad of the University of Edinburgh, amoebas ingest water and other molecules to which their cell membranes are impermeable by engulfing them with short pseudopods; the process is known as pinocytosis, or "cell drinking." Each pseudopod is pierced by a central channel one micron or more in diameter, into which the animal draws molecules that seem to be lined up along its surface. Once they are inside, the channel closes, pinching them off in droplets which migrate to the interior of the cell.

But what makes the cell membrane sticky enough to attract the molecules in the first place? Rustad believes that they are attracted by chemical forces. Writing in *Nature,* he mentions that basic (as opposed to acidic) dyes such as toluidine blue seem to attach themselves to active sites on the cell membrane; the basic proteins ribonuclease and protamine do the same. In a solution containing all three substances the dye and the proteins compete for surface sites. Since neutral and acidic proteins are not so easily attracted, Rustad postulates that the sites must be acidic. He observed that basic molecules stimulate cell-drinking when they attach themselves to these sites.

The next step will be to check the postulates by varying the acid-base balance of the environment of the amoebae. The work should lead to some interesting speculations, not only about the stimulation and inhibition of pinocytosis, but also about the curious workings of that inscrutable and highly selective biological barrier: the cell membrane.

What Kind of Universe?

A new test for deciding between the "evolutionary" and "steady-state" theories of the universe is described by Kurt Just of the Free University of Berlin in a recent issue of *The Astrophysical Journal.* Just believes that this test disproves the steady-state theory.

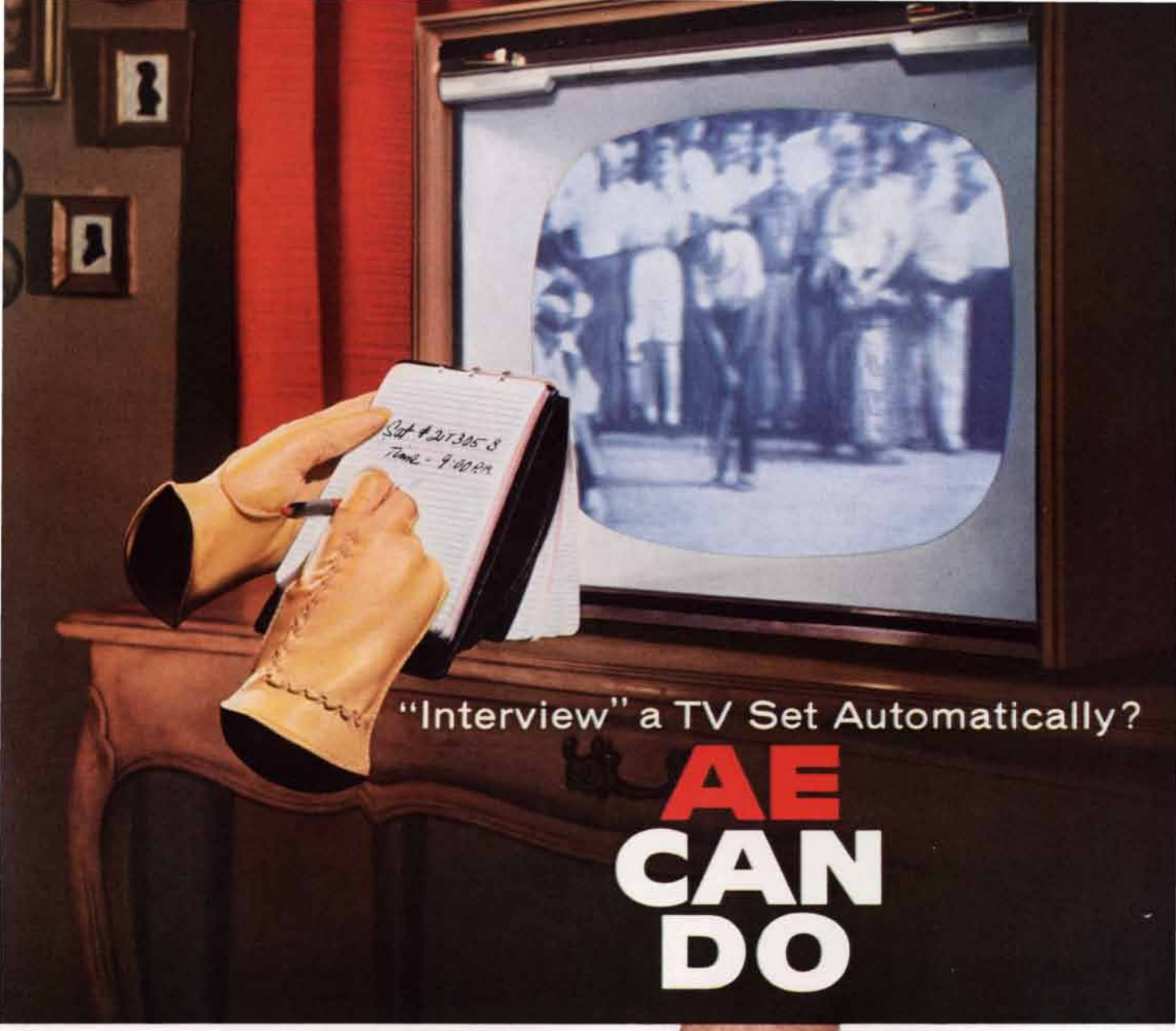
The evolutionary theory, accepted by most cosmologists, holds that the universe originated in the explosion of an enormous mass of superdense matter. It implies that the distribution of matter in the universe changes with time, and that distant galaxies, which because of the finite speed of light we see as they were some hundreds of millions of years ago, are more densely distributed than nearby ones. A group of cosmologists hold to the steady-state theory, which implies that the large-scale distribution of matter in the universe is the same at all times and places.

Just has studied the characteristics of some 2,700 clusters of galaxies which have been catalogued by George O. Abell of the Mount Wilson and Palomar Observatories. Abell has classified these clusters according to their brightness, which gives a rough measure of their age, and their "richness," which approximates the number of galaxies in a cluster. According to the steady-state theory, the average richness of the clusters should be the same regardless of their age. Just finds, however, that the younger and more distant clusters are as a group considerably richer than the older and nearer ones. Even after discarding nearly half the clusters as borderline cases that may have been wrongly classified as to age or richness, he finds that the very richest clusters account for 18 per cent of the "early" sample as against 10 per cent of the "late" sample.

As a further precaution Just assumes that Abell failed to count some 18 per cent of the faintest clusters in the early and more distant group. Even on this assumption, the probability that the difference in richness between the two groups is due to evolution rather than chance is better than 99 per cent.

Nuclear Thermocouples

Two recent projects—one at the Los Alamos Scientific Laboratory and one at the Martin Company—have drawn public attention to the direct conversion of nuclear energy to electricity. Los Alamos has developed the plasma thermocouple, a device that produces 40 watts of electricity when it is inserted into a reactor. Like all thermocouples, the device has two elements, one hot and one cold. The hot element is a tiny rod of uranium carbide encased in a capsule containing cesium vapor; the outer wall of the capsule is the cold element. The capsule itself is mounted in an oil-filled metal container about the size of a can of frozen orange juice. When reactor neutrons riddle the container, they trigger fission processes in the uranium rod which heat and ionize the cesium vapor, filling the capsule with a plasma of free electrons. The high temperature-difference between



Picture a system that "polls" 1500 TV sets in numerous cities, tells New York who's watching what every 90 seconds! It *has* been done with help from Automatic Electric.

The secret? A device in each TV set senses "on" or "off" and channel setting—sends this data to a central office over leased lines. Every 90 seconds the office in each city relays the results to New York where they appear on a continuous display board. Sponsors get ratings *while the shows are on!*

Making magic automatically is AE's stock in trade, because automatic control is a *telephone art* and AE pioneered its principles. *In fact, almost every device or system that is operated automatically uses the type of switching and relay units originated or manufactured by Automatic Electric.*

If you have a problem in communications or control, AE probably has the answer. We'll give you engineering support and deliver the basic components or a control "package." For a good start, just write the Director, Industrial Products Engineering, Automatic Electric, Northlake, Illinois.

MAKING
IDEAS
WORK
AUTOMATICALLY

AUTOMATIC ELECTRIC

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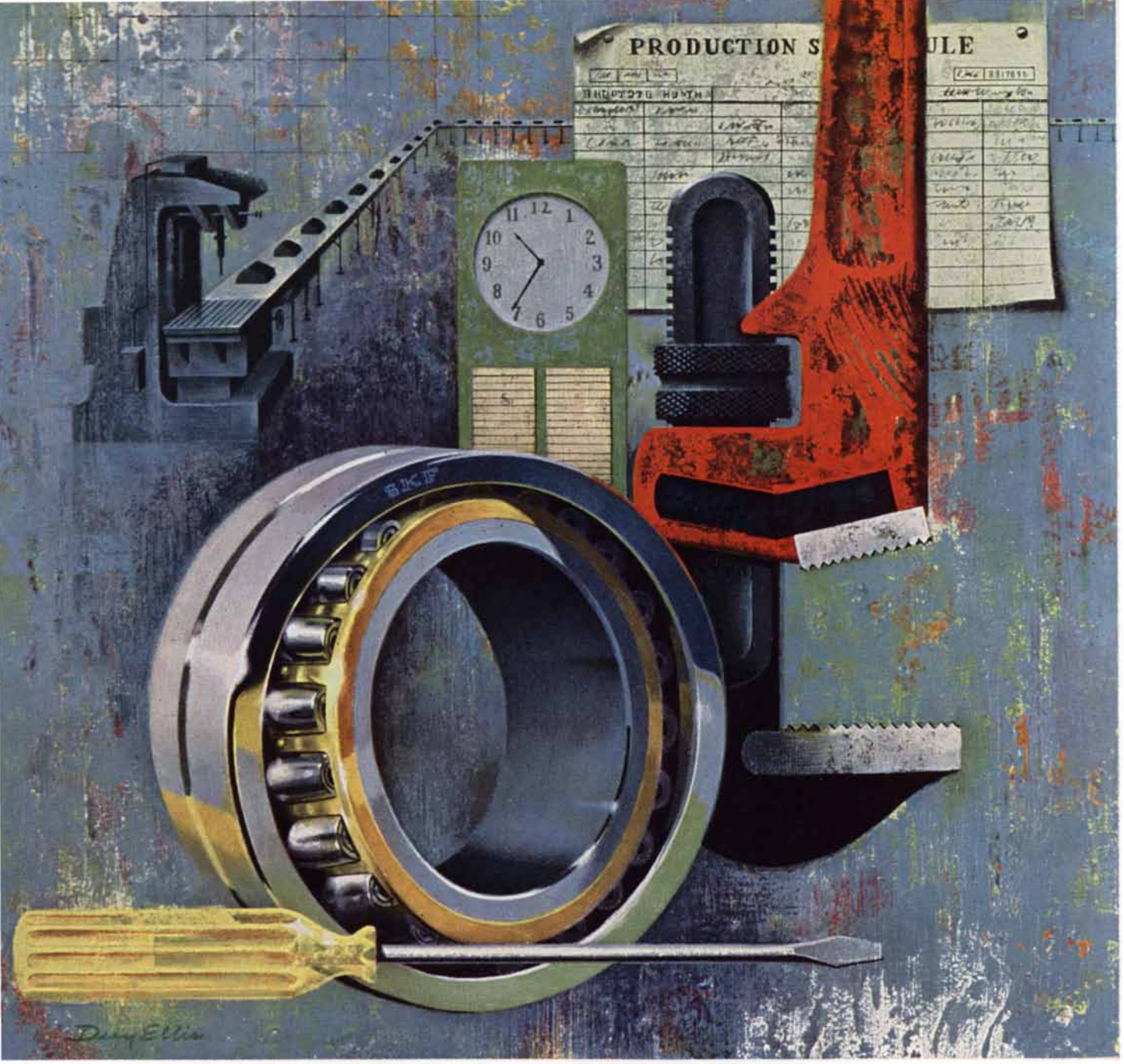

THIS PAINTING WON AN AWARD

It placed second in a field of sixty-three entries in the Eastern Industrial Advertiser's art exhibit. It was painted for SKF by Dean Ellis, an artist known for his ability to present a product in a strong industrial setting. In this instance the product is a SKF spherical roller bearing.

The painting originally appeared as the illustration of an advertisement headlined "Parts Determine Maintenance Cost". In this ad SKF outlined how the quality of a bearing can make the difference between profitable production or penalizing breakdowns. It also recommended that the reader look to SKF for prompt service and assistance. Does the equipment you build, or use, contain bearings?

SA-7828

Spherical, Cylindrical, Ball, and Timken® *Tapered Roller Bearings*

EVERY TYPE—EVERY USE

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the rod and the oil-cooled capsule wall drives the electrons from the hot to the cold element, generating an electric current in the circuit connected to the thermocouple.

Martin's grapefruit-sized SNAP III (Systems for Nuclear Auxiliary Power) device works in somewhat the same way. Its heat source is the alpha-emitting radioisotope polonium 210; alpha particles from a capsule of polonium heat one end of a number of semiconductor thermocouples arranged around it like the spokes of a wheel. The thermocouples are connected in series to multiply their effect, but 54 of them generate only 2.5 watts, at an efficiency of about 5 per cent.

The power and efficiency of both thermocouples are admittedly low, but their significance cannot be measured in these terms alone; they are the primitive forerunners of more sophisticated devices to come. An improved version of the Los Alamos thermocouple could cut nuclear power-plant size and costs sharply by eliminating the need for cumbersome generating equipment. And the designers of SNAP III predict that their unit could be used as a nuclear battery that would deliver 9,000 watt-hours of electricity instead of the 400 watt-hours that can be expected from the same weight of the best chemical batteries. If it matches their expectations, a modified SNAP III should be useful to power the communication systems of satellites and rockets.

Some designers have already suggested the use of small nuclear reactors, perhaps equipped with Los Alamos-type thermocouples, for this purpose. But in *Nucleonics* three of the men connected with the SNAP project question the usefulness of reactors for space applications. Melvin Barmat, G. M. Anderson and E. Wayne Bollmeier mention that despite power densities of up to 5,000 watts per pound, reactors are limited by the weight of their critical mass and the probable requirement of moving parts and coolants.

In turn, the selection of heat-producing radioisotopes in the SNAP project has also been questioned. Polonium 210 seems an unlikely choice for space applications because an unthinkable amount of this deadly alpha-emitter would be released into the air in rocket explosions and satellite burn-ups in the atmosphere. Also, as Stanley H. Clark of Medical Nuclear Consultants, Inc., has pointed out, polonium may not be the best radioisotope to use as a heat source anyway, because of its low power-density. A thousand curies of polonium produce only 32 watts, while 1,000 curies of a spontaneously fissioning radioisotope produce over 1,000 watts.

The most promising of the spontaneous-fission isotopes is californium 254, which is believed to be the primary energy source in some supernovae; it produces approximately four million watts of thermal power per pound. Of course there are problems here, too. Californium 254 releases enormous numbers of neutrons per fission, and would thus require extensive shielding if used in a populated area. It is a rare and hard-to-produce isotope, but its high power-density might provide an incentive to put it into large-scale production.

Energetic Detergents

"Surface active" substances such as soaps and synthetic detergents may be even more active than has been supposed. The ability of these substances to remove greasy dirt has been ascribed to their capacity to increase the "wetness" of water, thus permitting the water to adhere to grease. A. S. C. Lawrence of the University of Sheffield now suggests that soap and detergent solutions actively penetrate fatty substances.

In a recent issue of *Nature* Lawrence describes a series of experiments on fatty acids and related substances. He finds that when these compounds are mixed with water and a detergent, they go into solution over a wide range of concentrations. Under some conditions the three substances form a "liquid crystal," a form of matter with properties of both liquids and solids. By microscopic examination of fatty particles in a water-detergent mixture, Lawrence has established that the mixture converts the outer layer of the particles into a layer of liquid crystal. When this is broken up by agitation, more liquid crystal forms and the particle further diminishes in size. Such processes, he believes, explain how detergent solutions are able to penetrate sticky and adhesive layers of grease.

Lawrence finds that the ability of detergent solutions to dissolve fatty acids drops off sharply at temperatures slightly below the melting point of the acid. This fact, he says, helps explain the great superiority of hot water to cold water for washing.

Magnesium Deficiency

A new disease of man, caused by a deficiency of magnesium in the blood, has been discovered and speedily corrected by a group of workers at the Har-

vard Medical School and the Peter Bent Brigham Hospital in Boston. Five patients being fed intravenously came down with severe muscle cramps and convulsions. The symptoms suggested calcium deficiency, but the patients had been getting plenty of calcium in the nutrient solution. A spectrometric analysis of their blood showed that the level of magnesium, which had not been included in the intravenous diet, had dropped to only 50 per cent of normal. The remedy was simple; injections of magnesium sulfate (Epsom salt). The patients improved rapidly within a few hours, and soon their symptoms disappeared.

Up to now magnesium has not been regarded as a dietary essential, although in small amounts it is active in various enzyme functions. In a normal diet a man gets much more magnesium than he needs. But cattle suffer a magnesium-deficiency disease, known as "grass staggers," on early spring forage, which contains little magnesium.

The report on magnesium deficiency and its alleviation was presented at the recent annual meeting of the Society for Clinical Investigation in Atlantic City by David Ulmer, Warren Wacker and Bert L. Vallee.

Modern Midden

An ingenious means of investigating the history of mining camps and ghost towns has been worked out by Charles B. Hunt of the U. S. Geological Survey. Approaching the problem in the spirit of an archaeologist studying an ancient culture, Hunt examines the litter in the camp dump, or midden. He bases his reconstruction of the past largely on the design of cans and bottles, which has changed radically during the past hundred years.

Four fairly distinct eras can be discerned. Before 1900 can-seams were sealed with solder, beer bottles had hand-finished necks made for cork stoppers, and nails had a rectangular cross section. After the turn of the century and until World War I soldered cans were still common, but bottles were modified to accommodate metal caps. The third period began about 1920, when cans were crimped along the seams and bottlenecks were first machine-finished. Other artifacts associated with this era are automobile parts, including the Ford wrench known as the "knuckle breaker." The latest period, comprising the last 20 years, is characterized by aluminum cooking utensils and beer cans pierced by triangular holes.

METALGRAMS

. . . news about metals and metal chemicals

UNION CARBIDE METALS

Electromet brand ferroalloys, pure metals and metal chemicals

Recent harbingers of increased demand for tantalum metal are its improved weldability and availability in large sheets. These advances combined with tantalum's excellent corrosion resistance indicate wider use in pharmaceutical equipment where corrosion and product contamination must be minimum, and in the chemical processing industry for large reactor vessels. Continued prominence in the electronic industry is assured by tantalum's extreme heat resistance and the outstanding dielectric properties of its anodic oxide film. For more information, write for Bulletin TA1-S.

* * *

Tungsten carbide powder is now available from Union Carbide Metals for evaluation in the manufacture of cemented or sintered carbide tools, dies and other compacts. Produced by a patented single-stage process, it meets existing particle size and chemical specifications for powders now produced by conventional methods. Data Sheet WC1-S gives additional facts.

* * *

The pace toward wrought chromium has quickened. Chromium metal has been successfully extruded into rod, tubing, and flat stock by Nuclear Metals, Inc., using ''Electromet'' chromium. Starting materials for these extrusions have been 3/4 in. by D high-purity chromium flake and 325 mesh by D laboratory grade powder. Write for Data Sheet CR1-S.

* * *

Applications of chromium monoboride are being explored with prospective users by Union Carbide Metals Company's field men. The compound's low volatility and high reflectivity make it attractive for several purposes. Coatings of chromium monoboride can be applied by metallizing methods. Evaluations of these coatings have proved them satisfactory where resistance to high temperatures, erosion, and corrosion are required. Chromium monoboride has also been used as a constituent of super alloys, such as those containing alloys of chromium, nickel and boron. Data Sheet CM1-S gives additional information.

* * *

The stringent demands of nuclear applications have brought increasing interest in columbium's high thermal conductivity, corrosion resistance, and low nuclear cross-section. Further demand is assured by a new series of columbium-base alloys being developed to withstand temperatures in excess of 2000°F. Significant quantities of several alloys are already being prepared. Write for Bulletin CB1-S.

* * *

Engineers and scientists can now obtain high-purity titanium carbide with less than 0.3% free carbon, and close to the theoretical composition of TiC. Makers of cemented carbide cutting tools may find in this product a way to simplify quality control problems, since the reproducibility of composition is excellent. Union Carbide Metals field men are consulting with users to develop several applications for this product. Write for Data Sheet TC1-S.

* * *

Union Carbide Metals Company, Division of Union Carbide Corporation, P. O. Box 330, Niagara Falls, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

THE EXCLUSION PRINCIPLE

It governs both matter and antimatter, explains the internal structure of atoms and nuclei, and enables us to predict the behavior of a confusing assortment of fundamental particles

by George Gamow

One of the most powerful generalizations of modern physics states that each quantum orbit of an atom can contain no more than two electrons. It is sometimes called the Pauli principle, but its author, the theoretical physicist Wolfgang Pauli (who died in Switzerland last December), preferred to call it the exclusion principle. This may have been due to the fact that he did not wish to have it confused with the Pauli effect, a contribution to experimental physics of which he was especially proud.

It is well known that theoretical physicists are quite inept in handling experimental apparatus; in fact, the standing of a theoretical physicist is said to be measurable in terms of his ability to break delicate devices merely by touching them. By this standard Wolfgang Pauli was a very good theoretical physicist; apparatus would fall, break, shatter or burn when he merely walked into a laboratory. The explosion of some elaborate vacuum equipment in James Franck's laboratory at the University of Göttingen has been directly attributed to the Pauli effect: it was later definitely established that the mishap had occurred at the exact time a train carrying Pauli had stopped momentarily in the Göttingen railroad station.

Pauli's exclusion principle, on the other hand, acquired its importance because it helped to clarify the internal structure of the atom. According to Niels Bohr's model of the atom, electrons circling an atomic nucleus may move only along certain "quantized" orbits. (Any variable in nature restricted to a series of discrete values is said to be quantized.) Electrons can emit radiation by jumping from the outer orbits (which represent higher energies) to the inner ones. The illustration on page 76 shows the quantum orbits in the hydrogen atom along which that atom's single electron is allowed to move.

Closest to the nucleus is the first quantum orbit, a circular one which corresponds to the lowest energy-level; it is the permanent abode of the electron in its normal state. When the electron is excited to the next higher state of energy, it may reside in the second energy-level, in either the second circular orbit or any of three associated elliptical orbits, all of which have the same energy. A still more energetic electron may reside on the third energy-level, which consists of the third circular orbit and eight elliptical ones, and so on. Successive sets of orbits (or "electron shells," as they are usually known) correspond to ever higher energy-levels and have an ever increasing number of elliptical orbits associated with the principal circular ones.

Orbits and Periodicity

In the atoms of heavier elements (whose nuclei have larger electrical charges) the consecutive electron shells are arranged in the same pattern as those in the hydrogen atom, but the diameters of the shells are somewhat smaller. In these atoms the increased electrical attraction of the proton-packed nucleus is not completely balanced by the increased electrical repulsion of the negatively charged electrons, so the electrons are pulled closer to the nucleus. This presents something of a problem, because heavier nuclei have an increasingly larger number of electrons orbiting around them. In the oxygen atom, for example, there are eight electrons instead of the hydrogen atom's one; in uranium there are 92 electrons. We might then ask: How is the larger number of electrons in the atoms of the heavier elements accommodated in the smaller quantum orbits?

In terms of classical physics the answer to this question is almost trivial. The most stable state of any mechanical system is the one in which the system cannot lose any more energy by dropping to a still-lower energy level. Thus all the additional electrons in heavier atoms might be expected to drop into the first quantum orbit and play "ring-around-a-rosy," or, more exactly, ring around the nucleus. And because we know that the diameter of that ring becomes smaller in heavier elements, we might predict that it would also become more and more tightly packed with electrons. If this were true, the atoms of hydrogen, oxygen and uranium would look as shown in the illustration at the top of page 78. The fact is that this does not happen: regardless of the charge of the nucleus, the over-all size of atoms remains approximately the same.

It was to explain this situation that Pauli first postulated his now-famous principle that each quantum orbit may hold no more than two electrons. The Pauli principle showed further that if both these vacancies are filled, the next electrons must be accommodated in other orbits. When all the orbits in a given shell are filled, the orbits in the next shell (corresponding to a higher energy-level) begin to fill. Thus although the diameters of quantum orbits are smaller in heavier elements, a steadily increasing number of them is filled up. This explains why all atoms are of roughly the same size.

The electron shells of all the species of atoms in the periodic table are filled according to this fixed hierarchy of energy states. The first shell, which represents the lowest available energy-state, is the first to fill. In the helium atom this

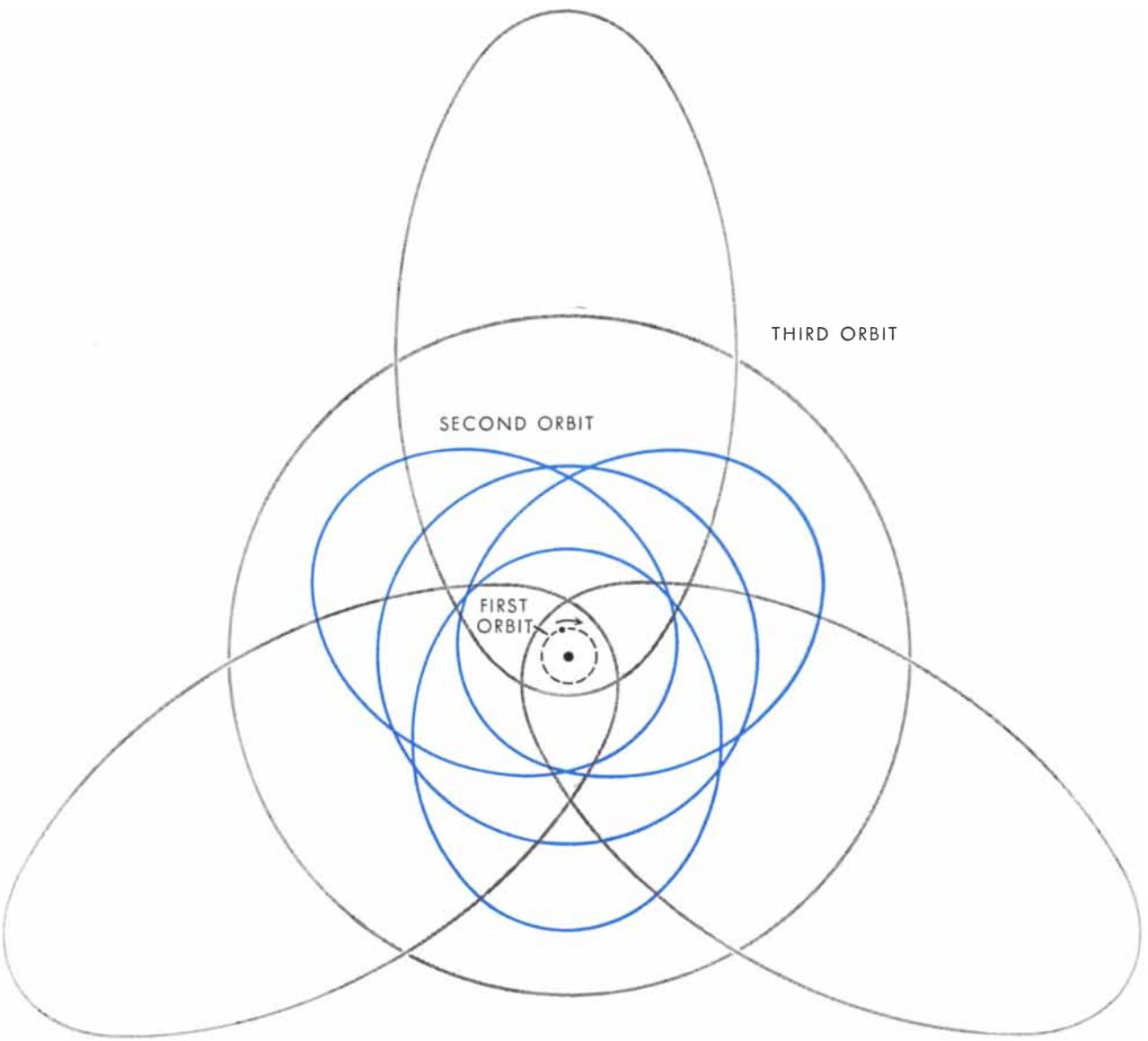
WOLFGANG PAULI, formulator of the exclusion principle, received the Nobel prize in physics for it in 1945. A brilliant theoretical physicist, Pauli was also famous for his work in particle physics (he postulated the existence of the neutrino) and in quantum electrodynamics, the set of theories that describes the behavior of electrons in electromagnetic fields. He died last December.

shell is completely filled by the two electrons chasing each other around the first quantum orbit. The next element, lithium, has three electrons, one of which, according to the exclusion principle, must be added in the second shell, consisting of one circular and three elliptical orbits. Since these four orbits can hold a total of eight electrons and the inner orbit holds two, both the first and second shells will be filled in the neon atom, which has 10 electrons. The extra electrons in still-heavier elements must be added in a third set of circular and elliptical orbits, and so on. Pauli's exclusion principle thus explains the internal structure of elements in terms of the way in which their consecutive electron shells are filled. The principle also underlies the external, or chemical, identity of an atom and the periodicity of chemical properties in the sequence of atomic species in the table of elements. These characteristics are determined by the number of electrons in the outer shells of atoms, which make contact when atoms collide with one another.

Electron Spin

When the Pauli principle was originally formulated, electrons were believed to be nothing more than point charges of negative electricity. It was soon discovered, however, that electrons must also be considered as tiny magnets: they possess a magnetic moment because they spin rapidly as they orbit around a nucleus. Having learned to regard electrons as tiny magnets, we must take into account both the electrical forces which are mainly responsible for their orbital motion and the magnetic forces set up by their spin.

An electron tends to spin in one of two ways: either in the direction in which it travels along its orbit, or in the opposite direction. It was shown that two electrons that follow the same orbit must spin in opposite directions [*see illustration at bottom of page 78*]. This discovery requires us to formulate the Pauli principle in a somewhat different way. Because electrons spinning in op-



BOHR MODEL OF HYDROGEN ATOM contains consecutive sets of quantum orbits along which a single electron moves around a one-proton nucleus. First circular orbit (*broken line*) represents the lowest energy-level and is the normal "home" of the electron. The second set of orbits (*color*) represents the next energy level, and the third set (*gray*) a still-higher level. Only the first three sets of orbits are shown; the additional sets have an increasing number of elliptical orbits associated with the principal circular ones.

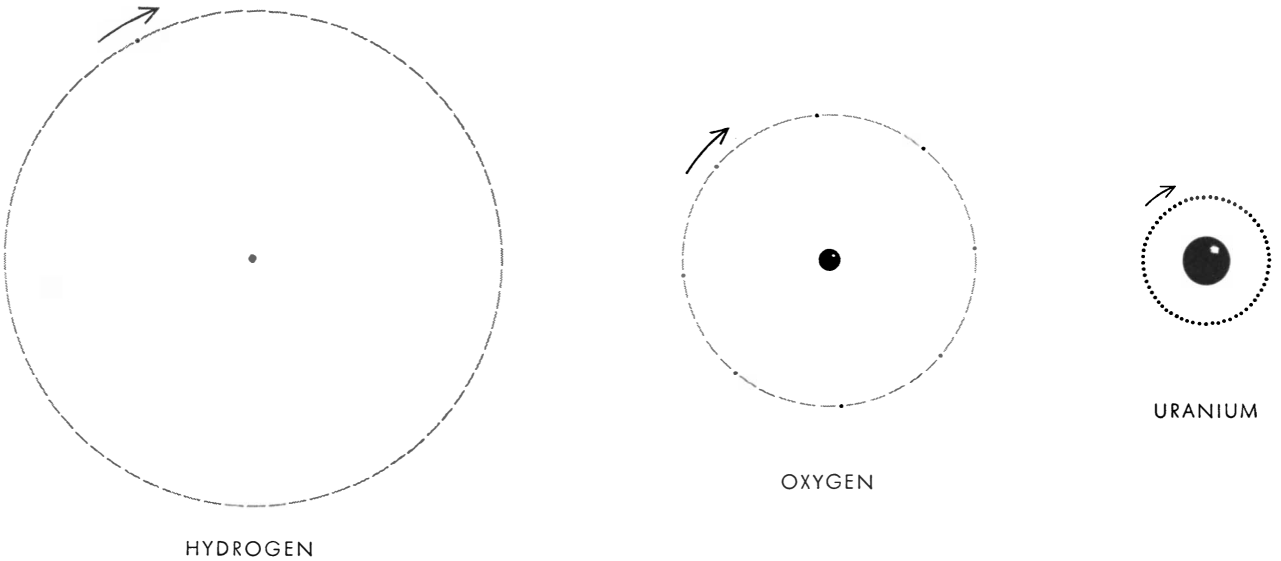
posite directions set up weak magnetic fields which slightly alter each other's orbits, we now say that the two electrons originally permitted to travel in the same orbit actually follow two different (though very similar) orbits. It is therefore more rational to regard the permitted orbits as close pairs split apart by weak magnetic interactions.

Pauli's exclusion principle applies not only to electrons in atoms but also to "free" electrons which have abandoned their atoms to drift freely through matter. We know that the electrical conductivity of a metal is due to the free electrons traveling through the metal's crystal lattice. When a voltage is applied to the metal, these free electrons move preferentially in the direction of the electric force acting on them, and comprise an electric current. We often speak of them as an "electron gas" which permeates the metal and is prevented from escaping from it by surface forces. This picture leads to a very satisfactory explanation of the phenomena of both electrical and thermal conductivity in metals, but it also leads to one very serious difficulty.

When a material is heated, the heat energy it absorbs increases the thermal agitation of its constituent particles. It was expected that in metals part of this energy would intensify the vibrations of the atoms in the crystal lattice and that part would increase the velocities of the free electrons. However, studies on heated metals showed that this is not so; all the heat absorbed by a metal goes to increase its lattice vibrations.

How can this possibly be? The answer is that the motion of the free electrons is quantized, even though they are no longer restricted to atomic orbits. Atomic electrons are generally restricted to one of a few hundred quantum orbits, but free electrons have literally billions of quantum levels available to them. These quantum levels are very closely spaced, forming, so to speak, a ladder with an almost infinitely large number of closely spaced rungs. The lower-energy rungs, being the first to be occupied, are filled to capacity by free electrons [*see illustration on page 80*].

Any gas in which particles are distributed among quantum levels in such a way is known as a "degenerate gas." Considering the enormous number of free electrons in metals, we realize that the energy spectrum of this gas must range from rather small values, for the lowest quantum-levels, to extremely high values, for the uppermost occupied levels. The energy of the fastest of the free



ATOMS WOULD DIFFER IN SIZE if the exclusion principle did not apply. The laws of classical physics would require all of an atom's electrons to occupy the first quantum orbit because it represents the lowest energy-state. The laws also predict that this orbit would be smaller in heavier atoms, because of increased electrical attraction between nucleus and electrons. Thus the atoms of hydrogen, oxygen and uranium would appear approximately as shown here. Actually all three atoms are approximately equal in size.

electrons greatly exceeds the mean energy of lattice vibrations at normal temperatures. In fact, the energy of the free electrons is so much higher than the mean energy of thermal lattice-motion that an elevated temperature will shake the atomic lattice apart (that is, melt the metal) long before it begins to affect the motion of free electrons.

We encounter another degenerate gas in the interiors of small, faint stars—the so-called white dwarfs, which represent the late stages of stellar evolution. The matter within these stars is completely dissociated and compressed to unimaginable densities. All the atoms are stripped down to bare nuclei; all their electrons are torn from their customary orbits, forming a free-electron gas. This gas is quantized, and the electrons are distributed according to the Pauli principle among a gigantic number of quantum states. Since the electrons possess much higher energies than the average thermal energy inside these stars, the gas exerts a tremendous pressure which prevents them from collapsing [see "Dying Stars," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, January].

Exclusion and Antimatter

We find another extremely important application of the Pauli principle in the theory, propounded 29 years ago by P. A. M. Dirac of the University of Cambridge, that predicted the discovery of the positive electron, or positron. Dirac's relativistic quantum-mechanics postulates that each fundamental particle can exist in one of two different physical states: the "ordinary" state, in which we find both atomic and free electrons, and the "extraordinary" state, in which the particles have negative (less than zero) energy. From the theory of relativity we know that particles with negative energy also possess what is known as negative mass, *i.e.*, the property of being accelerated in a direction opposite to that of an acting force. Particles in the extraordinary state had never been observed, but the perfectly consistent arguments of Dirac's theory led to the inevitable conclusion that not only does the extraordinary or negative-energy state exist, but also that because of its lower energy it is more stable than the ordinary state. It follows that all particles in the universe tend to change their state from the ordinary to the extraordinary one—which would turn the physical properties of matter into an unbelievable mess!

Why doesn't this happen? Dirac's answer was just as fantastic as his paradoxical particles. He postulated that quantum levels representing the extraordinary states of elementary particles

ORIGINAL EXCLUSION PRINCIPLE permitted two electrons (*black*) to move around a nucleus (*gray*) in the same orbit. Electron's spin and magnetic moment had not been discovered.

MODIFIED EXCLUSION PRINCIPLE, necessitated by the discovery of electron's magnetic moment, states that the two electrons must spin in opposite directions and move in two separate orbits.

Western Electric Pioneers Major Break-Through in Computer Technology

IN-line computers, those that process a continuous flow of information and up-date their memory units, are ideally suited to handle business transactions. Their usage has been limited, however, by the high costs of preparing data for input and the human errors associated with its preparation and transmission.

For example, in an experimental centralized computer installation handling orders from telephone company employees for equipment and supplies, Western Electric engineers found that preparing input data cost over four times as much as all subsequent clerical operations. The reason for the cost was the large number of individual orders, instructions, reports and the like flowing in from hundreds of locations. Each had to be prepared, typed, edited and transmitted.

Computers operate from holes punched in cards or tape, or from signals recorded on magnetic tape. Although there are a number of transmission systems that make data available in one or another of these forms, the cost is prohibitive unless the lot quantity of data is very large. Nor do these systems eliminate the initial preparation and translation into machine language.

There was a clear need for a simple, easily-operated remote input device that would be low in cost and could eliminate the manual preparation of needed information. It had to be capable of directly feeding the computer, or of punching standard cards at the receiving end if the computer was being utilized on another project at the time of transmission.

How Western Electric Met The Need

Original hand-made model of new data input device. Engineering now in progress at Western Electric will reduce the size of the unit to about that of a breast-pocket wallet.

The engineers decided that the best way to cut the cost of preparing, typing and editing orders was to eliminate these operations. Why not provide the many ordering locations with a punched card for each item handled, transmit the information over standard telephone lines using card readers and reproduce the information at the computer? While the solution sounds simple, extensive engineering development was necessary. Entirely new principles and applications were necessary at both the transmitting (or ordering) end and the receiving end.

At the receiving end, operator can feed incoming data directly to the computer or into a standard card-punching machine simply by throwing a key.

Final result of Western Electric's engineering will be a small unit that plugs into a standard telephone outlet. Prior-punched cards will be inserted in this unit, and the data they contain converted to pulses that will be transmitted over telephone lines to a centrally-located computer. Additional data such as quantity, delivery dates and so on, will be added by using a simple keyboard. When all the pertinent data has been transmitted to the computer, it will then take over. Orders, inventory control forms, packing slips, even routing instructions for the shipments, will all be automatically prepared and elimination of multiple clerical operations accomplished.

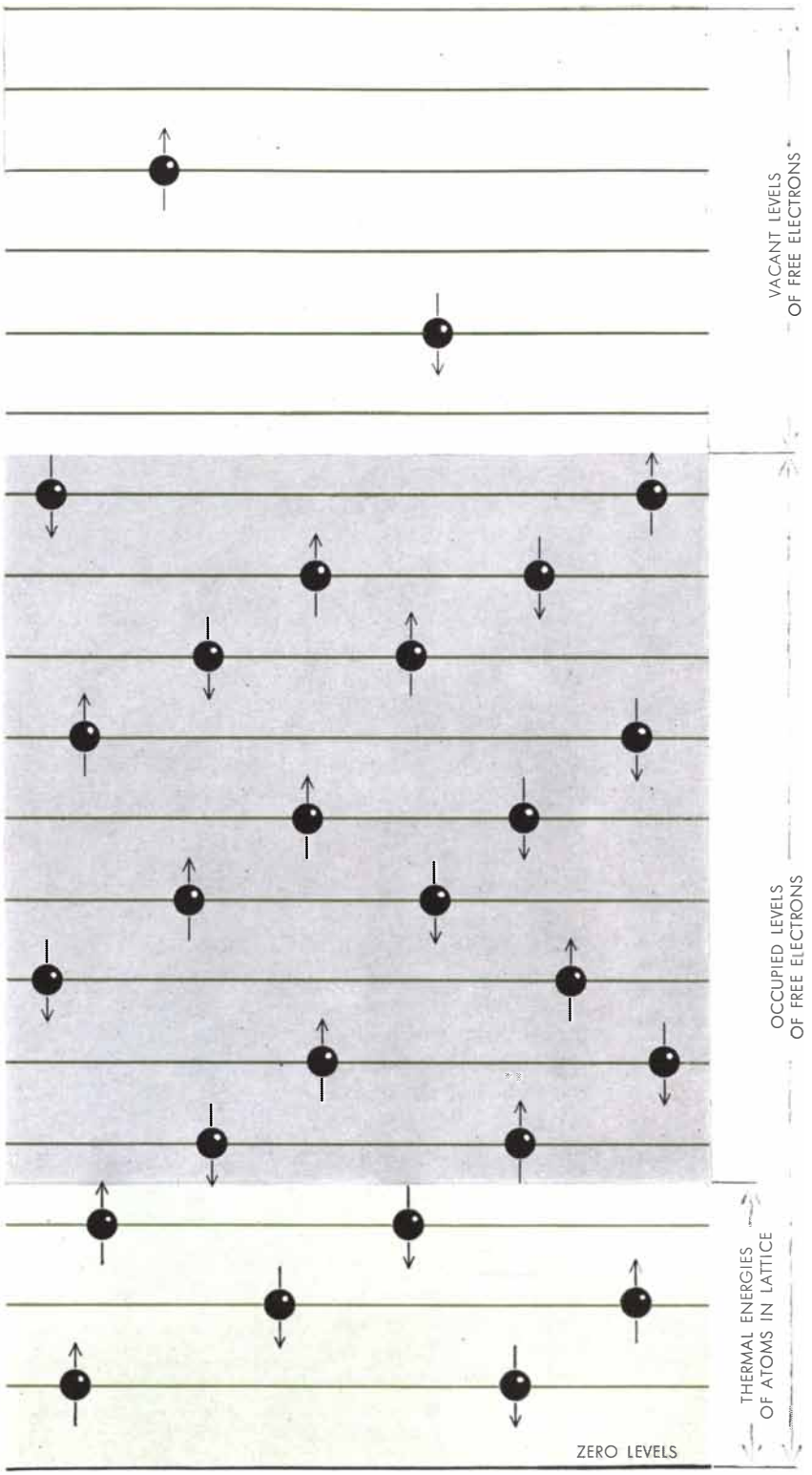
Significant Break-Through

Western Electric engineers are miniaturizing this multi-frequency oscillator, the transistorized electronic heart of the new remote data input system. It makes use of low voltages normally used in telephone lines and requires no outside power supply.

We expect this new development of Western Electric engineering to assist us in our assignments as manufacturing and supply unit of the Bell System. It will expedite order processing, eliminate much clerical work, simplify inventory control and aid in many ways to provide the equipment the Bell Telephone Companies need. Although Western Electric itself has no plans to market the remote input device, even the briefest reflection will indicate the implications of this latest break-through by Western Electric engineering—to National Defense and to business everywhere.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM



FREE ELECTRONS in a metal are forced by the exclusion principle to occupy a series of energy levels arranged like rungs on a ladder. Only two electrons of opposite spin (*arrows indicate spin orientation*) are permitted on each level. The energy levels of free electrons (*gray areas*) are much higher than the thermal vibration energies (*colored area*) of the atoms forming the metal's crystal lattice. When the metal is heated, thermal lattice vibration increases. Because of their higher energies, the motion of free electrons does not increase.

are already completely filled, and that the ordinary particles with which we deal in our everyday physical world are simply the excess that cannot be accommodated at the lower energy-levels because of the Pauli principle! According to this viewpoint, a vacuum is not really an empty space; on the contrary, it is a sea of tightly packed particles of negative mass. We are not aware of these extraordinary particles because they are distributed uniformly through space, putting us in somewhat the same position as a deep-sea fish which, though it is surrounded by water on all sides, may not be aware that it is floating in a physical medium. The ordinary particles that we can observe physically are those that are prevented by the Pauli principle from giving up their energy and falling into the negative energy-levels of the extraordinary state; ordinary particles must maintain their positive mass and all their familiar physical properties.

Unbelievable though Dirac's theory seemed (and it was strongly criticized by all theoretical physicists when it was first published), it led to one very important conclusion. If one of these extraordinary particles of negative mass is absent for some reason, it leaves a "hole" in the observable continuous distribution of particles. It is easy to see that we should be able to observe this hole, just as our fish is able to observe an air bubble (the absence of water in a small region) rising toward the surface of the ocean. What we perceive in the absence of negative mass is the presence of an equal amount of positive mass, just as we perceive the absence of charge in an electric field as the presence of an equal charge of opposite sign. In other words, a hole in the continuous distribution of extraordinary particles will seem to be an "antiparticle"—a particle of ordinary mass and opposite charge [see "Antimatter," by Geoffrey Burbidge and Fred Hoyle; SCIENTIFIC AMERICAN, April, 1958]. In fact, the discovery of positive electrons, the properties of which coincided exactly with the predicted properties of these holes, fully confirmed Dirac's conclusions a few years after he had published his paper.

The Quantized Nucleus

More recent developments in nuclear physics have extended the domain of the Pauli principle still further, this time into the nucleus itself. It has been found that protons and neutrons, the two main components of the nucleus, behave in many respects like the electrons that form the

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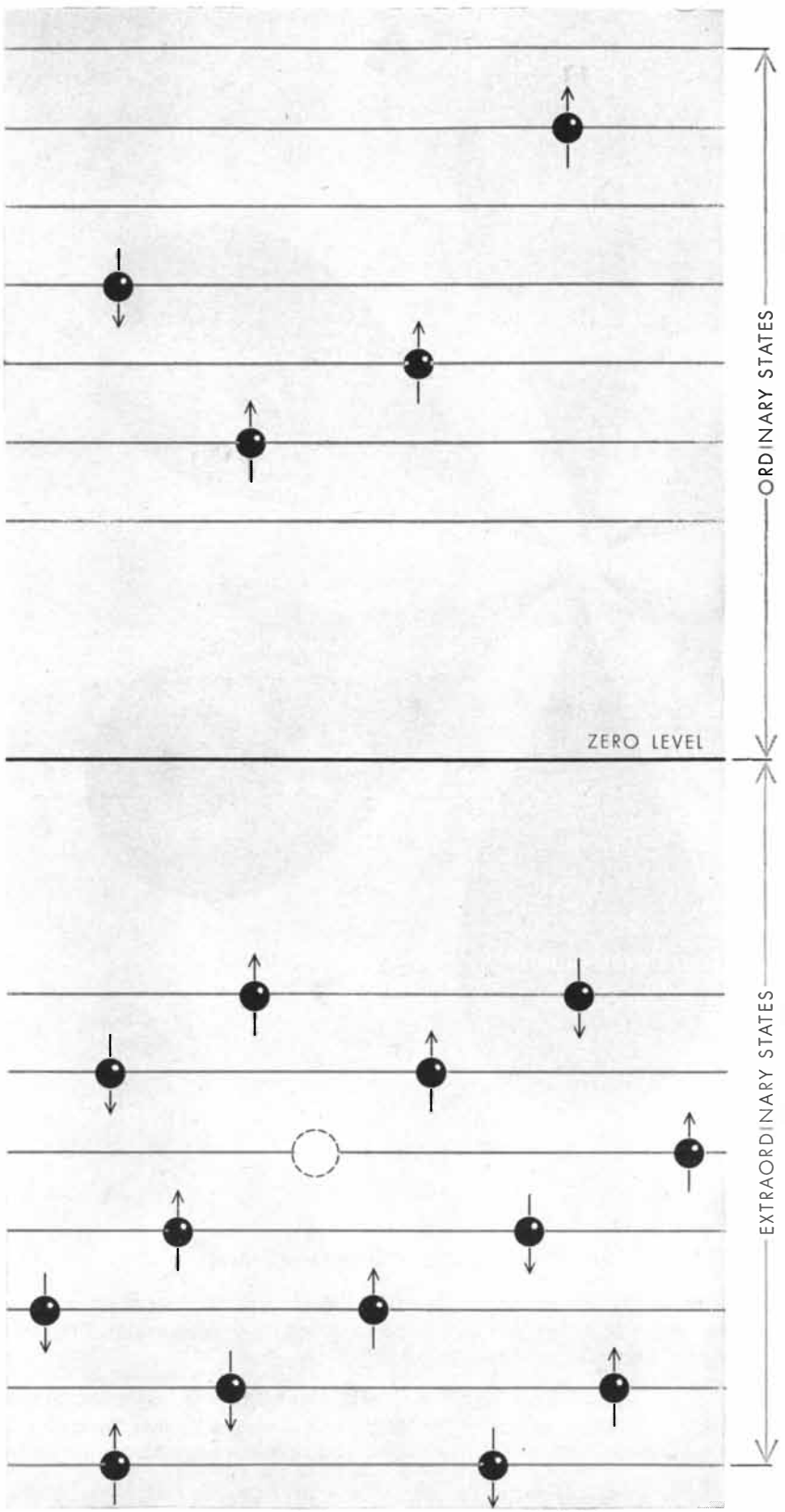


UNOBSERVABLE ELECTRONS, which have negative energy and negative mass, are distributed evenly throughout space. Observable "ordinary" electrons are those that the exclusion principle prevents from falling into the "extraordinary" negative-energy states. "Holes" (*open circle*) in the continuous distribution of extraordinary electrons can be detected as positrons, particles of antimatter having positive mass and positive charge.

outer shells of the atom. Like electrons, protons and neutrons possess magnetic moment and may be considered little spheres spinning in one direction or another; similarly the motion of particles within the nucleus is quantized so that only two particles of the same kind (with opposite spins) are permitted on each quantum orbit. But because the forces within the nucleus act rather differently from the electrical forces that hold the atom's electron shells in place, the pattern of nuclear energy-levels is also rather different.

It was first shown by observation and later explained by theory that consecutive shells inside the nucleus can accommodate 2, 8, 14, 20, 28, 50, 82 and 126 particles of either kind. These are the so-called magic numbers of the nucleus; they represent a complete analogy to the numbers of electrons that can be contained in the consecutive shells outside the nucleus. Just as atomic structure would be quite different if the Pauli principle did not apply to electrons, so nuclear structure would be quite different if the principle did not apply to protons and neutrons.

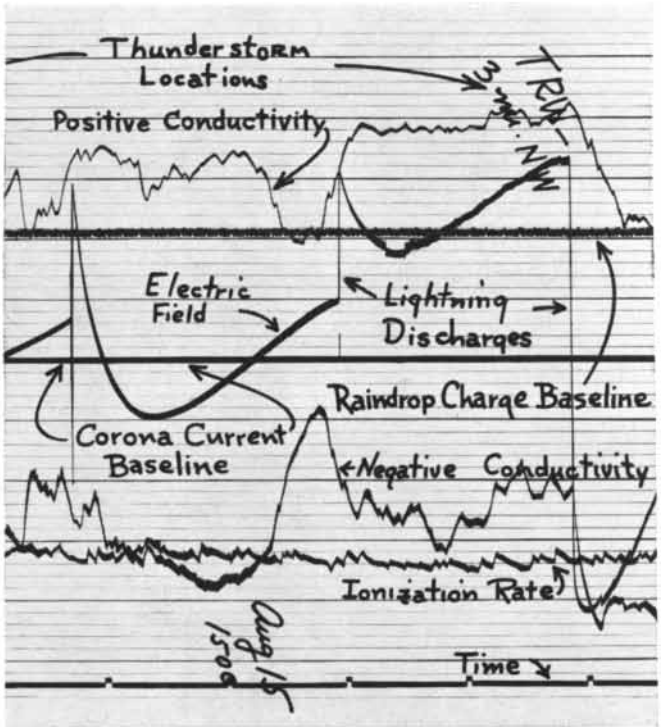
The discovery of positive electrons suggested that protons and neutrons might also occupy extraordinary states of negative energy. Physicists accordingly began to look for negatively charged protons (antiprotons) corresponding to holes in the continuous distribution of extraordinary positive protons of negative mass. And they instigated a search for the more elusive antineutrons, which represent holes in the continuum of extraordinary neutrons. They have found them both; particle-accelerator experiments in recent years have brilliantly confirmed Dirac's predictions of extraordinary energy-states governed by the Pauli principle.

Wave Mechanics

After a review of the application of the Pauli principle to atomic and nuclear structure, to metallic conduction and to stellar interiors, and finally to the theory of antiparticles, we might feel that we have at last grasped the principle's physical meaning. But we are mistaken. Full comprehension requires that we understand the principle in terms of modern quantum-theory. Up to this point our review has employed the old-fashioned metaphor that pictures electrons and protons as tiny, electrically charged spheres spinning on their axes and moving along circular or elliptical orbits. But we now know that this pic-

In research . . .

The analog record at upper right, made by a Model 906A Honeywell Visicorder oscillograph, gave U. S. Weather Bureau scientists immediate readout of thunderstorm data at Mt. Washburn in Yellowstone National Park. As the storm system passed, the Visicorder measured and recorded positive and negative air conductivity, rate of ionization of air, raindrop charge, corona discharge current from an insulated tree and a 4′x 6′ grass plot, times of camera exposure photographing droplet size and electrical charge, atmospheric potential gradient, and time. In any research field where high-speed variables are under study, the direct-recording Visicorder is providing instantly-readable, high-sensitivity data at frequencies from DC to 5000 cps. Models are available with 8, 14, or 36 channel capacities.



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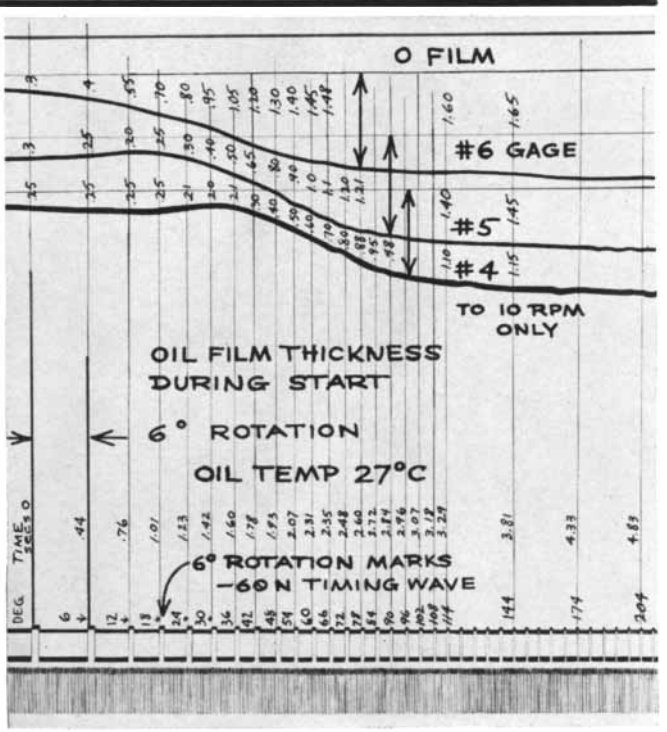

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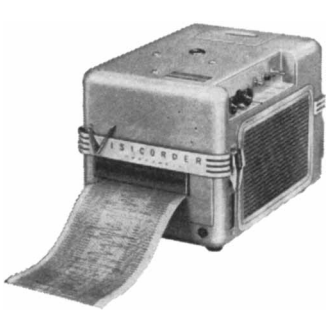

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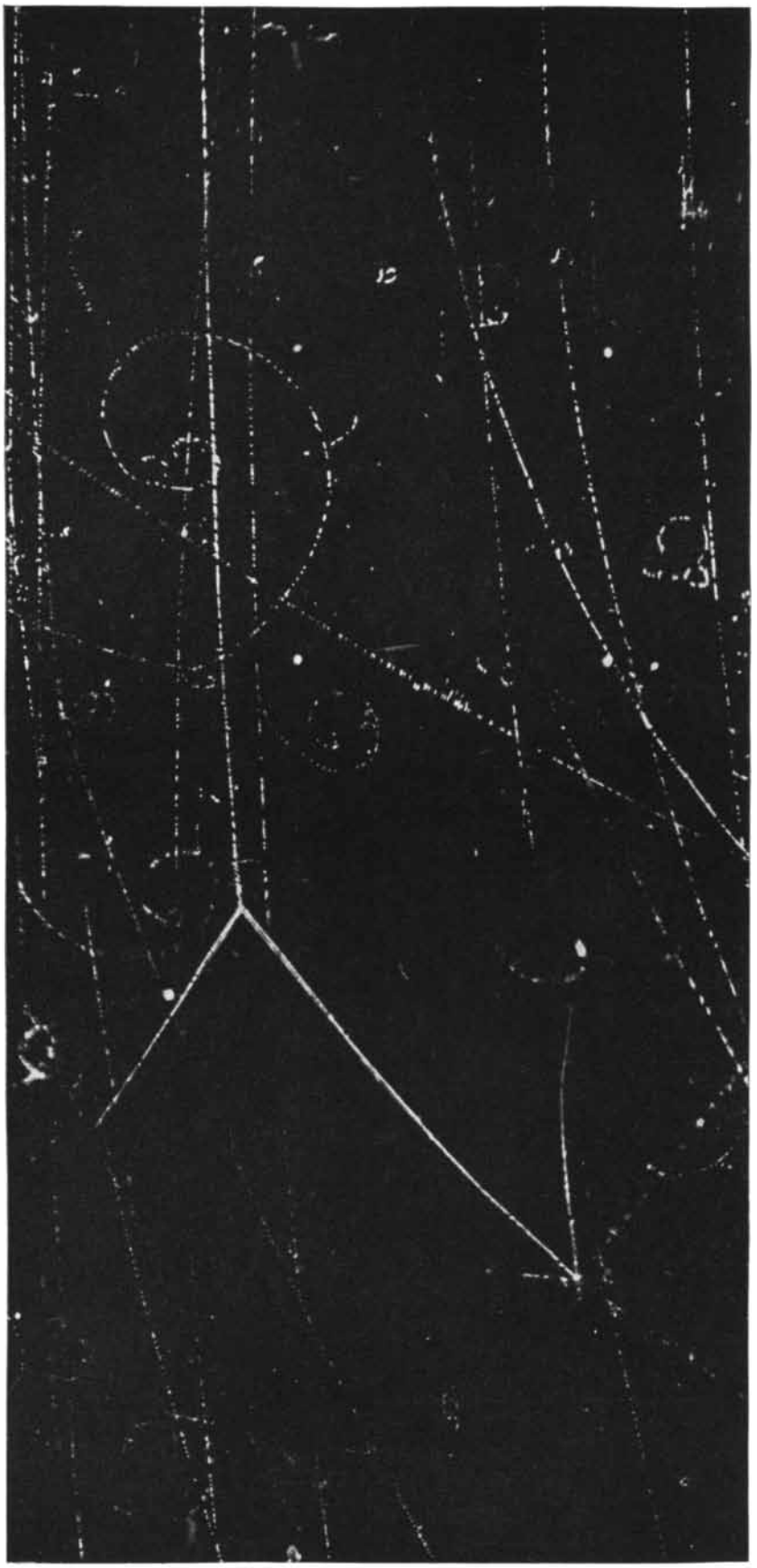
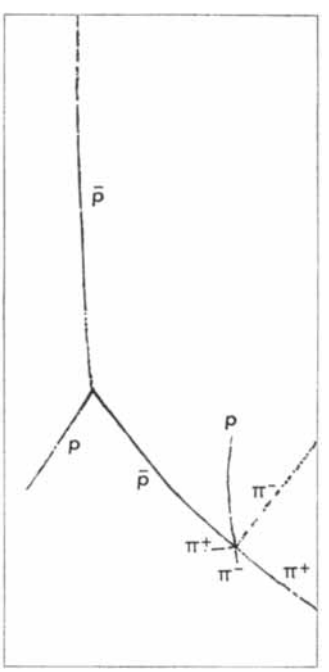


ture, which is based on our everyday experience with large bodies such as flying bullets and spinning tops, is naive and basically incorrect when it is applied to the atomic world. When we speak about atomic particles, we must abandon our mechanical cause-and-effect description of phenomena and use the cumbersome though exact language of wave mechanics.

In wave mechanics the different orbits in Bohr's hydrogen atom correspond to different probabilities of finding the electron at various locations within the atom. The "vibration modes" of these probability functions [*see illustration on page 86*] tell us all that can be told about the motion of atomic particles. In wave mechanics the old Bohr statement that "the electron moves along the first, second or third quantum orbit" is paraphrased to say that "the first, second or third vibration mode is excited within the atom." The jump of an electron from one quantum orbit to another is interpreted as the dying-out of one vibration mode and the simultaneous appearance of another. Thus the entire theory of electron motion within atoms takes on a physical meaning closer to the theory of organ pipes, violin strings or drumheads than to the theory of planetary motion



PARTICLE OF ANTIMATTER leaves its tracks in the bubble-chamber photograph at left, made by the research groups of Wilson Powell and Emilio Segrè at the University of California. The drawing at right traces the path of the particle in the photograph. A high-energy antiproton ($\bar{p}$) enters the chamber at upper left, and collides with a proton (p), which recoils toward the left side of the picture. The antiproton ricochets to the right and is annihilated in a carbon nucleus, producing four pi mesons (π) and a proton.

around the sun. In these terms the Pauli principle becomes equivalent to the statement that each particular vibration mode can either be excited or not, just as we can strike two different keys on a piano simultaneously but cannot strike the same key twice at the same time!

Pauli first stated his exclusion principle in terms of the mathematical "symmetry" of probability functions. A probability function is mathematically symmetrical if its variables (which, in the case of the electron, take account of both orbital motion and spin direction) can be interchanged without changing its sign (plus or minus). It can be easily shown that the exclusion principle is equivalent to the following statement: The probability function describing the motion of electrons within an atom is antisymmetrical with respect to any electron pair.

If we mathematically transpose the positions of two electrons moving along the same atomic orbit and spinning in the same direction, their probability function does not change in value. The Pauli principle, however, tells us that because their probability function is antisymmetrical, it must change sign as the result of such a transposition. But what function can change sign without changing in value? The only quantity that satisfies these conditions is zero. Plus zero equals minus zero; changing the sign of zero does not change the value of the function in any way. Thus it follows that the situation where two electrons with the same spin move along the same orbit has a probability function of zero. In other words, the situation is impossible. And this is exactly the way in which Pauli originally stated his exclusion principle in 1925.

Non-Pauli Particles

Like Dirac's antimatter theory, Pauli's exclusion principle was first postulated for electrons, then successfully applied to protons and neutrons. Since then physicists have raised the question of whether or not the exclusion principle applies only to elementary particles such as protons and electrons or whether it might also apply to whole nuclei or even to whole atoms. We can answer this question by theoretically applying the Pauli principle to two helium nuclei (alpha particles), which are composite particles composed of two protons and two neutrons. What happens to the probability function describing the motion of two alpha particles if we exchange their positions?

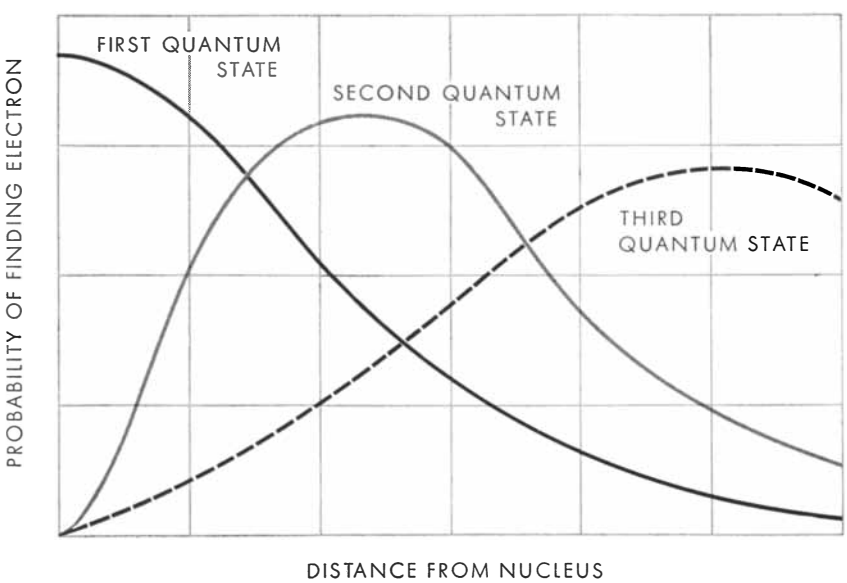
We can carry out such an exchange in

four mathematical steps. First we transpose one proton belonging to the first alpha particle with one of the protons belonging to the second. Then we transpose the other pair of protons and finally each of the two pairs of neutrons. Since protons and neutrons obey the Pauli principle, each transposition changes the sign of the probability function from plus to minus or from minus to plus, but at the end of four steps the function has the same sign as before. Thus we conclude that the probability function describing two alpha particles is symmetrical, or in other words that alpha particles considered as individual units are not subject to the Pauli principle.

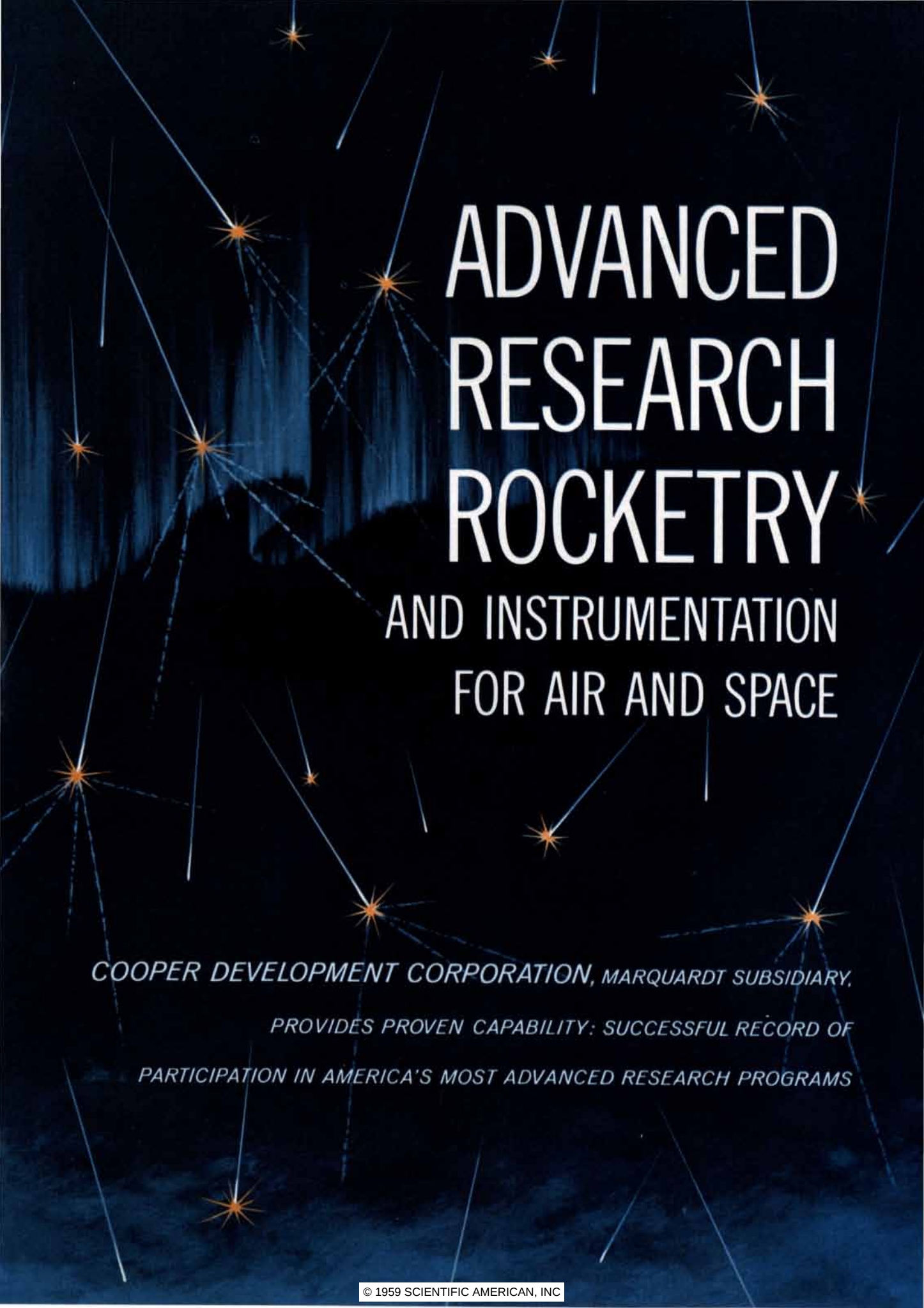
But not all composite particles are exempt from the Pauli principle. The transposition of two tritons (nuclei of hydrogen 3, or tritium, containing one proton and two neutrons) does result in a change of sign, so we must conclude that tritons are subject to the Pauli principle. Furthermore, we find that atoms such as those of oxygen (eight protons, eight neutrons and eight electrons), containing an even number of elementary particles, are not subject to the Pauli principle; and that atoms such as those of nitrogen (seven protons, seven neutrons and seven electrons), containing an odd number of particles, must obey it. This curious even-odd discrimination determines the statistical behavior of particles: The even-numbered or "non-Pauli" particles obey the laws of Bose-Einstein statistics and hence are called bosons; the odd-numbered or "Pauli" particles obey Fermi-Dirac statistics and are called fermions.

Until about two decades ago electrons, protons and neutrons were the only known elementary particles in nature. Later studies have revealed the existence of a large number of particles with a claim to elementarity. We now have three kinds of hyperons (unstable particles heavier than protons), three kinds of mesons (unstable particles with a mass somewhere between that of the proton and the electron) and neutrinos (with practically no mass at all). Although experimental studies of these new particles reveal new and exciting facts about them almost every month, theoretical progress in understanding their properties is almost at a standstill. We do not know why they have the masses they do; we do not know why they transform into another the way they do; we do not know anything! The one concept that stands like the Rock of Gibraltar in our sea of confusion is the Pauli principle, which separates the fermions (such as neutrinos and mu mesons) from the bosons (such as pi mesons and lambda particles).

Is the fact that some of these particles are "Pauli" and some "non-Pauli" connected with their internal structure, as it is in the case of alpha particles and tritons? Are some of these particles elementary, while others are not? We do not know. Let us hope that sometime soon the fog enveloping these questions will be dispersed by somebody's ingenious idea.



WAVE FUNCTIONS express the probability of finding an electron in a particular quantum state and at a given distance from the nucleus. These functions describe the energy and motion of the electron far more accurately than do the orbit concepts of classical theory.



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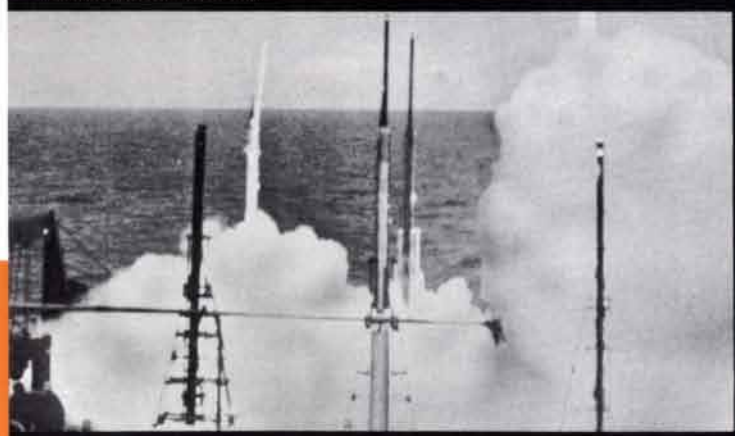

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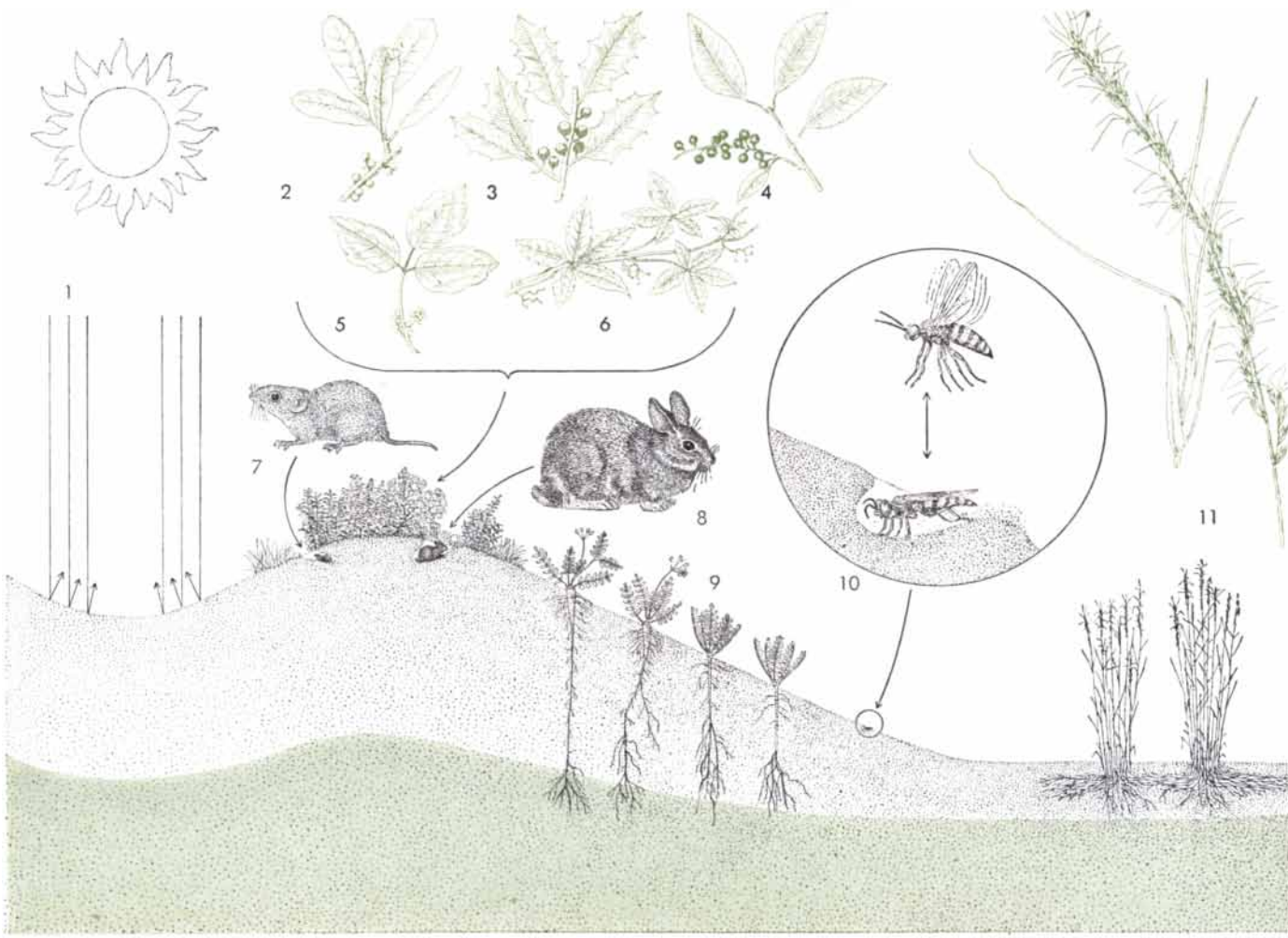
The Life of a Sand Dune

The region near the surface of these wind-driven hills can be an almost intolerably hot and arid environment, yet an entire community of plants and animals have become adapted to it

by William H. Amos

Few environments on earth are as hostile to life as a sand dune. The surface of a dune, heated by the midday sun, can reach a temperature of more than 150 degrees Fahrenheit. The same surface, baked by the sun and drained by the porosity of the sand, is almost perfectly arid. The very stuff of the surface is constantly shifted by the wind that both builds and destroys the dune. Yet wherever sand dunes occur, certain plants and animals take up residence and survive by remarkable evolutionary adaptations.

To people who live in the temperate zones the most familiar kind of dune is the foredune, a ridge of sand that rises behind an ocean beach. Sometimes a section of foredune will be blown inland, giving rise to the dramatic traveling dune. Such a dune can attain an im-



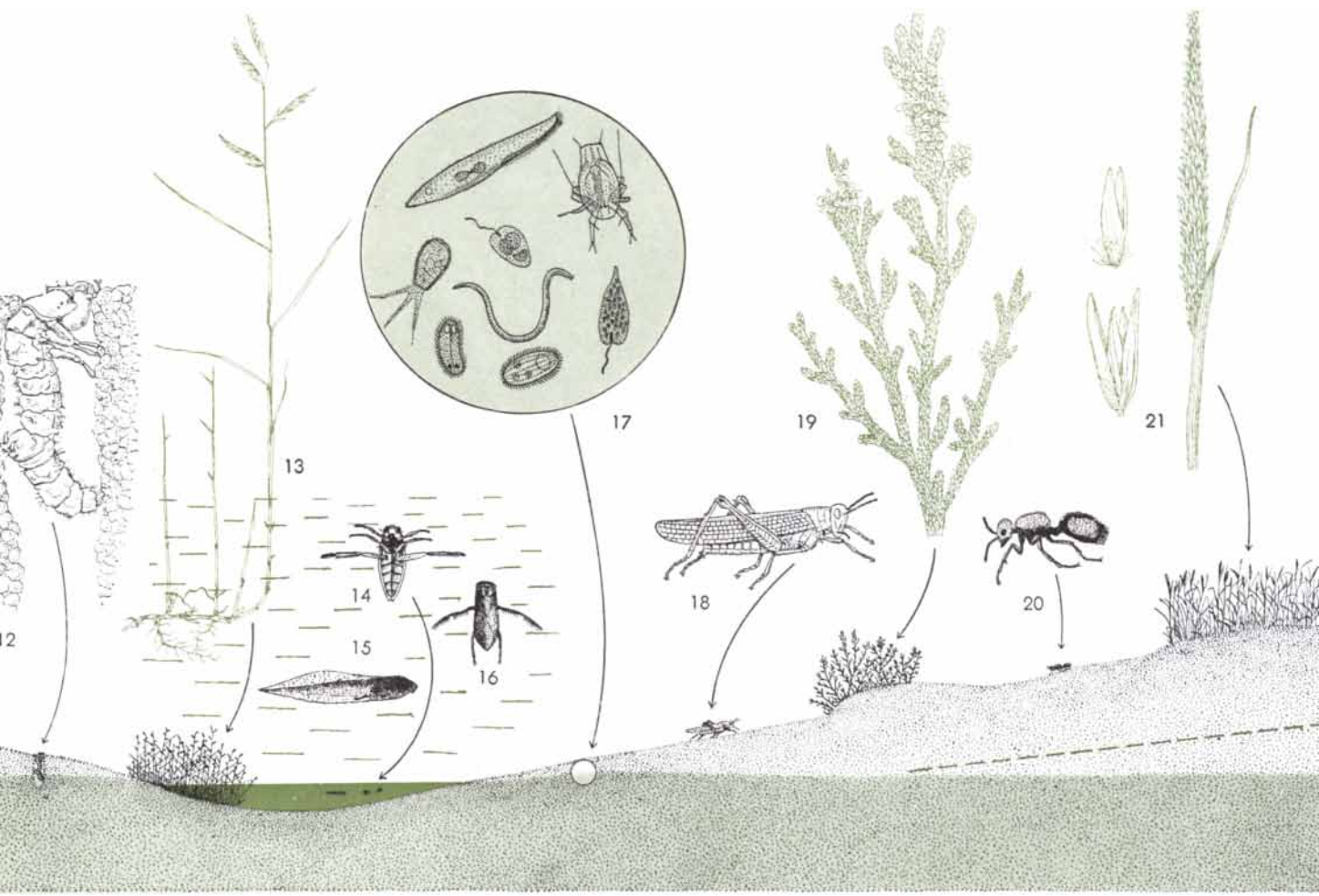
CROSS SECTION OF A DUNE is shown on this and the next three pages. The sand is hotter in a hollow because of the "condensing effect" (1). The bembecid wasp (10) repeatedly rises into the air to keep cool. Also shown are bayberry (2), American holly (3), wild black cherry (4), poison ivy (5), woodbine (6), meadow vole (7), cottontail rabbit (8), stork's-bill (9) and wire grass (11).

pressive rate of progress. The dunes of Cape Henlopen in southern Delaware once traveled 60 feet a year, overwhelming a historic lighthouse and its service buildings and then moving inland to inundate a forest. (The smaller buildings reappeared in a good state of preservation 50 years later.) It is on the life of the Cape Henlopen dunes that this article is largely based.

The fate of dunes and the fate of plants are inexorably drawn together. Certain plants (*e.g.*, marram grass, beach heather and sand cherry) flourish in sand. Once established on a dune, they are barriers to the wind; by slowing the wind and causing it to drop its freight of sand grains they hasten the growth of the dune. But as the dune grows the plants, if they are to survive, must grow with it. As a result certain shrubs often develop elongated stems. When the dune moves on, the plants left behind may have peculiar topknots of foliage, if they can stand erect. More often their stems, no longer supported by the sand, simply topple over.

As a dune travels, it overwhelms the plants in its path. If a tree can keep enough of its foliage above the sand, it will survive. What appears to be a small pitch pine on the crest of a dune may actually be the upper branches of a 30-foot tree. Even if their growth is accelerated, however, most trees cannot keep pace with the rising sand; they are inundated and die. Years later their bare, gaunt forms reappear on the windward side of the dune. Meanwhile the buried trees may have provided a curious oasis for large numbers of minute organisms. When such trees have been located and excavated in the dunes of Cape Henlopen, they have been found to be thoroughly saturated with water. In the dead, wet tissues of the wood dwell roundworms, protozoa and bacteria. Usually a few larvae of woodboring beetles, and sometimes colonies of termites, can be found deep in the buried tree. Occasionally the wood feeds the mycelium of a fungus, and mushrooms erupt on the dune.

The plants of the dunes are marvelously adapted to their rigorous environment. Marram grass and other sand grasses appear to be modest surface dwellers, but their roots reach down several feet for water. Other plants with extensive water-seeking root systems are poison ivy, grape, stork's-bill and woodbine. Many successful dune plants, both annual and perennial, have a long taproot; some species (*e.g.*, wild lupine) which do not have a taproot in good soils will grow one when they settle on a dune. Usually these roots are not very sturdy; they descend like a string for 10 or 15 feet until they encounter a supply of water, and then they branch profusely. Because water is so scarce on the



SECTION CONTINUED on these two pages contains a pool (*dark color*) where the level of the ground water (*light color*) is above the sand surface. The life near and in the water includes cord grass (13), back swimmer (14), the tadpole of Fowler's toad (15), water boatman (16). In pool or sand water are microscopic forms such as roundworms, copepods, protozoa and bacteria (17, 22).

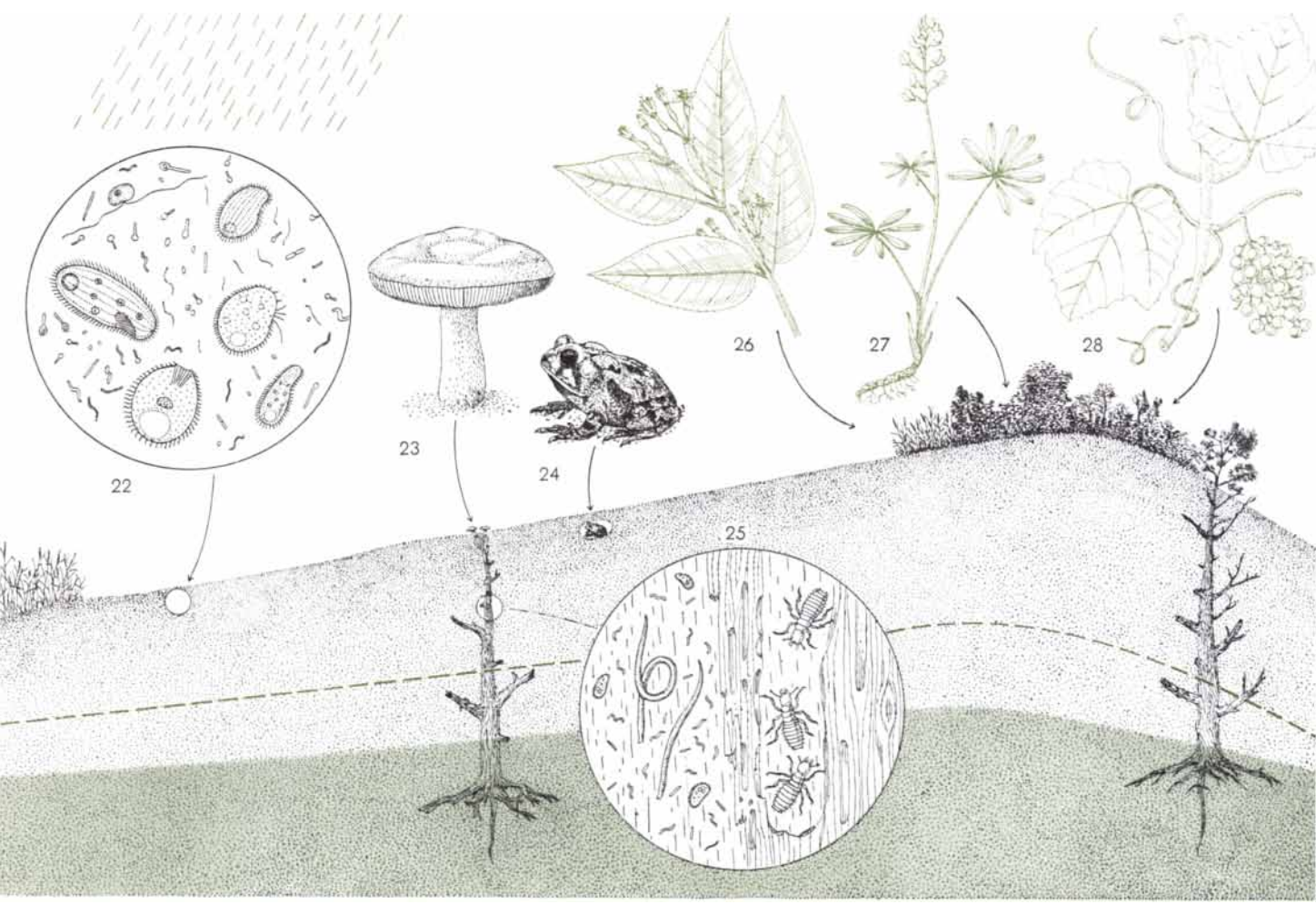
dunes, such plants are seldom crowded: competition for water would jeopardize the survival of their species.

Plants that spread their foliage close to the dune surface usually have specialized leaves that minimize the effects of intense light and heat, either direct or reflected and radiated from the sand. Even when they are not related, such plants may have similar leaf structures because they share the common hazard of losing water by the evaporative process of transpiration. Dusty miller exemplifies those plants that have leaves densely covered with matted white fibers, which provide an effective insulation against light and heat. In other dune plants the waxy cuticle that covers a leaf is thickened. The leaves of beach heather are heavy and scalelike; those of western burroweed have relatively few stomate pores, thus reducing transpiration. In the common wire grass found in most sandy regions the exposure of surface area is lessened by thick, heavy leaves with tightly folded blades. Some dune plants moderate the effects of heat and light with leaves that are held vertically rather than horizontally. Such leaves have symmetrical internal structures, so that both of their sides have the same capacity for photosynthesis.

There are plants such as the western white primrose that lose most of their leaves during a drought and grow new ones when the drought is over. Some plants have lost their leaves permanently. Of these leafless succulent plants one of the best known is the prickly-pear cactus, found throughout the coastal and southern regions of the U. S. This species has the remarkable ability to grow at a temperature as high as 136 degrees F.

Many dune plants are adapted to their environment not only by their anatomy and physiology but also by their life cycles. Dramatic examples of such adaptation are provided by desert plants, the environment of which closely resembles that of dune plants. Seeds alone demonstrate the resistance of desert plants to heat and drought. E. B. Kurtz, Jr., of the University of Arizona found that seeds of the saguaro cactus, a plant common to the deserts of the U. S. Southwest, would still germinate after they had been subjected for seven days to a temperature of 181 degrees F. The seeds of many plants in deserts throughout the world germinate in winter and early spring when there is a sufficiency of water followed immediately by temperature conditions that favor growth. If seedlings are to survive, they must take advantage of these intervals and produce both roots that quickly arrive at a permanently moist stratum and hardy foliage that resists heat and light long enough to permit the plant to bloom and go to seed.

There are times in late winter and



Wet wood of buried trees may also support the growth of mushrooms (23) and termites (25). Other animals of the dune are tiger beetle larva (12), grasshopper (18), Fowler's toad (24) and velvet ant (20). Plants include beach heather (19) and marram grass (21) on the windward slope; honeysuckle (26), wild lupine (27), grape (28), and the unburied tops of trees on the crest.

early spring when both deserts and dunes suddenly erupt with blossoms and foliage. In our western deserts, plants respond to an almost infinitesimal amount of rain, either by the germination of seed or the resuscitation of dying plants. Lloyd Tevis, Jr., of the California Institute of Technology recently reported that minimum conditions of rain and precipitation dramatically revived sand verbena, white primrose and desert gold. In the dunes of the eastern U. S. the common beach heather *Hudsonia* may seem to become entirely brittle and dry, yet will be restored to a brilliant green by a brief shower.

When we consider the distribution of plant species over an entire dune area, we see that the plant communities are divided into more or less distinct zones. In one zone there will be only a few grasses; in another there will be thicker cover vegetation; in another, trees will predominate. This zonation, as the ecologist terms it, can be understood as a sequence of events at a particular spot. First the raw, new dune is invaded by sand-loving grasses. Later, as the dune is stabilized by plants, it passes through various stages of cover vegetation. Finally a permanent "climax" community develops on the sand, which now can no longer be called a dune.

Dunes are also characterized by another kind of zonation. This is evident in the distribution and growth of both plants and animals, and is due chiefly to the vertical stratification of temperature. At noon on a summer day the temperature stratification, from top to bottom, is roughly as follows: warm air, hot air, exceedingly hot surface, hot sand, warm sand, cool sand. The highest surface temperature on the dunes of Cape Henlopen is about 125 degrees F.; in French Equatorial Africa a surface temperature of 183 degrees has been recorded. Naturally the temperature varies considerably with the season, the time of day, the wind, the humidity, the clarity of the atmosphere, the color of the sand and the configuration of the dune. A hollow in the sand, for example, will concentrate the sun's rays, and considerably raise the temperature. It is not simply due to the absence of wind that a hollow in a dune feels hot.

Each of the stratified temperature zones can be a favored environment for a specific animal, at least during part of the animal's life. The animal population of the dunes is almost entirely limited to joint-footed arthropods such as insects, and vertebrates such as mice. Notably absent are animals with moist skins, such as worms and amphibians. The dune vertebrates generally come out of their burrows only at night, so it is the insects that are most evident by day.

Only a few of the insects dwell directly on the hot surface. Of these the

LAST SECTION is the advancing front of the dune. A pitch pine (29) lies in the path; another is already partly buried. In this region, which is quite sandy, grow prickly-pear cactus (30), earth stars (31), post oak (32), goldenrod (33) and honeysuckle (34). Here the sand water again contains roundworms and protozoa (35). Nighthawks, owls, mice, rabbits and opossum also live in this region.

most conspicuous is the so-called velvet ant, which is actually a species of wasp in which the females are wingless. Velvet ants are covered with dense, colored hair which protects them against light and heat. They can be found coursing about the sand on extremely hot days, but as the surface temperature approaches 120 degrees they seek shelter in the shade of plants. This horizontal migration to a tolerable microclimate is also used by a number of other dune animals.

Certain beetles seek a comfortable environment by vertical migration, moving up and down the stems of plants as the heat increases and decreases. A sand-dwelling grasshopper can solve the heat problem temporarily by extending its long legs, thus raising its body into a perceptibly cooler stratum of air. From time to time it flies a few feet, and is further cooled while it is aloft. Predatory tiger beetles, bee flies and robber flies alight briefly on the hot sand; they are cooled as they range about above the dunes in search of food.

Of all the insects that spend part of their lives on the surface and rise into the air to cool off, none is more easily observed (or has been more thoroughly studied) than the bembecid, or digger wasp. The problem of the bembecid is this: Because it hunts other insects by sight, it must dig its small burrow and provision it during the hottest hours of the day. But the bembecid is not insulated with hair like the velvet ant; it is quite susceptible to overheating. If a bembecid is experimentally restrained at the hot surface, it will rapidly succumb to heat stupor. Accordingly it solves the heat problem by behavior.

A bembecid will hover in the air, descend almost vertically to the site of its burrow and dig like a terrier with its curved front feet. It does so only for a moment, leaving a small depression and an apron of sand. It now rises a foot or more in the air, where the temperature is at least 10 degrees lower. It hovers briefly, then drops down to resume its excavation. This happens repeatedly, until the hole is deep enough for the wasp to enter. When the burrow extends below the high-temperature zone of the surface, the bembecid remains in the relative coolness of the burrow to complete its digging and lay its eggs. Some burrows collapse before they are finished and must be redug or abandoned; when they are successfully made they extend several inches into the side of the

ADVANCING FRONT OF DUNE on Cape Henlopen in southern Delaware has covered all but the tops of these trees. If enough foliage remains above the sand, a tree can survive.

BACK OF THE DUNE on Cape Henlopen the dead remains of trees reappear as the sand which covered them moves on. This dune at one time traveled at the rate of 60 feet a year.

TRACK OF A SNAKE found in the early morning is evidence of the night-life on the sand. Many dune animals, particularly vertebrates, are only active during nocturnal hours.

dune and retain their shape in spite of the looseness of the sand.

Many insects spend a part of their lives not on the surface but immediately below it. The voracious larva of the tiger beetle dwells in a vertical burrow and seizes insects that blunder across the entrance. Another larva that lives in the subsurface zone is the ant lion, which faces away from the sun at the bottom of a conical pit. When an insect tumbles into the pit, the larva backs deeper into the sand and tosses up a shower of sand grains with its head. The sand falls about the rim of the pit and cascades down, carrying the scrambling insect with it. The prey is seized with large, sickle-shaped jaws, dragged beneath the surface, paralyzed by means of a fluid that also liquefies the inner tissues, and is sucked dry. Despite the formidable behavior of its larva, the adult form of the ant lion is a weak, graceful insect. After it has developed and emerged from its pit, it survives only long enough to mate and (in the case of the female) deposit its eggs in the loose sand under a shrub.

If the dry surface sand of a dune is examined under the microscope, there are a few indications of life; but when the sand is saturated with rain, even for a brief period, a bustling population of tiny organisms appears and pursues a short, vigorous existence. One-celled protozoans, some of them resembling the familiar Paramecium, emerge from an encysted state. They feed upon bacteria that have been similarly activated from resistant spores. Round worms may also hatch from eggs. The ability to remain dormant is well developed in these small creatures of the dune surface; water may be absent for extended periods, but when it is present they emerge, feed, grow and reproduce—veritable Rip van Winkles of the dune world.

The specializations of dune animals vary in detail, but all are directed toward enabling the animal to resist heat and desiccation. Consider desiccation alone: If the water content of an animal is to remain constant, the water gain must equal the water loss—a delicate balance not easy to maintain in the arid environment of the dunes. Fortunately animals have the capacity to obtain water not only by drinking but also by oxidizing foodstuff. In the insects and rodents that feed upon the grasses of the dunes this capacity is developed to a high degree; they obtain some moisture from the grasses but fill a substantial fraction of their water need by metabolic

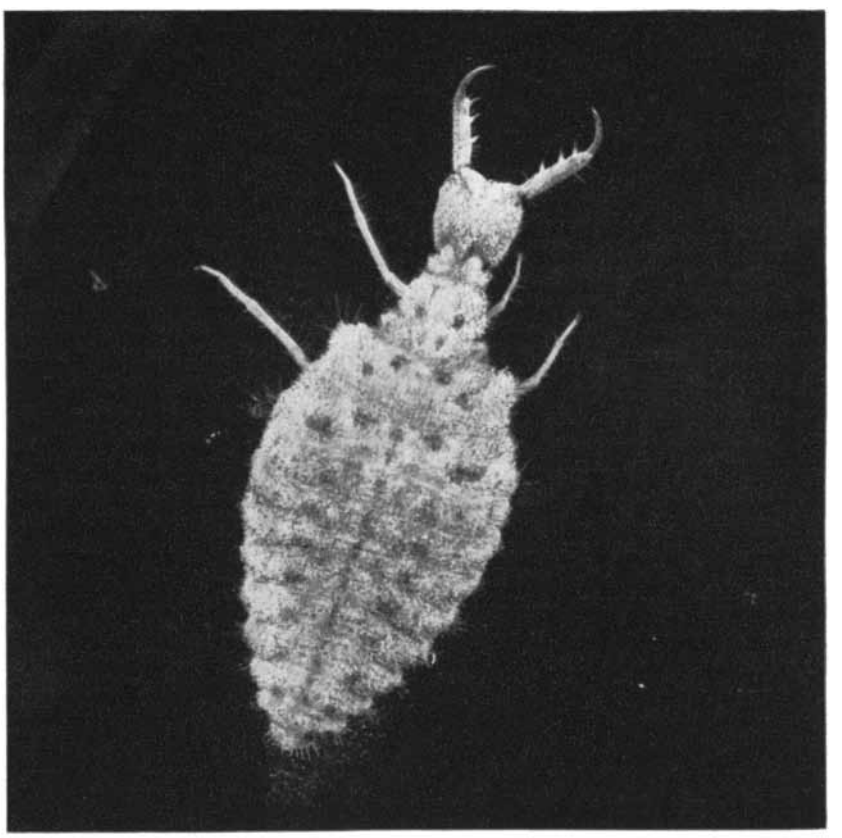
processes. Some rodents of the desert, such as the kangaroo rat and the pocket mouse, eat seeds that have no appreciable moisture content, and obtain virtually all of their water from their metabolism [see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; SCIENTIFIC AMERICAN, July, 1953].

Most dune animals are obliged not only to conserve or manufacture water but also to lose it by evaporation in order to cool themselves. In this way a dune insect can actually reduce its temperature below that of the surrounding air. It achieves this remarkable result by energetic ventilation of its tracheal breathing system. An increase in the temperature of the air can paradoxically decrease the relative temperature of the insect, because the insect's metabolism will be accelerated by the temperature increase. But the two factors—heat and evaporation—eventually work against each other; if the insect evaporates too much water, and cannot replenish its supply, its activity decreases until it falls into heat stupor and dies.

Many animals of the dunes are light in color, a phenomenon which has given rise to certain speculations. Light coloration is due to the lack of melanin, the dark pigment found in most animals. Melanin is formed in the presence of oxygen by an enzyme acting upon a colorless substance, the chromogen; its synthesis is enhanced at relatively low temperatures and suppressed in hot environments. This phenomenon has been demonstrated in the wasp *Habrobracon* and the bug *Perillus*; it is a matter of significance to the dune ecologist, although neither insect is a resident of dunes. There are a number of other factors that influence such coloration: A moist environment, for example, causes certain butterflies and grasshoppers to become darker, and an arid environment has the opposite effect. So some light-colored insects seem to be affected by the environment, while others remain pale for generations regardless of external conditions, resembling in this respect the colorless animals of caves. Coloration in insects and higher animals is not a simple affair; it may not only be dependent on external and internal factors, but also involves pigments other than melanin. The fact remains that the significant conditions of the dune environment—heat and aridity—produce pale insects in the laboratory, and may have the same effect on other animals.

Light colors that blend with sand are seen in a great many (but not all) grass-

LARVA OF THE TIGER BEETLE waits in the bottom of its vertical burrow (*seen here in a cutaway view*) to seize and eat any insects that blunder across the mouth of its lair.



ANT LION, another insect-eating larva that lives in the subsurface zone, seizes its prey with its large sickle-shaped jaws. The adult of this larva is a weak, short-lived insect.

hoppers, tiger beetles, spiders, reptiles, birds and mammals in dunes and deserts the world over. This characteristic presumably favors the survival of the animals by making them hard to see in daylight. It is an odd fact that light colors are also found in many nocturnal dune animals, which would not seem to need this protective device. It may be that the production of melanin in these animals that do not emerge in daylight is affected by the conduction of heat from the surface of the sand. (Aridity should not have an important role, since burrows that descend even a few inches are comparatively humid.)

On the other hand, light coloration may protect the nocturnal animal more than we think. In moonlight, or even on moonless nights, predators might be able to see a dark-colored animal against the sand more clearly than they could perceive a light-colored one. There is another possibility, though it is probably rather remote. Cold-blooded animals that are light in color do not absorb heat from the sand as readily as do similar animals that are dark. It is known that rattlesnakes can locate their prey with sensory organs that are extraordinarily sensitive to heat radiation. Could other predators hunt in the same way? It is probable that there is no single explanation for the pale coloration of animals in dunes and deserts; rather, a number of unrelated influences seem to lead to the same result.

The burrows of the animals that emerge at night or during the twilight hours usually extend deep below the surface of the dune. Most of the burrows are inhabited by the animals that excavated them, but some have been taken over by new occupants not capable of extensive digging. During the day the dune mice remain in their cool, humid tunnels; large predatory spiders rest quietly at the bottom of burrows that go down two feet or more; ants cluster and work in their galleries.

Although the dune ants may emerge only for brief periods at twilight, they are among the most successful residents of dunes. This success is due to the ease with which they excavate tunnels deep in the sand (some ants have special sand-carrying structures on their heads) and to the fact that they limit their activities to times when the surface temperature is moderate. The twilight activity of the dune is perhaps greater than either the nocturnal or the diurnal. Early in the morning the sand is etched with the tracks and trails, the signs of pursuit and capture, left by animals abroad in the gray hours before dawn. It is only from this record, soon to be erased by the wind, that one can gain full realization of the intense animal activity of the dunes.

What is it that induces nocturnal and crepuscular animals to migrate up and down at the appropriate time? One species of carabid beetle is as abundant on the surface of the dunes at night as the bembecid wasp is during the day. Other beetles, not necessarily residents of dunes, have been observed to remain head-up in the soil until twilight, at which time they emerge and fly away. In a recent issue of the journal *Ecology* George G. Gyrisco and W. G. Evans of Cornell University report their observations of how light triggers the twilight emergence of the European chafer, a member of the beetle family. It is a certain intensity of light that stimulates the chafer—an intensity characteristic of the twilight hours. Such environmental stimuli may also account for the vertical migration of dune animals. Many animals, however, are known to have inborn rhythms of behavior, and these "biological clocks" may provide an alternative explanation.

There is one dune population that never comes to the surface—the so-called sand-water organisms. That sand-water is an environment in itself was recognized some years ago by Robert W. Pennak of the University of Colorado and the late C. B. Wilson of the Massachusetts State Normal School, who found a considerable assortment of tiny organisms in the saturated upper levels of beaches adjacent to both salt and fresh water. Some species of this fauna appeared to be migrants from open waters, but others were adapted and restricted to wet sands. Investigations at Cape Henlopen and elsewhere indicate that the sand-water fauna is even more abundant than heretofore believed.

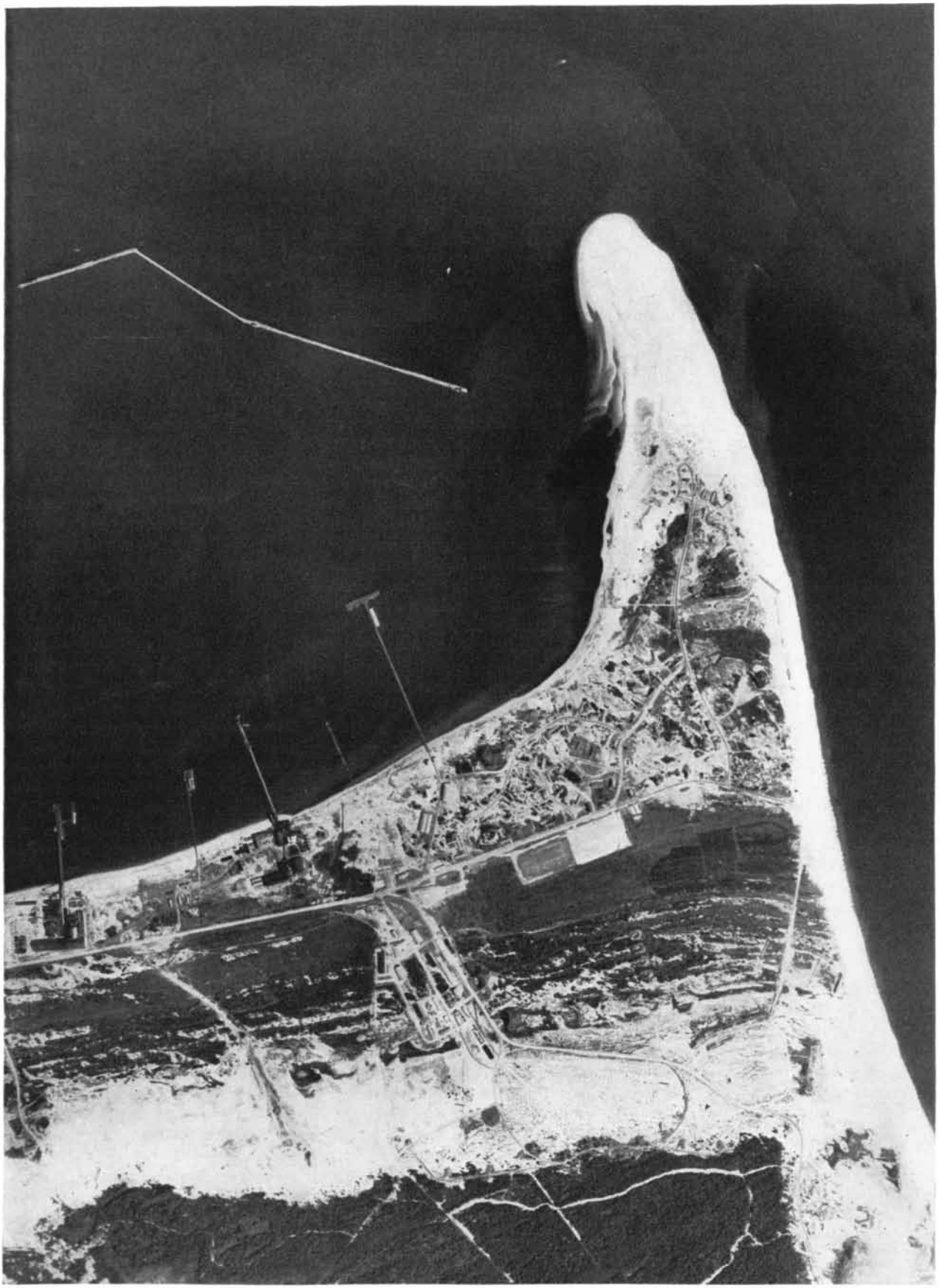
One of the most curious animals found in the sand-water environment is an elongated crustacean, related to the planktonic shrimp found swimming in surface waters all over the world. Such relatively large sand-water animals are most abundant in sand near visible surface water. But whenever we have sent cores into the Cape Henlopen dunes and collected water we have found an abundant smaller fauna: roundworms, ciliated protozoa, bacteria. And among them are occasional representatives of larger organisms such as rotifers, gastrotrichs, tartigrades and insect larvae.

The extent of the sand-water environment may even now be underestimated; though the surface of a dune is arid, its interior can contain large quantities of water. Because sand is porous, water circulates freely through it and does not stagnate. This movement can be due to surface evaporation, which causes a slow upward capillary flow; to rainfall, which causes a more rapid downward flow; or to the slope of the water table, which causes a lateral flow. Under a dune the water table bulges upward; it is this copious reservoir that supplies water to the deeper plant roots and constitutes the principal habitat of the sand-water organisms.

Despite their abundance, the sand-water animals probably play only a small role in the biological economy of a dune. This is because they are isolated from predators that dwell in the intermediate or surface levels. The surface layers of a dune are above all a world of predation. In most other environments the pyramid of life is based upon great numbers of plants, which are eaten by herbivores, which in turn are eaten by relatively few carnivores. In the dunes plant life is relatively scarce, so the carnivores must prey largely on one another.

The bembecid wasp is a case in point. Bembecids prey upon weak or weakened insects, but the bembecids themselves are prey. In her rapid, gyrating travels across the surface of the dune, the female velvet ant descends into the burrows containing bembecid larvae and lays her eggs. When the eggs hatch, the velvet-ant larvae feed upon the immature bembecids. Certain bee flies parasitize velvet ants, and robber flies have been observed to capture bee flies. When they are dead, any of these insects may be taken off by bembecids. Thus the bembecids, though they are predators themselves, provide the basis for the existence of a variety of predators. Of course such a pyramid must ultimately rest upon herbivores and plants, but in the dunes the pyramid has a narrow base, and the animal population is sharply limited.

The harsh environment of a dune is a transitory thing. The dune must drift on, and when it is finally anchored by vegetation it gradually fades into gray, humus-laden sand. It exists through successive populations of animals and covering grasses, shrubs, pines and climax hardwoods until only its vague contour is left. But elsewhere other dunes arise and creep across the land. Changing and changeless, the dunes provide an environment in which the almost infinite adaptability of living organisms is dramatically demonstrated.



CAPE HENLOPEN is backed by a great sand dune (*light strip in the lower part of this aerial photograph*). The moving sand has started to cover a forest (*at the bottom of the photograph*), and vegetation has grown up in the region left behind (*dark strip above dune*). The body of water to the left of the promontory is Delaware Bay; to the right is the Atlantic Ocean.

THE CITY OF MIDAS

Gordion, where Alexander cut the Gordian knot, dominated Asia Minor in the eighth century B.C. Recent excavations indicate that it was a link between preclassical Greece and the East

by Machteld J. Mellink

Then [Alexander the Great] conquered the Phrygians, at whose chief city, Gordion, which is said to be the seat of the ancient Midas, he saw the famous chariot fastened with cords made of the rind of the cornel tree, which whosoever should untie, the inhabitants had a tradition, that for him was reserved the empire of the world. Most authors tell the story that Alexander, finding himself unable to untie the knot, the ends of which were secretly twisted round and folded up within it, cut it asunder with his sword.

In the winter of 334-333 B.C., when Plutarch's chronicle takes Alexander to the Phrygians' already ancient capital, Gordion must have seemed no more than a second-rate provincial town in a hilly corner of the Persian Empire. Yet legend had preserved the memory of Gordion's wealthy and powerful past. Indeed, the Phrygian city's ancient monarchs—its founder Gordios, with his fateful knot, and his successor Midas, with his golden touch and asses' ears—still hold sway in the immortal world of folklore. But Midas, at least, is no mere fairy-tale figure. Greek historical literature gives ample testimony of his flesh-and-blood existence. And within the next few years we may expect a considerable increase in knowledge of the Phrygians and their ruling dynasty, for the capital city and the tombs of its kings are yielding their secrets to the picks and spades of archaeologists. Since 1950 the University Museum of the University of Pennsylvania, by arrangement with the government of Turkey, has been conducting a series of yearly campaigns at the site of ancient Gordion.

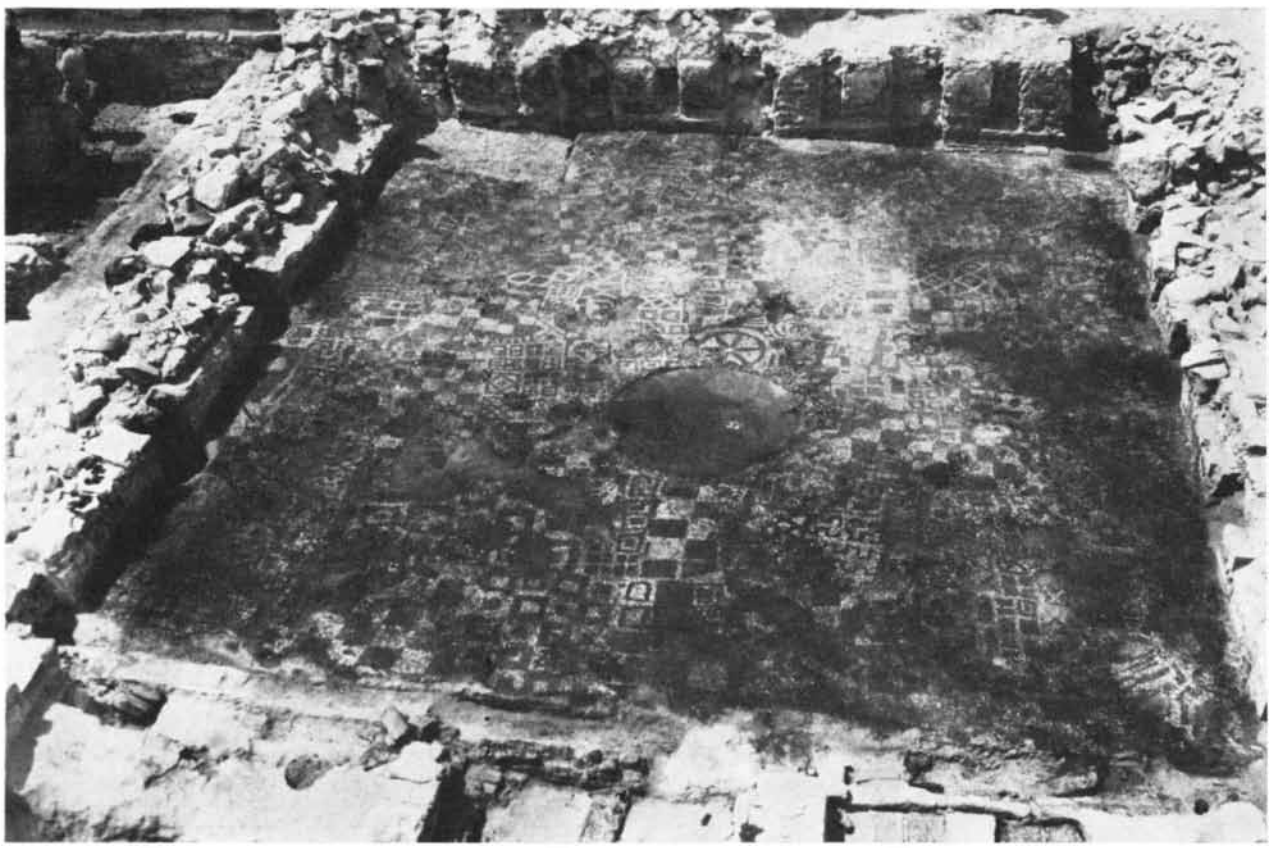
It is generally assumed that the Phrygians were an Indo-European people, fairly closely related to the Greeks in language and culture, who entered western Asia from the Balkans at the end of the second millennium B.C. They succeeded the Hittites as the dominant power in Anatolia (the classical name for the area that comprises the modern state of Turkey). The Phrygians built their cities in the heart of Anatolia's lofty central plateau, a region rich in wool and minerals. From their strategic eminence the Phrygians attempted to expand their influence to the Aegean coast to the west and threatened the Mesopotamian basin to the east. According to the Greek historian Herodotus, King Midas of Phrygia was the first "barbarian" (*i.e.*, foreign) monarch to recognize the Greeks' Delphic oracle. Herodotus saw and reported the royal throne sent as a votive offering by Midas to Delphi, and from his account we can safely date the reign of Midas in the latter part of the eighth century B.C.

Nineteenth-century archaeological discoveries greatly increased the historical respectability of King Midas. As ancient Near-Eastern history was reconstructed from the cuneiform-inscribed clay tablets of the Assyrian royal libraries, Midas re-emerged as Mita, king of Mushki, an ambitious adversary of King Sargon, who ruled Assyria from 722 to 705 B.C. Thus the Assyrian dating of King Midas confirms that of Herodotus. According to the Assyrian archives, the intrigues of Mita, or Midas, led to the formation of a powerful league of eastern and western Anatolian kings against Assyria. Midas's alliance was about to pursue his dream of conquest when barbarian tribesmen from the north raided his country and finally sacked his capital, Gordion. According to the Greeks, Midas committed suicide. From Greek and Assyrian sources we can identify these nomadic invaders of Asia Minor with the Cimmerians, a people who crossed the Caucasus under the pressure of the Scythians and whose name survives to this day in the word "Crimea."

The first excavations of ancient Gordion were made in 1900 by the German archaeologists Gustav and Alfred Koerte, who took advantage of the access provided by the new Berlin-Baghdad railway to dig at Yassihüyük, the "flat mound" on the east bank of the Sakarya River (the ancient Sangarios) in north-central Turkey. They had collected the theoretical material about Phrygia carefully and had chosen their site with acumen. The extent of the site, the presence of one of the largest clusters of burial mounds and the location as checked against ancient texts made it virtually certain that this was Gordion. It should be said, however, that no local inscription has yet provided conclusive evidence. In their one season of digging the Koerte brothers lived in the railroad station at Beylik Köprü and traveled daily by horseback, ferry and a fresh relay of horses to the mound on the opposite side of the river, where they dug in the city mound and opened up some of the burial mounds. Their venture was attended by luck. The considerable material they uncovered, exhaustively published in 1904, has served as the basis for subsequent understanding and speculation about Phrygian culture.

We now know, however, that the Koertes' sampling was scant, especially as it bore on what was concealed in the city mound. Their soundings did not penetrate below the level of the sixth century B.C., and the earlier period of Midas was represented only by a series of objects from one of the burial mounds which could not at the time be placed

CITY GATE of Gordion, faced with massive blocks of hewn stone, dates from the period of Midas (eighth century B.C.). Originally more than 30 feet high, these fortifications lay buried under many strata of debris until their excavation by the University Museum of the University of Pennsylvania. Gordion rose above the valley of the river Sangarios in Asia Minor (*see map on the next two pages*).



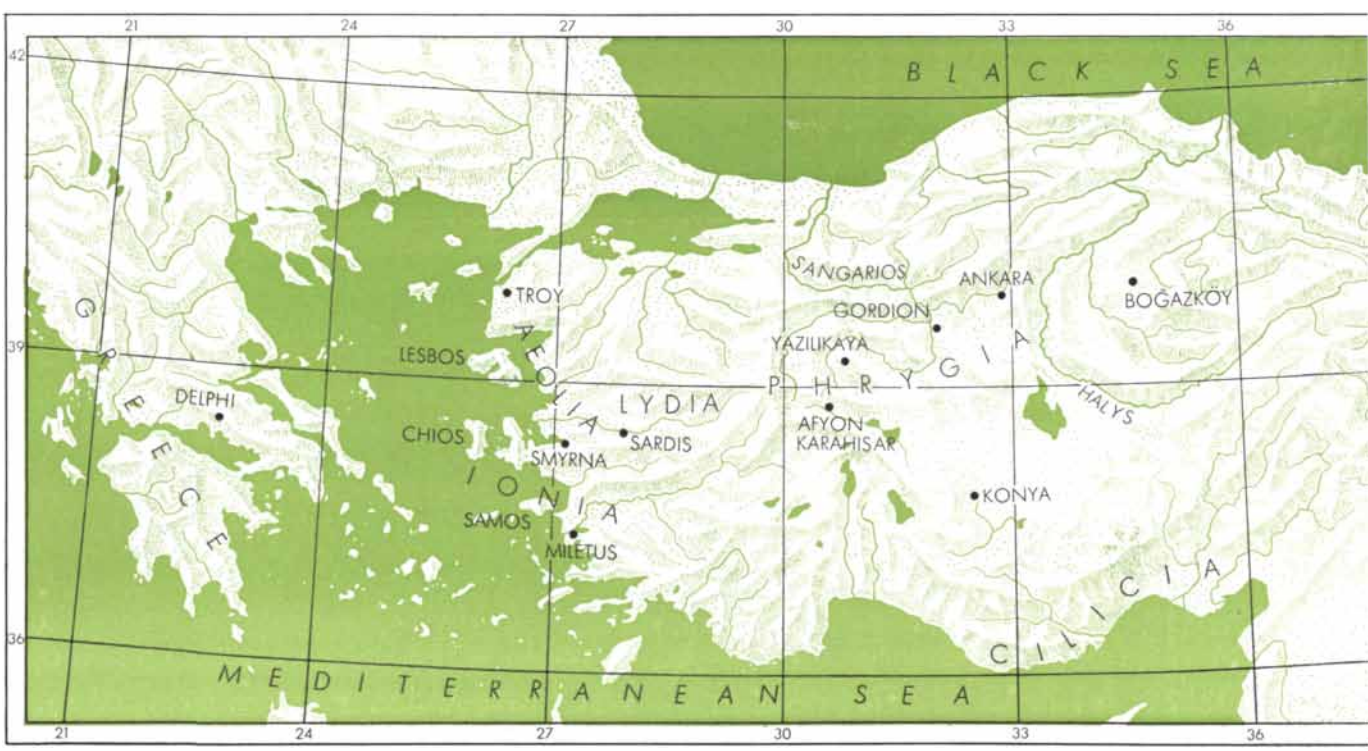
MOSAIC FLOOR of a "megaron" or large hall belongs to the same period. A round hearth originally occupied the central circle. The floor plan, hearth and perhaps the floor decoration relate this room to the megara of Mycenaean Greek palaces. The mosaic is executed in red, black and white. The irregularity of its embroidery-like design was partly original, partly the result of patching.

in context. On the basis of what they uncovered, the Koerte brothers characterized the ancient Phrygians as peaceful peasants who lived in open settlements. They concluded that future excavations at Gordion might produce minor finds, but that "imposing remnants of architecture will not be found."

When the University Museum started a new series of expeditions in 1950 under the direction of Rodney S. Young, Phrygia had assumed a new importance in historical research. The accounts furnished by Herodotus and the annals of Assyria had not changed, nor had the fanciful tales about Midas and his adventures. But the history of Greece and Asia Minor had been extended into the past. The vigorous culture of Mycenaean Greece had been discovered and extensively explored. But a 400-year lacuna, the dark ages of transition between the Bronze Age and the Iron Age, from 1200 to 800 B.C., separated the fall of Mycenaean Greece and the beginning of the era that was to flower in the Greece of the classical period. On the eastern side of the Aegean, scholars had encountered a parallel gap in history. There, also from 1200 to 800 B.C., four centuries of darkness had intervened between the sudden destruction of the Bronze Age Hittite Empire and the rebirth of civilization and culture in which the Phrygians seemed to have played a leading role. With the dispelling of the darkness, Greek art shows the stimulus of Oriental influences. Writing was reintroduced in Greece due to a revival of contact with the Near East, chiefly the regions of North Syria and Phoenicia. Did the Phrygians also act as productive and stimulating neighbors of the Greeks? Or were they a second-rate repository of retarded and borrowed cultural features?

The new archaeological campaign at the mound at Yassihüyük was planned to produce the material needed for a reliable historical and cultural reconstruction of Phrygia and its role in the ancient world. In seven campaigns between 1950 and 1958—the eighth is now at work on the site—the field archaeologists of the University Museum have begun to restore to the memory of man one of the great cities of history. Now we can say that Herodotus was right. At Gordion in the eighth century B.C. the Phrygians created a center, with powerful fortifications and enormous buildings, worthy of their status as successors of the Hittites. Their tombs contain proof of local and imported wealth, art and equipment, proclaiming the climax of Phrygian power in the days of King Sargon of Assyria. The excavations also confirm the story of the fall of the city, hinted at in Assyrian sources and in the Greek account of the fate of King Midas. Fire and plundering, the work of the Cimmerians, are evident in the physical devastation that befell the buildings of the monumental city. Later Phrygians buried the ruined capital so deep that no archaeologist before 1950 could have suspected its size and scope.

Today the University Museum excavators can point with a certain local pride to a set of eighth-century stone fortifications which in size and preservation hardly have their rival in Asia Minor. The city gate on the east side of the mound, with its oblique entrance, buttressed towers and large gate chambers, stands to a height of more than 30 feet, dwarfing and awing the tourists who walk over its cobbled roadway into the paved outer plaza of the city of Midas. The top of the walls is not preserved, but the evidence indicates that a stone rampart 40 feet high surrounded the 20 acres of the citadel. The stone walls of the sixth level at Troy, the largest citadel hitherto excavated in western Anatolia, are preserved to a height of not more

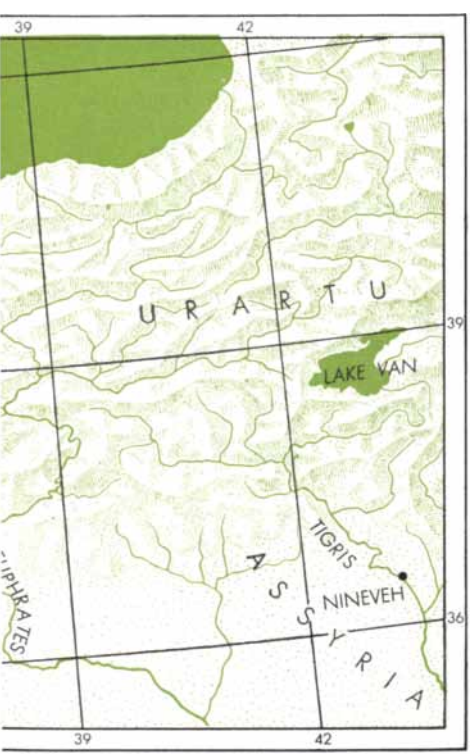


ANCIENT PHRYGIA occupied the central highlands of Anatolia, now the Asiatic part of Turkey (*middle*). At the beginning of the archaic period in Greece the Phrygian capital, Gordion, played an important role in cultural transmission westward from the ancient cultures of the Tigris-Euphrates valley (*far right*). Urartu (*upper right*) was a source of bronzes found in Gordian tombs.

than 25 feet and enclosed about five acres.

Only a few of the buildings within the walls have so far been excavated. The paved street leads in the direction which we presume to be that of the royal residence. But that edifice is still covered by a safe blanket of later strata, awaiting careful, systematic removal. But on our way to the palace we have made some valuable architectural discoveries. It is plain that the layout of structures in the citadel was well planned, with enclosure walls oriented uniformly. In the course of the eighth century the layout was changed and a vast structure, perhaps Midas's granary and magazines, was erected on a rubble terrace that covers a still-earlier level of the city. We can only estimate the size of this apparently single building by the distance between one of its rooms (a grain storage and grinding chamber 45 feet long) and another, similar in size and construction, that has been uncovered in a preliminary sounding 180 feet to the southwest.

Apart from such businesslike constructions we encountered two quite different earlier buildings facing the paved square. Both were subdivided into an anteroom and a main hall, nearly 30 feet square, and both seem to have had a porchlike entrance. The plan is suggestive of the Mycenaean Greek and Bronze Age Anatolian "megaron." As in the royal halls of Mycenaean kings we find a decorated floor, with a round hearth neatly set in the center. The design of the Phrygian floors is executed in a pebble-mosaic technique which we had found still popular in later levels at Gordion, before our excavations had reached the eighth century. In the curious style of the Phrygians the mosaic carries out continuous, irregular geometric patterns, in red, black and white, achieving rich embroidery-like effects without naturalistic allusions. Repairs to the floors carry part of the blame for the irregular appearance of the design, but even in its original form it seems to have been far from systematic.



Other great archaeological sites shown include Sardis, Troy and Boğazköy, chief city of the pre-Phrygian Hittite culture.

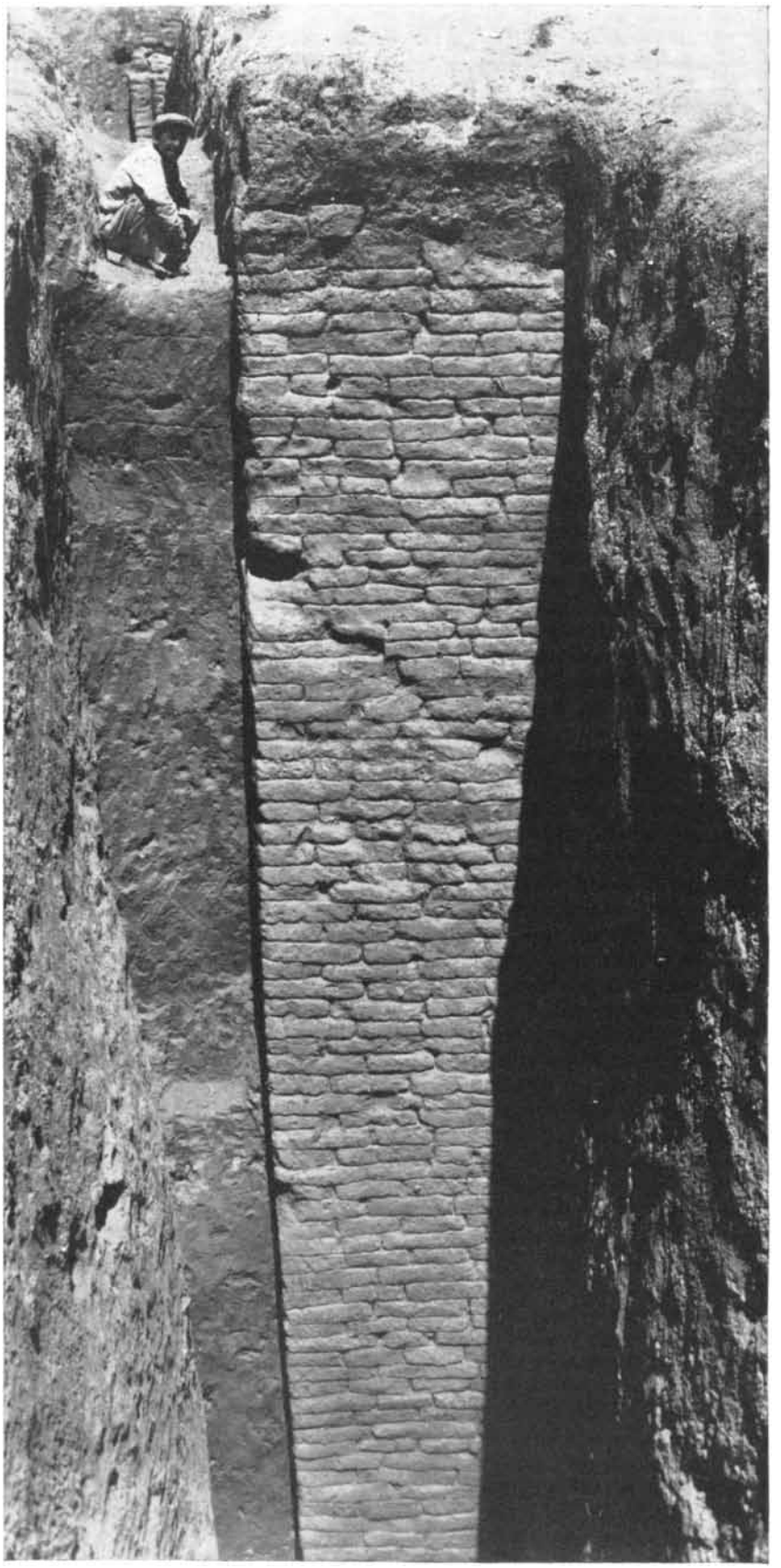
The use of these buildings is not clear from their appearance or contents. Before being set afire they had been thoroughly looted of any contents that might have told us what purpose they served. The fire consumed the superstructure also, for the chief building material, apart from stone foundations and mud-brick walls, was timber, used in an ingenious system of horizontal and vertical wall frames and in colossal roof beams. Fragments of burnt clay and the absence of tiles indicate that these buildings were roofed with clay and reeds.

By nice deduction from three pieces of evidence we have determined that the roofs were double-pitched, rather than flat, to span the large interior chambers. First a fallen stone with a voluted ornament was found by Rodney Young, who quickly identified it as an akroterion that had adorned the peak of the façade. The second bit of evidence was indirect: Rock façades carved as symbolic shrines on cliffs in western Phrygia show such roof construction, finished off with an akroterion. Any doubt left in the excavators' minds was quickly dispelled by the third, quite unexpected source of information. People lingering on benches set against the outer walls of one of the two buildings had scratched hundreds of graffiti in the soft limestone: many senseless doodles, some primitive sketches of people, dogs, birds, lions—and houses. They had drawn the latter in their essentials as a child would show them: the rectangular contour of the façade, the door, the gable and the akroterion. The contemporary evidence could not have been more cogent.

Outside the walls of Gordion the burial mounds hold precious evidence of a kind that was lost in the sacking and burning of the city. The entire site is, in fact, ideal in the combination of archaeological data offered by the city and contemporary cemetery sequences. The largest of the earth mounds heaped up over wooden burial chambers have turned out to belong to the period shortly before the Cimmerian invasions. The burial customs, including occasional horse sacrifices, are those identified also with the Scythians, nomadic cousins of the Phrygians who roamed the northern shore of the Black Sea and did not enter Asia Minor until the seventh century B.C.

The best-preserved burial chamber was reached in 1957 by tunneling into the 100-foot mound that dominates the scenery of Gordion now as it did in ancient times. The chamber was still intact, with its gabled timber roof protecting the skeleton of a 65-year-old king and his treasure. The king remains anonymous for the present, but his age and tomb gifts bring him close to Midas. Of all the wealth uncovered in this tomb and widely celebrated in the press at the time, archaeologists are most grateful for the woodwork. The furniture consisted of a funeral couch, tables and portable screens decorated in elaborate geometrical inlay. In wood as in other materials Phrygian art is revealed as possessing a repertoire of decorative motifs strikingly related to but not derived from early Greek ceramic patterns. If it had not been for such burial hoards, we would not have retrieved evidence of Phrygian excellence in this branch of arts and crafts. A child's tomb excavated in 1956, in addition to "geometric" furniture, contained animal carvings of a style entirely removed from the Greek tradition, and again clearly of local manufacture.

Less miraculously preserved in the tombs, but present in complete specimens and exceptional quantity, are the products of Phrygian metallurgy. The old king had the largest share of all. Fibulae (ornamental safety pins) had been known from occasional finds in the city mound and from Assyrian illustrations of Phrygian costumes, but nearly 200 specimens, representing a prolific sampling of types and variants, accompanied the royal burial. Bronze drinking bowls, pitchers and ladles added up to over 150 items. Here was the display of Phrygian industries of which the Cimmerians had deprived us in their sacking of the citadel. The special possessions of the king, such as the exotic dipping cups in the shape of a lion's or a ram's head, and the three large cauldrons standing along one of the walls of the burial



MUD-BRICK WALLS of Gordion date from the seventh century B.C. They were an emergency defense measure, carried out on a vast scale, against the Cimmerian raiders who had destroyed the earlier hewn-stone fortifications (*see upper illustration on page 101*)**.**

chamber, were the prize pieces. The decoration on one cauldron seems to indicate Phrygian workmanship. But the Sirens and "Ashur" heads on the other two cauldrons confirm materially what we read in the Assyrian records about the lively contact between Phrygia and Urartu, another famous center of metallurgy in which the best counterparts for the cauldron attachments have been found.

Close inspection of three of the bronze bowls revealed the most precious intellectual documents found in the tomb chamber. On their rims, below the handle, a strip of beeswax had been applied and incised with bold and clear Phrygian alphabetic lettering, in each case probably a name. Here was direct evidence that the Phrygians had adopted the alphabet for their Indo-European language well before 700 B.C. The implications again are enough to generate discussion in the pages of learned periodicals. Assuming that the Phrygians borrowed their alphabet from the Greeks, the Greek alphabet must already have had sufficient time to be developed from the Phoenician; it must have had time also to spread to the Greek center in Asia Minor (probably Aeolia, the habitat of Midas's semimythical bride) from which the Phrygians had borrowed it. This discovery will induce the historians of the Greek alphabet to re-examine their chronology with special care; some revisions seem imperative.

The curious labels on the bronze bowls had another and less heartening message for the archaeologist. Writing on beeswax applied to bronze might have served as an expedient to permit erasure without defacing the metal, but it is an unprecedented practice. Logically the notion was borrowed from the custom of writing on waxed wooden tablets. The find thus suggests that the city's archives may have been kept on wood. This is discouraging to the excavators of a city in ashes. Some consolation may be found, however, in the knowledge that the Near East by this time was using clay as well as wooden tablets. There is still hope that Midas may have carried on correspondence with his friends and rivals in the traditional medium of cuneiform on clay. But so far the city mound has not produced any writing in the level destroyed by the Cimmerians.

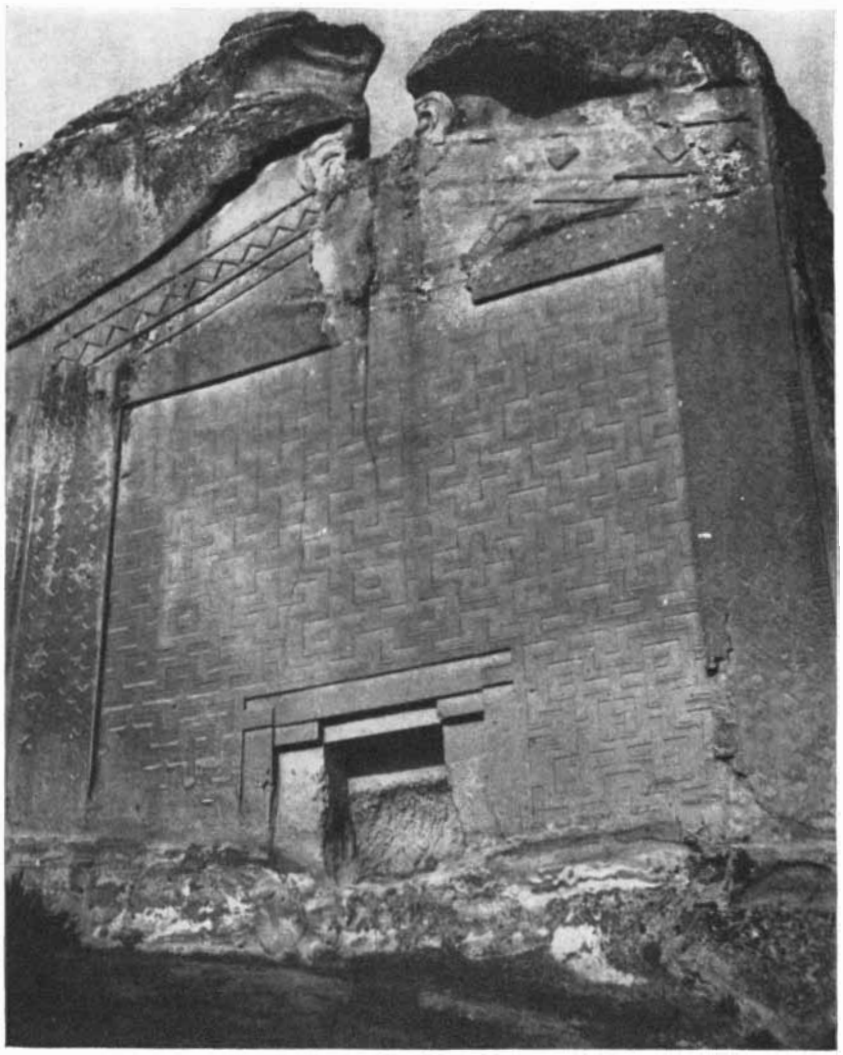
Although the written record is scant, the objects in the tombs have told us much about the economic and artistic relations between Gordion and its neighbors to the east and west. The Phrygian art styles are indigenous, but exchanges

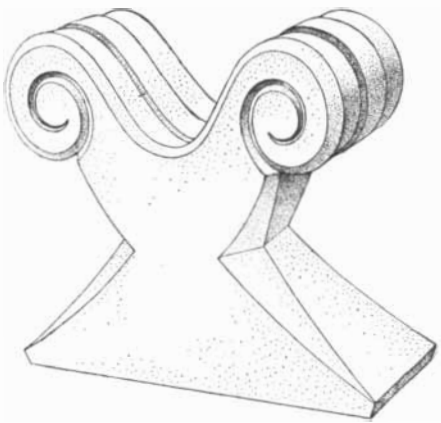
with the Orient are especially evident in the design of decorative metal objects. The Greeks were not yet in a position to influence Phrygian art, but their contact with Phrygia is clearly documented in the transmission of the alphabet. Phrygian art of the period of Midas must have been a known quantity at least in eastern Greece. New excavations in Aeolia may help to clarify the Phrygian impact on Greece and vice versa.

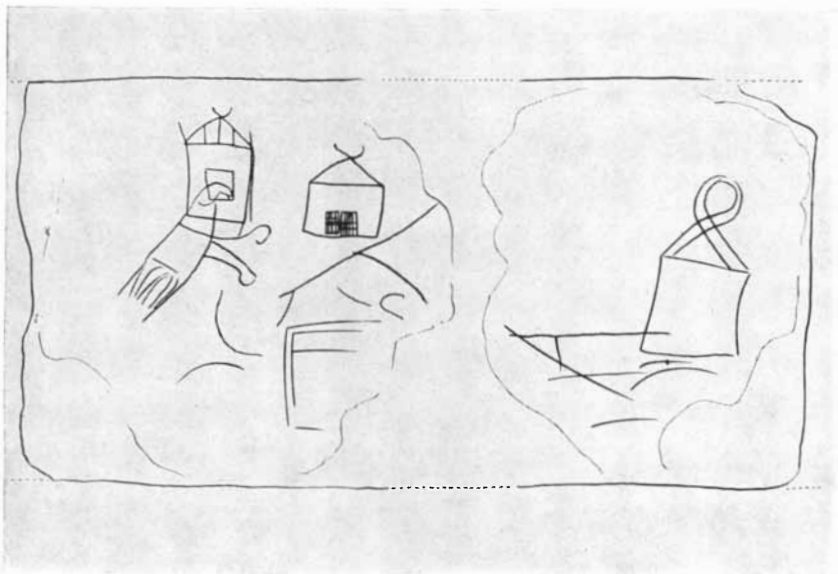
With the devastation of Gordion by the Cimmerian invasion Phrygian power went into irreversible decline. Historically we know that the Lydians succeeded the Phrygians as protagonists of Asia Minor against the invaders. It took several generations to rid Asia Minor completely of the plague of Cimmerian raids, and it was under Lydian auspices that order and peace were ultimately restored in Phrygia.

The post-Cimmerian, seventh-century burial mounds at Gordion yield evidence of increasing contact with the Greeks on the west coast of Asia Minor and the Hellenization of Phrygian culture. Greek ceramic imports become more numerous, and gold jewelry now begins to make its appearance among the finds.

The "Lydian" period is at present less well documented on the city mound than in the cemetery, but the reasons are evident. After the violent destruction of the city of Midas, the Cimmerians continued to keep the country in turmoil. On the east side of the citadel of Gordion the Phrygians rapidly built an interim fortification system. Instead of the stone ramparts that had been the pride of pre-







STONE AKROTERION found in the ruins of Gordion (*drawing at lower left*) is a clue to the appearance of buildings destroyed by the Cimmerians. The rock-cut representation of a building façade found at a Phrygian shrine at nearby Yazilikaya (*photograph at upper right*) has a similar akroterion ornamenting the peak of its pediment or gable. Thus buildings in Gordion must have resembled the Yazilikaya shrine. This evidence is confirmed by graffiti (doodles) of houses which were found in Gordion (*lower right*).

BRONZE BOWL from the royal tomb shown in color photographs on the opposite page bears a beeswax label inscribed in Phrygian alphabetic writing. This eighth century B.C. example of Greek-derived writing may force revision of the dating of the Greek alphabet.

BRONZE DIPPER from the same tomb is shaped like the head of a lion. Like other bronzes in tomb, it exhibits the influence in Phrygia of Mesopotamian and Urartaean arts and motifs.

WALL PAINTINGS from a shrine in Gordion, ascribed to the late sixth century B.C., survive only in fragments. They are examples of the eastern Greek influence in Gordian art.

vious generations, they put up a mud-brick wall about 20 feet thick and 35 feet high. Towers formed guard stations at regular intervals, a bastioned gateway controlled access from the east, and a towering citadel in the center housed the garrison. This colossal operation once more fills us with admiration for the energetic military architects of Phrygia. The mud-brick rampart bears dramatic evidence of its service in the hundreds of bronze arrowheads stuck in its outer face—invaders' arrows aimed too low.

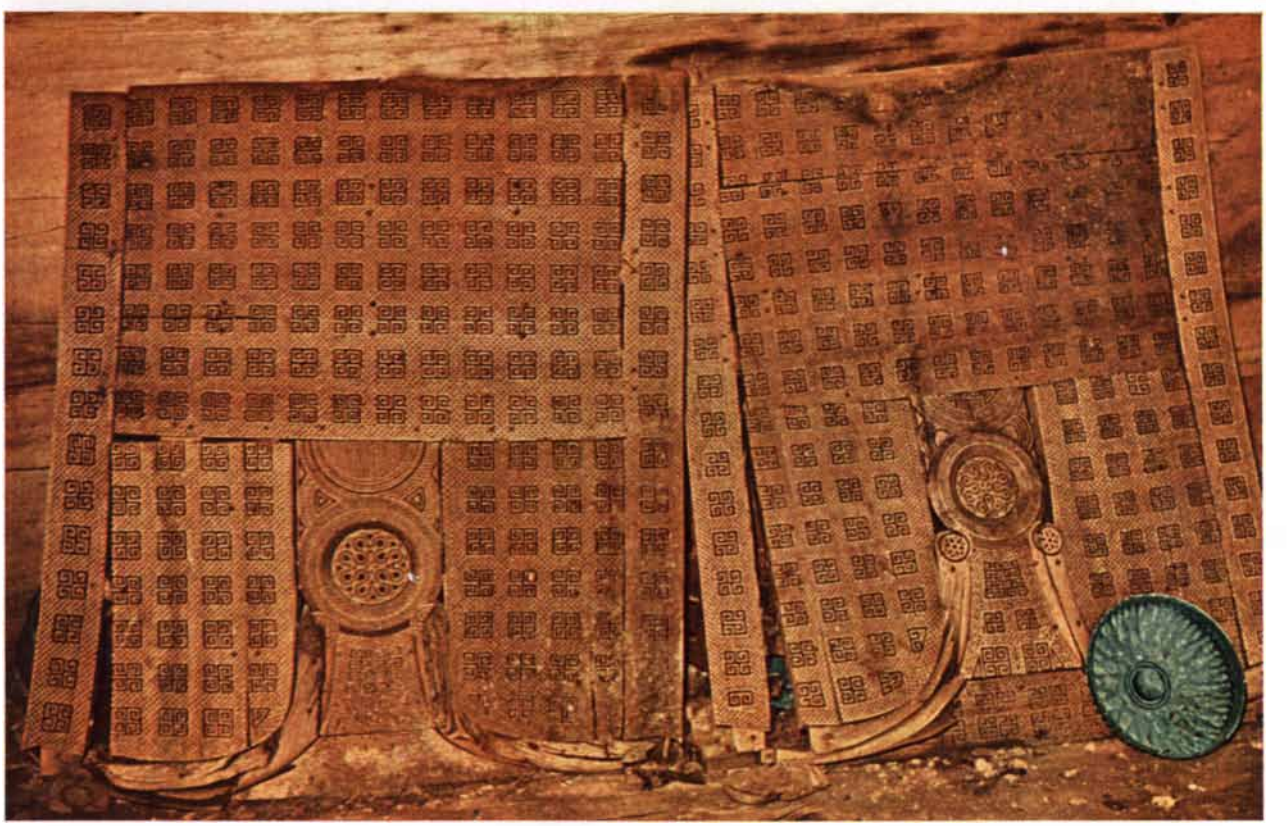
The ruins of the burnt stone citadel were considered a total loss. A colossal reconstruction was undertaken, worthy of the scope and ambition of Phrygian engineering. Considerations of safety seem to have recommended placing the citadel on a higher level. A clay-and-rubble fill was laid as an enormous terrace over the ruined town.

The plan of the rebuilt city, as we know it for the sixth century B.C., preserved much of the earlier city plan. Within the citadel, precinct walls again marked off special areas, and over the two buildings with the mosaic floors there arose two new buildings with similarly decorated floors, again parallel and facing the open area which we think forms the approach to the palace.

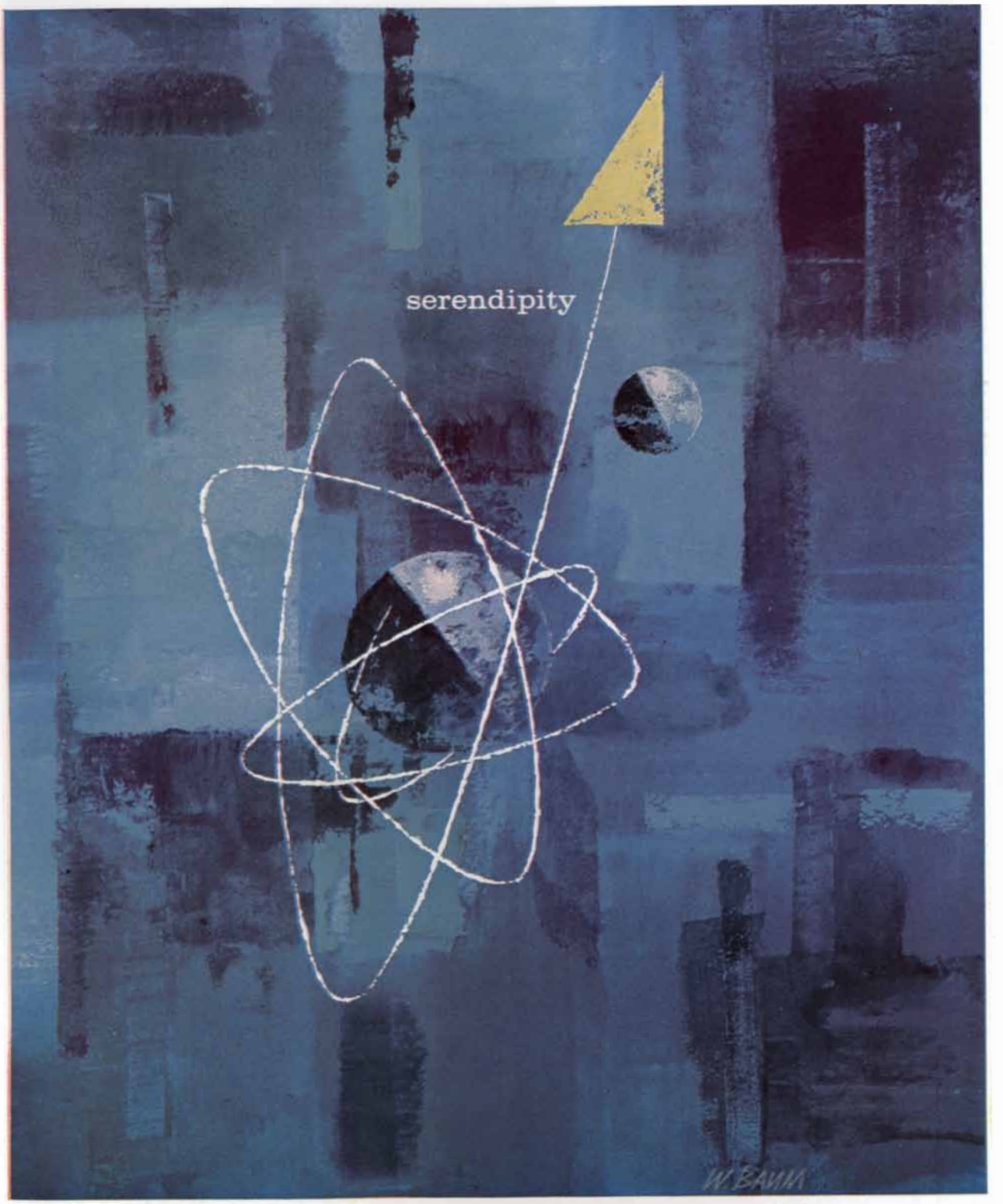
In the ruins of a small, windowless annex to one of these buildings we found the flaked and stacked remnants of plaster once decorating its walls. The first pieces to be lifted gave us a thrilling surprise: the plaster bore traces of vivid colors. With patience and ingenuity several members of the excavating staff have rescued all that could be saved of the designs. The "shrine" had frescoes on its walls, with a procession of festively dressed men and women as the chief motif, and with panels painted on a smaller scale showing youthful athletes. Friezes with architectural background framed these scenes; the ceiling bore a painted pattern. Reminiscent of Etruscan tomb chambers in shape, the room also recalls the style of the archaic Etruscan frescoes of Tarquinia.

Here in Gordion we seem to have the first authentic remnants of eastern Greek fresco-painting of the late sixth century B.C., provincial in execution perhaps, but true to the style of eastern Greek art. In this period, when Gordion was still essentially a Phrygian city, there were strong bonds with the Greeks living on the west coast of Asia Minor. The Lydians may still have been acting as intermediaries, but their supremacy was

ROYAL BURIAL CHAMBER at Gordion is shown as it was found when excavated in 1957. The bronze vessels, patinated with age, are lying amid the debris of collapsed wooden tables. On a tripod (*right*) stands a cauldron imported from the kingdom of Urartu.



INLAID WOODEN SCREENS were found leaning against a plank wall in the same tomb. Decomposing nails have stained the planks with rust. The wooden chamber lies under a large tumulus, or earth mound. It dates from the eighth century B.C., the era of King Midas.



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MARTIN
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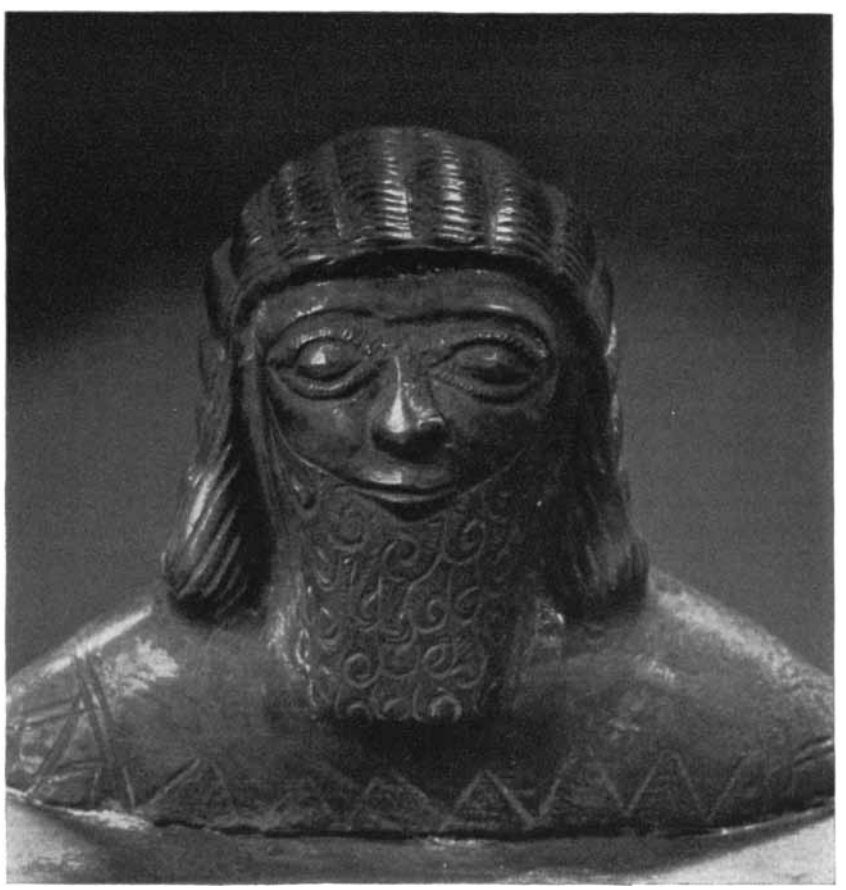
a thing of the past. In the east a new adversary, the king of the Medes, had been consolidating his power only to pave the way for the Persian Empire under King Cyrus, who took sway over Phrygia as well as Lydia in the latter half of the sixth century.

Prosperity continued for some time under the new rulers of Gordion, but in the course of the fifth century matters changed. The magnificently rebuilt city fell gradually into ruins. Some monumental buildings were abandoned, smaller residential areas took over, plundering and re-using the masonry of earlier levels. By the time of Alexander, Gordion had fallen from greatness. So far we have been unable to locate any building respectable enough to have been the temple of Zeus where Alexander found the relics of the Phrygian kingdom.

For some generations, however, the city maintained an aura of importance because of its associations with the past. The Galatians menaced it once more as their Cimmerian predecessors had done in the seventh century, but the place was still inhabited on a small scale in Roman times. Then was formed the taller southwest ridge along the banks of the Sangarios which marks the last habitation at Gordion. In Byzantine times the site was given up, and when the last Romanized Phrygians disappeared from the mound, the name of Gordion went into oblivion.

As archaeologists working from the known to the unknown peel off layer after layer of history, the story of Gordion is being played in reverse. From the period when classical authors referred to Gordion as a once-famous site back to the time of Herodotus's allusions and Assyrian reports, archaeology now has reached the days of King Midas. Before Midas, Phrygia was outside the orbit of Assyria and the record is silent. There is occasional mention of the Phrygians under the name of Mushki, the Meschech of the Old Testament. But the next solid historical fact we reach in history is the destruction of the Hittite Empire, back about 1200 B.C. In the cemetery of Gordion as well as in soundings in the city mound we have found good evidence for a previous Hittite occupation of the city. Future campaigns will tackle this possibility, confident that the work of the spade will fill the gap left by the dark ages in the historical record. The arrival, development and expansion of the Phrygians will be the next installments of history to be reclaimed from the flat mound of Yassihüyük.

CAULDRON mounted on a tripod is one of three found in the royal tomb. One of the cauldrons, which contained offerings to the dead, is shown *in situ* at the top of page 107.



BRONZE HEAD is a detail of Urartaean cauldron shown at top of page. It is possibly a representation of Ashur, the winged deity who presided over the Assyrian pantheon.

How Du Pont Fibers Are Solving Product and Process Problems

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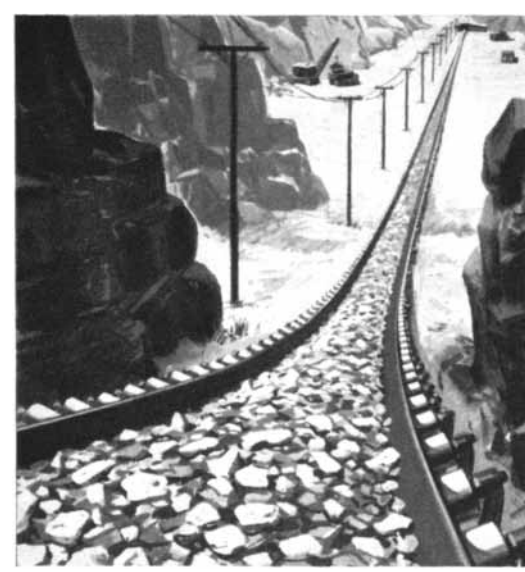

WORLD'S LONGEST SLOPE CONVEYOR will carry 700 tons of taconite per hour, traveling at a speed of 460 fpm. The ore will be carried upward approximately 800 ft. The belting — over 7,500 ft. long, with a center distance of 3,791 ft. — is reinforced with Du Pont high-tenacity rayon and nylon. The light weight and high strength of these fibers help make so long a conveyor-belt system economically feasible.

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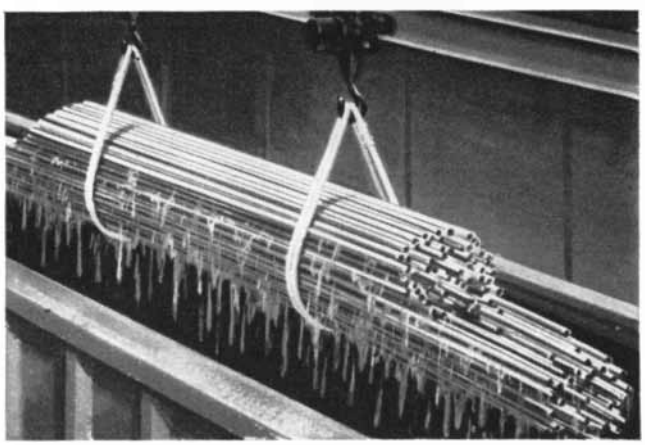
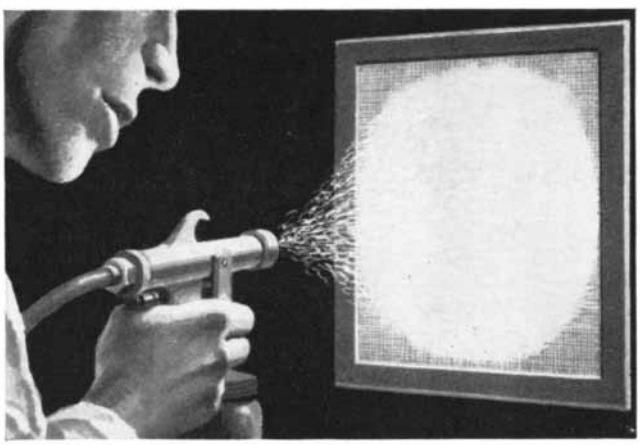
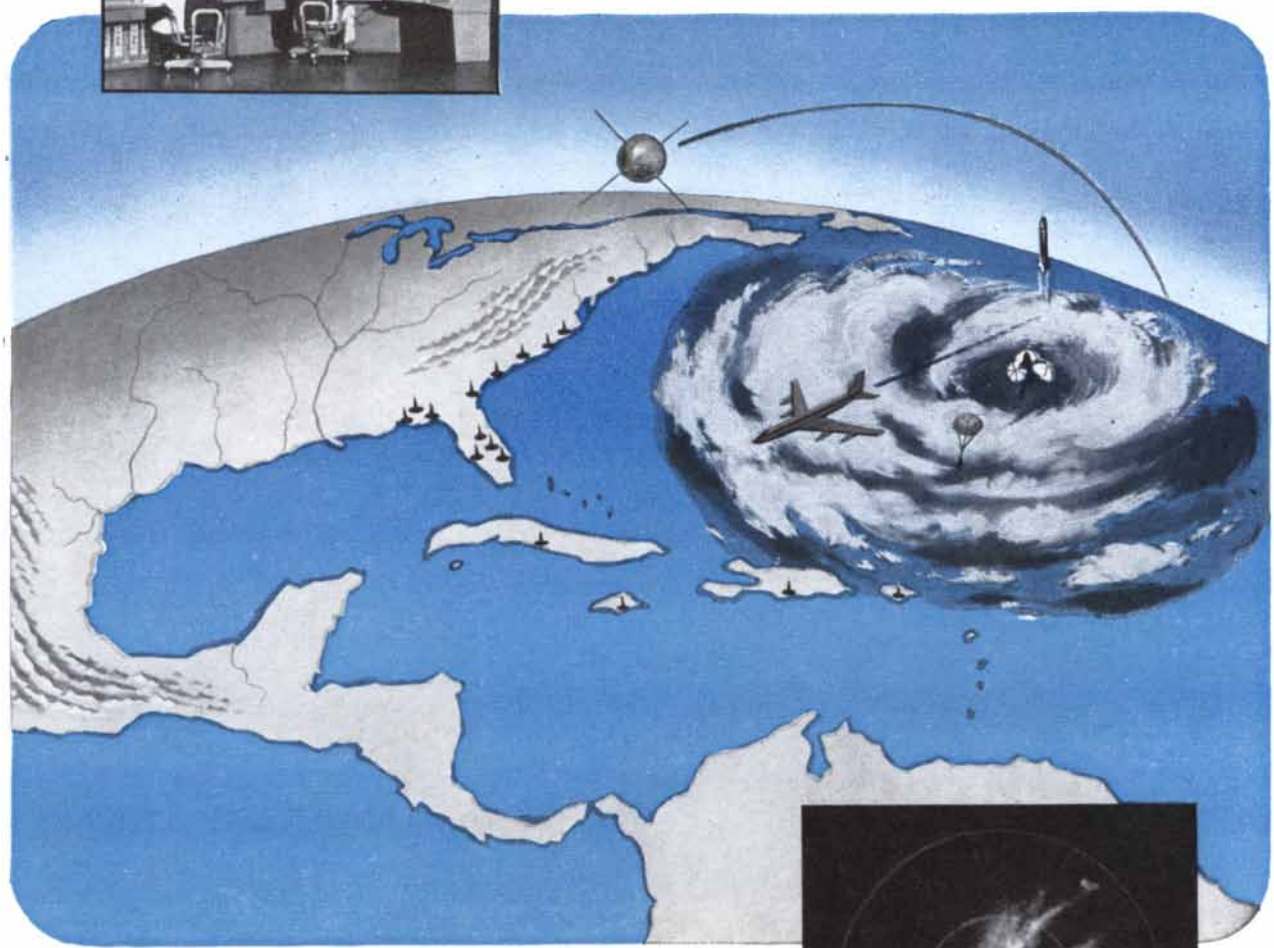
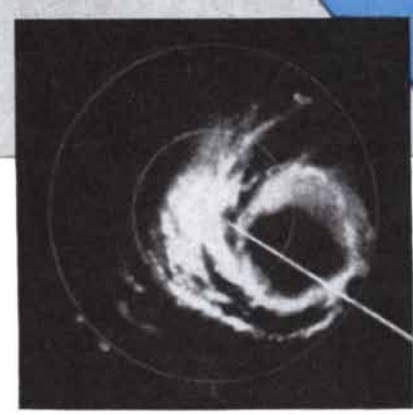


ACID-RESISTANT ROPE SLINGS made with ¾″ filament rope of "Dacron" polyester fiber support up to 5,000 pounds of stainless-steel tubing in pickling operations. The tough, low-stretch properties of "Dacron" permit repeated immersion of these slings in acid pickling baths for continuous periods of service up to six months long. When slings of "Dacron" are used instead of stainless-steel chains, dents and handling marks on the tubes are drastically reduced, with a resultant saving in cost.



HIGH-EFFICIENCY SUPERFINE FILTERS are easily produced in a new process utilizing "Dacron". This method involves spraying a 10% solution of polystyrene in methylene chloride at 50 psi onto a backing mesh of "Dacron". The solvent evaporates almost instantaneously, leaving thin fibers less than 1 micron thick and 1 in. long. The mesh of "Dacron" is then peeled off, and the mat is rolled to produce a completely organic filter that retains 99.5% of the particles it picks up, down to 0.01 micron.





SKY HIGH

integrated hurricane hunting

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ALKALOIDS

This ill-defined group of plant compounds includes many that are both useful and toxic. Though most of them strongly affect human physiology, their functions in plants are still obscure

by Trevor Robinson

The alkaloids are a class of compounds that are synthesized by plants and are distinguished by the fact that many of them have powerful effects on the physiology of animals. Since earliest times they have served man as medicines, poisons and the stuff that dreams are made of.

The alkaloid morphine, the principal extract of the opium poppy, remains even today "the one indispensable drug." It has also had an illicit and largely clandestine history in arts and letters, politics and crime. Quinine, from cinchona bark, cures or alleviates malaria; colchicine, from the seeds and roots of the meadow saffron, banishes the pangs of gout; reserpine, from snake root, tranquilizes the anxieties of the neurotic and psychotic. The coca-leaf alkaloid cocaine, like morphine, plays Jekyll and Hyde as a useful drug and sinister narcotic. In tubocurarine, the South American arrow poison, physicians have found a powerful muscle relaxant; atropine, said to have been a favorite among medieval poisoners, is now used to dilate the pupils of the eyes and (in minute doses!) to relieve intestinal spasms; physostigmine, employed by West African tribes in trials by ordeal, has come into use as a specific for the muscular disease myasthenia gravis. Aconitine is catalogued as too toxic to use except in ineffective doses. On the other hand, caffeine and nicotine, the most familiar of all alkaloids, are imbibed and inhaled daily by a substantial fraction of the human species.

Our self-centered view of the world leads us to expect that the alkaloids must play some comparably significant role in the plants that make them. It comes as something of a surprise, therefore, to discover that many of them have no identifiable function whatever. By and large they seem to be incidental or accidental products of the metabolism of plant tissues. But this conclusion somehow fails to satisfy our anthropocentric concern. The pharmacological potency of alkaloids keeps us asking: What are they doing in plants, anyway? Investigators have found that a few alkaloids actually function in the life processes of certain plants. But this research has served principally to illuminate the subtlety of such processes.

The pharmacology of alkaloids has inspired parallel inquiry in organic chemistry. Some of the greatest figures in the field first exercised their talents on these substances. But nothing in the composition of alkaloids has been found to give them unity or identity as a group. The family name, conferred in an earlier time, literally means "alkali-like." Many alkaloids are indeed mildly alkaline and form salts with acids. Yet some perfectly respectable alkaloids, such as ricinine (found in the castor bean), have no alkaline properties at all. Alkaloids are often described as having complex structures. The unraveling of the intricate molecules of strychnine and morphine has taught us much about chemical architecture in general. Yet coniine, the alkaloid poison in the draught of hemlock that killed Socrates, has a quite simple structure. Nor is there much distinction in the characterization of alkaloids as "nitrogen-containing compounds found in plants." Proteins and the amino acids from which they are made also fit this definition.

From the chemical point of view it begins to seem that alkaloids are in a class of compounds only because we do not know enough about them to file them under any other heading. Consider the vitamin nicotinamide, the plant hormone indoleacetonitrile and the animal hormone serotonin. All these compounds occur in plants, and all contain nitrogen. We would call them alkaloids except that we have learned to classify them in more descriptive ways. As we come to know the alkaloids better, we may select other substances from this formless group and assign them to more significantly defined categories.

Though all alkaloids come from plants, not all plants produce alkaloids. Some plant families are entirely innocent of them. Every species of the poppy family, on the other hand, produces alkaloids; the opium poppy alone yields some 20 of them. The Solanaceae present a mixed picture: tobacco and deadly nightshade contain quantities of alkaloids; eggplant, almost none; the potato accumulates alkaloids in its foliage and fruits but not in its tubers. Some structurally interrelated alkaloids, such as the morphine group, occur only in plants of a single family. Nicotine, by contrast, is found not only in tobacco but in many quite unrelated plants, including the primitive horsetails. Alkaloids are often said to be uncommon in fungi, yet the ergot fungus produces alkaloids, and we might classify penicillin as an alkaloid had we not decided to call it an antibiotic. However, alkaloids do seem to be somewhat commoner among higher plants than among primitive ones.

Some 50 years ago the Swiss chemist Amé Pictet suggested that alkaloids in plants, like urea and uric acid in animals, are simply wastes—end products of the metabolism of nitrogenous compounds. But the nitrogen economy of most plants is such that they husband the element, reprocessing nitrogenous compounds of all sorts, including substances such as ammonia which are poisonous to animals. Indeed, many plants have evolved elaborate symbiotic arrangements with bacteria to secure additional nitrogen from the air. From

the evolutionary standpoint the tying-up of valuable nitrogen in alkaloids seems an inefficient arrangement.

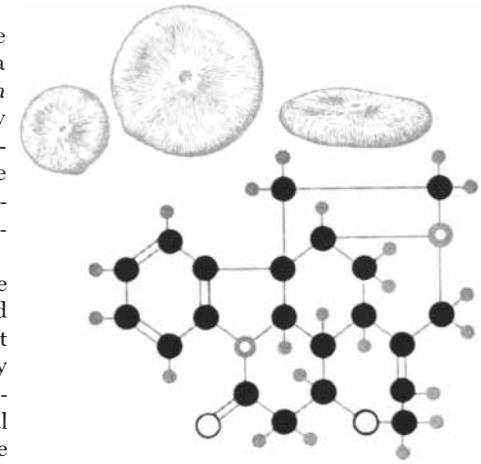
More recently investigators have come to regard alkaloids not as end products but as by-products thrown off at various points along metabolic pathways, much as substandard parts are rejected on an assembly line. That is to say, alkaloids arise when certain substances in the plant cell cross signals and make an alkaloid instead of their normal product. This idea is certainly plausible when it is applied to the alkaloids formed by the action of the commonest enzymes on the commonest metabolites. The alkaloid trigonelline, for example, is found not only in many plant seeds but also in some species of sea urchins and jellyfish. It is merely nicotinic acid with a methyl group (CH_3) added to it. Now nicotinic acid is one of the commonest components of plant cells. Compounds that can donate methyl groups are also common, as are the enzymes that catalyze such donations. A "confused" enzyme, transferring a methyl group to nicotinic acid instead of to some other substance, could thus form trigonelline by mistake [*see illustration at top of page 121*]. Nicotine, which has an equally wide distribution, may likewise be produced by everyday biochemical processes.

The more frequent occurrence of alkaloids in higher plants suggests another idea. More highly evolved organisms have obviously made more experiments in metabolism. Some alkaloids may represent experiments that never quite worked. Others may have originated as intermediates in once-useful processes that are no longer carried to completion. Since most alkaloids seem neither to help nor to hurt the plant, natural selection has not operated for or against them. Thus the modern plant that produces alkaloids may do so for no other reason than the persistent pattern of its genes.

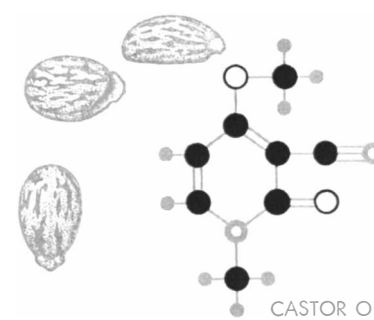
Such explanations for the presence of alkaloids in plant tissues find support in what we know about the synthesis of these substances. In 1917 the noted British chemist Sir Robert Robinson showed that the structures of scores of alkaloid molecules could be built up from amino acids by postulating reactions of a few simple types: dehydration, oxidation and so on. For example, he showed that the amino acid tyrosine could easily be transformed into the alkaloid hordenine. Even the complex molecule of reserpine could be built up, according to his scheme, from tyrosine and the amino acid tryptophan, plus a methylene group [*see illustrations on pages 118 and 119*]. More recently Robert B. Woodward of Harvard University has proposed that the same three substances, through another series of reactions, may yield the extremely complex molecule of strychnine.

During the past 40 years considerable experimental evidence has accumulated to show that these reactions are not just paper-and-pencil chemistry, but actually occur in nature. Robinson himself correctly predicted the structures of several highly complex alkaloids before these structures were worked out. Later experimenters have shown that enzyme-containing plant extracts can promote amino acid-alkaloid transformations such as the tyrosine-hordenine synthesis. Other investigators, by simply mixing together the postulated precursors of certain alkaloids, have obtained compounds of approximately the correct structure even in the absence of enzymes. Tracer experiments have furnished additional support for Robinson's scheme. If labeled amino acids are injected into alkaloid-producing plants, the plants produce labeled alkaloids. Moreover, the alkaloids contain labeled atoms at just the points that theory predicts.

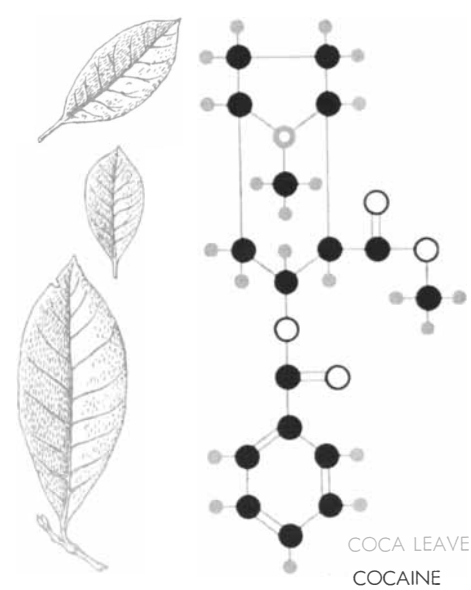
We know, however, that many steps intervene between the introduction of a labeled precursor and the production of a labeled alkaloid. Moreover, a compound that yields an alkaloid when it is injected in high concentration may not be the normal precursor. Some intermediates go to form all sorts of things, and may only get to alkaloids by quite devious routes. The problem of alkaloid biosynthesis resolves itself into the task of establishing the point at which the alkaloid-producing process diverges from the other metabolic processes of the plant. In principle we might feed various labeled compounds to a plant and ascertain whether the labeled material shows up only in alkaloids or in other substances as well. But we must decide which intermediate compounds we are going to feed. It is fruitless to test a versatile intermediate like glucose, which enters into many processes. In a sense, therefore, we must know our intermediate before conducting the experiment that will identify it. One way of breaking out of this impasse may be to work backward by feeding the alkaloid itself to the plant. By building up high concentrations of alkaloid in the plant's tissues we can perhaps block the alkaloid "production line" and thus cause the im-



STRYCHNOS NUX-VOMICA
STRYCHNINE



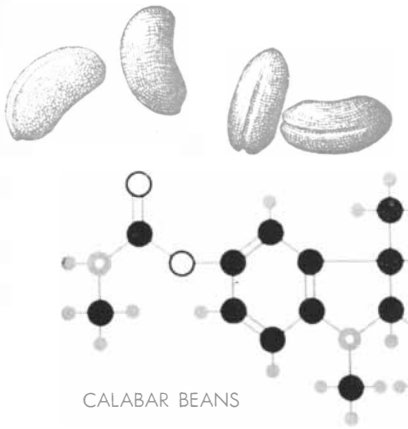
CASTOR OIL BEANS
RICININE



COCA LEAVES
COCAINE

CARBON
OXYGEN
NITROGEN
HYDROGEN

ALKALOIDS show great structural variety. Depicted in this chart are molecules of nine typical alkaloids together with

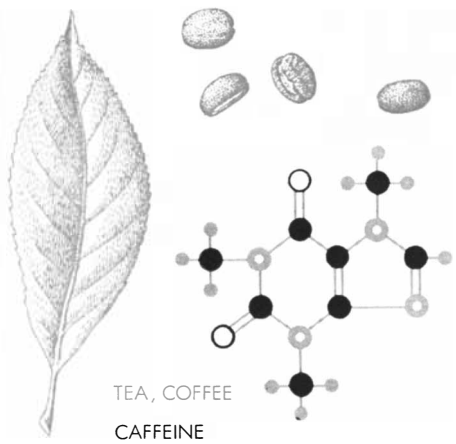


CALABAR BEANS

PHYSOSTIGMINE

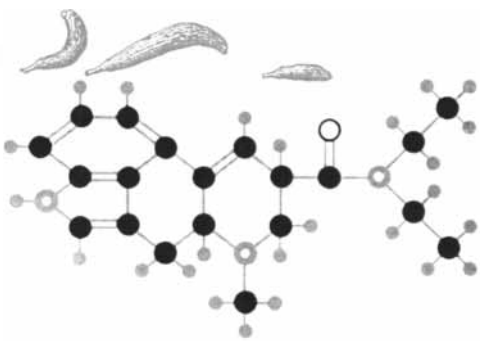
OPIUM POPPY

MORPHINE



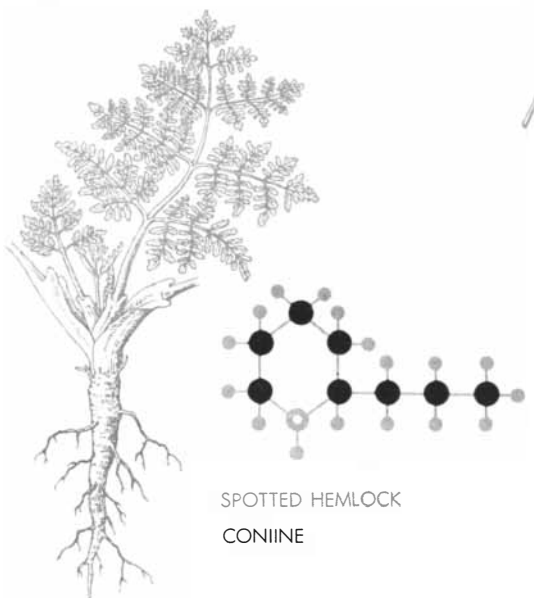
TEA, COFFEE

CAFFEINE



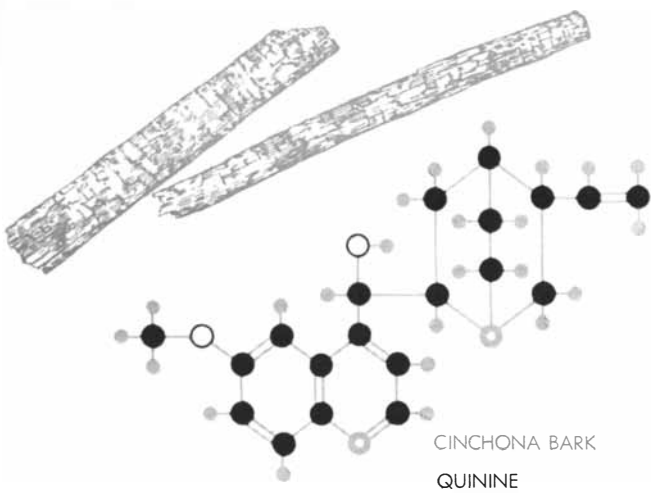
ERGOT FUNGUS

LSD



SPOTTED HEMLOCK

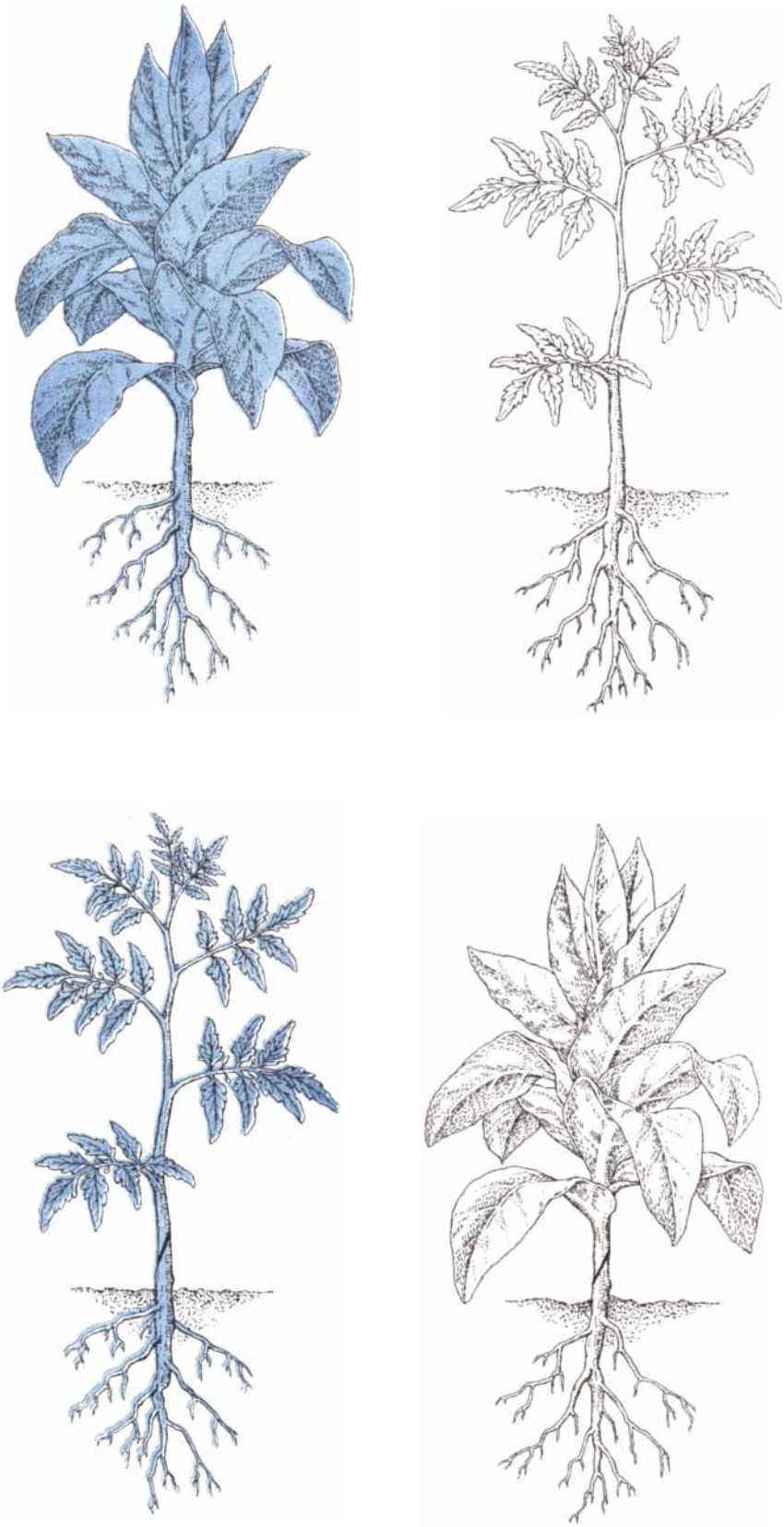
CONIINE



CINCHONA BARK

QUININE

the plants or plant substances from which they derive. At left is the key to these diagrams and those elsewhere in this article. Strychnine, a violent poison, is one of the most complex alkaloids; coniine, the poison which killed Socrates, one of the simplest. Physostigmine, a West African "ordeal poison," is now used to treat the muscular disease myasthenia gravis; LSD (lysergic acid diethylamide) produces delusions resembling those of schizophrenia. Ricinine is one of the few alkaloids that exert little effect on human beings.



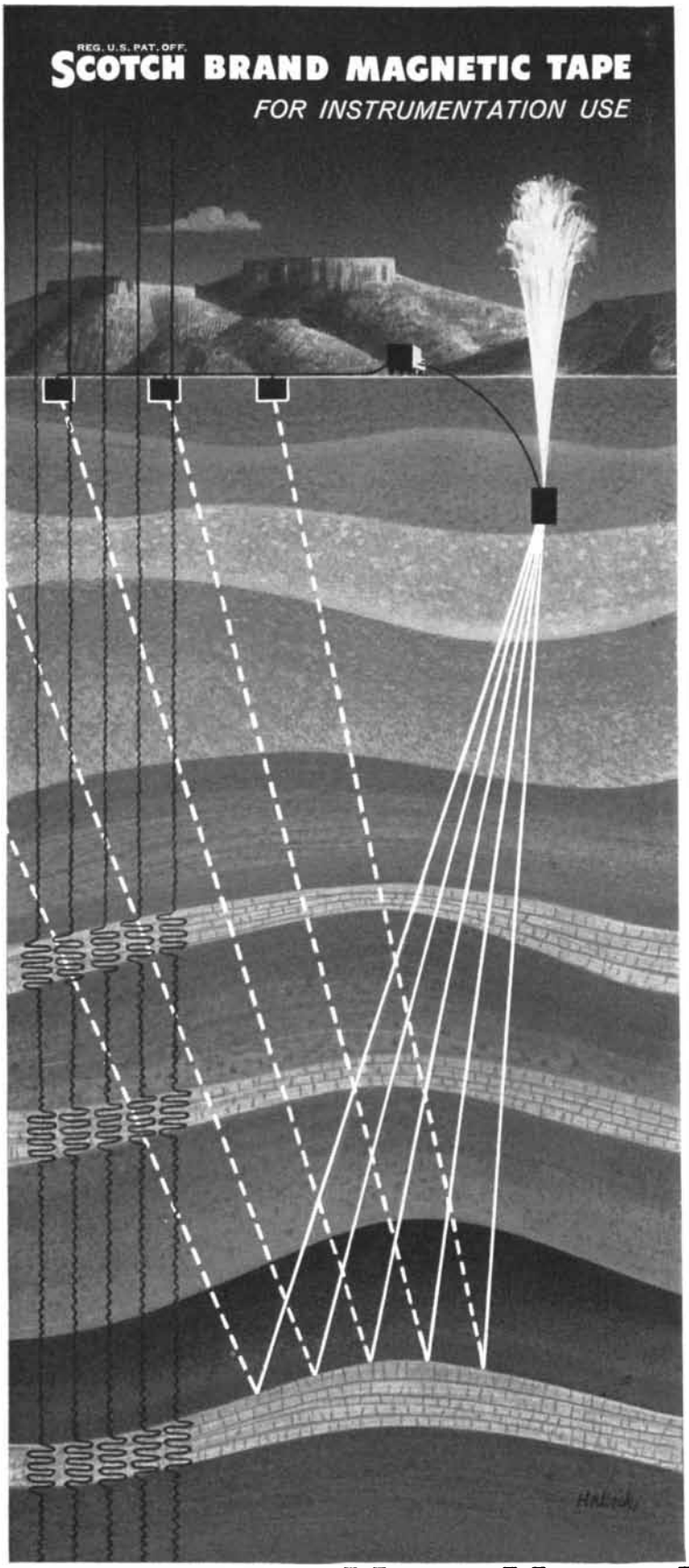
GRAFTING EXPERIMENT indicates that nicotine has no effect on plants. Tobacco plant (*top left*) produces nicotine (*color*) in its roots; the alkaloid then migrates to the leaves. Tomato plant (*top right*) produces no nicotine. A tomato top grafted to a tobacco root (*bottom left*) becomes impregnated with nicotine with no apparent ill effects; tobacco top grafted to tomato root (*bottom right*) is unaffected by the absence of alkaloid. Similar grafting experiments with other alkaloid-producing plants have with few exceptions yielded similar results.

mediate precursors of the alkaloid to accumulate to the point where they can be identified.

With this information in hand, we can go on to inquire which enzymes transform these precursors into alkaloids and whether these enzymes function only in alkaloid formation or in other metabolic processes as well. If we find, for example, that a certain enzyme catalyzes the transfer of a methyl group to an alkaloid precursor but does not function in other methylations, we will have to regard this alkaloid synthesis as a definitely programmed process, and not as a mere aberration. Our present sparse knowledge strongly suggests that at least some alkaloids are programmed. Thus ricinine contains a nitrile group (CN), which rarely occurs in living organisms. If the formation of this group is catalyzed by an enzyme that normally does some other job, we have no indication of what the other job might be. From intimate understanding of this kind we may yet help the plant physiologist to discover what there is about different plants that causes one to make reserpine, while another makes strychnine from the same starting materials.

Of course the study of any metabolic process involves not only the synthesis but also the breakdown of the substances involved. If a given alkaloid is just a waste product or by-product, it has no future and there is no breakdown to be considered. In this case it may simply accumulate in the plant's tissues. For example, quinine piles up in the bark of the cinchona tree, and nicotine in the leaves of the tobacco plant. Some ingenious grafting experiments have furnished additional evidence that many alkaloids, once synthesized, become inert and play no further role in the plant's metabolism. The tobacco plant, for example, manufactures nicotine in its roots, whence the alkaloid migrates to the leaves. However, if we graft the top of a tobacco plant to the roots of a tomato plant, which produces no nicotine, the tobacco flourishes despite the absence of the alkaloid. Conversely, a tomato top grafted to a tobacco root becomes impregnated with nicotine with no apparent ill effects.

But the alkaloids in plants are not always inactive. Hordenine, for example, is found in high concentrations in young barley plants, and gradually disappears as the plant matures. By the use of tracers Arlen W. Frank and Leo Marion of the National Research Council of Canada have found that the disappearing hordenine is converted into lignin,



MAGNETIC MEMORY OF AN OIL RESERVOIR 3 MILES DOWN . . . "FOUND" AT THE SURFACE

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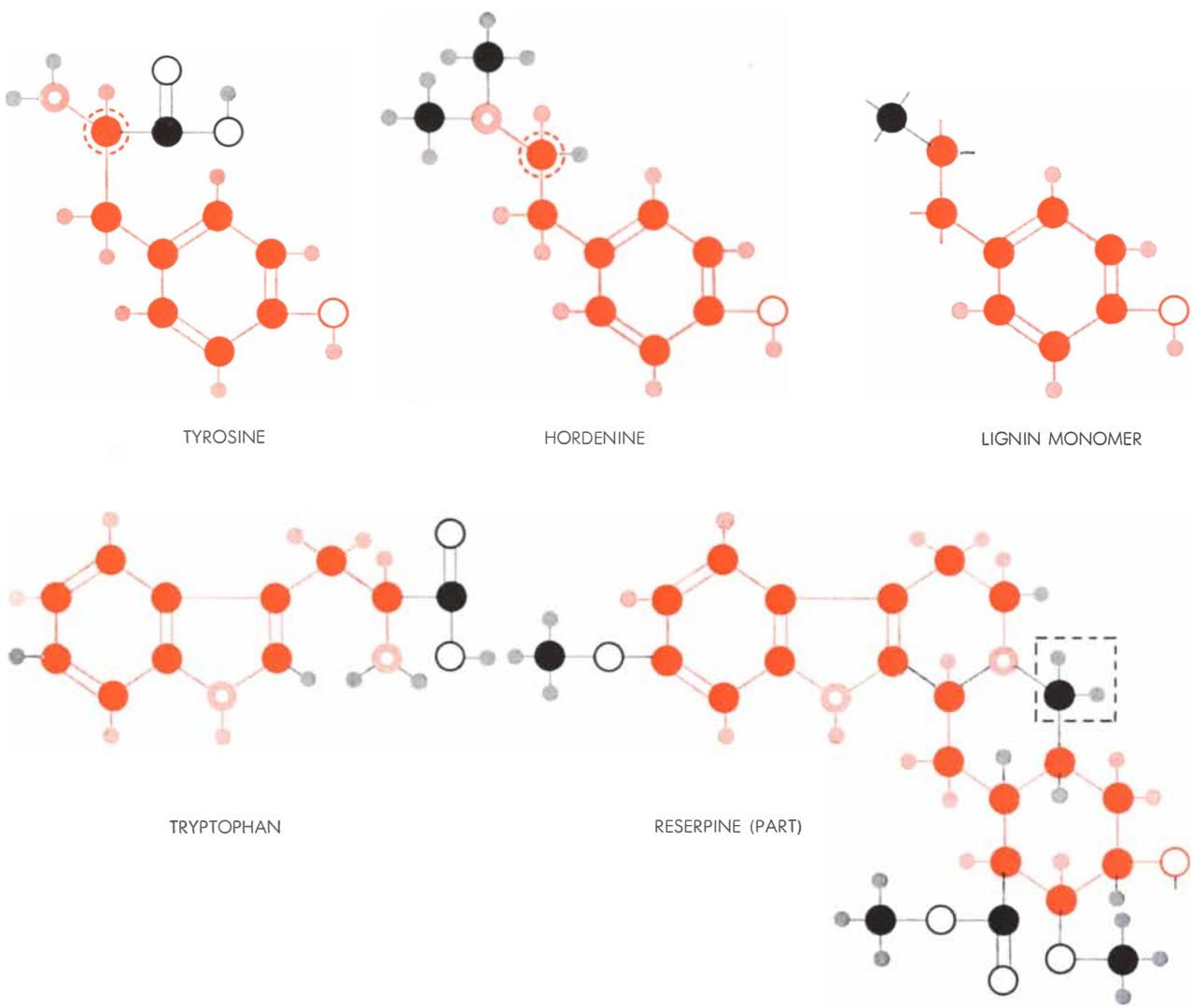
the "plastic" that binds the cellulose fibers in the structure of plants. To be sure, not all plants employ hordenine as an intermediate in making lignin [see "Lignin," by F. F. Nord and Walter J. Schubert; SCIENTIFIC AMERICAN, October, 1958]. But it is gratifying to find at least one case in which an alkaloid performs an identifiable function. Similarly, Edward Leete of the University of Minnesota has shown that in some plants nicotine serves as a "carrier" for methyl groups which it ultimately donates to other molecules.

Such modest findings are a far cry from the first grand-scale function assigned to alkaloids a century ago by the great German chemist Justus von Liebig. Since most alkaloids are alkaline, he proposed that plants use them to neutralize deleterious organic acids by forming salts with them. Many alkaloids do, in fact, occur in plants as salts of organic acids. But no one could explain why alkaloid-producing plants should elaborate poisonous acids when closely related plants manage to get along without either the acids or their metabolic antagonists. The question "Why?" still persists. Today it stimulates more modest but sometimes quite intriguing proposals.

Some experiments by the French physiologist Clément Jacquiot suggest a variant of Liebig's neutralization theory. Jacquiot has shown that the tannin produced in cultures of oak cells inhibits cell growth. The alkaloid caffeine counteracts the effects of the tannin and allows growth to proceed. Unfortunately this suggestion merely replaces one question with another, since the function of tannins in plants is itself unknown. The suggestion has another flaw in that oak cells produce no caffeine of their own. But here, at any rate, is one case in which caffeine is good for something other than providing a pleasant stimulant for coffee-drinkers.

Botanists and ecologists have speculated that the bitter taste of some alkaloids may discourage animals from eating a plant that contains them, and that poisonous alkaloids may kill off pathogenic organisms that attack the plant. One species of wild tomato does produce an alkaloid that protects it against Fusarium wilt, a common fungus disease of the cultivated tomato. However, the "protection" idea must be handled with

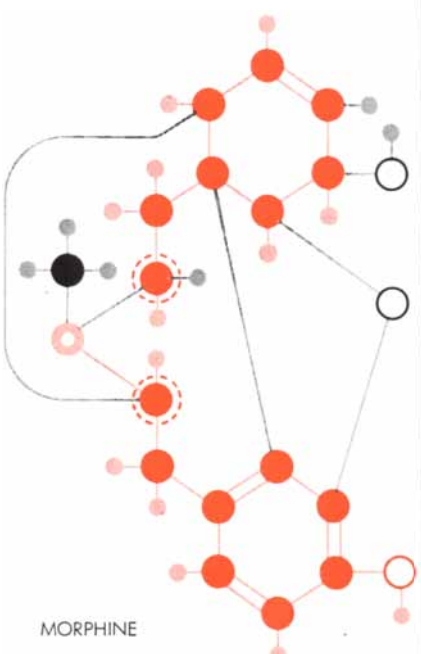


AMINO ACIDS appear to be the source of most alkaloids. Thus the skeleton (*color*) of tyrosine, an amino acid, can be easily transformed into hordenine, an alkaloid; broken circles indicate the "labeled" atoms which confirm the synthesis. Two tyrosine skeletons similarly form morphine, as shown at right; the morphine molecule shown here is distorted (*see diagram on page 115*) to emphasize its derivation. Tyrosine and tryptophan, another amino acid, could join with a methylene group (*broken square*) to form part of the molecule of reserpine, an alkaloid tranquilizer. Hordenine is one of the few alkaloids known to undergo further metabo-

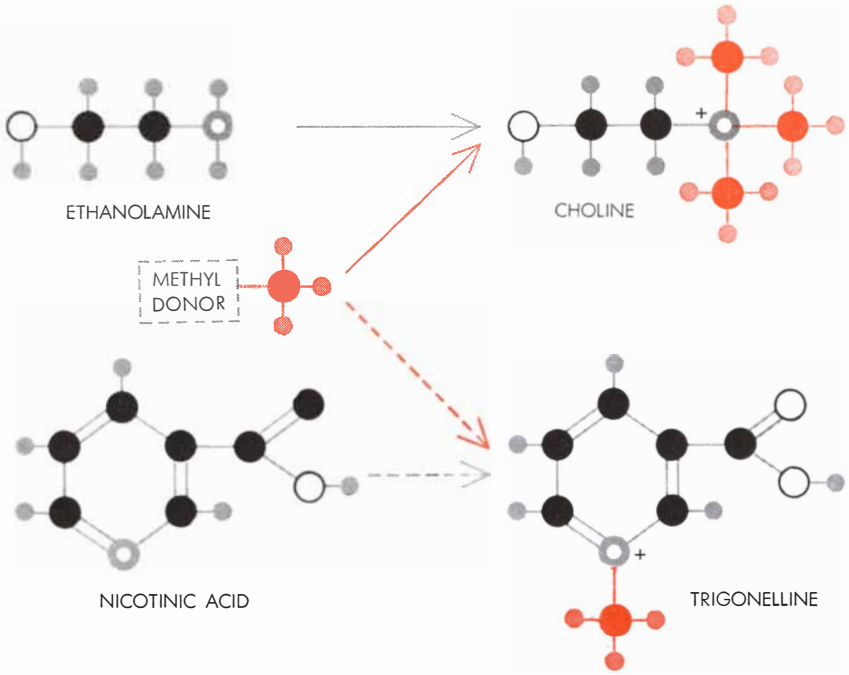
caution because of its anthropocentric bias. What is unpalatable or poisonous to a man may be tasty and nourishing to a rabbit or a cutworm.

More recently the concept of chelation, the process by which certain organic molecules "sequester" the atoms of metals, has suggested another possible alkaloid function. The structures of some alkaloids should permit them to act as chelating agents. The structure of nicotine is temptingly similar to that of dipyridyl, a common chelating agent for iron [*see illustration at bottom of page 121*]. Such alkaloids might help a plant select one metal from the soil and reject others. Alternatively, they might facilitate the transport of the metal from the roots, where it is absorbed, to the leaves, where it is utilized. Quite a few alkaloids, including nicotine, migrate from roots to leaves, but no one has yet determined whether any of them carry metals along with them.

The structures of many alkaloids re-



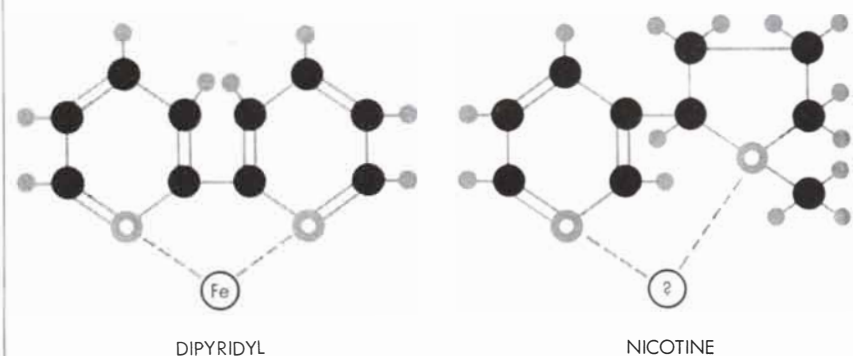
lism in plants; it is converted into one of the units that form the long-chain molecules of lignin, an essential structural material in many plants. The complete structure of the lignin monomer is not known.



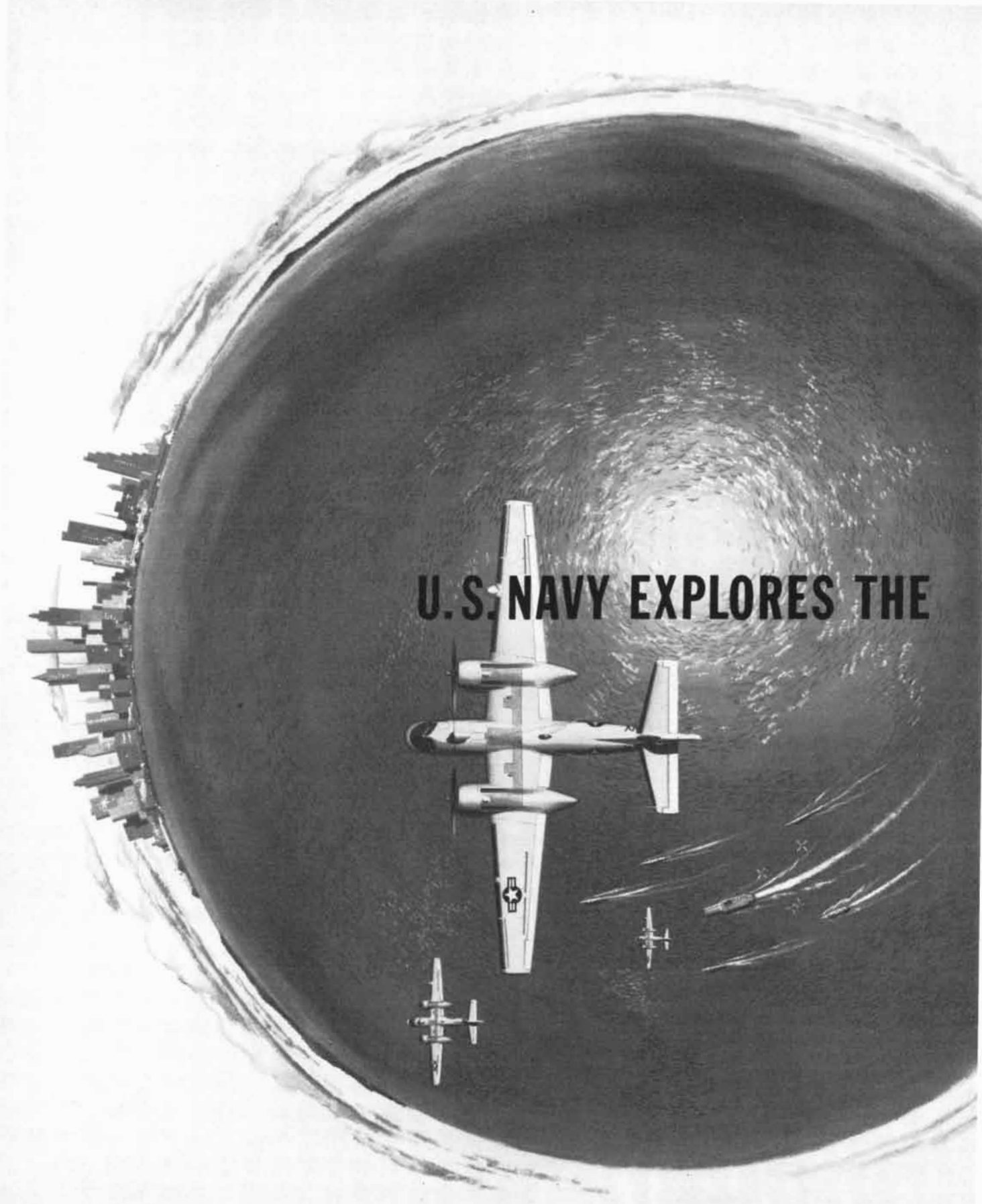
METABOLIC ACCIDENTS may account for the synthesis of some alkaloids. Changing one compound to another by adding methyl groups (*color*), as in the ethanolamine-choline transformation, is a common biochemical process. If a methyl group were added "by mistake" to nicotinic acid, a common plant substance, the alkaloid trigonelline would result.

semble those of hormones, vitamins and other metabolically active substances. This resemblance suggests that such alkaloids may function as growth regulators. In a way this hypothesis fits in with the chelation theory, since certain important growth regulators seem to owe their activity to their chelating capacity. Some alkaloids do affect growth processes: Alkaloids from the seeds of certain lupines can inhibit the germination of seeds of related species that produce no alkaloids. Presumably they help the former species to compete successfully with the latter. Similar alkaloids may function as "chemical rain gauges" which prevent germination until sufficient rain has fallen to leach them away and provide adequate moisture for plant growth. Many plants in arid and semi-arid environments depend on such rain gauges for survival [see "Germination," by Dov Koller; SCIENTIFIC AMERICAN, April].

No one theory can account for the functions of so heterogeneous a group of compounds. The steroid compounds, a much smaller and structurally a far more homogeneous group, play a wide variety of physiological roles. Future research will probably reveal an even greater functional diversity among the alkaloids. Certainly we must learn a good deal more about the functions of a few alkaloids before we can safely propose generalizations about all of them.



STRUCTURE OF NICOTINE resembles that of dipyridyl, a compound that can "chelate" or bind atoms of iron. This similarity suggests that nicotine, and perhaps other alkaloids, may function as chelating agents in some plants. Whether they actually do so is not yet known.



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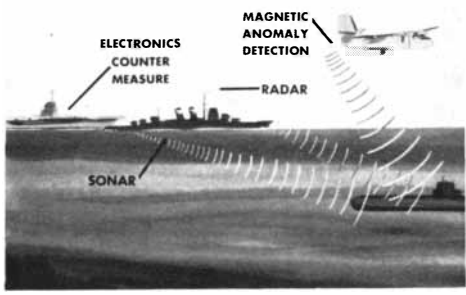
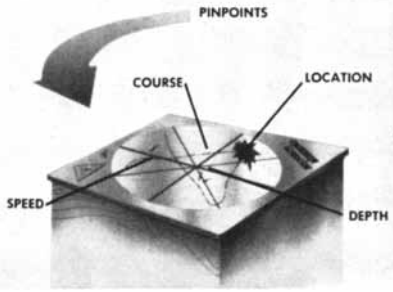


Detection with latest electronic equipment enables the ASW force to determine the enemy's presence.

LOCALIZATION Of Target

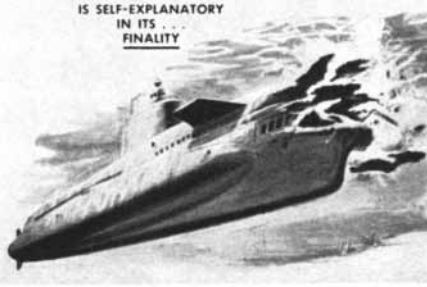


Localization starts immediately, plotting general location of enemy sub.

CLASSIFICATION Of Target

Classification utilizes sophisticated electronics equipment to determine exact nature of intruder.

DESTRUCTION Of Target



The Moment of Fertilization

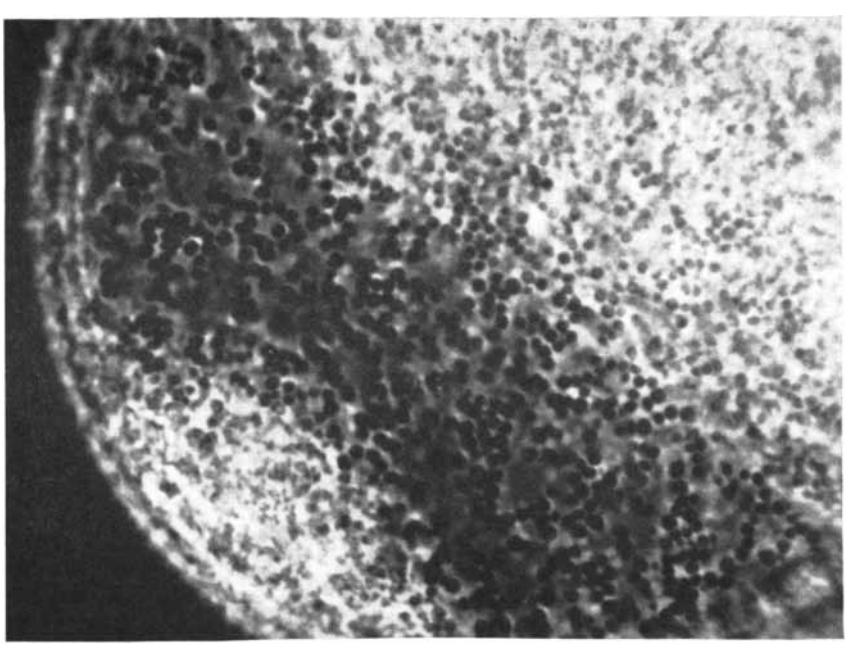
When a sperm attaches itself to the surface of an egg, the egg is almost immediately impervious to other sperm. What happens in the egg during this critical biological event?

by Robert D. Allen

The moment of fertilization marks the beginning of a new life through the mating of two specialized cells: an egg and a sperm. Although it constitutes but a tiny fraction of the life span of the individual, no other time is more crowded with important events. Not the least of these is the one which provides that the egg will be fertilized by only one sperm. As Aldous Huxley observes in his "Fifth Philosopher's Song": "A million million spermatozoa,/All of them alive:/Out of their cataclysm but one poor Noah/ Dare hope to survive." If more than one sperm succeeds in entering the egg, further development is almost invariably deranged. Upon making contact, the fertilizing sperm triggers reactions in the egg that exclude supernumerary sperm and activate the cytoplasm of the egg for the events that are to follow. In a sense the life of the new individual may be said to begin at this first contact. After three generations of investigation we cannot yet fully describe and sort out everything we see happening during that moment.

Nature equips the sex cells with the basic structures common to most cells—a nucleus containing genetic material, mitochondria to provide energy, a host of enzymes to synthesize the materials needed for growth, and so on—but each of the two cells is highly specialized for its unique role. The sperm, which is small and active, has a three-part structure, consisting of a head, a middle piece and a tail, designed to accomplish four main tasks, all usually within the space of a few minutes. First it must swim to the egg. It does so by means of an "engine in the rear," energy from mitochondria in the middle piece driving the whiplike tail. Second, the sperm must become attached to the egg. Third, it activates the egg to begin the processes leading to embryonic development. Fourth, after it has become incorporated in the egg it provides the nucleus containing the paternal set of genes.

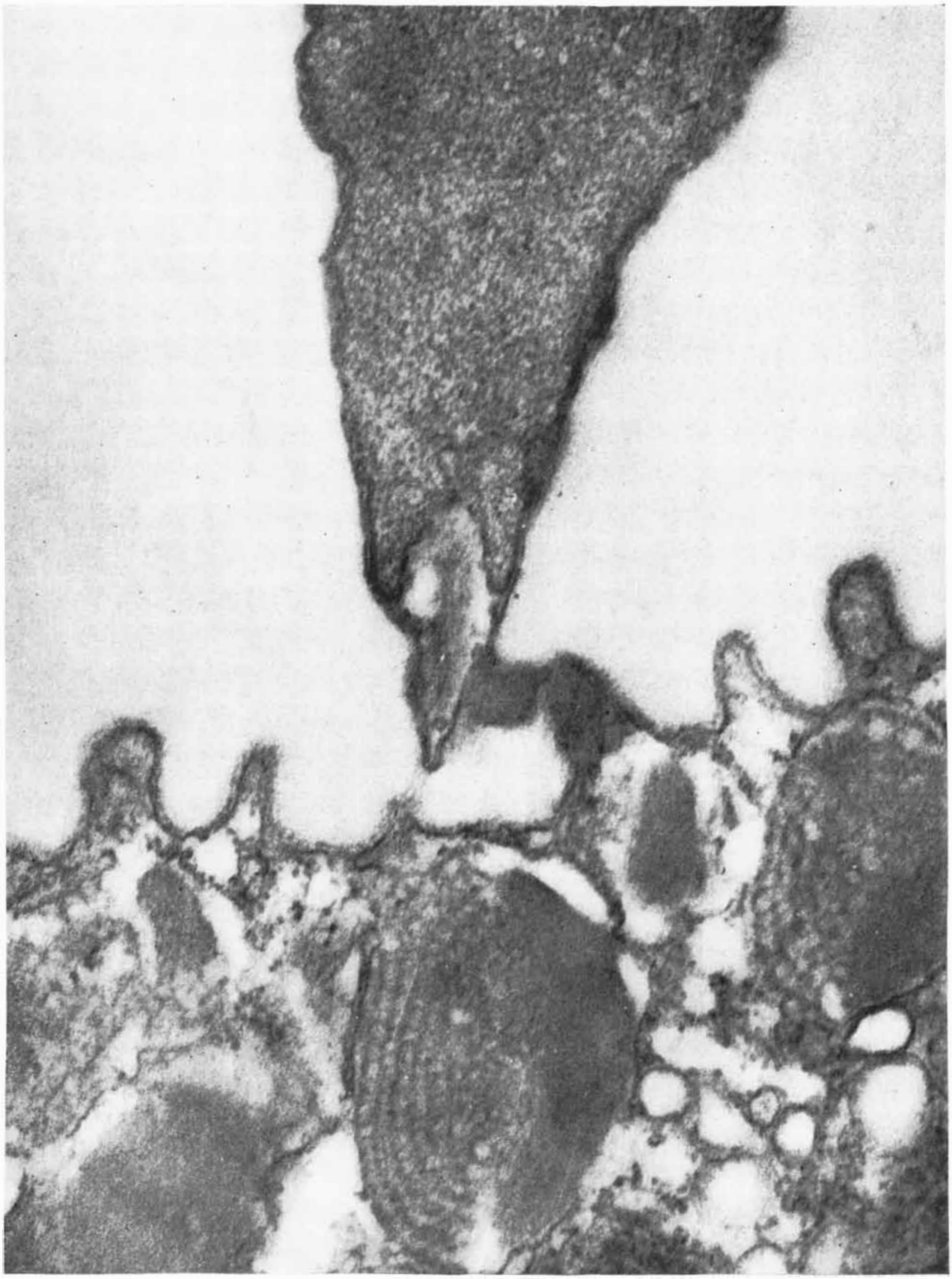
The egg, in contrast to the sperm, is a huge, immobile cell. Its first function is to be receptive to one fertilizing sperm and to reject all others. For its role in embryonic development its cytoplasm is loaded with stored foods to provide energy and building materials, and its nucleus contains the maternal genes. Despite their food reserves, the eggs of most species die within a matter of hours if they are not fertilized. Thus, for the egg, fertilization is a particularly urgent business.



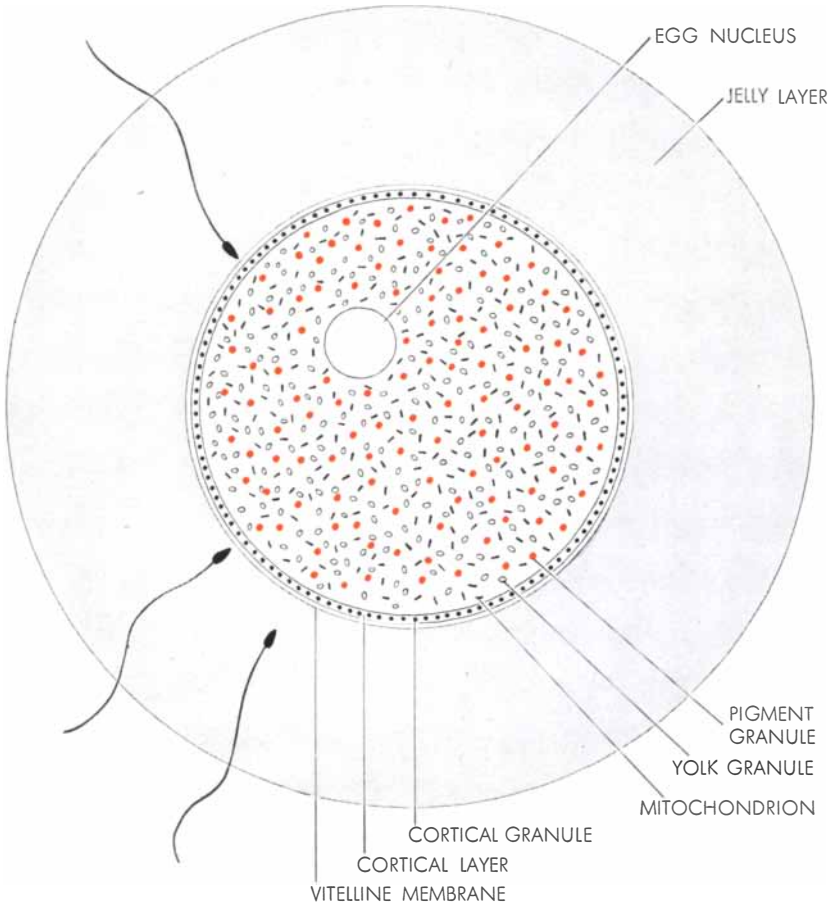
SEA-URCHIN EGG, enlarged about 1,800 diameters in this phase-contrast photomicrograph, contains many cortical granules (*small dark spheres*) before fertilization. These granules explode and disappear within seconds after the fertilizing sperm attaches itself to the egg.

The process of fertilization has been studied most extensively in the sea-urchin egg, which is without doubt the biologist's favorite egg. Sea urchins and their echinoderm relatives, the sand dollars and starfish, can be picked up along the shore at low tide or dredged at moderate depths on most seacoasts. A fully mature female sea urchin may, when tickled by a gentle electric current, yield millions of eggs; some males may contain 100 billion sperm!

Unlike plant sperm, which are attracted by chemical substances released by the egg, the sperm of sea urchins and other animals are apparently "unguided missiles," arriving on target quite by



HEAD OF A SPERM (*large triangular structure at top*) **is enlarged about 70,000 diameters in this electron micrograph made by Bjorn Afzelius of the Wenner-Gren Institute in Stockholm. The sperm has attached itself to the sea-urchin egg** (*bottom*) **by a filament extruded from the "acrosome"** (*diamond-shaped area*) **at its tip. The two oval structures within the egg are cortical granules.**



EGG OF SEA URCHIN ARBACIA, diagrammed in cross section, is shown before (*top*) and after (*bottom*) fertilization. Within seconds after sperm attachment the cortical granules disappear and the fertilization membrane forms during the so-called cortical reaction. Later the hyaline layer appears, and the pigment granules move outward to the surface of the egg.

chance and by virtue of their numbers. A spermatozoon responds to the presence of an egg, even to sea water that has merely contained eggs, by suddenly producing a filament at its front end from a structure called the acrosome (from the Greek word for "sharp body"). The filament forms so rapidly that no one knows the details or mechanism of the process.

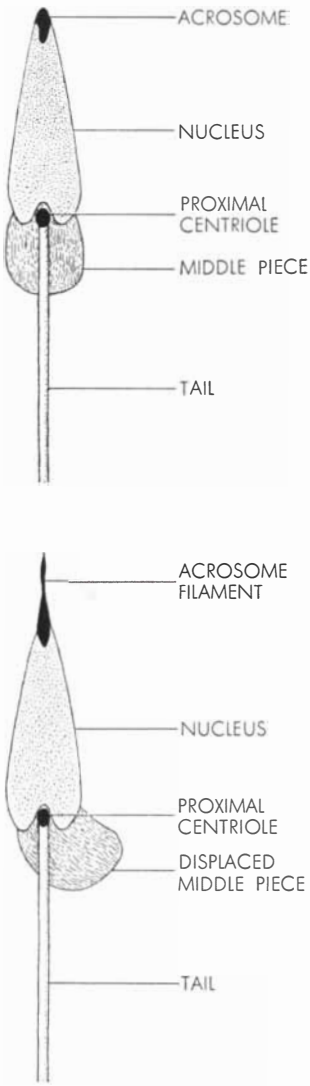
As soon as the fertilizing spermatozoon has attached itself to the egg by means of the filament, the egg can be considered fertilized; this, however, is only the start of events leading to a complete union of the two cells. Within about a minute a series of spectacular changes takes place in the outer layer or cortex of the egg. These somehow "close the door" to other sperm. At the same time changes begin to take place inside the egg. The cytoplasm of the egg creeps up the acrosomal filament of the sperm and simultaneously withdraws from the tip of the filament, thus forming a funnel-shaped path which reaches into the interior of the egg. The filament is apparently anchored to the base of the funnel, and serves as a handle by which the sperm is drawn inside.

As the sperm, complete with tail, moves deeper into the egg, it disappears from view. Its nucleus, however, reappears near the center of a system of rays, the "sperm aster," which reaches out into the surrounding cytoplasm. The astral rays gradually extend to the cortex of the egg and apparently serve to guide the sperm nucleus toward the center of the cell. The egg nucleus also moves to the center, where the nuclei finally meet. The whole process, from the attachment of the fertilizing sperm to the union of the nuclei, takes only an hour or so. Then, with the formation of the mitotic spindle and the first cleavage of the cell, fertilization is completed and embryonic development has begun.

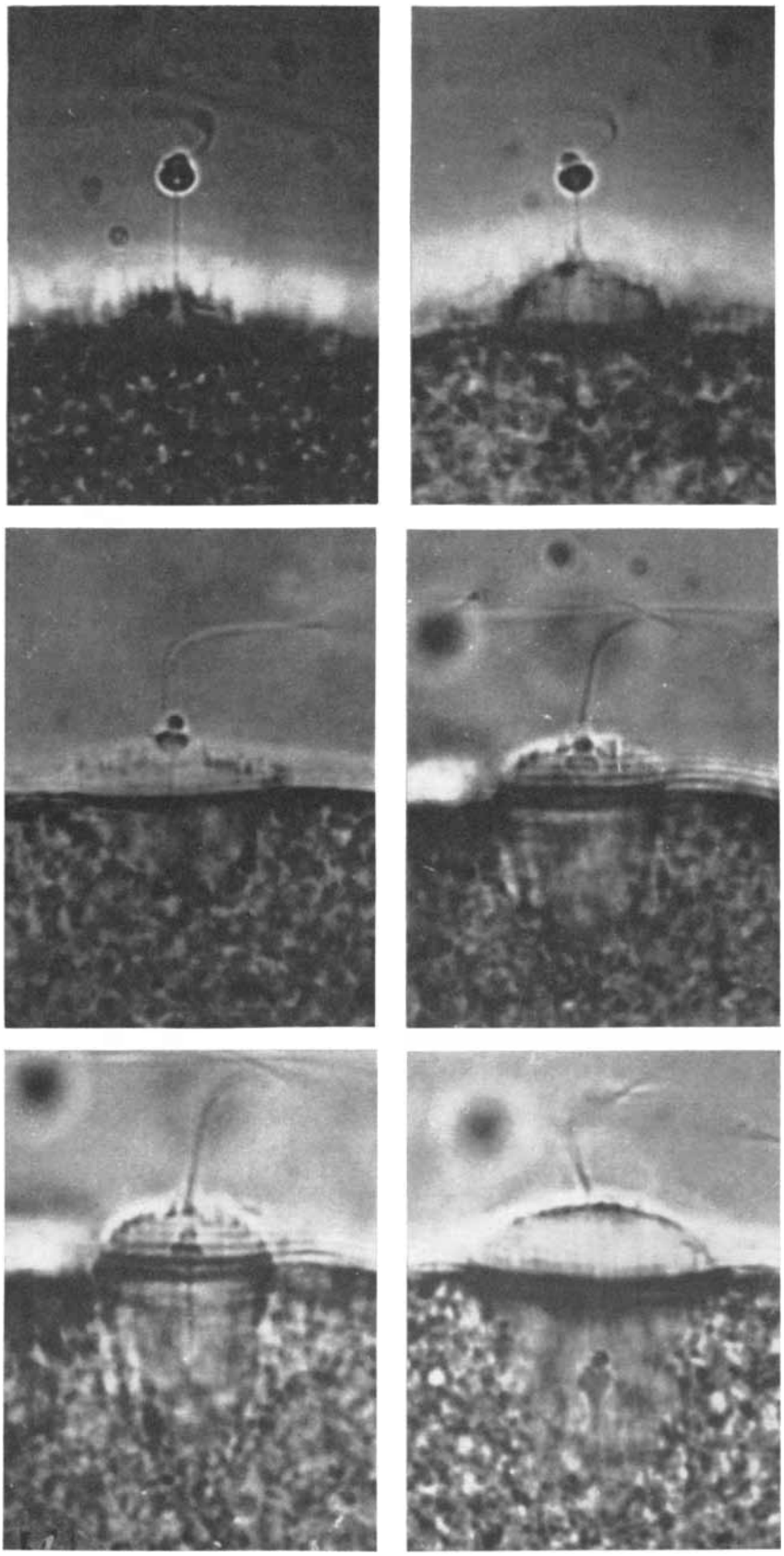
This broad outline of the process does not begin to suggest the complexity of events at each stage, starting with the very first. In the sea-urchin egg, at the instant the first sperm makes effective contact, a most intriguing transformation sweeps over the egg's cortex. The process was first adequately described by the French biologist Hermann Fol in 1879; he actually watched a sperm enter a sea-urchin egg, a rare privilege because of the small likelihood that the restricted area of the egg being watched through a microscope will contain the fertilizing sperm. We now have a fairly detailed picture of the reaction, thanks especially to the work of John Runn-

ström of Sweden and I. Motomura and Yanuparo Endo of Japan.

The unfertilized sea-urchin egg is surrounded by a thin membrane, the so-called vitelline membrane; the cortex beneath contains a layer of granules. In a dark-field microscope, which presents the subject against a dark background, the egg appears to have a thick, yellowish surface. Soon after the sperm attaches, the surface of the egg seems to whiten in a wave of transformation that spreads from the point of attachment. This color change is accompanied by the almost explosive breakdown of the granules in the cortex. Simultaneously a colloidal material released from the ex-



SPERM OF A SEA URCHIN is diagrammed before (*top*) and after (*bottom*) "acrosome reaction." When stimulated by presence of eggs, sperm expels acrosome filament, and middle piece is displaced to one side.



ENTRY OF SPERM into the living egg of the sea cucumber *Holothuria atra* was photographed at various stages in different eggs by Arthur and Laura Colwin of Queens College. The egg cytoplasm bulges up around the acrosome filament of the sperm (*two pictures at top*) and the sperm gradually moves into the funnel-shaped path which opens beneath it (*next three pictures*). Finally sperm has moved completely into the egg (*last picture*).

ploding particles pulls water beneath the vitelline membrane by osmotic pressure. The membrane, now called the fertilization membrane, is thereby separated and lifted away from the egg surface. Materials from the granules apparently add to the fertilization membrane and strengthen it.

As Frank R. Lillie showed in 1911 at the Marine Biological Laboratory in Woods Hole, Mass., the attachment of the fertilizing sperm also sets off changes in the cytoplasm within the egg. Lillie pulled the fertilizing sperm away from the egg surface while it was still attached only by its acrosomal filament (the existence of the filament was not yet known at the time), and found that development proceeded in the egg to the stage where the sperm nucleus is required. Indeed, full embryonic development may be initiated in the eggs of some species (including frogs and rabbits) by salt solutions, electric shock and a host of other artificial agents. This was shown by Jacques Loeb of the University of Chicago and Thomas Hunt Morgan of Columbia University in the first demonstration of artificial parthenogenesis at the turn of the century. Even in these eggs membrane elevation and the other features of the cortical reaction accompany activation.

A few years ago, while I was visiting Runnström's laboratory at the University of Stockholm, I tried to find out whether the cortical reaction was essential to the initiation of development. The most direct approach was to see if the propagation of the cortical reaction could be blocked part of the way around the surface of the egg. Luckily the first effort worked: By sucking the eggs into small glass capillaries I could deform them from spheres into cylinders with round ends. By means of a finer pipette I introduced a group of sperm at one end. Then, watching through a microscope, I could see the cortical granules exploding in a wave sweeping over the egg surface from the fertilized end. If the eggs had been sufficiently stretched and also warmed a few degrees above normal, the cortical reaction gradually slowed down and stopped along the cylindrical part of the egg. Later Berndt Hagström and I found that slight warming alone, or treatment with the drug nicotine, would often block the cortical reaction without the use of constricting tubes.

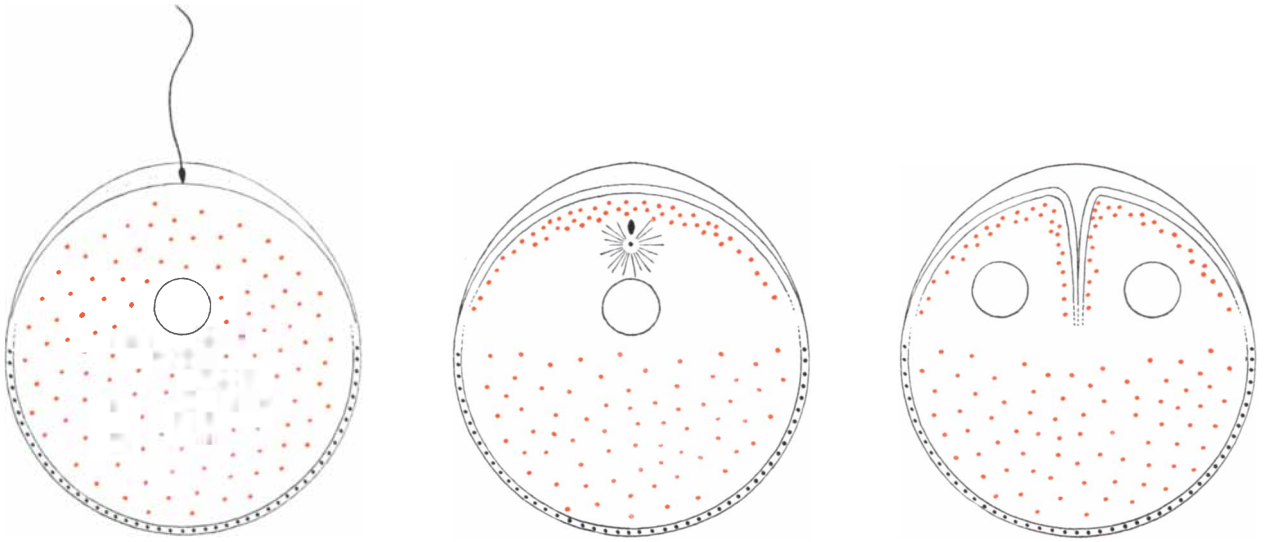
Eggs with blocked cortical reactions are strange indeed. The surface transformed by the cortical reaction looks just like the surface of a fertilized egg. On

the other hand, the surface not reached by the cortical reaction is indistinguishable from the surface of unfertilized eggs. In fact, even after an hour or more a second sperm can enter any "unfertilized" surface of these "partially fertilized" eggs. The cytoplasm beneath the two different kinds of cortex shows a corresponding contrast: beneath the fertilized cortex it looks like the cytoplasm of a fertilized egg and beneath the unfertilized cortex it looks like the cytoplasm of an unfertilized egg. Furthermore, neither the egg nucleus nor the sperm nucleus can move toward the center of the egg unless the surrounding cytoplasm lies beneath fertilized cortex. This is particularly clear in the case of eggs fertilized in capillary tubes, for here the border between fertilized and unfertilized cytoplasm remains almost entirely distinct, whereas in spherical eggs, the two kinds of cytoplasm undergo some mixing.

The eggs of the sea urchin *Arbacia* show still another difference between fertilized and unfertilized cytoplasm. These eggs contain many beautiful red pigment-granules which are distributed more or less at random throughout the cytoplasm before fertilization, but which migrate to the egg surface about 10 minutes after the sperm has become attached. In partially fertilized eggs the pigment granules migrate only to that portion of the surface transformed by the cortical reaction. This part of the egg surface can somehow attract pigment granules from a considerable distance in the cytoplasm; the unfertilized surface, however, has no such attractive power. These eggs are promising subjects for further study of the part played by the cortical reaction in the initiation of development.

Partially fertilized eggs can divide, but cleavage is blocked in approximate proportion to the amount of unfertilized cortex present. If the cortical reaction covers about half the surface, the eggs usually achieve at least the start of cleavage. Thus it appears that the cortical reaction that initiates the process of fertilization constitutes a necessary link in the chain of events leading to development of the embryo; it is not a useless incident of fertilization.

But the cortical reaction holds other interest for the biologist. Ever since Fol first observed the reaction, investigators have suspected that it had the function of preventing excess sperm from penetrating the egg. If we were to build a hypothetical egg, and had to devise a mechanism to prevent more than one



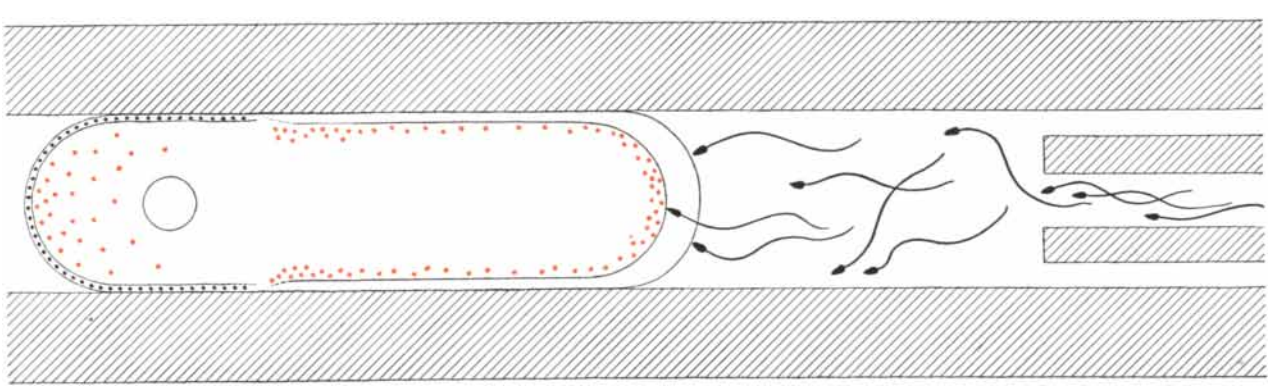
"PARTIALLY FERTILIZED" EGG is the result of blocking the cortical reaction before it is complete. At left is a diagrammatic cross section of an *Arbacia* egg 30 seconds after sperm attachment. If the cortical reaction is stopped at this point, the hyaline layer forms only on the part covered by the cortical reaction, and the red pigment-granules migrate to the surface only in this area (*middle*). Later, when and if the cell starts to divide, the furrow usually cuts through the fertilized cortex, then stops (*right*).

sperm from entering it, we would undoubtedly try to invent some kind of "curtain" that could be drawn over the surface of the egg as soon as the first sperm had attached. The idea naturally occurred to a number of workers that some part of the cortical reaction served this purpose.

Fol himself believed that the barrier was set up by the elevation of the fertilization membrane. Later workers came to doubt this, however, because eggs from which the membranes had been removed failed to admit sperm when reinseminated. Hagström showed that eggs deprived of membranes are protected from invading sperm by a thin layer of jelly-like substance, the "hyaline layer," which appears on the egg surface within a few minutes after the fertilizing sperm attaches. When he removed this layer chemically from fertilized eggs, sperm were able to penetrate, even into eggs that had started to develop and had divided several times. Under normal circumstances, therefore, the egg is doubly protected by the fertilization membrane and by the hyaline layer, either of which can stop supernumerary sperm from penetrating.

Unhappily we now know that neither of these structures entirely satisfies the specifications of our hypothetical curtain. The missing element is speed. The egg rejects additional sperm almost immediately after the fertilizing sperm has become attached. Lord Rothschild of the University of Cambridge and M. M. Swann, now at the University of Edinburgh, showed a decade ago that the hypothetical curtain would have to cover the egg in a couple of seconds or less. On the other hand, they found that it takes 20 seconds for the visible changes to spread over the egg surface. Their experiments seemed to exclude any possibility that the cortical reaction might be involved in the initial block against sperm.

About five years later, however, Hagström and I examined the resistance to sperm of partially fertilized eggs, inhibiting the cortical reaction by warming the eggs suddenly in a spermicidal solution several seconds after sperm attachment. We reasoned that if some kind of "rapid block" had been established, then even the surface of the egg not yet reached by the cortical reactions should be resistant to further invasion. But this was not the case! Sperm entered easily wherever unfertilized cortex was present. Either there is no rapid block in the



CORTICAL REACTION WAS BLOCKED in one of the author's experiments by putting a sea-urchin egg into a capillary tube (*hatched area at top and bottom*). Sperm introduced at one end with a finer tube (*far right*) started a cortical reaction in the rounded part of the distorted egg, but the reaction died out along the straight sides before it had covered the whole surface of the egg.

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PAPER TAPE READER

Punched paper tape from almost any device or system equipped with a punch can now be read directly and at high speed into the Bendix G-15 computer. The unique Model PR-2 photoelectric reader accepts paper tapes *punched in any numeric* code by cash registers, accounting machines, adding machines, typewriters, analog-to-digital converters, and similar devices, whether operated manually or as part of an automatic data collecting system.

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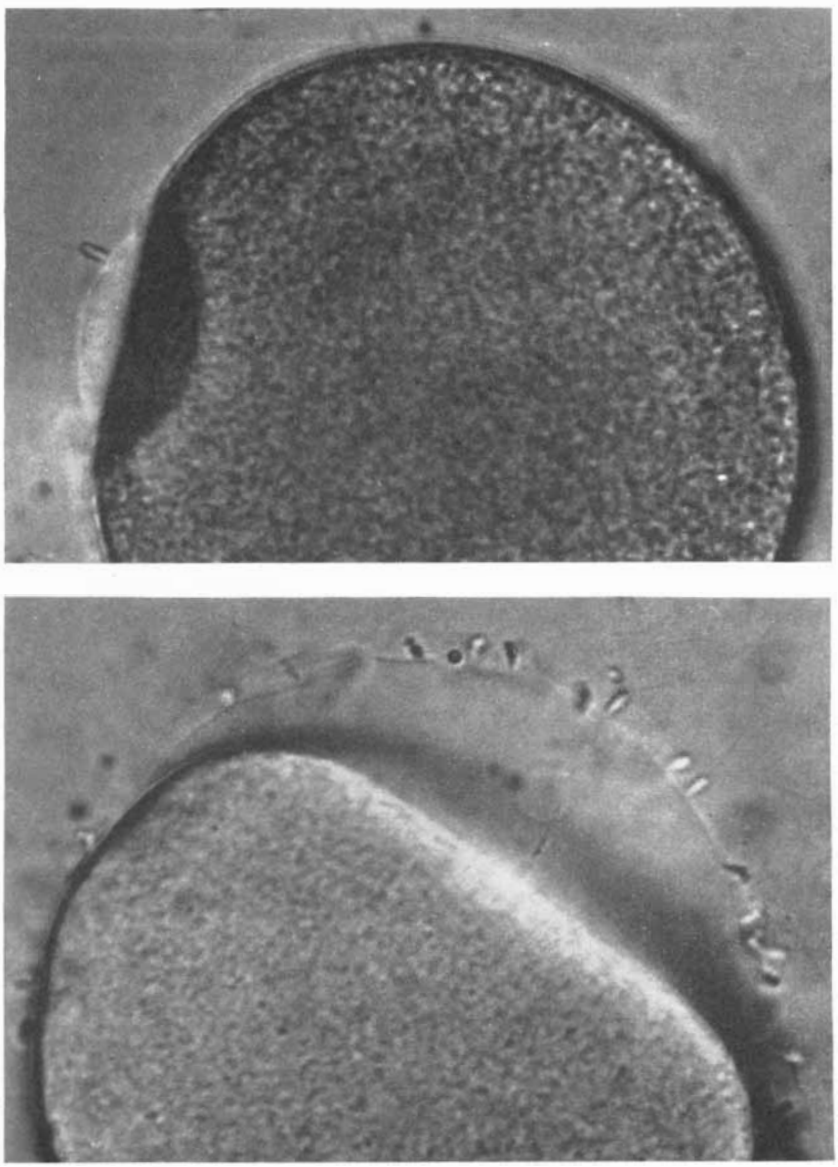
"curtain" sense, or it is temporary, effective only until the mechanical barriers of the fertilization membrane and hyaline layer can form.

J. L. Griffin and I have recently succeeded in timing more exactly the structural processes of the cortical reaction. We could not, of course, depend on microscopic observation of single eggs to determine the times at which the successful sperm attaches, the cortical granules begin to break down, the membrane begins to elevate and the sperm begins to enter the cytoplasm. Instead we sampled a large batch of eggs at intervals of a few seconds after fertilization. Half of each sample was mixed with a detergent solution, and the other half was mixed with formalin. The detergent solution killed only unattached sperm and allowed eggs to which sperm already had attached to develop. The formalin killed both eggs and sperm and "fixed" them. By comparing the sampling time at which we found that 50 per cent of the detergent-treated eggs had been fertilized with the time at which we found that cortical reactions had started in 50 per cent of the formalin-fixed eggs, we found that there was a 17-second lag, or "latent period," between attachment of the fertilizing sperm and the beginning of the cortical



FORMALIN-FIXED EGG at top was killed some 20 seconds after sperm attachment. The cortical reaction had just begun, but after fixation the fertilization membrane (*outer layer of light area at left*) elevated and pulled the fertilizing sperm from the cortex (*dark layer around egg*). Egg at bottom was fixed half a minute later; its cortical reaction was still incomplete, but the fertilizing sperm (*barely visible on flattened part of egg*) had started to penetrate the cortex. Supernumerary sperm are attached to the fertilization membrane.

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reaction. This left no doubt whatever that the cortical reaction is not only too slow but also starts much too late to play a "curtain" role in the initial rapid block against excess sperm.

Yet the question of how the egg withstands the approach of dozens or hundreds of sperm during its latent period still remains. Surely some protective mechanism exists. There is one other way in which the cortical reaction may conceivably play this role. It used to be thought that the sperm passed into and through the egg cortex within a few seconds after attachment, but observations of our formalin-fixed sea-urchin eggs show that this is not true. At 35 seconds after attachment, when the cortical reaction covers only 50 to 75 per cent of the egg surface, the fertilizing sperm is just beginning to sink into the cortex. At the same time we can see in a dramatic way how the fertilization membrane might provide protection; even after the egg has been killed in formalin the elevation of the membrane yanks other sperm out of the surface of the egg. The delay in the penetration of the fertilizing sperm may thus give the cortical reaction a chance to help in preventing other sperm from entering. But this deduction leaves other questions unanswered. For example, how does the egg prevent a cortical reaction from starting at each point of sperm attachment?

While most of us have been looking for some kind of a "curtain" mechanism to explain how eggs keep out extra sperm (indeed, hopes are high that such a mechanism will be found), some investigators have considered another possibility. The egg may somehow choose which attached sperm should initiate the cortical reaction. Seiji K. Wada of Japan has recently made an intriguing observation along these lines. He has described a process by which the egg of the mussel appears to "pull in" the fertilizing sperm while at the same time rejecting the supernumerary sperm. It is too early to say how the mussel egg accomplishes this feat, let alone to speculate on the possible occurrence of a similar process in sea urchins. When fertilization has been carefully studied in many more kinds of eggs, we may be in a better position to explain how it happens that the offspring of sexual reproduction have only one father. The importance of this question is suggested by the second verse of Huxley's "Fifth Philosopher's Song": "And among that billion minus one/Might have chanced to be/Shakespeare, another Newton, a new Donne—/But the One was Me."

FLUORINE BOMB CALORIMETRY

Fluorine bomb calorimetry has been considered by many a thermochemist as he vainly struggled to react a stubborn compound with oxygen. However, the extreme chemical reactivity of fluorine presents difficult problems in handling and containment. Recently at Argonne, thermochemists have collaborated with scientists skilled in the techniques of fluorine chemistry to make fluorine bomb calorimetry a reality. Important thermochemical data is now being obtained on substances not amenable to conventional oxidation bomb studies. Many of the compounds which are used in high temperature chemistry because of their resistance to oxidation will be studied with this promising new thermochemical tool.

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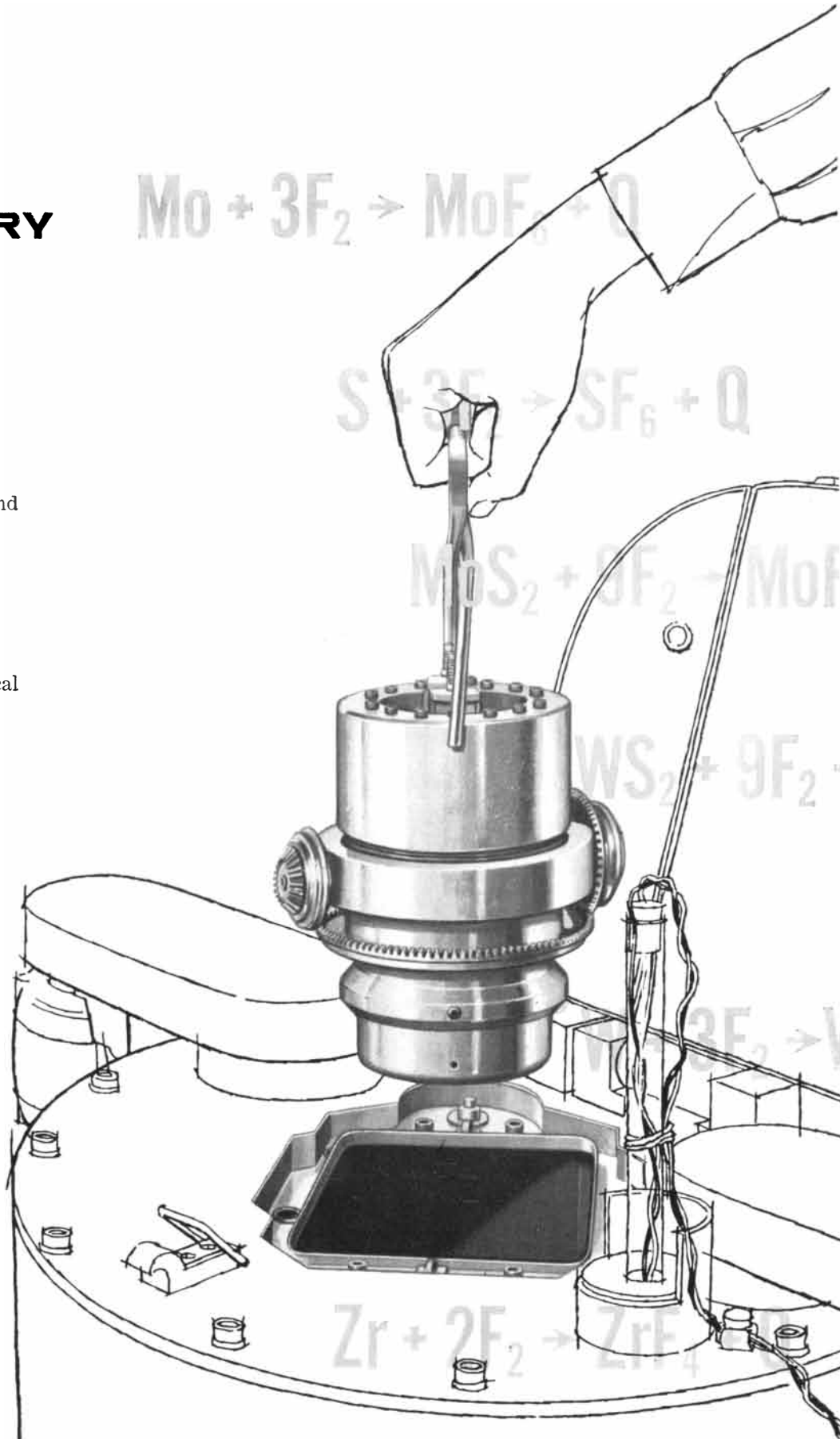

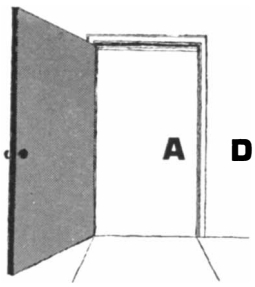

A DOOR IS OPENED... TO NEW ADVANCES IN MISSILE PROPELLANTS

". . . a high throughput, lightweight flying chemical process plant in which quantities up to the order of a ton per second of liquid (or solid) reactants are converted to hot gaseous products at a precise, automatically controlled rate."

BY NOW YOU'VE PROBABLY GUESSED that the first paragraph is a description of a rocket engine from the chemist's point of view.* Of course, there are other viewpoints, such as those of the electronics expert, or the airframe specialist. Chemicals, however, are a specialty with us, and we would like to stick to that side of the subject and cover a few of the more interesting developments in propellants for the "flying chemical process plant."

A good starting point is the question of solid and liquid fuels. Generally speaking, most solid fuels have good storability. However, we're glad to say that you can also get excellent storability with some liquids. Chlorine trifluoride and nitrogen tetroxide, for example, require no refrigeration and have been stored without difficulties for a period of over ten years. They can be shipped easily in ordinary steel containers. Both of these liquids are excellent storable oxidizers, each having certain advantages for specific missions. Let's look at some of the more important characteristics of N_2O_4. It is an effective oxidizer which can be used with most fuels, including those containing carbon. And it's effective because of high combustion efficiency. This is especially important. Generally, we feel lucky if most oxidizers reach within 90% of theoretical Isp during combustion. N_2O_4 hits well over 95% efficiency during actual combustion. In addition, count-down can be reduced to seconds with nitrogen tetroxide as an oxidizer. Since it is hypergolic with amine-type fuels, ignition is simple and reliable. Ignition delay is so brief you eliminate rough starts due to accumulation of unreacted propellants in the thrust chamber. Moreover, motors burning such propellants are throttleable.

All of this makes our chemists pleased with the product—a chemical which they really know and understand because we have produced it *commercially* (we deliberately italicized) for more than 10 years at our Nitrogen Division. If you are in the missile business and looking for a storable oxidizer, why not check with us? We have special 125-lb. and 2,000-lb. cylinders available for experimental purposes. And if you feel that's rushing it, we also have plenty of literature, including a 59-page Product Bulletin that covers everything from applications and physical properties to specifications and a bibliography.

THE BATTLE FOR THRUST OR Isp. In addition to nitrogen tetroxide and chlorine fluoride, another entry creating more and more interest in the propellant field is fluorine. Our chemists point out that fluorine is not suited for *all* missiles. But for any space projects or other special missions where ultrahigh performance is needed, they feel fluorine is worth investigating. There have been published reports, for example, that booster rocket systems for a manned satellite laboratory would consist of a 321,000-lb. thrust engine burning a hydrogen-fluorine combination for 200 seconds. This is only one of several possible applications. Naturally, the question of handling arises. Here's an area where experience counts—and that's where our General Chemical Division enters the picture.

Fluorine, as you know, once presented seemingly insurmountable problems in handling and transportation. Our research people of the General Chemical Division,

Measuring rocket power of guided missile engine in static test stand at Rocketdyne, a division of North American Aviation, Inc.

Rocket thrust chamber firings at Bell Aircraft Corporation's rocket facility.

in cooperation with the Air Force, have solved many of these problems and have come up with a safe and practical solution for transportation of liquid fluorine. They designed a refrigerated and insulated tank truck of a special type. Essentially a giant "thermos bottle," the truck consists of three horizontal tanks, one inside the other, with spaces between serving as insulating mediums. Fluorine is kept in the inner tank in a liquid state. Liquid nitrogen is located in the second tank. The nitrogen cools the fluorine below its boiling point of minus 306° Fahrenheit and keeps it liquid. In the third outside tank, a granular insulator under vacuum is used to minimize boil-off losses of liquid nitrogen. The idea has proved practical and effective.

Result: Instead of shipping six pounds of gas in a 200-lb. cylinder, we can now ship fluorine in 5,000-pound units by *tank truck;* and have been doing so for over three years.

If you are interested in learning more about practical handling methods for fluorine, and would like to hear how this material can be used wherever high specific impulse is required, why not get in touch with our product development people? They have worked with elemental fluorine for over 10 years, and would be glad to tell you some of the important things they have found out about the material as a propellant.

MORE "INPUT" for the flying chemical plant. Many other chemical materials also help put rockets into space. And some of that help comes from several of our products. Urethanes, for example, are made with isocyanates produced by our National Aniline Division. Used alone, or combined with polyester resins, these materials form combustants and binders for solid fuels. They also cushion sensitive instruments.

From our Plastics & Coal Chemicals Division come high-temperature-resistant phenolic resins which show possibilities for use in the fabrication of rocket nose cones. Also, from this same division, come polyester resins which are used in reinforced plastics in certain parts of rockets now under test.

Basic chemicals play important roles, too. Hydrogen peroxide, hardly a new product, is made by our Solvay Process Division. It was originally used as an oxidizer in the German V-2 rockets and in early American rocket developments. It has now been replaced by more sophisticated chemicals and is employed in some specialized applications. And MUTUAL chromic acid from Solvay is used in the chrome plating of precision parts for guided missile components.

THESE APPLICATIONS, *however, are only a few of what we like to call the chemical side of the missile and propellant business. If you want to find out more about any of the subjects we have discussed, we would be glad to share our background and experience with you. Please write to Allied Chemical Corporation, Dept. 79-S, 61 Broadway, New York 6, N. Y. (In Canada: Allied Chemical Canada, Ltd., 1450 City Councillors Street, Montreal.)*

*Quotation cited from article entitled "Rocket Propellants" by R. J. Thompson, Jr., appearing in *Chemical & Engineering News,* June 23, 1958.

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BASIC TO AMERICA'S PROGRESS

MATHEMATICAL GAMES

About Origami, the Japanese art of folding objects out of paper

by Martin Gardner

Among the many aspects of Japanese culture that have recently engaged the interest of Americans is Origami, the ancient Japanese art of paper-folding. Several books on the subject are now available in English, an Origami workshop flourishes in Manhattan (sponsored by Mrs. Harry C. Oppenheimer, who also edits a new periodical called *The Origamian*), and the country's first paper-folding exhibit is open to the public through the summer at Cooper Union's Museum for the Arts of Decoration in New York.

The origins of Origami are lost in the haze of early Oriental history. Folded-paper birds appear as kimono decorations in 18th-century Japanese prints, but the art is certainly many centuries older in both China and Japan. At one time it was considered an accomplishment of refined Japanese ladies; now its chief practitioners seem to be the geisha girls and Japanese children who learn it in school. During the past 20 years there has been a marked upsurge of interest in Origami in Spain and South America. The great Spanish poet and philosopher Miguel de Unamuno helped pave the way by writing a mock-serious treatise on the subject and developing a basic fold that led to his invention of many remarkable new Origami constructions.

Traditionally Origami is the art of folding realistic animals, birds, fish and other objects from a single sheet of paper, without cutting, pasting or decorating. In modern Origami these restrictions are sometimes by-passed—a small scissor-snip here, a dab of paste there, a penciled pair of eyes and so on. But just as the charm of Oriental poetry lies in suggesting as much as possible with a minimum of words and within a rigid framework of rules, so the attraction of Origami lies in the extraordinary realism that can be obtained with nothing more than a square of paper and a pair of deft hands. A sheet is folded along dull geometrical lines. Suddenly it is transformed into a delicate piece of miniature semi-abstract sculpture that is often breathtakingly lovely.

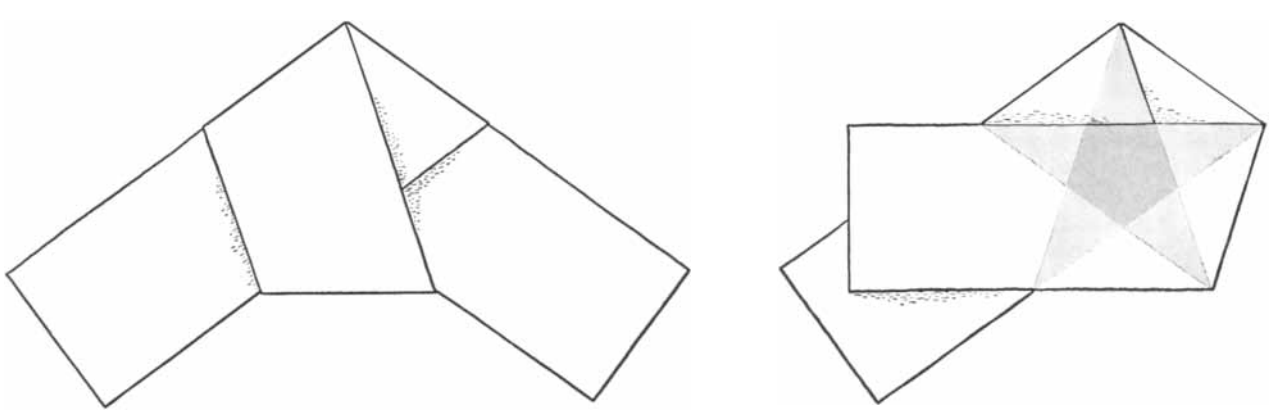
In view of the geometrical aspect of paper-folding, it is not surprising that many mathematicians have been fascinated by this whimsical, gentle art. Lewis Carroll, for example, who taught mathematics at Oxford, was an enthusiastic paper-folder. (His diary records the occasion on which he first learned with delight how to fold a device that made a loud pop when it was swished through the air.) The literature of recreational mathematics includes many booklets and articles on folded-paper models, including those curious toys called flexagons which have been the subject of two previous articles in this department.

The very act of folding raises an interesting mathematical question. Why is it that when we fold a sheet of paper the crease is a straight line? High-school geometry texts sometimes cite this as an illustration of the fact that two planes intersect in a straight line, but this is clearly not correct because the parts of a folded sheet are parallel planes. Here is the proper explanation, as given by L. R. Chase in *The American Mathematical Monthly* for June-July, 1940:

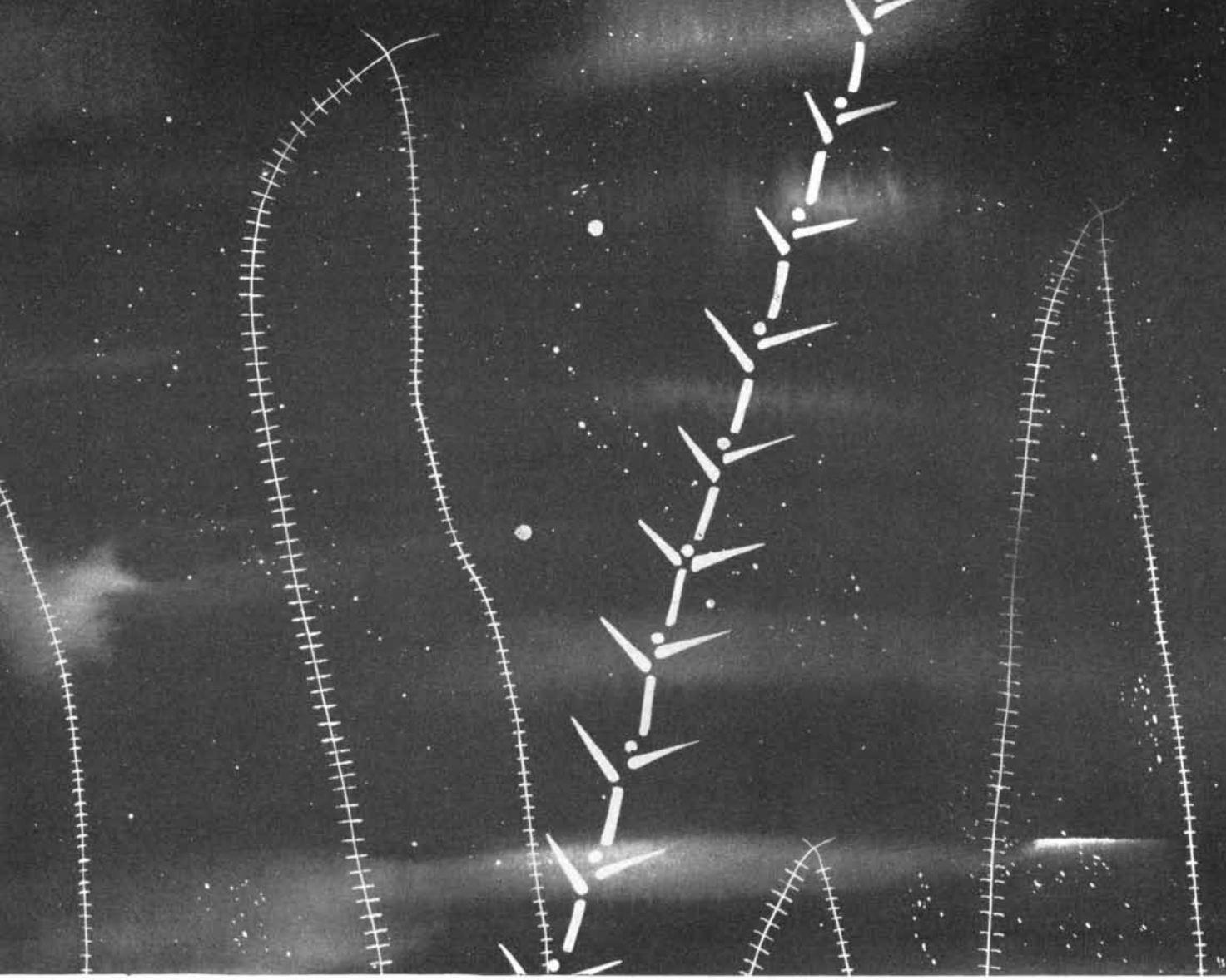
"Let p and p' be the two points of the paper that are brought into coincidence by the process of folding, then any point a of the crease is equidistant from p and p', since the lines ap and ap' are pressed into coincidence. Hence the crease, being the locus of such points a, is the perpendicular bisector of pp'."

The folding of regular polygons, though not part of classic Origami, is a challenging classroom exercise. The equilateral triangle, square, hexagon and octagon are quite easy to fold, but the pentagon offers special difficulties. The simplest way to do it is to tie a knot in a strip of paper and press it flat [*see illustration at left below*]. This model conceals a topper. If we fold over one end of the strip and hold the knot up to a strong light [*see illustration at right*], we see the famous pentagram of medieval witchcraft.

Paper can also be folded to produce tangents that have as their envelope various low-order curves. The parabola is particularly easy to demonstrate. We first mark a point a few inches from one edge of the paper, then we crease the paper about 20 times at various spots, making sure that each crease is made when the edge is folded so that the edge intersects the point. The illustra-



A strip is folded in a pentagon by tying it in a knot (left). *If the strip is folded again, and held up to the light, a "pentagram" appears*



Report from IBM *Yorktown Research Center, New York*

WALLS THAT WALK THROUGH MAGNETIC MATERIALS

The track-like patterns above represent iron oxide tracings of boundaries between magnetic domains in thin films. The behavior of these boundaries is now under study by a group of scientists at the IBM Research Laboratories in Zurich, Switzerland. This is one of the laboratories serving IBM Research with headquarters at the Yorktown Research Center.

To map the boundaries between domains of opposing magnetic polarities, the Zurich group employs the "Bitter" method in which iron oxide particles in liquid suspension are deposited on a magnetized film. On either side of a given domain wall, electron spins are oriented in opposite directions. As a wall moves in a changing magnetic field, spins reverse polarity as they pass from one domain into another. It has been found that spins reverse their polarity by gradually turning in a direction out of the plane of the film and perpendicular to it. Spins turning out of the film plane generate a large magnetic stray field. It is the tendency to minimize the energy of this field that leads to the complicated arrangements of spins observed in the walls.

The motion of domain walls in thin films is one aspect of a broad area of study at IBM seeking new insight into the physics of magnetism. A deeper understanding of magnetic phenomena may be expected to yield fruitful applications in improved or even unique magnetic devices.

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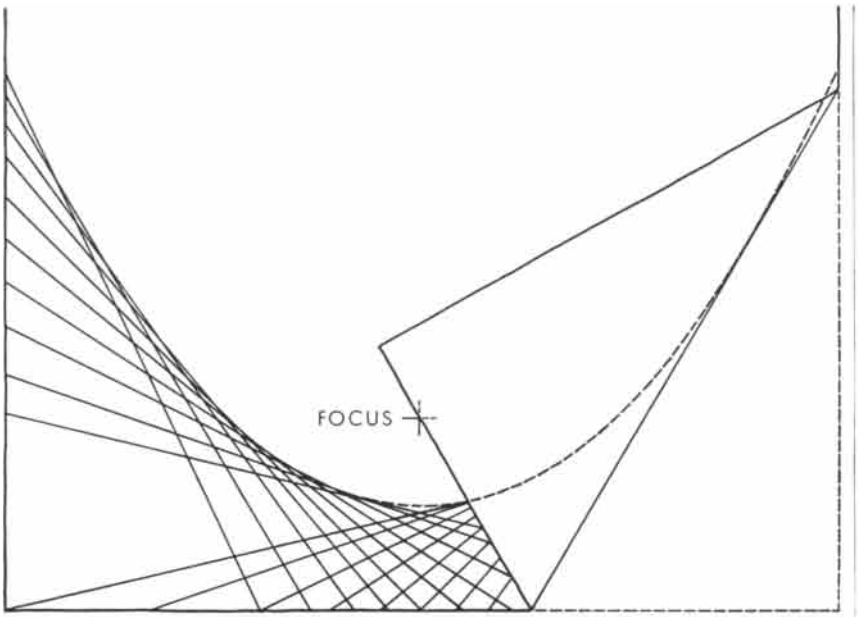


The tangents of a parabola are formed by folding the bottom edge of paper to the focus

tion at the top of this page shows the striking illusion of a parabola that results. The point is the focus of the curve, the edge of the paper is its directrix, and each crease is tangent to the curve. It is easy to see that this method of folding ensures that every point on the curve is equally distant from the focus and the directrix, a property which defines the parabola.

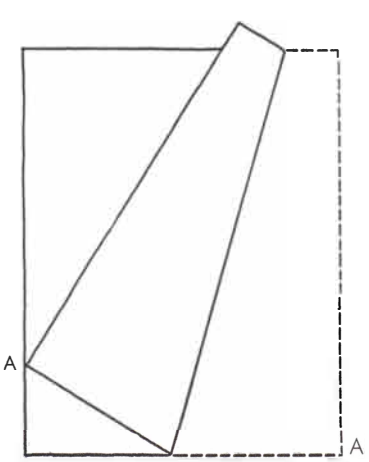
Closely related to this folding procedure is an interesting problem in elementary calculus. Suppose we have a sheet of paper that is eight by 11 inches in size. We fold it so that corner A [*see illustration at bottom of this page*] just touches the left edge. By moving the corner up and down the edge, creasing at each position, we obtain tangents to a parabola that has corner A for its focus. At what spot along the left edge must corner A be placed so that a crease that intersects the bottom edge will be as short as possible? What is the length of such a crease? Readers unfamiliar with calculus may enjoy tackling the following simpler variation. If the paper's width is reduced to 7.68 inches and the corner is folded to a spot 5.76 inches above the base, exactly how long will the crease be? The answers will be given next month.

And now, without apologies, I leave the more mathematical aspects of paper-folding to explain how to make what is in many ways the most remarkable of all Origami constructions: the bird that flaps its wings. This object is both a thing of beauty and a mechanical masterpiece. The reader is urged to take a square of paper (patterned wrapping paper is excellent) and master the intricate folds.

A square eight inches on a side is a convenient size to use. (Some experts like to make a miniature bird from a dollar bill that is first folded into a square.) Crease the sheet along the two diagonals, then turn it over [*1 in the illustration on page 142*] so that the "valley folds" become "mountain folds." (In the illustrations all valley folds are shown as broken lines; all mountain folds, by solid lines.)

Fold the paper in half, unfold, then fold in half the other way and unfold. This adds the two valley folds shown at 2 in the illustration.

Fold two adjacent sides over to meet [*3 in illustration*]. Unfold, then do the



A calculus problem in paper-folding

Philco takes the picture tube out of the chassis ...protects it with a face of tough Butyrate plastic

The new line of Philco Predicta TV sets is another example of how Tenite Butyrate plastic can be used to improve the design and sales appeal of products.

Thanks to the toughest "face" on TV—a one-piece molding of clear Tenite Butyrate, tinted to minimize glare—Philco now features a picture tube that is dramatically set apart from the chassis.

Although many factors contributed to the choice of Butyrate here, the basic consideration was its inherent toughness, since a separated picture tube would be exposed to extra hazards.

In Butyrate, Philco engineers found a material with all the toughness and impact resistance they needed. Moreover, this Eastman plastic also satisfied the other requirements involved... light weight... optical clarity... resilience... easy moldability... high dielectric strength.

Incidentally, the color that imparts an eye-easing tint to the face is part of the plastic itself. Philco designers were able to specify the color desired, and Tenite molding compound was supplied to the molder in an exact match. Result: the tinting color is an integral part of the face, not merely a coating that might wear, chip or flake off.

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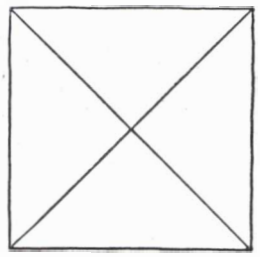
TENITE
BUTYRATE
an Eastman plastic



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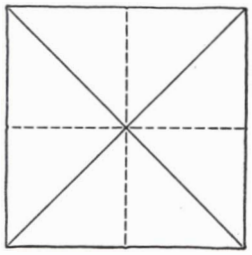

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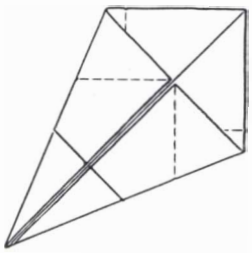

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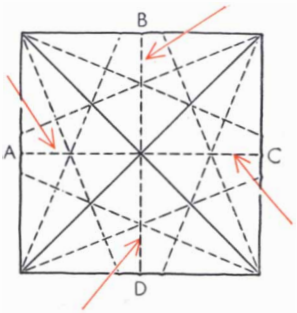

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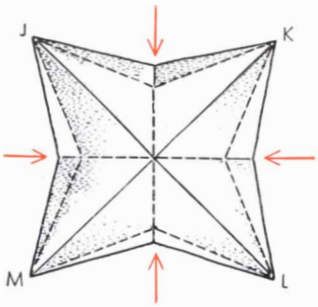

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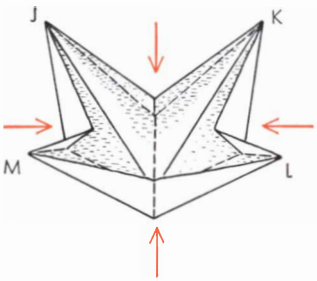

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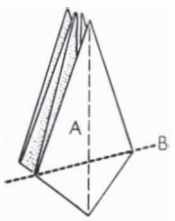

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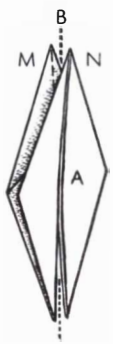

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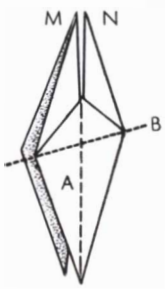

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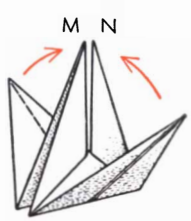

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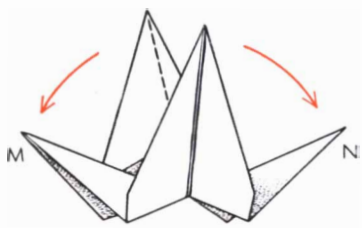

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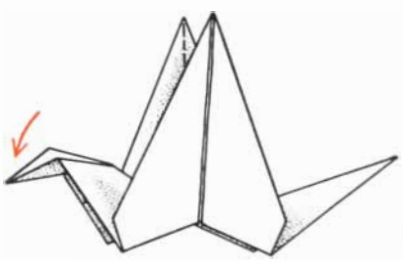

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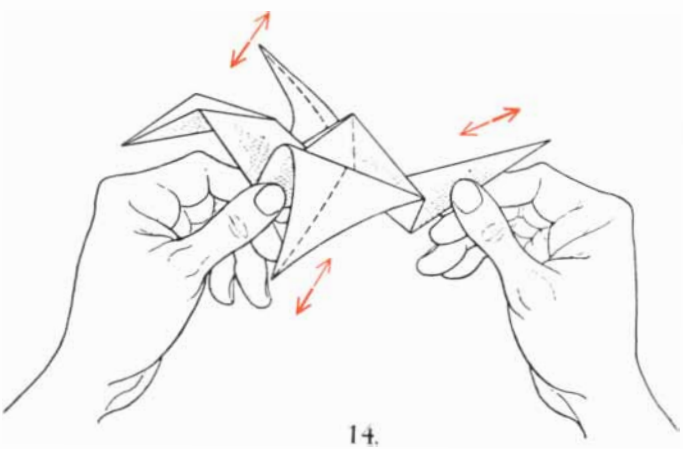

14.

How to fold the Origami flapping bird

same thing at each of the other three corners. The paper will now be creased as shown at 4.

The next step is extremely difficult to describe, though it is easily done once you get the hang of it. Note the four short valley-segments indicated by arrows at 4 in the illustration. Pinch these segments so that they become mountain folds. The centers of each side [*labeled A, B, C and D at 4*] are pushed inward. The result is shown at 5. This raises the corners of the square [*labeled J, K, L and M*] so that an oblique view of the model now appears as at 6.

If all the folds are in neat order (be sure the center of the square is pushed down as far as it will go), it should now be easy to bring all four corners together at the top as illustrated at 7. Flatten the model by bringing the sides together as shown at 8.

Flap A [*at 8*] is folded down along line B. Turn the paper over and do the same on the other side. The paper now has the form shown at 9.

Flap A [*at 9*] is folded to the left along vertical line B. Turn the model over and do the same on the other side. The result is depicted at 10.

Flap A [*at 10*] is folded up along line B. Turn the model over and repeat on the other side. Hold the resulting isosceles triangle so that it points upward [*11*]. For the remaining steps it will be more convenient to hold the model in the air rather than to rest it on a table.

Pull M to the angle shown at 12 and press the paper flat at the base. Do the same thing with N. Now push down the corner of M, reversing the fold, and press flat to form the bird's head [*13*].

Shape the wings (do not fold them) so that from their base to top they curve slightly outward and forward. Hold the bird as shown at 14. When you pull gently on the tail, the wings flap gracefully.

A number of Origami animals have action features: a fish that opens its mouth, a frog that hops when its back is stroked, and so on. Unamuno's translator tells us that the Spanish writer liked to fold such animals while he sipped his midday coffee in a Salamanca café. Little wonder that wide-eyed street urchins kept their noses glued to the window panes!

The secret rule behind the series of playing cards in last month's illustration for the induction game of Eleusis is: Play a club or diamond if the top card of the pile is even; a heart or spade if the card is odd.

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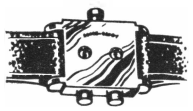

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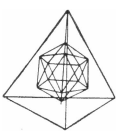

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THE AMATEUR SCIENTIST

How to keep various reptiles healthy and happy in the home

Conducted by C. L. Stong

Most people are rather afraid of snakes and other reptiles, and not without reason. After all, many reptiles *are* poisonous, and not everyone can immediately tell which are poisonous and which not. But reptiles are interesting animals, and the amateur who chooses to learn something about them can gain much pleasure from observing them. Consider, for example, the well-known fact that, because reptiles have no internal mechanism to regulate their temperature, they must warm or cool themselves by means of their behavior [see "How Reptiles Regulate Their Body Temperature," by Charles M. Bogert; SCIENTIFIC AMERICAN, April]. The pattern of this behavior is fascinating to observe, as are many other aspects of reptilian life. The trick is how to observe them.

Robert H. Wilson, assistant professor of industrial hygiene at the University of Rochester School of Medicine and Dentistry, makes a hobby of reptiles. He writes: "It is not easy to study reptiles in nature. Most of them are shy animals that rapidly disappear at the approach of *Homo sapiens*. Even in the Southwest, a veritable reptile sanctuary because of its desolation and sunny weather, one must have infinite patience to observe these animals going about the absorbing business of staying alive.

"A much more satisfactory approach is to keep them in the home. They are not good pets in the ordinary sense. You cannot teach a snake or a lizard to do much more than respond when you approach with food. The rewards come in observing at first hand the ordinary life functions of these unusual creatures. Watching a healthy snake shed its skin still fascinates me, even though enough cast skins now hang in one of my windows to obscure the view. The courting activities of some of the small desert lizards are at once comical and enthralling. And a particular satisfaction comes in raising a juvenile reptile to impressive size and health.

"If one recognizes the fact that reptiles have specialized dietary requirements, the rest of reptile-keeping is relatively simple. It is even inexpensive, provided one controls one's enthusiasm for collecting specimens. Of the 40-odd reptiles of various species in our house, we bought only four, all pet turtles from a store. The rest were acquired by gifts, trades, hatching and capture. The most important route of acquisition is the first. Once it becomes known in the neighborhood that you like snakes, your collection will grow as small and large boys appear at your door with boxes and paper bags. Trading specimens with reptile fanciers, especially those in parts of the country remote from yours, can bring in a wealth of species that you are not likely to see any other way. Capturing your own specimens has all the thrills of the hunt, and can enrich the dullest countryside.

"The art of capturing snakes is greatly simplified by the cut-down golf putter shown in the accompanying illustration [*next page*]. With this tool it is easy to pin down the snake so that it may be taken by hand as illustrated. Another useful accessory is a net made by stitching one end of a tube of muslin to a heavy wire ring and tying the other end with a string. A fairly long handle should be attached to the wire ring. Tying the end of the net shut simplifies the problem of transferring a netted snake, particularly a biter, into a bag. The net should be deep enough so that a half-turn of the handle closes the net on itself but leaves room for the snake at the bottom.

"Snakes are caught where you find them. A slow drive down a deserted road at night will frequently turn up an amazing number of snakes, particularly in the Southwest. Turning over stones and rotted logs is also productive, but in rattler country this should not be done with bare hands; use your snake putter or a stick. Most of my snake-catching is done by the putter-and-net technique.

"Traps are not satisfactory for capturing snakes, but they are quite successful with lizards. Two kinds of trap are illustrated here [*page 148*]. Spoiled meat inside such traps will attract those lizard species that have a well-developed sense of smell. A simple box trap is preferable for desert regions where shade is scarce, because lizards seek the shade when the sun becomes too hot for their comfort. The box may be two feet square and six inches deep. It is closed at the top with a wooden door and at the bottom with a wire screen. Two or three two-inch holes are drilled in one side about half an inch from the bottom. The trap is placed with the holes on the shady side, and jiggled down into the sand until the bottom of the holes are flush with the surface. The box is then covered with sand (except, of course, for the side with the holes). This keeps the temperature inside the box from rising too high in the hot sun. Lizards approaching from the shady side will find the holes and enter the box. Once inside, they will stay for several hours during the heat of the day. The specimens should be harvested two or three times before the heat subsides.

"Netting lizards is usually unsatisfactory because they are far quicker than the netter. The lizard is much less likely to scamper off if it is approached with a noose at the end of a trout-fishing rod. The noose can then be maneuvered over the lizard's head and pulled tight simply by raising the rod. The noose should be made of silk thread rather than nylon, because nylon tends to curl.

"Turtles that are accustomed to sunning themselves on half-submerged logs can be trapped by assembling four logs in a rectangle and suspending a net in the water beneath it. The turtles come out of the water from the outside of the rectangle, but they may depart to the inside, particularly if the turtle-trapper appears suddenly from the right direction. They can be kept from climbing out of the trap by studding the inside of the enclosure with nails that point downward at an angle. Turtle-collecting should be done with the knowledge that

a number of species are protected by law. The desert tortoise, for example, is protected throughout its range, and the penalty for possessing one can be as much as $500. Eastern turtles that are protected include the box turtle and the wood turtle.

"All reptile specimens are best transported in muslin bags 18 inches wide and a yard long. The bags should have double seams so that the specimens will not become entangled in loose threads. When poisonous snakes are transported, an external tab should be attached to the bottom of the bag so that one can empty the bag without exposing oneself to a bite.

"Once you get the captive home, you must think of where to put it. A good container for small reptiles that cannot climb is an aquarium. Of course a wooden box will do as well, though it is desirable to fit the box with a glass front so that you can easily observe what is going on inside. With nonaquatic reptiles it is necessary to cover the box with a snug (but not airtight) cover. Snakes especially have a rare talent for finding a small opening. I use several different kinds of cover: wire screen, perforated masonite and occasionally glass, raised slightly from the top of the container to provide adequate ventilation. The design of the cover is governed largely by the animal inside. Wire screen is generally unsatisfactory for snakes. They have a tendency to rub their noses on the screen and injure themselves. For some of the stronger species of snake a sturdy top is needed, and masonite fills the bill. A glass cover is used when it is desirable to keep the temperature and the humidity high.

"Most discussions of reptile-keeping emphasize the importance of avoiding decorative effects in the cages, pointing out that sanitation is a problem and that the humidity resulting from the presence

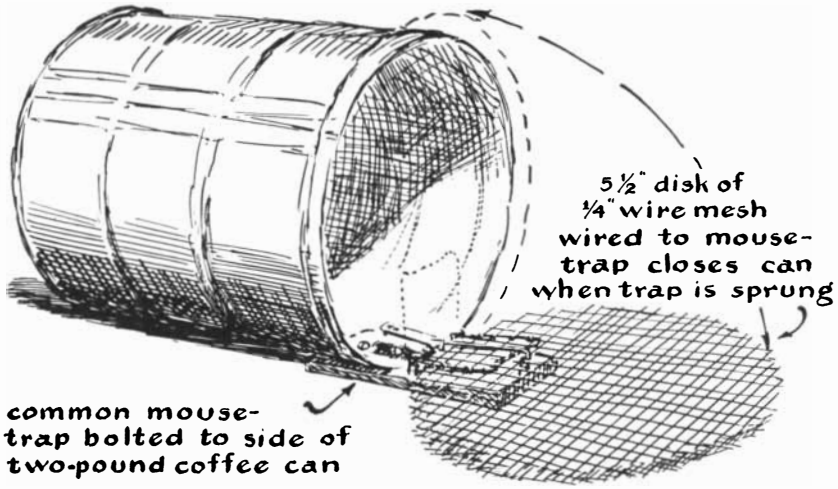
An amateur's method of catching and holding a snake

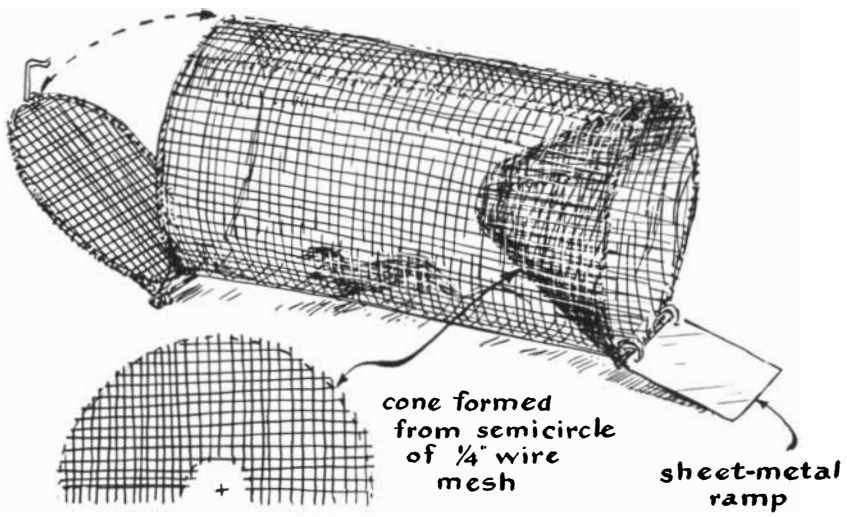
of plants is detrimental. I do not agree with this. Animal cages in the home should be attractive. Moreover, the animals themselves appear to feel more at home in cages that roughly approximate their natural habitat. One can divide cage climate into broad categories—for example, desert, temperate-zone region or bog—and select plants and other surroundings that are compatible. Properly managed, a reptile cage can be as decorative as the handsomest aquarium. One warning: reptiles to be placed in a decorated cage should be carefully inspected for mites. Once introduced into such a cage, mites hide themselves in crevices and are almost impossible to eliminate.

"The sanitation problem is most easily met by placing a deep layer (one to two inches) of aquarium gravel in the bottom of the cage. It is a simple matter to pick up excreta and contaminated gravel with a scoop and to replace the gravel from time to time. Many terrestrial reptiles are fond of burrowing on occasion, and aquarium gravel is a good medium in this regard because it does not pack or cake.

"The illumination of the cage is important, both for the welfare of the animals and for satisfactory viewing. Most reptiles do best at temperatures slightly above 70 degrees Fahrenheit, the desert species preferring temperatures as high as 100 degrees. I achieve good temperature-control by balancing the radiant heat of incandescent lamps against the heat loss through the sides of the cage and by whatever air circulation there may be. Reptiles govern their body temperature by absorbing heat in varying amounts from their surroundings. Incandescent lamps at the top of the cage, together with the judicious location of furniture such as rocks or sticks at various distances from the light source, permit the animals to select their own temperature conditions. It is astonishing to observe how quickly these not especially bright creatures learn that they can warm up most quickly by climbing to the highest point in the cage. When several lizards are in a cage and the light comes on after a cool night, an amusing scramble for top position usually ensues.

"An effective source of light and heat is the 75-watt spotlight lamp available in most hardware stores. The reflector of the lamp is highly efficient for both visible and infrared radiation, and incidentally lends itself to dramatic lighting effects. The radiation is concentrated, however. It is therefore important to direct it so that the animal can get out of the beam and avoid overheating. I usually mount the lamp so that the front





Two designs for traps suitable to catch small lizards

of the glass envelope is about 10 inches from the highest piece of furniture in the cage.

"The main problem in keeping reptiles is to provide them with the proper diet. Few reptiles are vegetarians, though some turtle and lizard species will eat lettuce. The rest demand meat in various forms. Most turtles will eat any kind of meat proffered (including a bit of finger if you are not quick). Cod or ocean perch seems particularly tasty to aquatic turtles. Several of the more terrestrial species thrive on dog food, particularly Pard. It is important to remember that the aquatic turtles (all those sold in variety stores) are unable to eat when they are out of water. The turtle bowls sold with them are almost always inadequate. Such a turtle is properly kept in an aquarium measuring at least 10 inches wide and 12 inches long. The aquarium should contain six to eight inches of water, a sunning platform and an ample heat source such as the 75-watt spotlight lamp. One should be forewarned that these turtles will grow, some of them to as much as eight or 10 inches long if they are properly nurtured.

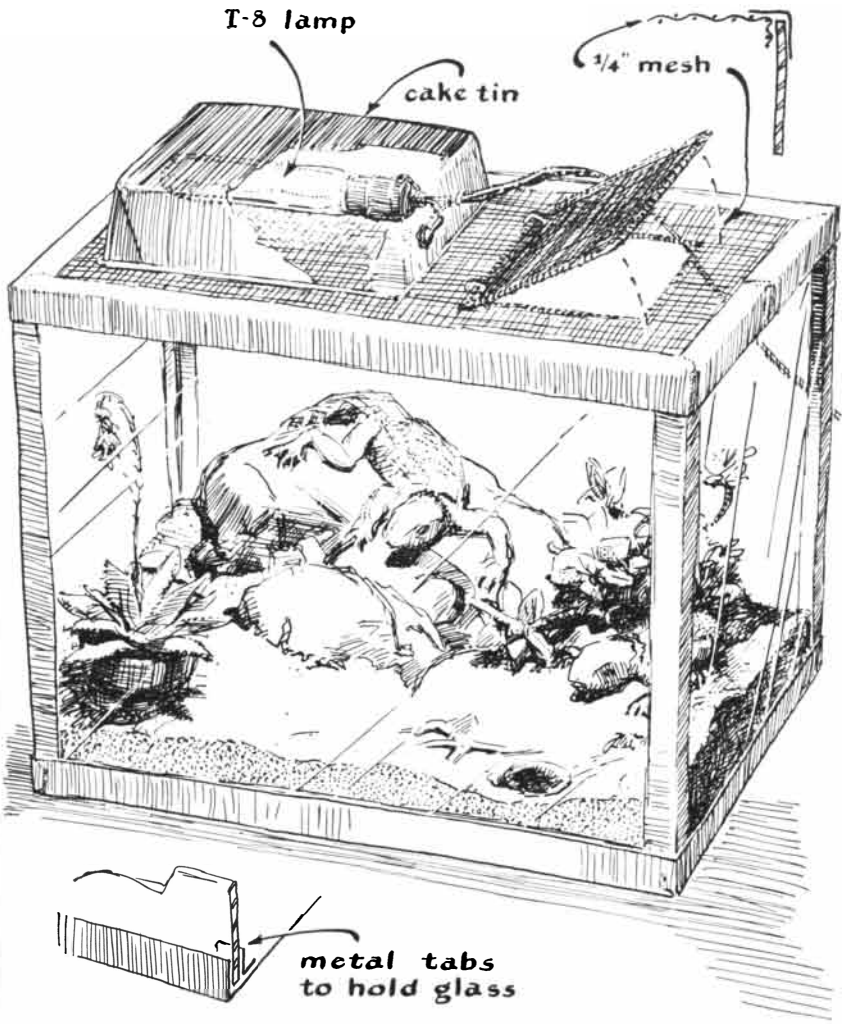
"Most of the lizards are insectivores, eating moths, flies, beetles, grubs, grasshoppers and so on. Such prey are not easy to come by in the winter, and it is almost impossible to convert a lizard to foods such as beef or fish. However, there are solutions to the problem. Meal worms can be bought in pet stores. These worms, the larval form of the darkling beetle that commonly occurs around granaries, are a splendid food for insectivores, apparently supplying all the important trace nutrients.

"Recently I have found that Russell Vance of Lincoln, N.Y., maintains a year-round supply of crickets that bids

fair to revolutionize the keeping of reptiles. It is not difficult to raise meal worms in amounts sufficient for one or two small lizards, but a larger lizard can put away 75 to 100 worms a week. This calls for a rate of production that is difficult to maintain in the home. Moreover, some lizards ignore meal worms. The crickets, however, are a different story. In the first place, they are larger, so that even our fairly sizable African agamid is satisfied with three or four. Second, they do not contain so much chitin, the horny substance of the insect skeleton. If a small lizard is fed a steady diet of meal worms, the indigestible chitin of the worms may actually block its gastrointestinal tract. Crickets also seem to provide more dietary essentials than do meal worms. My lizards are all in much better health as a consequence of the shift to crickets. My one insectivorous snake, a member of the smooth green species, eats crickets to the exclusion of all other food.

"The snakes are probably the most fascinating of all the reptiles. All snakes are carnivorous. In most cases this means one must supply them with mice or rats for food, although water and ribbon snakes will eat fish (minnows or thawed pieces of frozen fish). Garter snakes can be induced to eat chopped earthworms mixed with hamburger; later they can be graduated to hamburger alone. Working as I do in a biomedical laboratory, procurement of mammalian food for my specimens is no problem. I simply set up a breeding colony of mice in an out-of-the-way corner and harvest as needed. Our rat colony generally produces an adequate surplus to supply my modest needs. The less fortunate reptile-keeper, however, can doubtless make arrangements with a biological or medical laboratory for a supply of surplus rodents, usually at a reasonable cost. Breeding in the home is not recommended. It is accompanied by an odor problem that even the most tolerant wife can seldom ignore.

"Of the readily available snake species, some are more adaptable to the home terrarium than others. The list is headed by bull snakes, which are unusually docile. I have picked up wild bull snakes in the deserts of Nevada and Idaho that struggled no more than those in my cages. Corn, fox and rat snakes are somewhat more excitable, but still adapt nicely to confinement. An unusually charming little specimen is the red-bellied snake, which grows to a maximum length of 10 inches. These require a steady diet of small angleworms or garden slugs (the brown ones, not the



An aquarium modified to hold small reptiles

gray), which are easily raised in leafy litter, with lettuce and chicken mash as food.

"Most of the racers and coachwhips are best left *in situ*. They are nervous and irritable, and they bite severely. The poisonous varieties should be left strictly alone. (I must confess that I have a couple of juvenile Great Basin rattlers that I caught in Idaho last summer; I keep telling myself that as soon as they are big enough I shall give them to the zoo.) Although many of the pit vipers (which group includes the rattlesnakes) are attractive and interesting, the risk is severe. Moreover, not all neighbors are as tolerant and understanding as mine.

"Perhaps the most important item in reptilian diet is an adequate supplement of vitamins. Virtually all reptiles are sun worshipers, and in captivity they must have vitamin D to compensate for the lack of sunshine. My procedure, which seems to work extraordinarily well, is to include one or two drops of 'Abdec' per ounce of drinking water. This water-soluble polyvitamin preparation appears to suit reptiles ideally. The effect of vitamins can be most dramatic. A reptile specimen that is lethargic and off its feed can become a ravening brute ready to eat almost anything one or two days after the direct administration of one or two drops of Abdec. Once the reptile is in condition, the maintenance dose in drinking water seems to be sufficient. Turtles are particularly sensitive to the lack of vitamins and should be given a direct dose every month or so.

"Reptiles can be watered in several ways, depending on the species. A snake will drink from any dish large enough to admit its head and an equal length of neck. Some lizards will drink from a dish; others, from a watering bottle. Some, such as the anoles, or 'circus chameleons,' must be watered with a dropper or by sprinkling the plants in their quarters.

"When one keeps reptiles in the home, it is difficult not to be anthropomorphic about them. Lowly though they are, rep-

$$\dot{x}_{j+1}(t)=\dot{x}_j(t-h) \text{ if } x_j(t-h)-x_{j+1}(t-h)=\beta S_c$$

● Problem: what doctrine for a motorized military convoy will mean the highest over-the-road speed? Solving such a problem by experimental, trial-and-error methods is difficult, long, and costly . . . yet answers to such questions are vital to our modern, mobile U. S. Army. Scientists of *tech/ops* solved this one by devising and applying a mathematical model to describe a convoy, programming this model for a large digital computer. *Result:* another application of tech/ops' research techniques to solve a problem whose solution by conventional means would have been prohibitively expensive . . . and a typical example of *tech/ops'* pioneering work in *operations research and broad scientific research and development for industry, business and government.*

. Two other formulas complete this model:

$$x_{j+1}(t) = V_c \text{ if } \beta S_c < x_j(t-h) - x_{j+1}(t-h) \leq S_c \quad (2)$$

$$\dot{x}_{j+1}(t) = \frac{1}{T}[x_j(t-h) - x_{j+1}(t-h)] \text{ if } x_j(t-h) - x_{j+1}(t-h) > S_c \quad (3)$$

The symbols have these significances: $x_j(t)$ is the position of the j^{th} vehicle at time t; V_c is the assigned convoy speed; S_c is the assigned spacing between succeeding vehicles in the convoy; h is the driver reaction time; β is a constant. Boundary conditions: $\dot{x}_j(t) \geq 0$; $\dot{x}_1(t)$ is a given (known) function.

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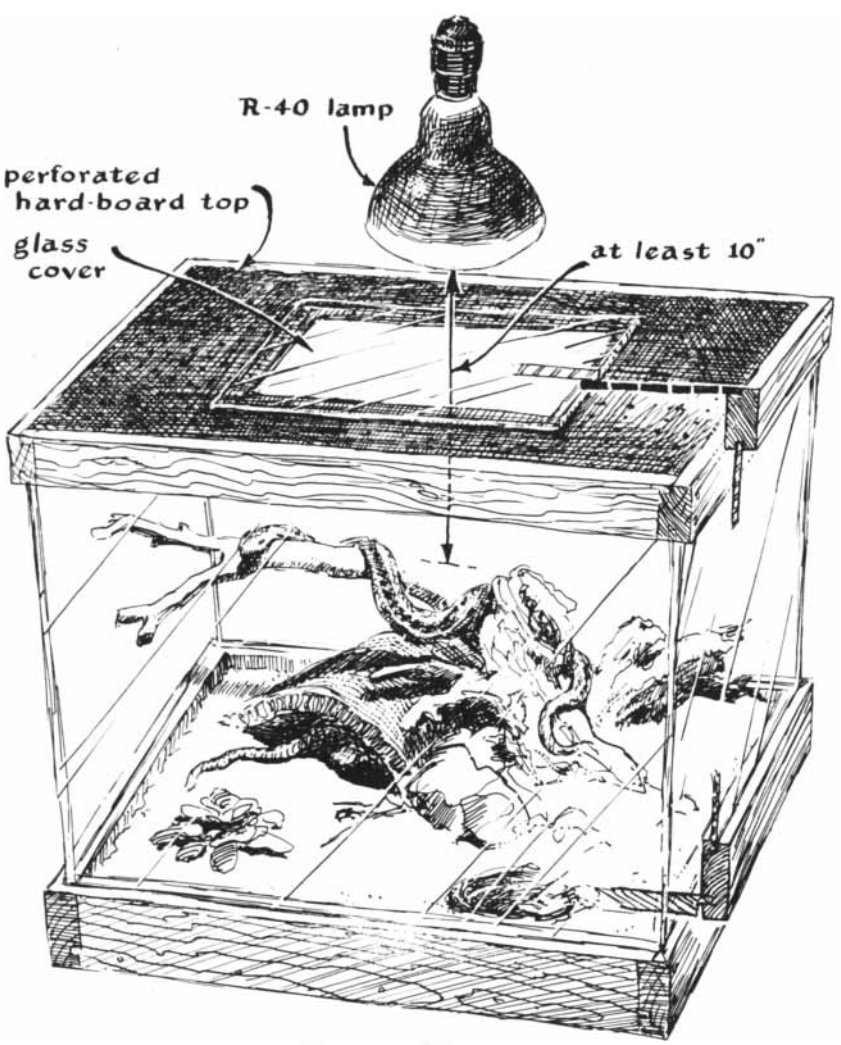
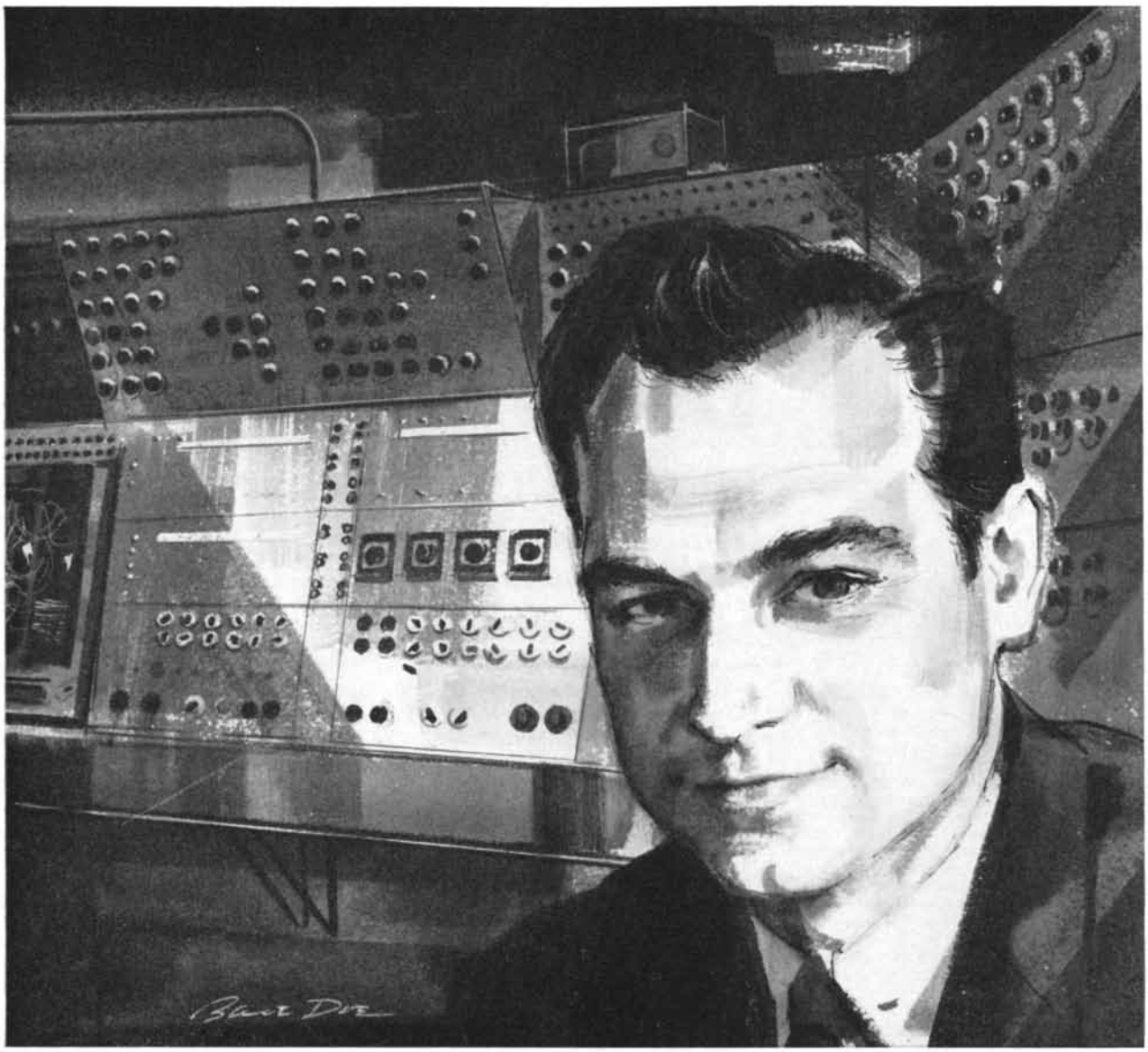
tiles are individualistic, and one cannot avoid assigning them personalities. In the final analysis, why not? Each animal has a behavior pattern that is partly instinctive but partly the result of experiences during its lifetime. To me it seems only reasonable that individuality should develop. My three bull snakes are an excellent example. All were taken at the Nevada Test Site of the Atomic Energy Commission, and they look pretty much the same. Yet there are marked behavioral differences among them. One of them, which was caught as a very young specimen, has been in captivity most of its life, and probably as a consequence has come to enjoy being handled. It rests quietly for long periods in the hands of anyone who will hold it. Another of the snakes, almost identical in appearance, was mature when taken, and although evidently satisfied with the food supply and creature comforts, has never really resigned itself to handling, preferring to wander about unconstrained when released from the cage. The third snake is intermediate between the first two; it enjoys a trip but is willing to settle down after it has investigated its surroundings.

"The challenge of keeping these animals, coupled with the opportunity to observe at first hand their functions and behavior and, above all, their remarkable adaptations to their environment, make reptile study in the home a particularly rewarding avocation. The formal background requirements are certainly minimal. I am an engineer and my biological training consists of only one year of high-school biology. I find, however, that I have absorbed an astonishing amount of biology and zoology without half trying; so much so that I am about to undertake some laboratory experiments in reptilian physiology."

R. Stuart Mackay of the University of California calls our attention to an interesting property of the "flints"



A terrarium made of wood, glass and perforated masonite



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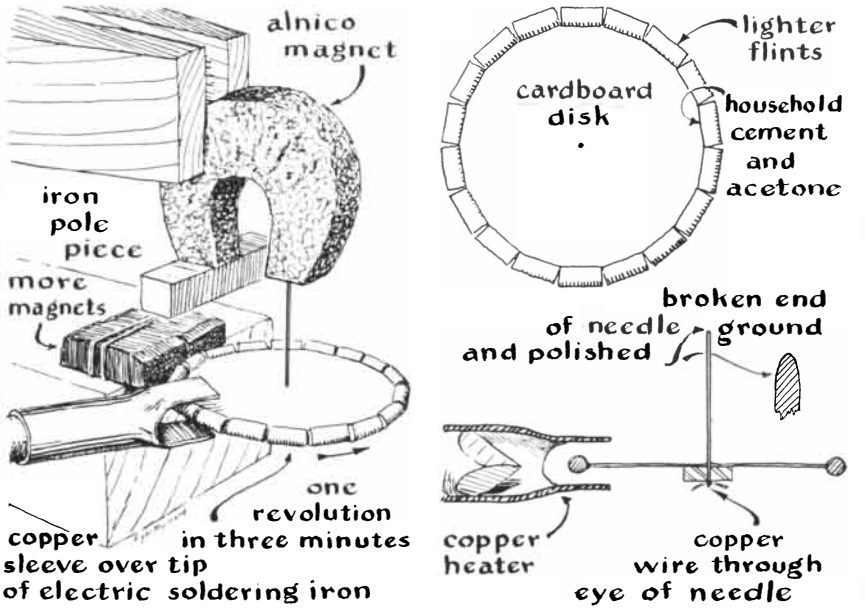


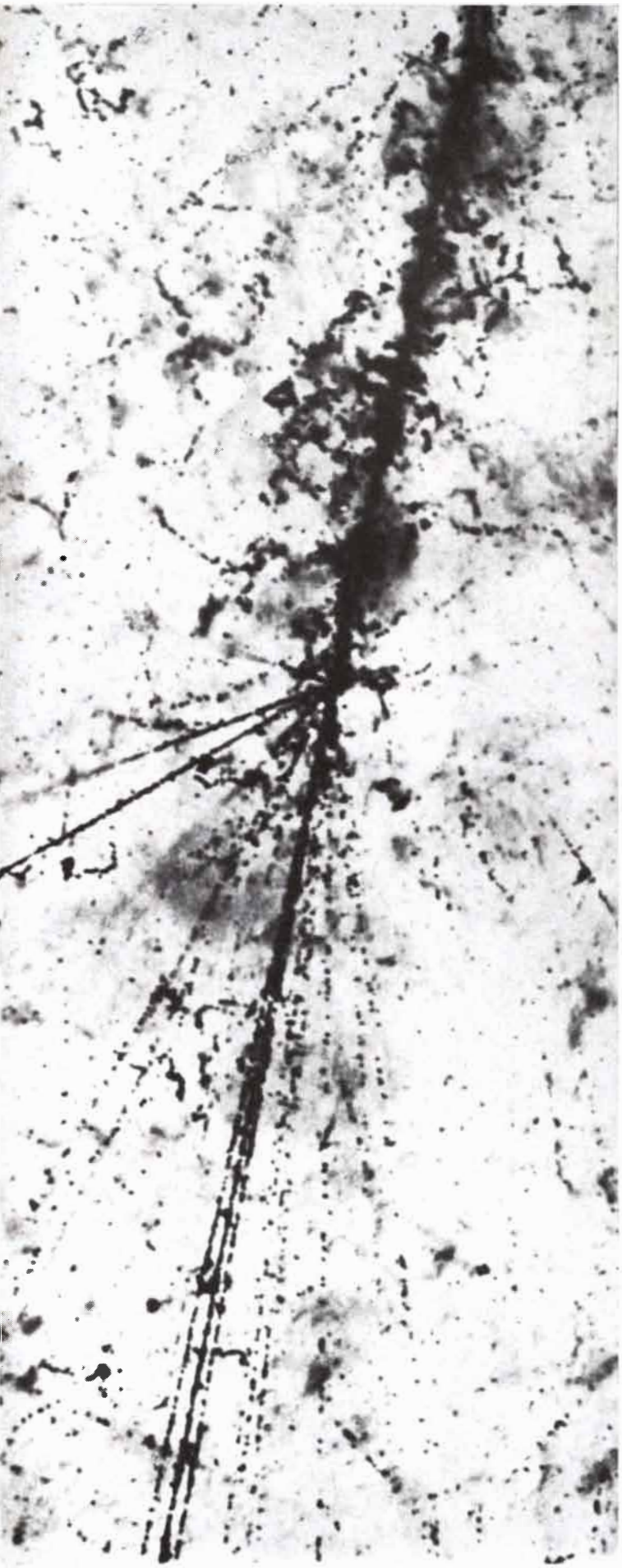
A heat engine made out of lighter flints and magnets

used in cigarette lighters. At room temperature they are strongly attracted to a magnet, but when they are heated to 125 degrees centigrade they abruptly become nonmagnetic. In effect, they exhibit the property of bistability with respect to temperature and magnetism. Hence they may be used as the active element in novel heat engines. For example, a quantity of flints (the active material is the metal cerium) could be attached to the bottom of a pendulum and energized by focusing a beam of infrared radiation on them at the point where they pass through the bottom of the swing. A strong magnet would also be located at this point, almost close enough to touch the metal. Once started, the pendulum would continue to swing as long as the infrared was supplied. Because the flints would be heated at the bottom of the swing, they would be strongly attracted to the magnet during the downswing and less strongly attracted to it during the upswing. Accordingly a net transfer of energy from the infrared beam to the pendulum bob would occur.

Mackay suggests that the effect can also be applied to a device for converting heat into rotary motion by fixing a number of flints to the rim of a disk free to turn on an axle. A source of heat and a magnet would be located at adjacent points on one side of the disk. A motor of this type has been constructed by Roger Hayward, who illustrates this department. According to Hayward, the motor does not run very fast, and its output is in the "flea-power" class.

"The power of the engine was so minute," writes Hayward, "that I had to fit it with a magnetic bearing to make it run at all! As an interesting demonstration, however, it is well worth the time spent on its construction. I chanced to have 18 lighter flints on hand; this determined the size of the engine that is shown full scale in my drawing [*above*]. The axle was an ordinary sewing needle broken near the middle. The sharp end was discarded and the broken end of the remaining part rounded and polished. The eye was then threaded with a quarter-inch of fine copper wire as a stop for a washer made of lucite which supported the disk, as shown in the lower right detail of the drawing. The rounded end of the needle is attracted to one pole of a small alnico magnet clamped in position as shown. The flints are stuck to the edge of the rotor by quick-drying cement which has been thinned with acetone.

"Energy to drive the engine is taken from an electric soldering-iron fitted with a short length of copper tubing split at the outer end. The magnet which exerts force on the flints actually consisted in my case of a pair of small alnico bars salvaged from a discarded magnetic ash tray. They were assembled with the north poles and south poles pointing the same way, and were held together with a rubber band. This assembly was placed close enough to the flints to pull the disk about five degrees out of plumb. The split portion of the hot copper tube was placed over the flints at a point as close as possible to the driving magnet. When heat was applied, the rotor turned somewhat unevenly at about a third of a revolution per minute."



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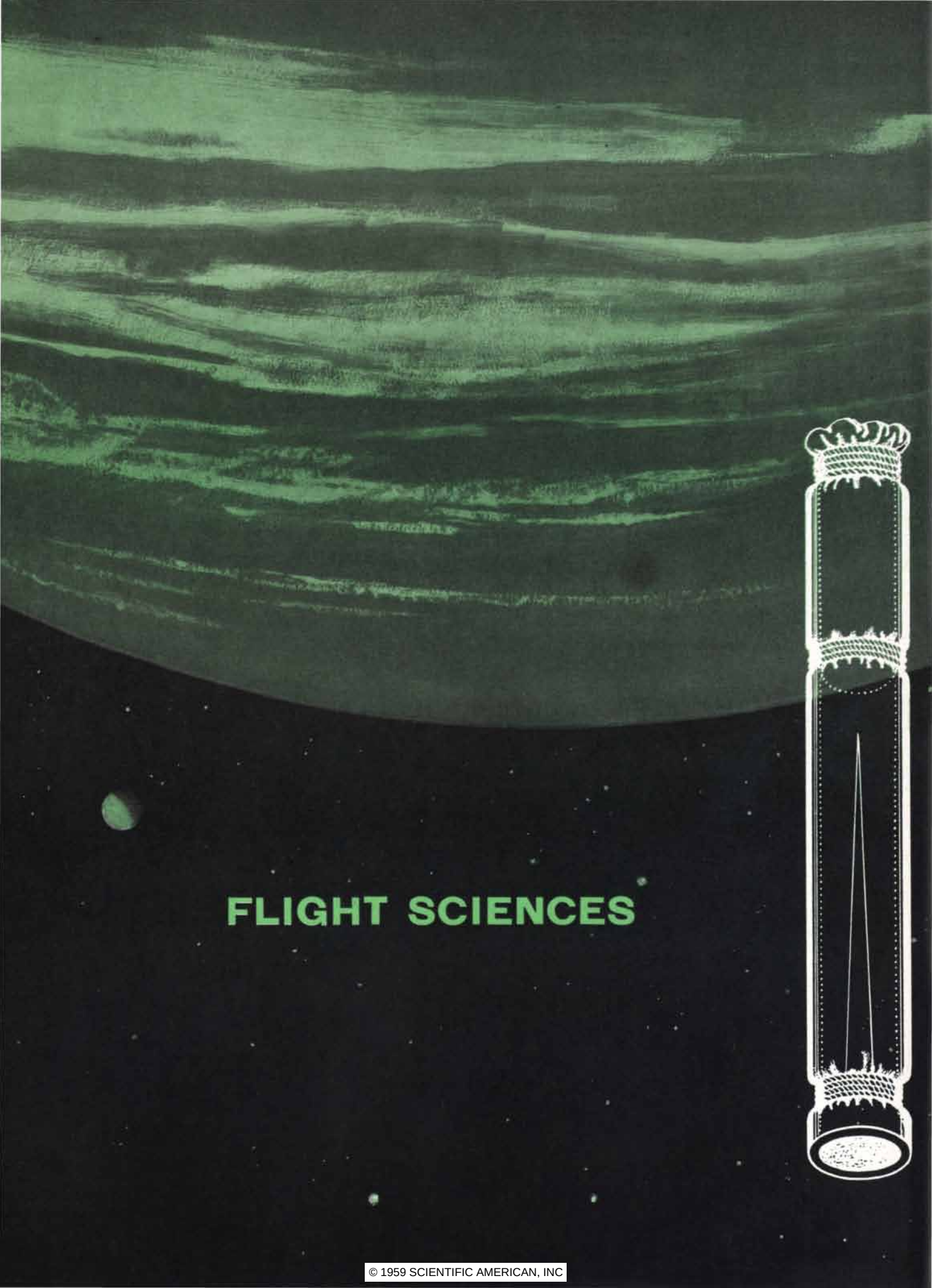
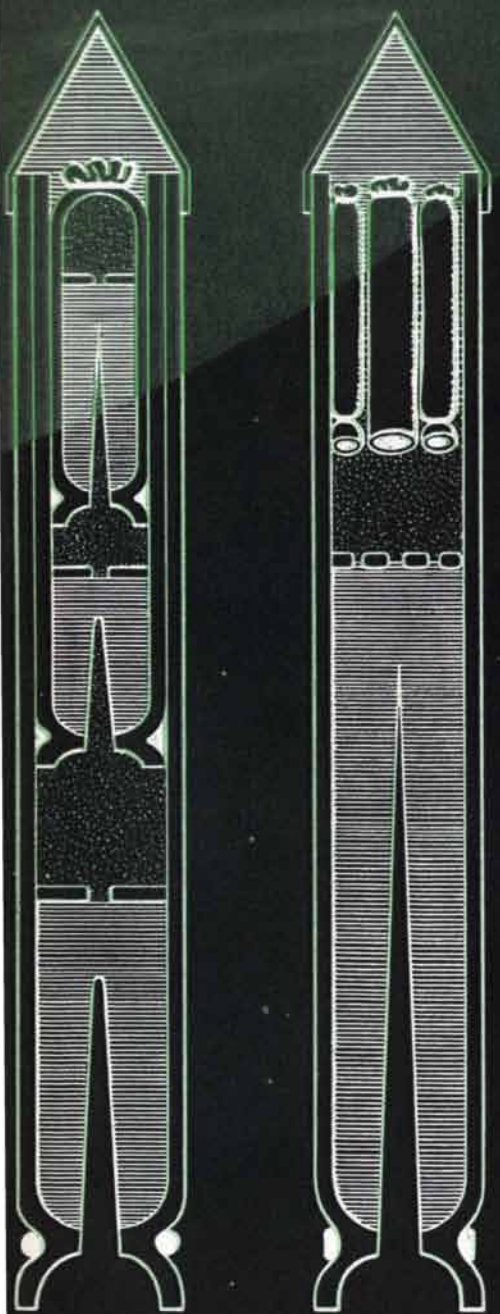
Cosmic ray (an iron nucleus) smashes a nucleus in a photographic emulsion exposed by Herman Yagoda of the Air Force Cambridge Research Center. Such events are a primary source of high-energy radiation.



FLIGHT SCIENCES: Principle of the step or multi-stage rocket, considered fundamental to the art of modern missiles and space flight, was set forth as long ago as 1650 by Kazimierz Siemienowicz, lieutenant-general of ordnance to the king of Poland. His design featured a 3-stage rocket with each step having its own gunpowder fuel, fuse, and nozzle.



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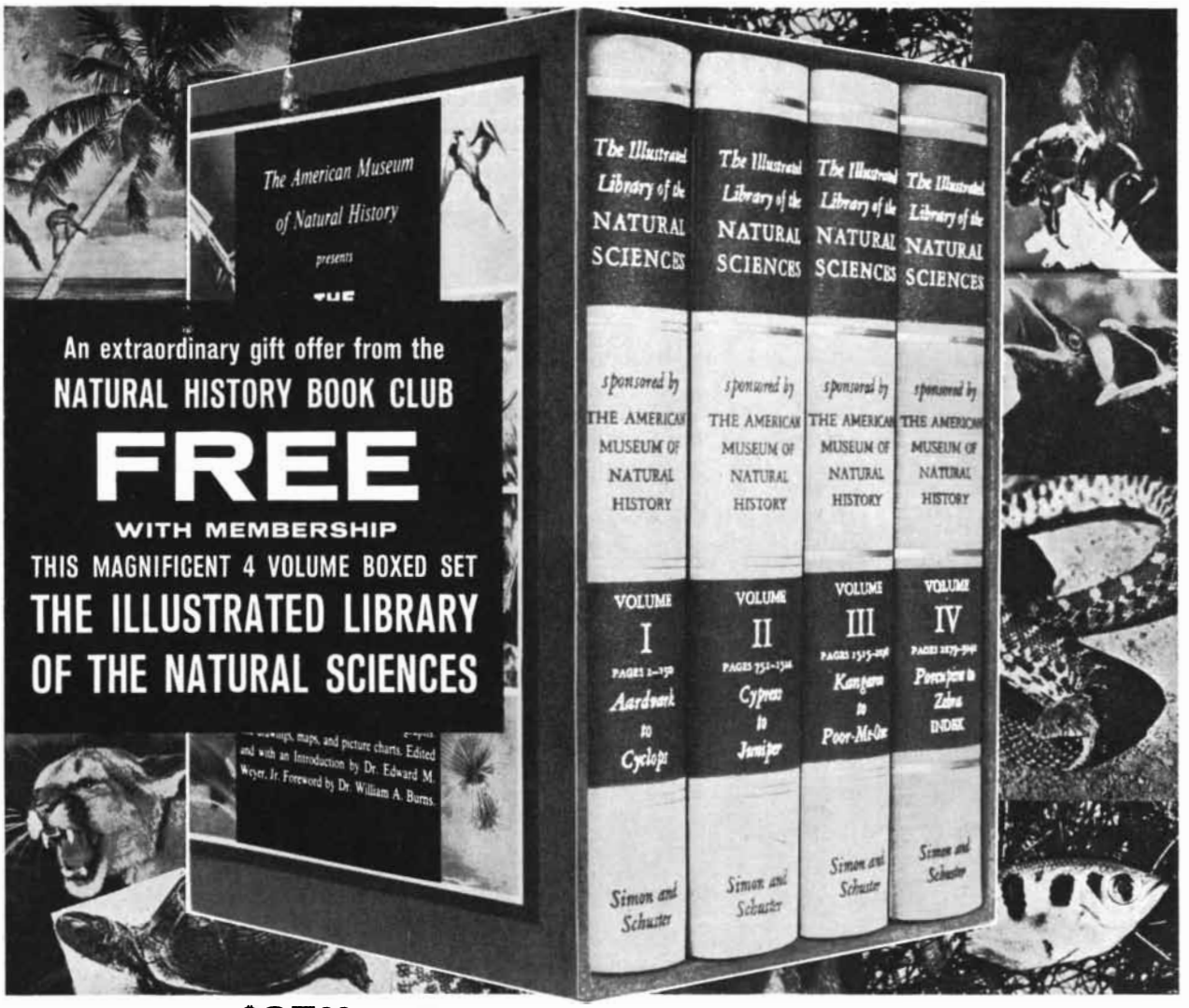

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BOOKS

Pearl Buck's novel about physicists and the bomb

by V. S. Pritchett

COMMAND THE MORNING, by Pearl S. Buck. The John Day Company, Inc. ($4.50).

In the middle of such macabre disputes as whether radioactive fallout causes a substantial increase in leukemia, it is almost a relief to get back to Hiroshima. The event is already out-of-date. We begin to look back on it as we look back on the Lisbon earthquake that broke up the complacency of the 18th century and inspired, in Voltaire's *Candide*, the most searching and destructive satire on human nature ever written. Hiroshima put an end to the long honeymoon period of science and society. The union is now until death do them part. For the first time the scientist has been obliged to admit the common guilt into what E. M. Forster called the "ivory laboratory." Religion has the massacre of St. Bartholomew and its *autos-da-fé*; politics has the massacre of the kulaks and the gas chambers of Dachau; science now has its city of 300,000 burned in a flash. It was the work of superbly gifted men, most of them under the age of 30.

This is the subject of Pearl Buck's new novel *Command the Morning*. Her book is the story of three top U. S. scientists engaged before 1940 in nuclear physics, and of how they were drawn together with a number of Europeans into making the bomb during the war and were persuaded to assent to its use. Miss Buck has documented herself well and follows closely the known outline of events. Her chief characters are fictitious. In a novel—at any rate, a modern novel—this must be so. However, it debilitates the real story, which in character and complexity of moral entanglement is far richer than the psychological Western, with dummy figures and moral simplifications, that she has written. There are only two realized characters in the book, both women, both utterly ignorant of science, politics and moral theory: a Tennessee peasant woman who comes back to visit her shack and finds it has vanished in the new atomic city, and the chief organizer's cheerful wife, who has a blaze of temper at the end. They are the only characters without the temperament of cowboys. I think any reader who is not too gripped by the suspense of the story, and who knows that feeling plays a profound and devious part in moral conflict, will be struck by the small emotional range of Miss Buck's characters: like early Hemingway figures they merely feel "bad" or feel "good." Between times they have "problems." Still, Miss Buck is a capable, bustling novelist of the journalistic school. The book will do well enough as a motion-picture script; she is earnest and she is fair-minded as far as she goes. At the end of the book I could not make up my mind whether she was being ironical about the vicious circle or hoping for the best. I have the old European taste for savagery and irony; they clear the head.

The questions Miss Buck raises in *Command the Morning* are the important ones. We know that science gives with one hand and takes back with the other. A new discovery becomes a new weapon. Since scientists are at the source of power, why do they allow this? Can they stop it; can we stop them; are they responsible; can they decline responsibility; is it possible for them to refuse? They are a special kind of brain, but are they, when it comes to decisions outside the privacy of science, any different from ourselves? How irrational are they? How hypocritical? How much does the pursuit of objectivity in a special field qualify them for life? Do they now have a dangerous position of privilege? Or is their work perverted by military, political and industrial interests? Are they the victims of bureaucratic techniques that they are not trained to understand? Is science subject to periods of decadence? What about the philosophy of the rights of the eternal quest? One thing emerges: If at any time these questions could be answered, they cannot be answered in black and white. Hiroshima indeed announced a new age—the age of the great gamble. In 14 years the stakes have become much higher.

Miss Buck's story opens in 1940, but the gamble had begun long before that at Cambridge, at Göttingen and in Copenhagen. In 1940 the refugee scientists have alarmed the U. S. Government. The Nazis are almost certainly making the bomb; the British are working on it; the U. S. is years behind. Burton Hall, a scientist of the organizing kind, a manager of men in Chicago, combs the universities for a team of nuclear physicists. At this stage U. S. scientists are living in a state of innocence and academic freedom. Pearl Harbor puts the question to them. Hall has no doubts. But his chief theoretician, Stephen Coast, a man of fanatic scientific genius, holds out. He will work on atomic theory; he will have nothing to do with making a weapon of war. While Hall is the son of a Methodist circuit preacher who inherits his father's breezy talkativeness and can honestly talk himself out of all dilemmas, Coast is a man of Quaker upbringing. He is a terse man of peace. If other scientists make the bomb, that is their business. He cannot stop it, but he can keep a clean conscience himself. He is supported in this by Jane Earl, a woman scientist brought up in India under the influence of Indian quietism. She is a beautiful woman of uncommon gifts and integrity. She and Coast are resisting a passionate attraction to each other with all their might, not only because he is married, but also because he fears passion as he fears the bomb.

It is Miss Buck's business now to show the stages by which the scientific conscience is compromised step by step. Although she may not allow for the ordinary process of human drift and half-decision, this is a well-managed part of the story. Coast is an honorable and sensitive man but a moral coward. Jane Earl sees that their knowledge has already committed them, that they cannot just slip out of responsibility. They must work for the bomb and stay on to control its future. Her argument is that the very

existence of the bomb will be a deterrent to its use—a theory that has most uncomfortingly come to the fore in the last few years. This does not convert Coast. What does convert him is something which is morally lamentable. The authorities have seen to it that he receives a report on the Japanese atrocities against U. S. prisoners; the pacifist is seized with a sudden rage to kill. It is odd and significant that he does not feel this rage at the Nazi massacre of the Jews. He could not have known at this time, long before the successful making of the bomb, whether it would be used first against the Germans or the Japanese. The incident suggests to me (it is not clear whether Miss Buck suggests it) that revenge for Pearl Harbor may have been as much a motive in the final act as the morally more presentable motive of "getting the boys home."

Now that Stephen is converted, we can examine the entanglement of the whole group working on the project. The process by which they lose their innocence is professionally infuriating. They are put under military discipline. Burton Hall has the task of calming down a group of men who have the intellectual's contempt for soldiers, who regard military discipline and obedience as stupid and stupefying. The scientists, like artists, require freedom because they live under a stringent discipline of their own. They do not hide their contempt for the general put in charge of them, but he is no fool. One of the pleasantest touches in Miss Buck's novel is the account of how the wily old man sees that one way to win over the scientists is to get at them through their wives. Another serious entanglement is the industrial one. Success, for the scientists, is in the laboratory. They work with speed, they are brilliant and casual in improvisation. But to make a real bomb is not a laboratory affair. The scientists find themselves in the hands of industry. Miss Buck gives a vivid account of the building of the atomic city, the sudden transporting of a huge community of men, women and children who have to be provided with everything. The making of the bomb was, as one of the characters says, the result of the interplay of two kinds of genius: the creative scientific genius of Europe and the American genius for techniques and production. And (the moralist must reflect, when he thinks of the outcome) if nothing will stop a scientist from experimenting and playing with his toys, nothing will stop a producer from producing and delivering his productions.

At this point the bomb is still regarded as a deterrent by its very existence, but here we have to raise another matter of conscience, a historical and crucial matter which throws a long shadow forward over the events of our time. To whom does the scientist owe his loyalty? Is it to mankind or is it to some sections of mankind and not to others? It is a question which has roused strong passions, nowhere stronger than in the U. S. Miss Buck funks it; or rather, she treats it in the most nervous and cursory way. Yet during the war, and indeed long before, it was a central question for scientists. No examination of scientific morality can ignore it. It comes up in the case of the villain in this Western piece, a gifted British scientist named Hard. Hard sells information to the Russians. Hard is, alas, a character from a juvenile Western. Like Miss Buck's "good" foreigners, even the great ones, he is a "longhair" and is known for his mannerisms and foolishly un-American speech. He is a music hall Englishman of the "I say, old boy" type. Novelists frequently fall into such conventions when they raise issues which they wish to dodge.

Now Hard is an important case. He may have shared the pre-war ethic, common among distinguished scientists, that science was privileged or supranational; he may have thought it strange not to share knowledge with allies; he may have been a Communist for sincere or opportunist reasons. (He certainly did not sell secrets to the Nazis.) He may have been unrealistic; he may have been too realistic and have been reduced to neurotic cynicism by the collapse of the great hopes science seemed to offer. He is not allowed to state his own case nor is it subjected to criticism; it is given us in a few throwaway lines by Mrs. Coast, whose lover he has become:

"He had an ethic, too [she tells her husband after Hiroshima]. You'll not believe it, but he does. He thinks that science should be shared with everybody—even the atomic stuff. He says it's the only safety. If everybody knows, nobody will use it. Maybe there's sense in it. Anyway there's no sense to what we've done."

Hard has the vanity, instability and intensity common to the gifted. He also has a certain cynical courage. He is a moral type common in the profession. His case may be compared with that of the German scientists. Readers of Robert Jungk's angry book *Brighter than a Thousand Suns* must reflect on the claims of Werner Heisenberg and C. F. von Weizsäcker (who were usually regarded as Nazi fellow travelers) that they "went slow on the bomb" out of regard for humanity! In the history of the period everyone's case looks thin: If the Ger-

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mans went slow, it was due to the destructive effects of an irrationalist philosophy, to the attack on Jewish and other intellectuals and to the fact that, being close to the battle, they did not have the conditions for production.

The high point of the novel—indeed, of the true story—is not Hiroshima but the successful test in New Mexico. In that terrifying flash the scientists *know*. But presently an unexpected access of long-repressed personal emotion is released. Burton Hall, a man who has breezily talked around his feelings, suffers remorse and runs off to see an old Japanese artist who is shut up in a concentration camp. Coast, the repressed Puritan, is suddenly flooded with his love for Jane Earl. But her situation has changed: she has actually seen a young scientist unspeakably burned in the laboratory, and she has nursed him. She has withdrawn. But before any of these released personal feelings have time to develop, the fatal gnaw of half-decisions is once more at work upon the protagonists.

Burton Hall is the weakest because he has tried so hard to play the game. The decision to drop the bomb is creeping up, but the "old circuit preacher's" son saw made real in New Mexico what he had read in the Book of Revelations as a child. He collapses and so evades the instant of decision. Coast is now in charge; how will he act? It is well known that a panel of scientists was asked to give its opinion and that the majority was for using the bomb. Coast is of the majority, and for a bad reason. The men who wanted revenge, the men who wanted the boys back, the men who thought the world would be taught a lesson once and for all, had the courage of their convictions. Coast, the good man, the worried man, is a coward. He has not the courage of his hatred nor, in private life, of his love. He falls back, in a dismal scene, on the Quaker habit of his upbringing:

"Then Jane had come in, Jane whom he knew he loved and yet even love was a listless thing in his heart, dwarfed by the monstrous object he had helped to create. What meaning had love, if the world were destroyed? Love could not save so much as a single life, even his own. And she had looked so beautiful, pale with sadness, and her eyes great and dark and unutterably lonely. He longed to be single-minded, as she was, sure of what she thought was right—the impractical right, the non-existent absolute. His scientist mind combined, he supposed, with the compromise that was part of the Quaker faith in which he had been reared. Long ago he had cast aside that faith, but its habits remained. 'The sense of the meeting . . .'—how often he had heard his father say those words after the long gatherings when tight-lipped men and women sat defying each other, waiting, in bitter disagreement, always repressed, for the first sign of yielding, so that there could be a sense of the meeting! Let the majority decide this fearful question now. He would not take sides."

Jane is on the minority side. One is reminded of the satirist who showed the Ten Commandments being thrown out one by one on the principle of the majority vote.

The end of the book is not tragic. It is simply depressing. Burton Hall goes to Japan to repent, but somehow comforts himself that horror is eventually forgotten. Coast, as one would expect, has a good job in industry; one suspects that he is going to be in a tight corner when the McCarthy inquisition gets to work on him, for he went very far with the "unreliable" Hard. Will he hedge again? Jane departs for India, but her Indian mentor makes her return to the States because she will be able to help India more from there. We end with the sight of a new generation of excited young scientists working on space travel.

Despite its literary and philosophical defects Miss Buck's novel obviously comes to grips with some harrowing issues. When any collective body has committed monstrous crimes—a political party, a priesthood, in the name of this religion or that—it has always had its plausible ethic. The ape in us always wishes to wear clothes. We can only struggle against our criminal tendencies by severe introspection; this reveals, in all cases, that there has been a failure to connect one value with another. The philosophy of the endless quest cannot be put unconditionally before everything else; it is dishonest to use it as an excuse for making weapons, when, in fact, you mean you are quite willing to accept and indeed forward the prospect of mass devastation. It would be better if we announced our hatred of civilization and our excitement at the prospect of the jungle. The scientist is quite justified in saying that his discoveries are controlled not by him but by politicians who need education in collective morality on the one hand, or in the value of individual freedom on the other.

The bombing of Hiroshima was a political decision made in time of war. I find it hard to grant that it had the dignity of an ineluctably tragic act, though it was an instance of the complexity of the general human tragedy. (There is

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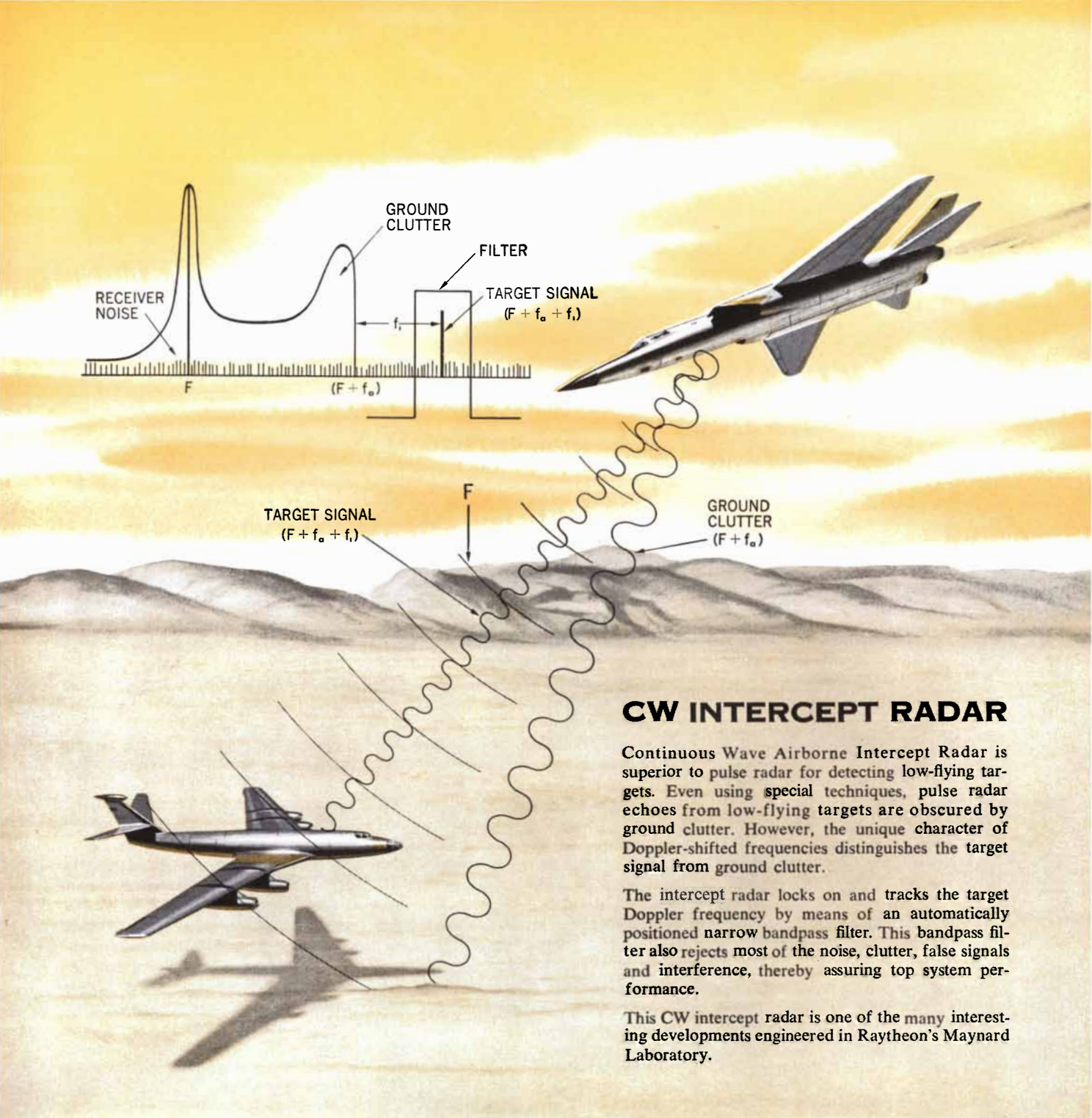
something more genuinely tragic in the present frightening preparations for a gamble on World War III.) Was Hiroshima worse than the devastating raids on Tokyo and Berlin? Many people have thought that these were excessive. There is an intoxication with destruction and some superstition that toughness is a virtue in itself. But the atomic bomb was not merely one more powerful high-explosive. It was the result of a new science, nuclear physics, which was about to open up vast benefits for the human species. We have to concede that the fear of Nazism was genuine and that we could not know of the German failure. It was certainly right, in the middle of war, to make the bomb. But the bomb was not used against the Nazis. My own view is that the decision was to a great extent made on a profound desire for revenge. All its consequences have been politically disastrous: for the NATO powers a loss of prestige in the East and a frightful arms race. But Hiroshima has led also to political decadence: science has been militarized; military strategy directs political policy; civil governments—which ought to be supreme, humane, far-seeing, concerned with bringing the blessings of the new age—are simply the servants of soldiers. Military servitude—I remember Einstein saying some years ago, in so many words—leads to the decadence of science. Few scientists, by the nature of their work, can easily separate themselves from this servitude; perhaps those who can separate themselves from weapon-making should do so, but it obviously depends on the individual case. This is not an age of saints and renunciations. It is the age of the inextricable, and one does not get out by making gestures. But, as human beings, scientists and technicians certainly can think and act against the disconnection of human values and for their unity.

Any one who has read the real story of Hiroshima must have noticed the crucial part played by the strategic arrangement of committees. The great projects of our society are organized by masters of departmentalization, so that we know only our own small role in the ant heap and willingly allow our opinions and even our morality to be limited to the field of our functions. The Franck committee's anti-bombing report went to the scientific panel of the interim committee appointed to advise the U. S. Government, but the panel considered itself able to judge questions only on technical grounds, and let the moral issue go by default. It is the classic road to disaster. The transcendent questions of life are not technical. The nearer the top the greater the likelihood of political accident or a decision by prejudiced or even incompetent people. We are not individually as expert as our machines and organizations, and we are slow to learn how to guide our judgment through the mazes of managerial society without fatal compromise.

The fabulous success of science has led us away from the correcting humility of the tragic sense of life—a sense we know to be true but have repressed. If we lose that sense, life loses its dignity, becomes a gambler's farce and degenerates into suicide. But no nonscientist has the right in the present difficulties to congratulate himself on his clean hands. To attack the intellect, to say that the ordinary man would never do such wicked things, and that he is a virtuous victim, is ridiculous. The decision to bomb was made by very ordinary men indeed. There are no innocent societies, but there are no innocent secret societies or priesthoods, either.

Short Reviews

PERSONAL KNOWLEDGE, by Michael Polanyi. The University of Chicago Press ($6.75). How do we know? What is the nature of knowledge? Is science dispassionate, and is scientific knowledge dispassionate knowledge? It is with these questions that Polanyi's book, based on his Gifford Lectures at the University of Edinburgh in 1951 and 1952, is concerned. He spent nine years, as he tells us, almost exclusively on the preparation of this work. It is less of a philosophical inquiry than a terribly long and passionate affirmation of a creed, with supporting evidence drawn from every corner of human activity, from quantum theory to Marxism. The main target of Polanyi's attack is the notion that science is objective and impersonal. We are taught to believe that these attributes are the guaranty of science's integrity. Scientific knowledge, it is said, is unmarred by human frailty or whim or prejudice; therein lies its value and dependability. The invariants of observation provide the basis of our understanding of and control over the physical world; it is precisely because such invariants can be found and are independent of personal bias and variability that we have hope of knowing. Polanyi calls this "a false ideal." Science is not and cannot be detached or impersonal. In the exact sciences this false ideal is perhaps harmless because scientists disregard it; but it exercises a "destructive influence in biology, psychology and



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sociology, and falsifies our whole outlook far beyond the domain of science." True knowledge has in Polanyi's view an essential personal component. To know is to make an intellectual commitment; to make such a commitment is "inherently hazardous" because one can obviously be wrong. But only by taking the risk of being wrong can one hope to gain anything resembling so-called objective knowledge. Knowing is an art; into every act of knowing "there enters a passionate contribution of the person knowing what is being known, and this coefficient is no mere imperfection but a vital component of his knowledge." What is the character of this "passionate contribution"? Evidently there must be more to it than passion, or the desire to know, or love of knowledge or respect for truth. These play important roles, to be sure, in the making of science, but Polanyi insists on a more substantive element which we ourselves add to the end product. He is, however, quite unable to pin this element down, to make clear why it is that we appear to know more than we know. Is it a built-in capacity, an inherent feature of organism? Is it an evolutionary accrual, a "racial memory"? Personal knowledge may be undefinable, but there are innumerable examples, Polanyi maintains, of appraisal, choice, learning and discovery throughout the sciences and in less exalted activities where such knowledge seems to play a crucial part. His illustrations are extraordinarily varied: he discusses piano-playing, bicycling, theorizing in astronomy, swimming, research in spectroscopy, the use of language in the practice of politics, manufacture, abstract art, Gödel's proof, legal procedures, genetics, animal psychology, philosophy, biological research, relativity, economics, Gestalt theories, evolution. Even Stalinism, espionage and Soviet trials are pulled into the discussion. Everywhere he finds witness to buttress his creed that knowing draws and depends upon the living self, that knowledge is not bloodless or inorganic, that a machine, however brilliantly contrived, cannot of itself either know or make knowledge. Certain of his examples are pretty farfetched. He devotes a good deal of space to a historical anecdote purporting to show that, contrary to what every physics textbook asserts, Einstein was not impelled to the special theory of relativity in order to account for the negative result of the Michelson-Morley experiment. At Polanyi's request, one of Einstein's assistants questioned him in 1953 and reported, with Einstein's approval, that he became acquainted with the Michelson-Morley result on reading a paper by H. A. Lorentz but that the result "had no role in the foundation of the theory." The author's point is that Einstein came to his theory because of his search for "rationality in nature" (a search characteristic of the operations of personal knowledge), and with the aid of observations that had been available for at least half a century; in order to preserve a philosophical prejudice, "positivistic textbooks promptly covered up the scandal by an appropriately embellished account of his discovery." It is not difficult to see that the example offers little support to Polanyi's thesis—apart from the fact that one need not regard as conclusive Einstein's personal recollection of formative influences on his thinking 60 years earlier. The example is related in an irritable, unpleasantly hectoring tone (quite typical of the book), as if the textbook writers and historians were engaged in a great conspiracy from which the author alone has the wit and courage to save us. Despite these blemishes, and Polanyi's failure to define what he calls personal knowledge or to appreciate the danger of gross misuse of the concept in the analysis of intellectual activities, this is a provocative and often engrossing book.

MAPPING THE TRANSMISSISSIPPI WEST: VOL. I, THE SPANISH ENTRADA TO THE LOUISIANA PURCHASE, 1540-1804; VOL. II, FROM LEWIS AND CLARK TO FREMONT, by Carl I. Wheat. The Institute of Historical Cartography ($120). These splendid folio volumes, the first two of a promised set of five, are the vehicles of a work of great scholarly skill and love. The first volume opens the fascinating story of how the American West was mapped, beginning with Francisco Coronado's chart of his route to Tiguex in what is now New Mexico—"the very first map of any part of what is now the American West to be drawn by one who had been there"—and extends to the transfer of Louisiana to the U. S. in late 1803. Though much was learned about this vast region in these two and a half centuries, most of its geographic features still remained obscure, and the magnitude of Lewis and Clark's contribution to knowledge, considered in the second volume, is strikingly brought out by comparison of the maps drawn after the expedition with those they used as guides when they started. In the first volume Wheat discusses 16th-century Spanish mapping, European maps of the 17th century, Spanish mapping up to Humboldt,

the products of the commercial ateliers of London, Paris, Venice, New York, Boston (and even Pomfret, Conn.) from 1750 to 1800. Fifty maps are reproduced in this volume, together with a formal bibliocartography, which describes all the maps considered and lists them chronologically. In the second volume Wheat writes about the transfer of Louisiana, a transaction involving a huge land mass about which so little was known that he calls it a "geographic pig-in-a-poke"; about Zebulon Pike's mapping of the Southwest; the Lewis and Clark maps; the products of such cartographers as Aaron Arrowsmith, Stephen Long (who explored the front range of the Rockies), Henry S. Tanner (who engraved a monumental map of North America) and Joseph C. Brown (who made that rare thing, a real map —"no imagination, no apocryphal rivers, no dreamed-up mountains"—which a traveler could depend upon). He also touches upon the British mapping of the Northwest; upon the remarkable cartographic achievements of the fur-trader Jedediah Smith, who embodied the geographical knowledge gained in nine years of "almost constant movement [over] the length and breadth of the West" in the first map on which "we may recognize the Farther West as we know it today"; upon the final opening of the cartographic floodgates in the 1840's. The bibliocartography of this volume comprises almost 250 maps, of which 59 —one in color—are reproduced. The text is admirable, filled with out-of-the-way details and names that re-create the atmosphere of this exciting period; the design and typography is in keeping with the grandeur of the subject. There is only one flaw: Despite the size of these sumptuous volumes, some of the maps have suffered so much in reduction that the legends and writing upon them—even the geographic details—are almost impossible to read.

ENDURANCE, by Alfred Lansing. McGraw-Hill Book Company, Inc. ($5). On October 27, 1915, Sir Ernest Shackleton, leader of the imperial trans-Antarctic expedition, gave orders to abandon his ship *Endurance*, which lay crushed in the ice of the treacherous Weddell Sea, midway between the South Pole and the nearest known habitation, some 1,200 miles away. For three months he and his men lived on an ice floe, and then in three open boats made their way to Elephant Island. From there he and five others sailed in a 22-foot open whaleboat 870 miles across the "most dreaded bit of ocean on the

globe" to South Georgia Island. It was an impossible voyage; even after it was over Shackleton's battered, starving men had to cross a sizable mountain range before reaching the whaling station at Grytviken on May 21, 1916. The epic story has been told before, notably in Shackleton's famous *South*, but it is well and simply retold in these pages. It is enough to say of Lansing's account that though one knows in advance that the ending is a happy one, the suspense until the final moment of triumph is almost unbearable.

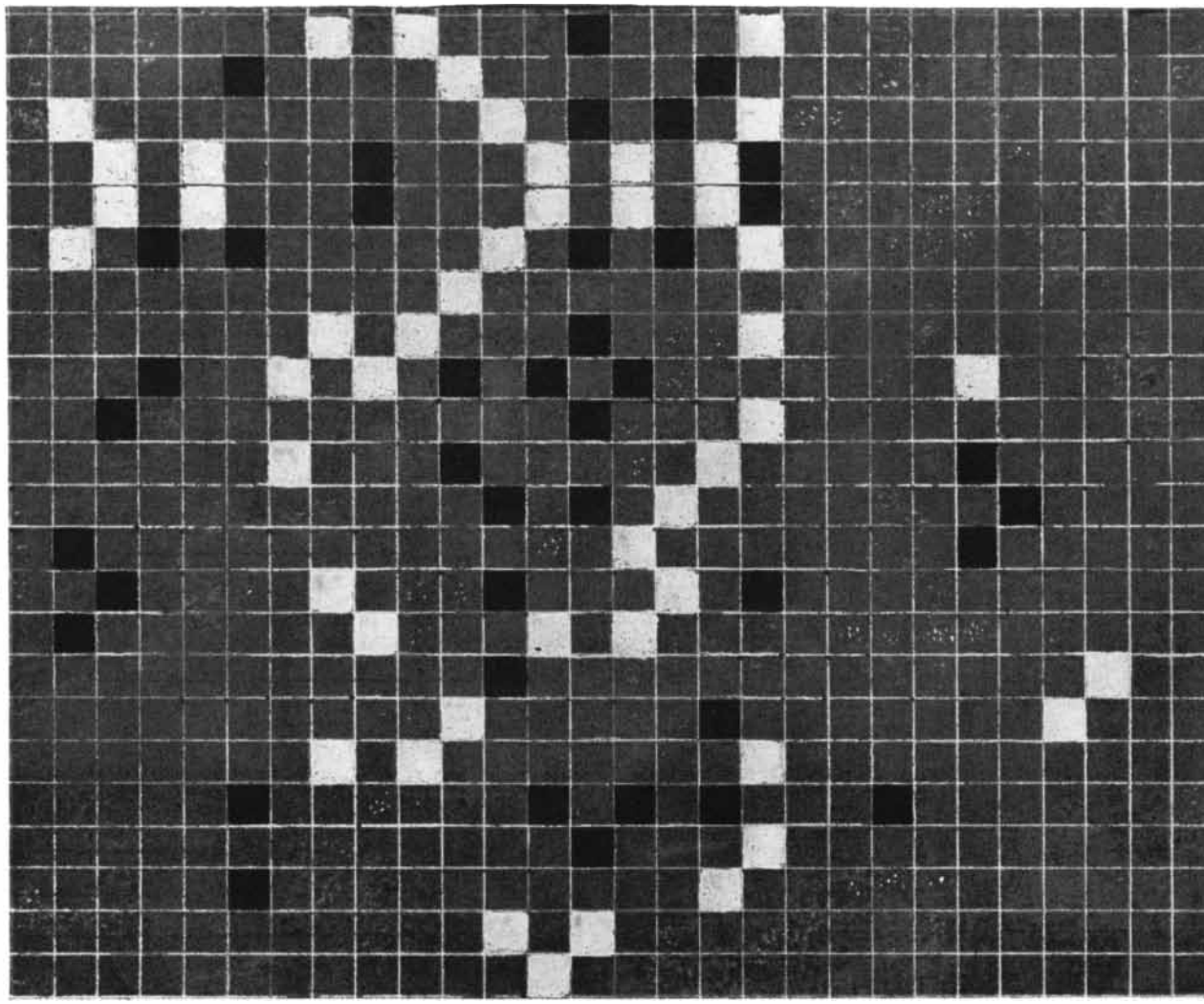
THIRST, by A. V. Wolf. Charles C. Thomas ($12.50). A comprehensive monograph on the physiology of the urge to drink and problems of water lack. The author has worked in the field of water and salt metabolism for more than 20 years, and on the basis of his own researches and an intimate knowledge of the literature presents a masterly survey of the subject. Among the topics Wolf considers are how long a man can go without water, fundamental aspects of body fluids, the rationing of water in emergencies, the complex and often paradoxical character of thirst, problems of drinking after severe water deprivation, the use of snow and ice to quench thirst, the potability of sea water, the individual idiosyncrasies of drinking capacity, cases of intemperate drinking, fish and fish juices as sources of water, desert thirst as a disease, the records of certain castaways at sea, the real and legendary thirst of battle casualties. His book includes excerpts from certain well-known accounts of thirst (*e.g.*, Rickenbacker's 21-day ordeal in the Pacific, the plight of the survivors of the sinking of the *U. S. S. Indianapolis*), a useful glossary and a valuable bibliography of 900 items.

THE SCIENCE OF PHOTOGRAPHY, by H. Baines. John Wiley & Sons, Inc. ($7.50). The Royal Institution Christmas Lectures have inspired another excellent book. This introduction to photographic theory, which includes the material of Baines's 1956 lectures to a "juvenile auditory" but covers a much wider range, fully lives up to its promise to make picture-making intelligible to the nonscientific reader. There is in fact no other survey that handles the material so plainly and agreeably. After sketching the beginnings of photography the author explains the elements of such topics as light and optical images, camera lenses, the structure and function of shutters, the chemistry of photography, the nature of light-sensitive materials, the meaning of the latent image, the principles of developers and development, fixation and stabilization, sensitometry, color sensitivity and filters, after-treatment of the negative, the positive process, graininess, different processes of color photography, applications of photography. The book is just as clear in describing the beautiful Mott-Gurney theory of latent-image formation as in telling you when to snap the shutter or in elucidating the effect of aperture on depth of field. The many illustrations are directly to the point. Any photographer who wants to know what he is doing, besides pointing, clicking and then deploring the results, will be grateful for a copy of Baines.

MAN'S WORLD OF SOUND, by John R. Pierce and Edward E. David, Jr. Doubleday and Company, Inc. ($5). A semipopular account of the physics and physiology of speech and hearing. The authors discuss the power of sound; the character of waves, frequencies and resonators; the acoustic nature of speech; what and how we hear; speech and hearing defects, automata and talking machines; information theory and communication. The exposition is uneven. It is obviously authoritative, but while some chapters are lucid and readable, others are crammed full of factual details that are neither easy to assimilate nor especially interesting. The conscientious reader who works his way through the book will nonetheless find the effort rewarding.

SIGMUND FREUD: REMINISCENCES OF A FRIENDSHIP, by Ludwig Binswanger. Grune and Stratton, Inc. ($4.50). The author, a Swiss psychiatrist, met Freud in 1907, and became his disciple and friend. Although marked differences developed in their theoretical outlook, their friendship held firm until Freud's death. Binswanger saw Freud only a few times in his life but they exchanged many letters, these being the meat of the book. They shed some light on personalities. The price of this 100-page volume is exorbitant.

THE AMERICAN HIGH SCHOOL TODAY, by James B. Conant. McGraw-Hill Book Company, Inc. ($1). After Conant resigned as ambassador to Germany he undertook, under a grant from the Carnegie Corporation of New York, a study of the U. S. high school. With a number of co-workers he briefly visited 100-odd of the so-called comprehensive high schools and prepared this report of his observations and recommendations. The



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conclusions are not profound, but they contain practical suggestions which in Conant's opinion would improve public secondary education.

A Source Book in Greek Science, by Morris R. Cohen and I. E. Drabkin. Harvard University Press ($7.50). The second edition, with minor corrections and additions, of a valuable source book. Harvard University Press has taken over from another publisher the entire series on the history of science in which this volume appears. That the series will be kept in print will be very welcome news to scholars and students.

The Fitness of the Environment, by Lawrence J. Henderson. Beacon Press ($1.95). A paper-back reissue of Henderson's famous essay on the biological significance of the properties of matter. As George Wald remarks in his introduction, the monograph is a classic because its intelligence and insight have survived many of its facts. The chapter on water is a jewel.

Notes

The History of Rome, by Theodore Mommsen. Meridian Books, Inc. ($8.50). Dero A. Saunders and John H. Collins have prepared a revised translation (which cuts the original to about half its size) of this great work of historical literature.

Jane's All the World's Aircraft, 1958-1959, compiled and edited by Leonard Bridgman. McGraw-Hill Book Company, Inc. ($30). The new edition of this standard annual has been substantially revised and updated, and for the first time includes a full-blown missile section of 36 pages.

Egyptian Religion, by Sir Wallis Budge. University Books, Inc. ($5). A reprint, with additional illustrations, of a book published in 1900 by a famous Egyptologist, describing the religious ideas that survived, substantially unaltered, over 5,000 years in great funereal and religious works.

Polymers and Resins, by Brage Golding. D. Van Nostrand Company, Inc. ($15). This book covers the theory, chemistry, properties, manufacture and application of commercial polymers and resins.

Peter the Great, by Vasili Klyuchevsky. St. Martin's Press ($6.75). This admirable biography, which not only describes the man but also deals with the social and economic life of Russia during his time, has been taken from Klyuchevsky's famous five-volume history of Russia, first published in Moscow between 1904 and 1921.

Researches in Geochemistry, edited by Philip H. Abelson. John Wiley & Sons, Inc. ($11). A collection of reviews of the present status of geochemical research.

The Polish Peasant in Europe and America, by William I. Thomas and Florian Znaniecki. Dover Publications, Inc. ($12.50). A two-volume reissue of an influential sociological work that traces "the erosion of social organization, the radical change in values and attitudes, and the demoralization of the Polish immigrant in America."

Perkin Centenary London. Pergamon Press ($7.50). In 1856 William Perkin made his great discovery of mauveine, the first synthetic organic dye. This volume, which commemorates the discovery, includes papers on Perkin's life and work, and the development of the industry he founded, by John Read, Clifford Paine, John Gwynant Evans and Sir Alexander Todd.

The Enzymes: Vol. I, edited by Paul Boyer, Henry Lardy and Karl Myrbäck. Academic Press, Inc. ($24). A second, and revised, edition of a comprehensive treatise on enzymes and on enzyme action at the molecular level.

Environmental Conservation, by Raymond F. Dasmann. John Wiley & Sons, Inc. ($6.50). An ecological approach to the conservation of natural resources, stressing underlying principles and philosophy.

The World of Learning, 1958-59. Europa Publications Ltd. ($22). The ninth edition of an established guide to educational, cultural and scientific institutions throughout the world.

The Autobiography of Charles Darwin: 1809-1882, edited by Nora Barlow. Harcourt, Brace and Company ($4.50). This is the U. S. edition of a book reviewed in these columns last summer.

Conduction of Heat in Solids, by H. S. Carslaw and J. C. Jaeger. Oxford University Press ($13.45). A second edition of a standard work in the literature of this subject.

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Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

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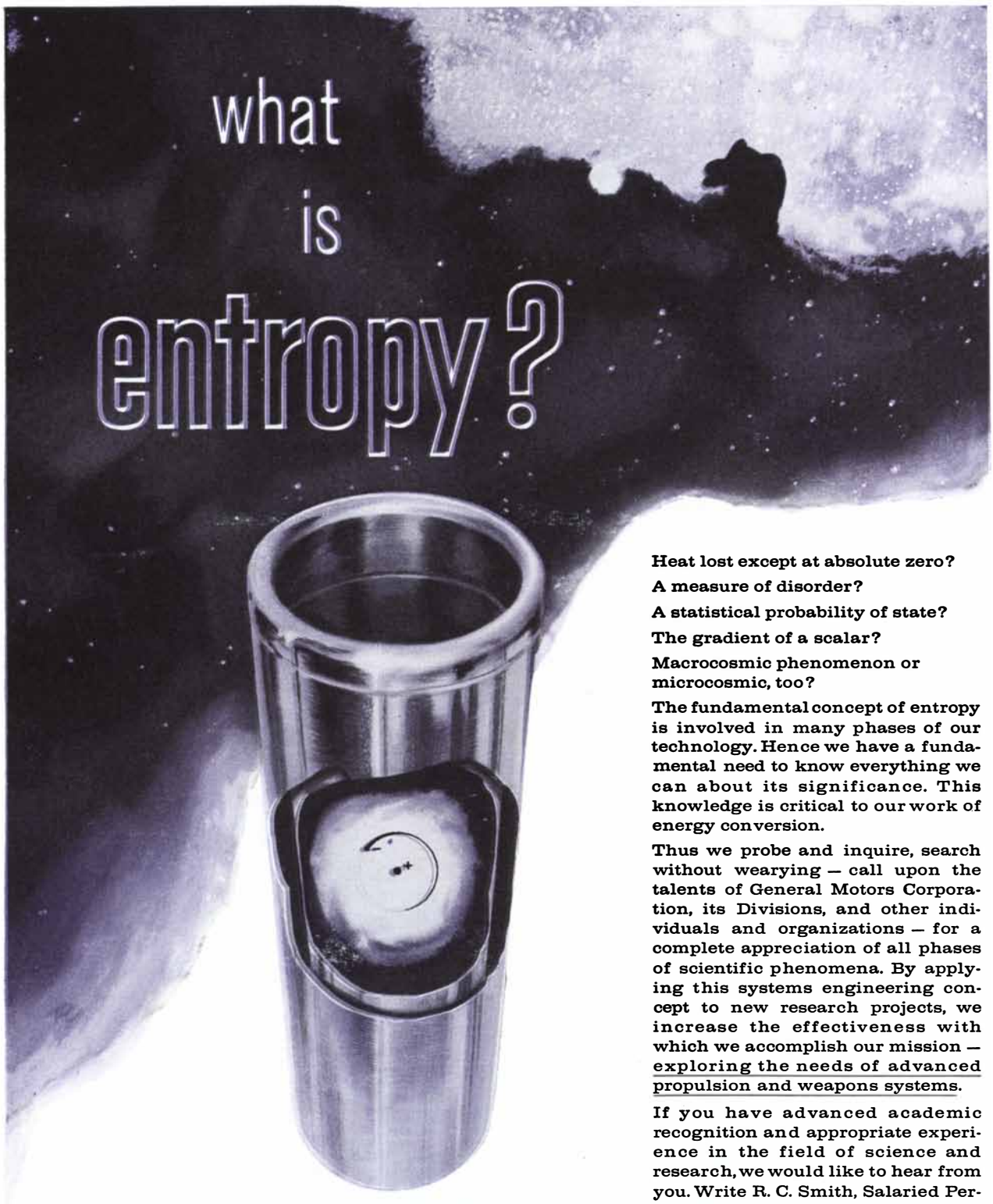

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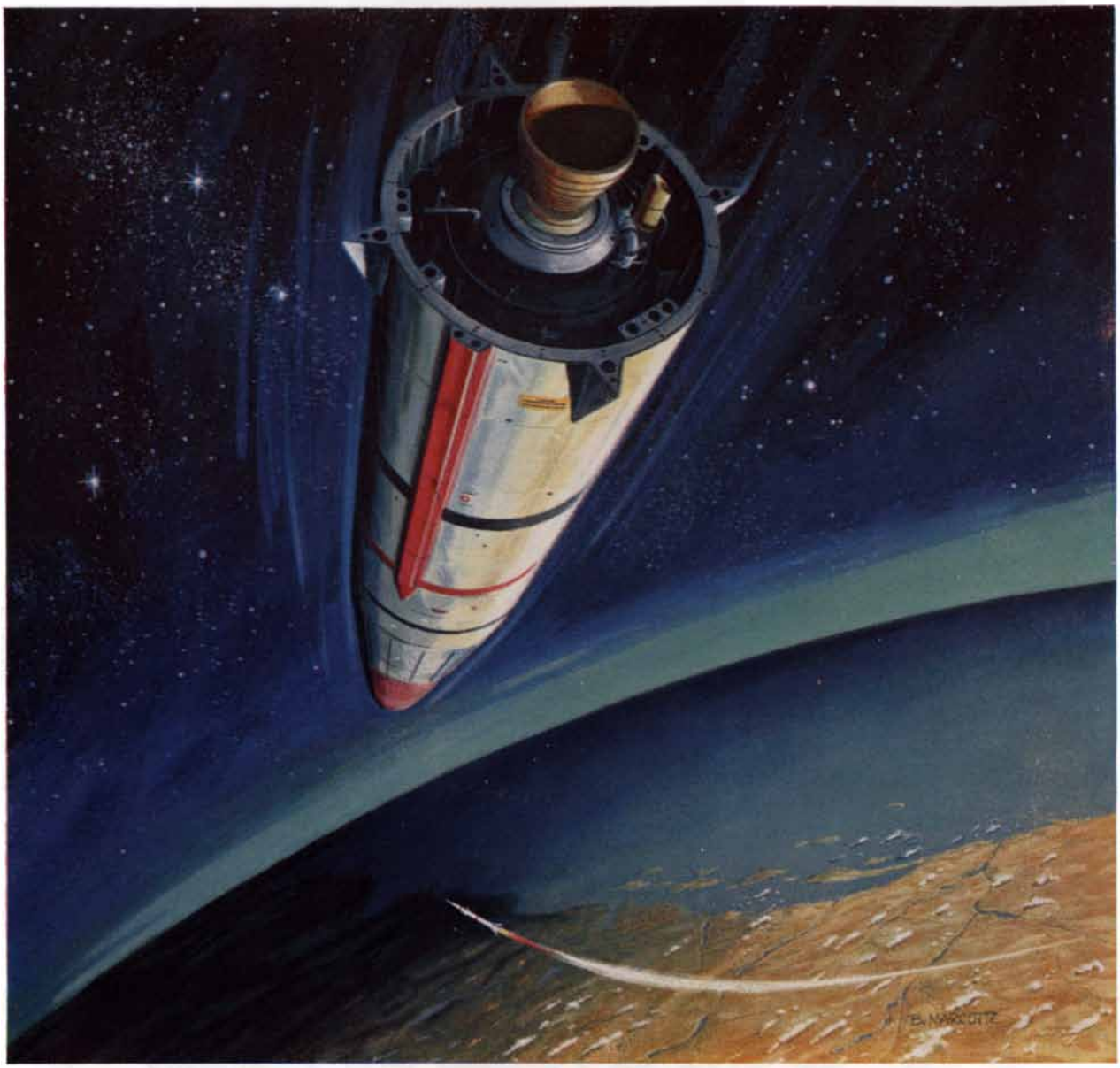

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