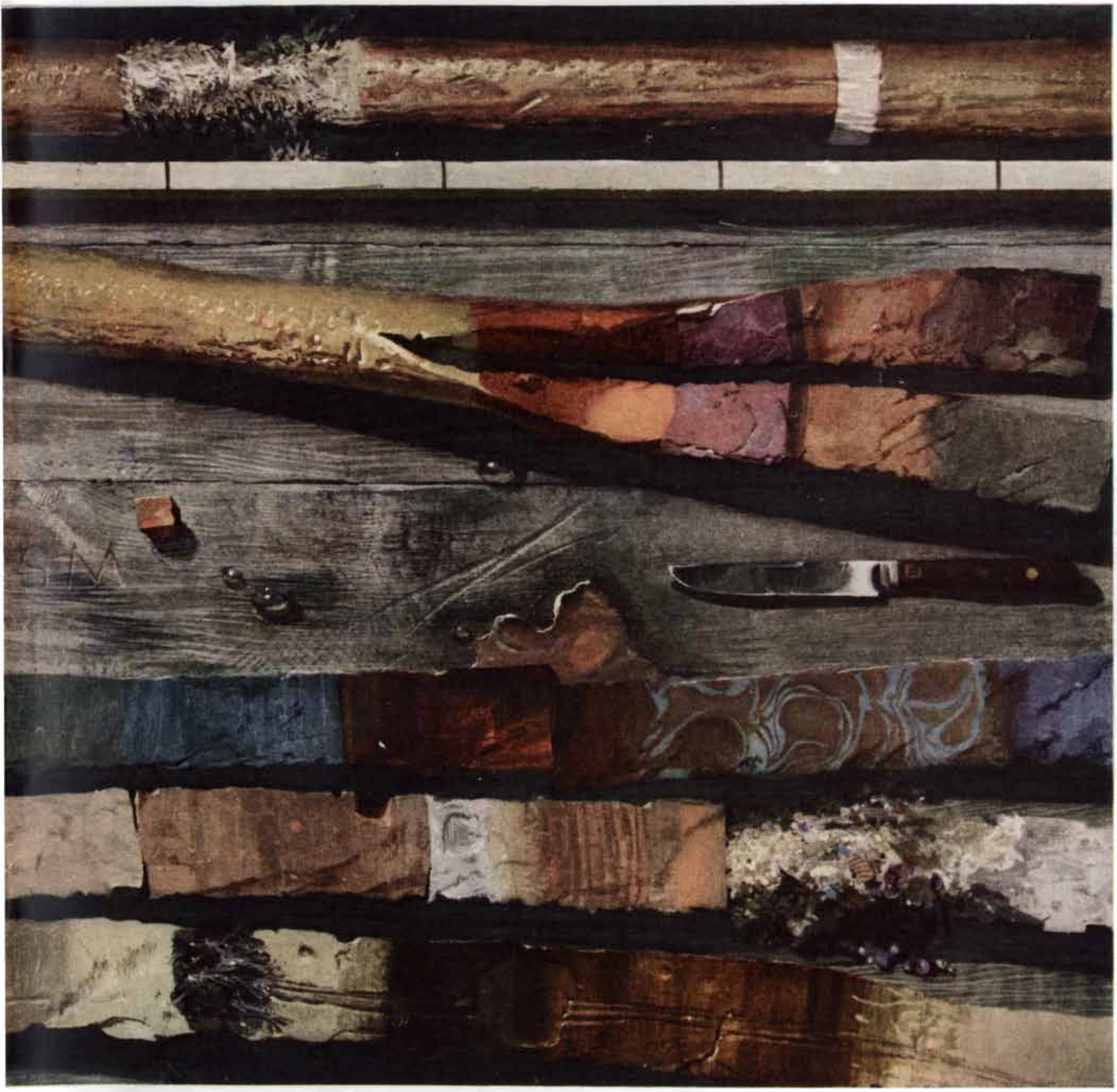
SCIENTIFIC AMERICAN



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FIFTY CENTS

August 1956

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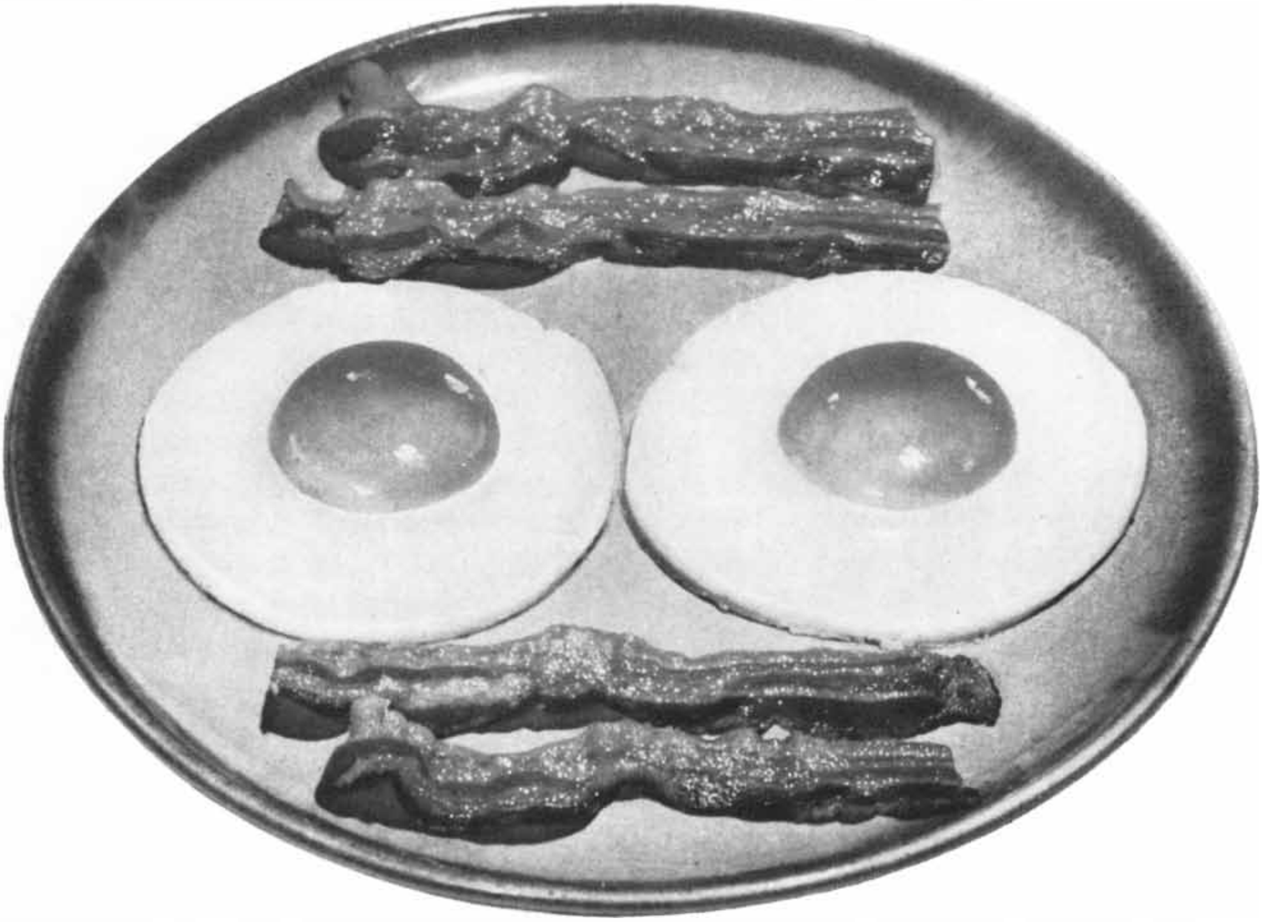

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Established 1845 SCIENTIFIC AMERICAN August, 1956 Volume 195 Number 2

ARTICLES

DEPARTMENTS

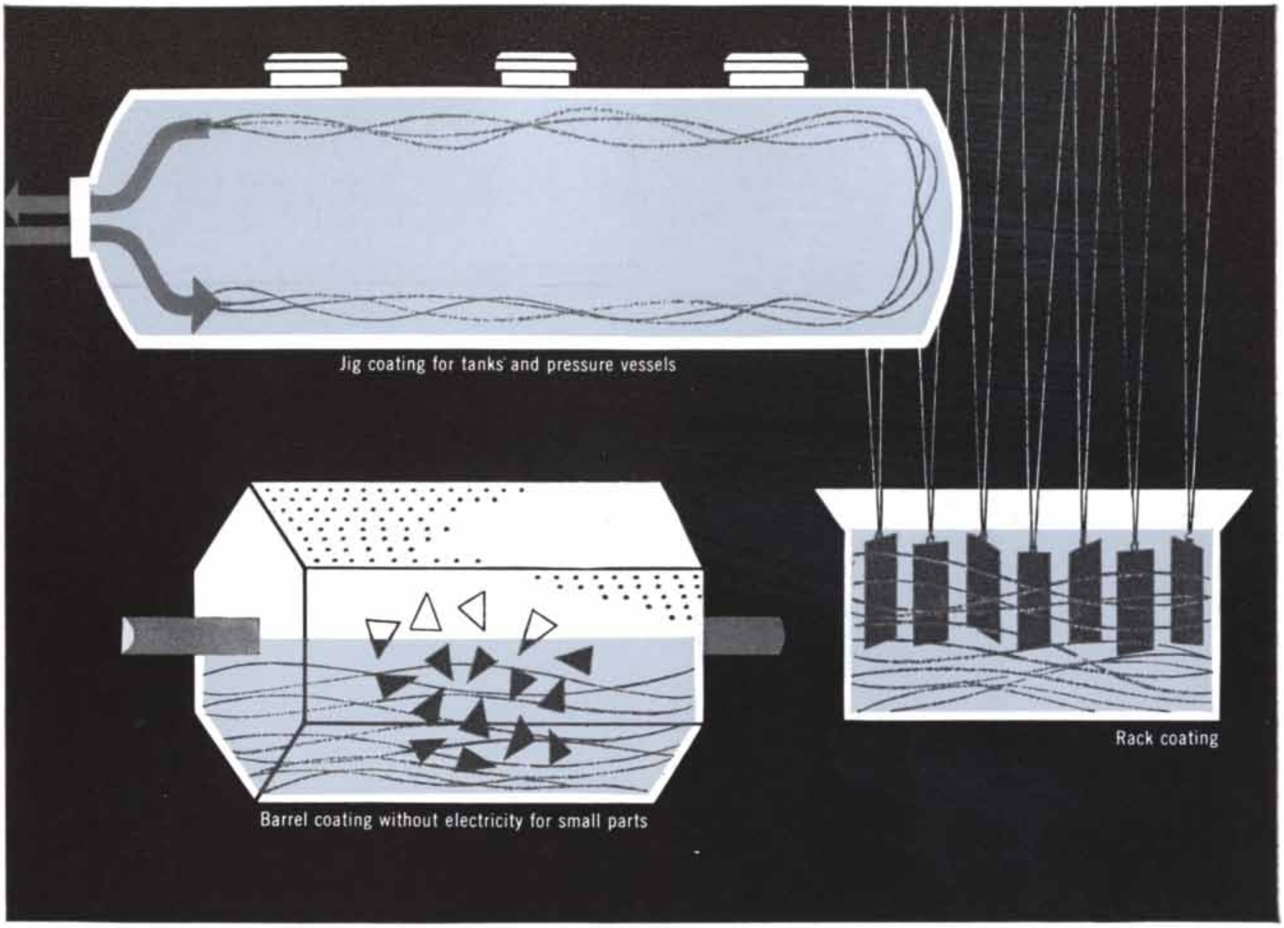
THE COVER

The painting on the cover shows five "cores" of sediment from the deep-sea floor. The cores were made by a device which brings up a thin vertical cylinder of sediment; hence each core is a vertical cross section of the bottom. Until recently it was thought that the deep-sea floor was overlaid with an unstratified ooze consisting entirely of microscopic shells and fine clay. The five cores show vividly that, on the contrary, deep-sea sediments are often stratified into beds of sand, gravel and other materials characteristic of shallow water. These materials are carried into the depths by currents of turbid water which flow along the ocean floor like rivers (*page 36*).

THE ILLUSTRATIONS

Cover painting
by Stanley Meltzoff

Page	Source
29	Sovfoto
30-31	Robert E. Marshak (*first and second from left*), Keith A. Brueckner (*third*), Sovfoto (*fourth*)
33	Bunji Tagawa
34-35	Sovfoto
37-41	Bunji Tagawa
42-46	Bernarda Bryson
58	Donald Stanley Marshall
60-61	Eric Mose
62	Donald Stanley Marshall
64	Eric Mose
66-67	Donald Stanley Marshall
68-70	Eric Mose
75	Atomic Energy Commission
76-82	Sara Love
87	Department of Biochemistry, University of Oxford
88-94	James Egleson
96	University of California
97	Fred Swartz
98-104	University of California
107-112	Irving Geis
129	Stevens Institute of Technology
130-136	Roger Hayward



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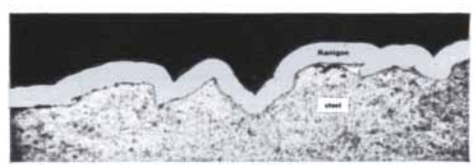
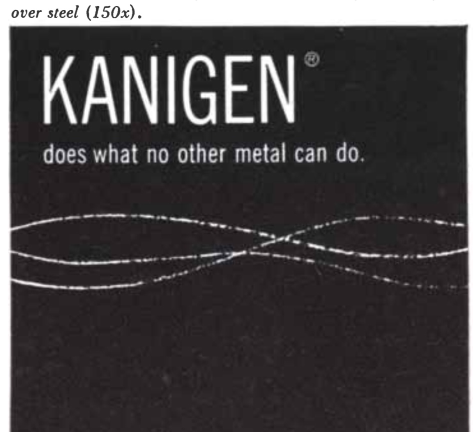


photomicrograph showing uniformity of Kanigen coating over steel (150x).



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Life ...on the Chemical Newsfront

BETTER MILK-CONTAINER STOCK is among many improved paper products made possible by CYFOR® Fortified Rosin Size. To fortify rosin size, which ordinarily has one carboxyl group, small quantities of organic acids are added, thereby increasing the carboxyl groups to three. The rosin becomes more reactive to cellulose, increasing the sizing effect which prevents passage of fluid through paper. This helps keep wax coatings on the surface where they are most effective, and helps prevent leakage should the coating crack. CYFOR Size makes it possible to get higher sizing effects than ordinary size, or attain equal specifications using less size. It is increasingly used by paper mills to improve paper quality and reduce costs. (Industrial Chemicals Division, Dept. A)

NURSES GRADUATING THIS YEAR will be even more radiant in uniforms made of fabrics treated with CALCOFLUOR* White ST. This new textile brightener, applied during fabric processing, absorbs ultraviolet radiation, transforms it and reflects it as visible light in the blue range of the spectrum. Counteracting yellowness in the material, the blue radiation makes the fabric whiter and brighter. CALCOFLUOR White ST works equally well in white-background prints and stripes, or drapery florals, in printed dress fabrics and in woven or knit goods. It is used primarily on cottons and is applied with standard equipment. Washing with commercial soaps or detergents containing CALCOFLUOR White restores the whitening effect. (Organic Chemicals Division)

*Trademark

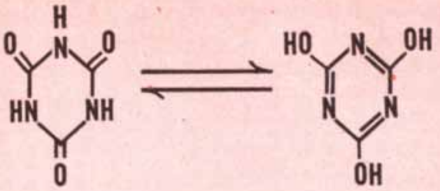
LAMINAC® RESIN TRAYS OUTLAST METAL for drying dye intermediates, pigments and other corrosive chemicals in nine-month evaluation just completed at two Cyanamid plants. Fabricated of glass fiber and LAMINAC Polyester Resin 4109 by Molded Fiberglass Tray Company, some 61,000 drier trays have given highly satisfactory service. Light and easy to handle, they have high impact and dent resistance, and with no coating to chip or flake, eliminate danger of contaminating materials being dried. In several industries, molded LAMINAC trays are replacing other materials because they are non-corrosive, uniform, smooth, rugged, low in cost and easy to maintain. (Plastics and Resins Division)

NEW PIGMENTS developed by Cyanamid for use in exterior finishes must first pass rigorous tests on accelerated weathering equipment in the Pigment Development and Application Laboratory. Test-fence and field-exposure tests follow for final proving. These tests ensure that Cyanamid's pigments meet the critical, highly demanding levels of color stability required in exterior finishes. Protective coatings formulated with such pigments as Phthalocyanine Blue and Green, Chrome Yellow, Orange and Green, Iron Blue, Toluidine, Permaton, and UNITANE® Titanium Dioxide, among others, in this way meet conditions of exposure as taxing as any nature can provide in actual use. (Pigments Division)

IMPROVED LUGGAGE and other leather products will go along on vacation this year with many of the natural advantages of leather enhanced and controlled by chemistry. Among chemicals supplied to tanners by Cyanamid, TANAK® MRX Tanning Agent proves especially valuable in white or colored leathers. Applied at the tanning drum, TANAK MRX permeates the stock and polymerizes, filling the body of the leather. Leather comes out softer and more supple, with a tighter break, thicker grain and better temper. Other Cyanamid chemicals for tanners include bating and dehairing agents, dyes, pigments and extracts. **(Organic Chemicals Division)**

NEW PRODUCT DATA

CYANURIC ACID



I II

PHYSICAL PROPERTIES

Appearance	White solid	Solubility	Water at 20° C: 2.5 g./l. Moderately soluble in hot water. Soluble in concentrated sulfuric acid and alkali. Insoluble in most organic solvents.
Molecular Weight (Theory)	129.08		
Melting Point	Infusible		
Dissociation Constants, K_a at 25° C			
First	6.31×10^{-8}		
Second	7.94×10^{-12}		

CYANURIC ACID, an interesting s-triazine derivative, is now being offered by Cyanamid in pilot-plant quantities. Both as a solid and in aqueous solution, cyanuric acid exists principally in the lactam or iso-form (I). It yields salts with most inorganic cations and with some organic bases and many alkaloids. Highly colored salts are formed with metallic ions in the presence of ammonia. Reactions with ammonia, phosphorus pentachloride, methyl iodide, diazomethane and sodium hypochlorite have been reported. Cyanuric acid may be used to prepare trichloroisocyanuric acid, a solid bleaching agent. It has a herbicidal action that may be selective, and should also be interesting in pharmaceuticals, microanalysis, resin formation and dyestuffs. **(New Product Development, Department A)**

Additional information may be obtained by writing on your letterhead to the Division of American Cyanamid Company indicated in the captions.

Building for the Future Through Chemistry

LETTERS

Sirs:

In "Pneumatic Buildings" [SCIENTIFIC AMERICAN, June] Murray Kamrass's statement that the idea of a pneumatic structure "was never investigated on a thoroughgoing scale until after World War II," requires some correction.

There was a project of the War Production Board, Office of Production Research and Development (W.P.B.–89) in 1943-1944 at New York University, College of Engineering, entitled "Air Supported Roofs" in which the idea, various designs and stress analysis were extensively studied, large structural models and wind-tunnel tests were undertaken, and detailed information on previously built pneumatic structures was obtained.

Balloon-fabric structures similar to those illustrated in *Scientific American* were proposed during World War I by Frederick William Lanchester, an English aeronautical pioneer.

Actual pneumatic structures investigated in the War Production Board project included the sheet-aluminum airship of Ralph Upson, built in 1929, a 50-by-250-foot half-cylinder, sheet-steel grain bin devised and built by John H. MacMillan, Jr., in Minneapolis in 1934, and a series of Wiggins inflatable tanks built by the Chicago Bridge and Iron Company up to 300 feet in diameter.

An invention of mine (U.S. Patent No. 2,355,248), a sheet-metal roof built on the ground inside a concrete anchor ring, and raised and stretched into a shallow dome by air pressure, was carefully investigated and pronounced technically feasible in the War Production Board study.

In 1945, while designing a 900-foot diameter aluminum stadium roof for Glenn L. Martin that was never built, I had occasion to visit the Curtiss-Wright facilities at Buffalo that later became the Cornell Aeronautical Laboratory. I have sometimes wondered if my talk about pneumatic structures was seminal of the radar domes. . . .

HERBERT H. STEVENS, JR.

Long Island City, N. Y.

Sirs:

I am grateful to Mr. Stevens for bringing forth additional historical information concerning pneumatic structures. It should be noted, however, that the units mentioned by Mr. Stevens are thin metal shells. These are essentially complete structures and are not pressurized, although internal air pressure may be necessary for stabilization. The pneumatic radomes and other forthcoming fabric structures are basically different in that they are nonstructural until they are pressurized. I am not aware of any detailed investigation or development of pressurized-fabric buildings prior to that conducted by the Cornell Aeronautical Laboratory.

MURRAY KAMRASS

Cornell Aeronautical Laboratory, Inc.
Buffalo, N. Y.

Sirs:

It is surprising to find one of your able reviewers contributing, even in a passing reference, to the persistence of a popular myth. In his review of Leonard Bertin's *Atom Harvest* [SCIENTIFIC AMERICAN, June] James R. Newman, perhaps following the author, writes, "When the Germans tore through the Maginot Line, the plan was put into execution." When did the Germans tear through the Maginot Line?

They tore past it, they tore round the end of it, but no direct attack was made on it until June 14, a month after the break-through at Sedan, and 10 days after the last British and French troops had been withdrawn from Dunkirk. The

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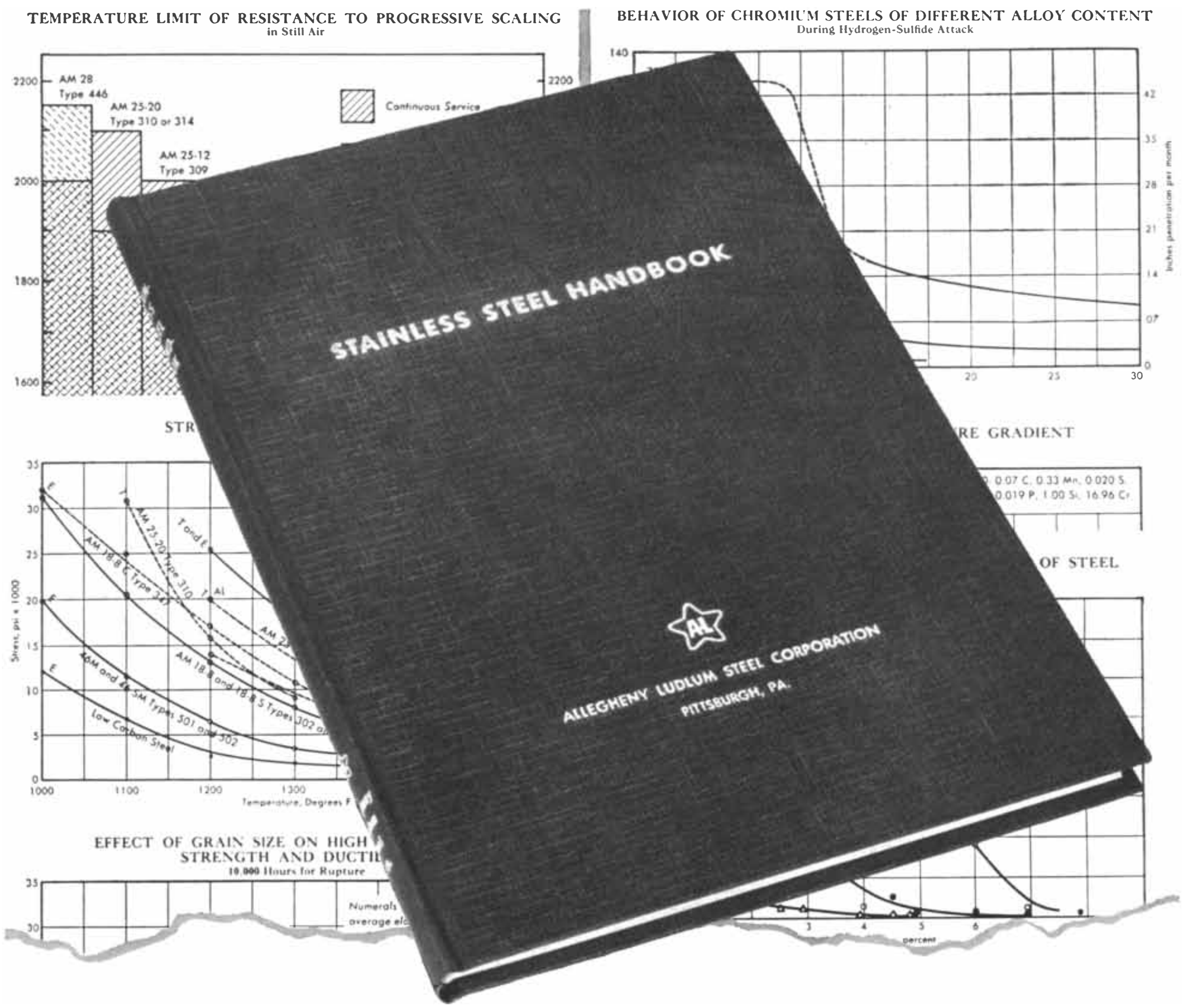

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Seine had already been crossed before the Maginot Line was attacked, and Paris fell on the day of the attack. By the time the Germans had penetrated the lines a few miles beyond Colmar and Saarbrücken, other German armies had reached Dijon and Besançon. On June 23 the French Government announced the signing of an armistice; the last forts of the Maginot Line did not surrender until June 30.

That is hardly what one would call "tearing through the line." It is a small point, and does not affect the general excellence of an admirable review, but it is myth masquerading as history, and no one is better aware than Mr. Newman that myth has no place in history except to be discredited.

L. A. MACKAY

Berkeley, Calif.

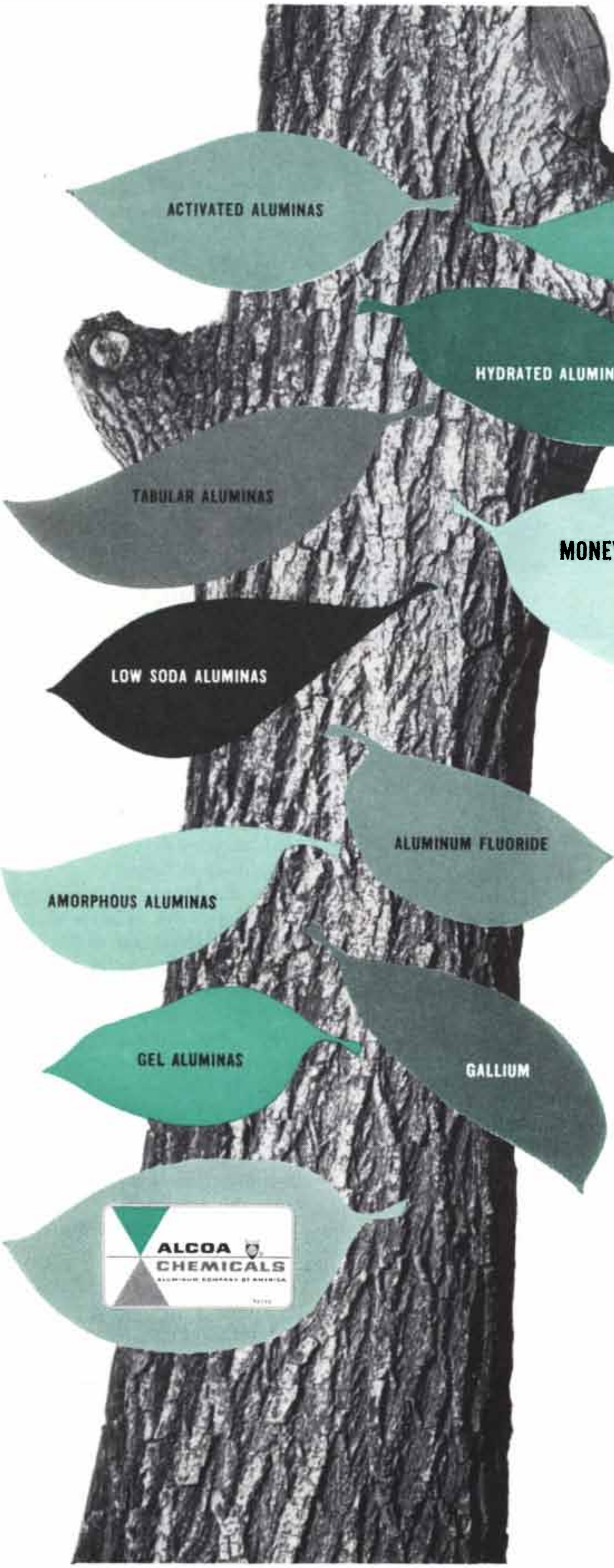
Sirs:

In your department "Science and the Citizen" for September, 1955, you printed a report on the investigations of an Englishman, C. C. Balch, in connection with his theory that ruminants do not sleep stretched out prone because of their peculiar digestive arrangements, and that, in fact, ruminants do not truly sleep in the generally accepted sense of the word. To test his theory he had corresponded with zookeepers around the world, and had spent many nights in cow barns. In all cases the observed animals had merely rested, chewed their cuds, and only occasionally shown signs of drowsiness. The cows had kept a wary eye upon him throughout the night.

This report might be interpreted either as additional evidence of the world-wide research upon human beings being carried out by animals or as confirmation of the fact that Englishmen need watching. Would it not be true to surmise that any intelligent creature, having been yoked in a position which prevents lying prone, and having a total stranger camp himself for the night a few feet away, would be somewhat cautious about sleeping?

It might be a more tenable theory that ruminants with large antlers or horns protruding from the sides of their heads find it uncomfortable to lie stretched out on their sides. Young hornless animals, or those which have shed their antlers, would use the stretched-out position most, while those which have been dehorned might require a little time to realize that the horns are not still there.

Nevertheless, many ruminants do



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sleep stretched out on their sides: dairy cows sleeping in this position are especially familiar to farmers in the spring; caribou and reindeer often lie this way, usually after shedding their antlers; goats will even sleep on their backs with their feet in the air. And our musk oxen—true ruminants—always sleep in this stretched-out position both in the wild and up here in Vermont. During any rest period the musk oxen might appear to the unaware as a herd of dead animals scattered about the pasture. So deep is their sleep that one must prod and shake them to wake them up, whereupon, depending on their dreams, they are either off with a bound or stretch lazily, licking the taste of sleep from their lips.

JOHN J. TEAL, JR.

Director
Institute of Northern Agricultural Research
Huntington Center, Vt.

ERRATA

In the June issue of this magazine a sentence was inadvertently omitted from the letter by Warren Weaver on pages 20 and 22. The relevant portion of Dr. Weaver's letter reads as follows:

"In the *Principia Mathematica* of Alfred North Whitehead and Bertrand Russell, one of the basic rules of procedure is the so-called Principle of Exportation. This may be stated in words: If p and q jointly imply r, then p implies that q implies r. As applied to our situation, this Principle of Exportation permits one to proceed from the statement:

"If Carr and Allen are both out, then Brown must be in

"to the statement:

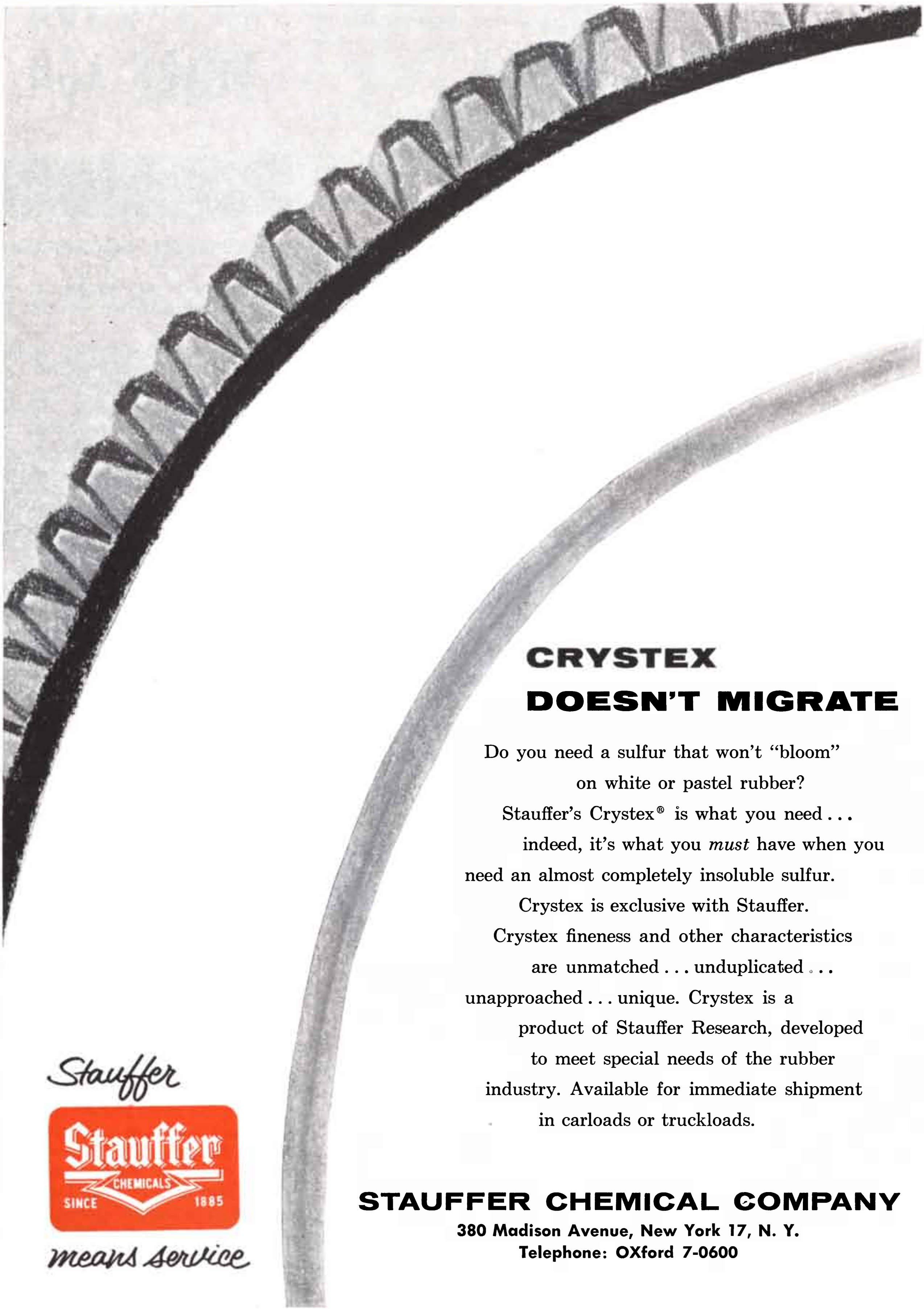
"If Carr is out, then if Allen is out Brown is in."

In the same issue the table on page 83 of the article "Gödel's Proof" was in error. As published, the first two lines of the table read as follows:

A 125,000,000
B 64 × 125 × 15,625

These lines should actually be:

A 243,000,000
B 64 × 243 × 15,625



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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1906: "Valuable information concerning the thickness of the earth's crust has been obtained as the result of a series of investigations by the Hon. R. J. Strutt, F. R. S., the well-known British scientist and son of Lord Rayleigh. Since the first discovery of radium by Madame and Prof. Curie, this scientist has been engaged in a careful computation of the average amount of radium contained in the various representative igneous rocks to be found on the external surface of the earth. The fragments of rock were decomposed by means of chemicals, thereby breaking up the various constituents, the yield of radium present being determined in a quantitative manner by the extent of its emanations. As the result of prolonged investigations, Strutt has ascertained that the presence of radium can be easily denoted in all rocks of igneous origin, but the percentage is highest in granitic formations."

"Kollmann, the professor of anatomy, has recently written an exhaustive article on the subject of the relationship between man and the *Pithecanthropus erectus* of Dubois. It will be remembered that some years ago Dubois discovered on the island of Java some bones—the femur and several bones of the cranium—which resembled both the corresponding bones in the human frame and also in the frame of a monkey. It was the scientist Schwalbe who christened this hypothetical animal with the name *Pithecanthropus erectus*, or man-monkey standing erect. A minute examination of the bony remains of Java permitted the hypothesis that they had belonged to a being of great stature, with habits still arboreal, and which probably passed a great part of its time in the trees, but which, like man, already possessed the faculty of speech. But Kollmann now shows that although these bones discovered in Java are of great paleontological importance, they should be interpreted in quite a different manner. He asserts that the animal to which they belonged could not have been a precur-

sor of man, for, although they certainly belonged to one of the most highly developed of the anthropoid apes, the animal's habits and customs could not have differed from those of its cousins still living—the chimpanzee, the gorilla, the orangoutang—all species of animals which have reached the extreme limit of their variability. Kollmann is rather of the opinion that the direct antecedents of man should not be sought among the species of anthropoid apes of great height and with flat skulls; but much further back in the zoological scale, among the monkeys with pointed skulls."

"The phonograph is being diverted to valuable scientific account in Great Britain in preserving records of rapidly decaying dialects of the Isle of Man and Guernsey. In the former island the dialect language is one of the Gaelic group, and so rapidly is it disappearing that it is anticipated that it will become extinct during the present generation. The Manx Language Society is dispatching phonographs to remote parts of the island, the aged inhabitants of which still retain a pure accent, and the numerous records thereby obtained are to be preserved. In Guernsey the dialect is the old Norman French, and in its main features is exactly the same as that used by the cultured class in England many centuries ago. In this instance the phonograph is to be utilized for the collection of the dialect poems, folk songs and folklore of the island."

SCIENTIFIC AMERICAN

AUGUST, 1856: "The American Association for the Advancement of Science is now holding its tenth annual meeting in Albany, N. Y. The president, James Hall of Albany, called the Association to order, and Dr. Sprague opened the proceedings with prayers. American dons of science are present in strong array—Agassiz, Henry, Peirce, Horsford, &c. &c., and a delegation from Canada consisting of Prof. Smallwood, Sir Wm. Logan and others."

"Prof. Morse, who is now in Europe, has received great attention from most scientific men and from the most eminent electricians in England. A correspondent of the Philadelphia *Ledger* says: 'In Paris Prof. Morse was received by the Count de Nourhy, the Director General of Telegraphs, with the utmost

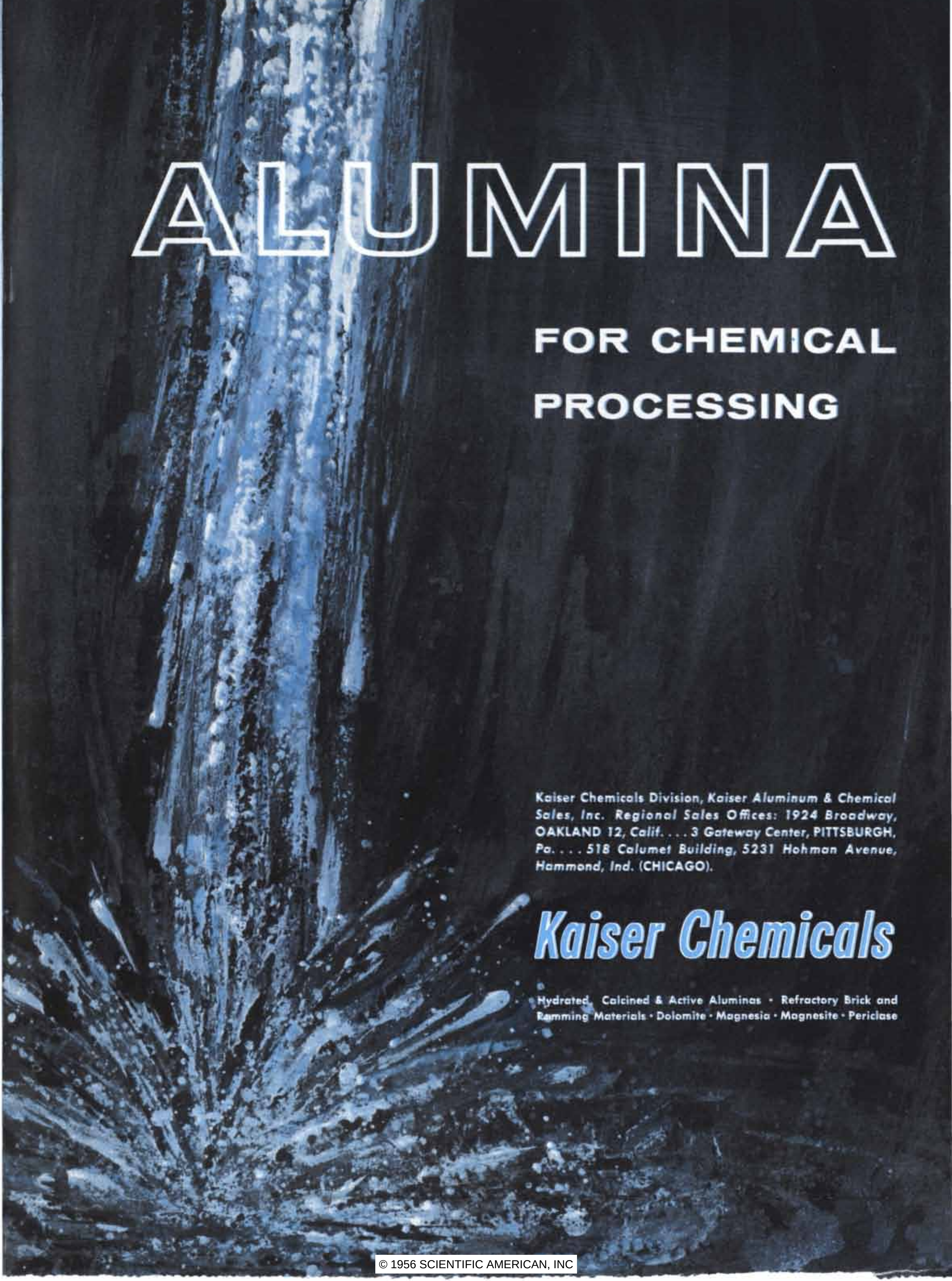
"FIGHTERS-
DROP YOUR TANKS"

courtesy, and, being ushered into the telegraph rooms of the central station, about thirty instruments of his invention welcomed him with the music of their filial voices. A reminiscence made this scene peculiarly interesting. These instruments were in the building which formed the central station of the French Semaphore Telegraph, by whose outstretched but now unmeaning arms it is still surmounted. In that same building, eighteen years ago, Prof. Morse exhibited his instrument, and endeavored, in vain, to satisfy the managers of the Semaphore that he had brought them a superior system. What he could not do for his instrument it has done for itself, and now it constitutes the only telegraph in the French Empire.' "

"The remains of a magnificent palace have been discovered under a garden on the Isle of Capri. It must not only have been splendid in structure, but in situation, commanding a view of the Bay of Palermo and Naples. Marbles of various colors were used in its construction, and all its apartments, so far as the examinations have proceeded, are of the most spacious and elegant character. The doorway is twelve feet wide, and of white marble, and the rooms are paved in mosaic, while the walls are painted red, blue, yellow, &c. Several coins of the reigns of Augustus and Tiberius have been found, some of them disclosing the curious fact that the coins of one reign were at times recoined in another."

"According to a Milan newspaper the Rev. Father Secchi, director of the observatory at Rome, has succeeded in taking photographs of the moon. Among them there is one in which the mouth of a volcano of Copernicus is distinctly represented. The same volcano was shown on photographs taken by Mr. Whipple, of Boston, four years ago, and sent to this office."

"A patent granted to Gail Borden, Jr., of Brooklyn, N.Y., for concentrating sweet milk *in vacuo*, embraces the discovery made by him that, to render concentrated sweet milk capable of long keeping and solution in water, it must be kept out of contact with the atmosphere during concentration, to prevent incipient decomposition. Milk concentrated by his process requires no antiseptic, like other concentrated milks; it is perfectly soluble in water and it has been tested with great satisfaction in voyages across the Atlantic. Pure sweet milk can be concentrated in the rural districts and sent to cities in tin canisters."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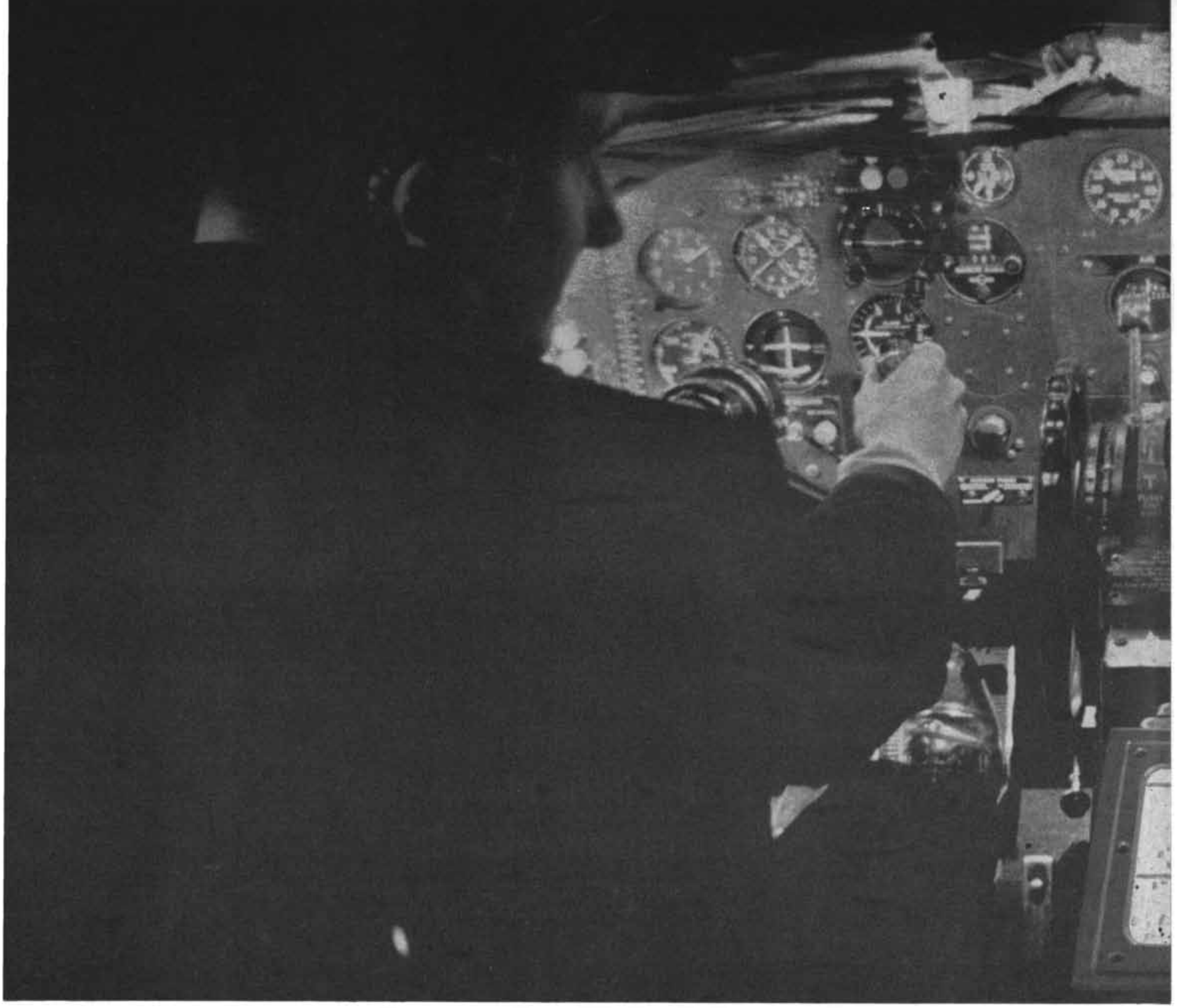

1,000 TIMES MORE SENSITIVE THAN A TELEVISION CAMERA, this optical amplifier (shown center foreground) now being

SUPER-TV GIVES PILOT WITH DAYLIGHT BRIGHT

On a black, moonless night, recently, U. S. Airmen flying over the Wright Air Development Center at Dayton, Ohio, saw ground installations with daylight brightness. They saw by means of a new optical amplifier, conceived by the Aeronautical Research Laboratory, and popularly known as "Cat Eye." It greatly intensifies light which is always present but unseeable by the human eye.

Westinghouse has been asked to perfect the key transducer for this amazing electronic instrument, already 1,000 times more sensitive than a television camera. Results have been achieved by Westinghouse which were considered hardly possible by other companies. Westinghouse was a logical choice. For nearly eight years, the X-ray Image Intensifier, invented by Westinghouse, has been lifting the horizon of sight. With it, doctors can see clearly what goes on inside the body—the heart beating, food being swallowed, lungs breathing.

In fact, modern radio and television were born at Westinghouse. No one ever heard an officially scheduled broadcast until Westinghouse radioed the Harding-Cox

perfected for the U. S. Air Force will enable pilots to see in the dark with daylight brightness. Pilots view the ground on a TV screen.

PICTURES OF GROUND NESS ON DARKEST NIGHT

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THE AUTHORS

E. P. ROSENBAUM ("Physics in the U.S.S.R.") is a member of the board of editors of SCIENTIFIC AMERICAN. In gathering information for this article he interviewed Robert R. Wilson and Robert E. Marshak, two of the 14 U. S. physicists who attended the recent conference on high-energy physics in Moscow. Wilson, director of the Laboratory of Nuclear Studies at Cornell University, designed Cornell's billion-volt electron synchrotron, the first accelerator to make use of the strong-focusing principle. Marshak, Harris Professor and chairman of the physics department at the University of Rochester, in 1947 predicted the discovery of the pi meson.

BRUCE C. HEEZEN ("The Origin of Submarine Canyons") is research associate at the Lamont Geological Observatory and lecturer in submarine geology at Columbia University. While he was an undergraduate at the University of Iowa, preparing for a career in invertebrate paleontology, Maurice Ewing, director of the Lamont Observatory, came to Iowa on a speaking tour. His lecture on the geology of the sea floor so interested Heezen that he decided he wanted to investigate "the problems that lay unanswered beneath the sea." Ewing invited him to accompany the 1947 cruise of the research vessel *Atlantis*, but he passed up the opportunity in order to head a much smaller expedition which reconnoitered the continental shelf and slope off New England. Since then he has spent three to nine months a year in deep-sea exploration.

GEORGE A. MILLER ("Information and Memory") is associate professor of psychology at Harvard University. As an undergraduate at the University of Alabama "I wanted to be a writer, but since I lacked talent, I migrated from English to speech." The migration continued when he became an instructor in psychology at Alabama and two years later enrolled at Harvard for graduate study. During the war he worked at Harvard's Psycho-Acoustic Laboratory analyzing voice communication. He got his Ph.D. there in 1946. "I suppose my persistent interest in communication is a symptom of intellectual claustrophobia. In any case, when Claude Shannon's mathematical theory of communication appeared in 1948, it provided exactly the

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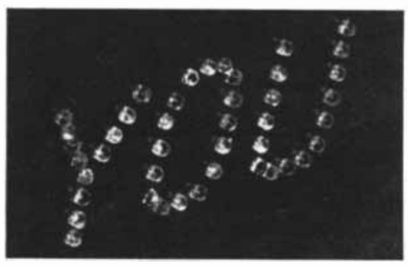

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stimulation I was looking for. It took me four years to realize the significance of the fact that the amount of information we can remember is not an invariant measure of our mnemonic capacity. At about the time the light broke I became involved in the work of the Lincoln Laboratory and had to postpone further development of this line of thought until I returned to Harvard last year. The present article, therefore, is the result of eight years' wondering in the bewilderness. And as careful readers are sure to detect, I'm not home yet."

DONALD STANLEY MARSHALL ("The Settlement of Polynesia") is research anthropologist at the Peabody Museum of Salem, Mass., which is one of the oldest ethnographic museums in existence and is noted for its Polynesian collection brought back by whalers and traders. He holds three degrees from Harvard—A.B., A.M. and Ph.D.—and also taught there as Earnest A. Hooton's assistant. During three years of field study in the Pacific Marshall has visited Fiji, Hawaii, New Zealand, Samoa, the Cook Islands, Tahiti, the Austral Islands and the Tuamotus. He has done most of his field work on linguistics and general cultural anthropology. Marshall is now completing a comprehensive book on the Polynesian language.

FREDERICK SEITZ and EUGENE P. WIGNER ("The Effects of Radiation on Solids") are among the physicists who have pioneered the field of atomic energy. Seitz was born in San Francisco and got his doctorate at Princeton. He did work for the Office of Scientific Research and Development and for the Atomic Energy Commission. Since 1949 he has been professor of physics at the University of Illinois. Wigner was born in Budapest and educated in Germany. In 1930 he joined the faculty of Princeton University, where he is now Thomas D. Jones Professor of Mathematical Physics. At the Metallurgical Laboratory in Chicago he helped to design and build the first atomic pile underneath the stands at Stagg Field. Just after the war he was director of research and development at the Clinton Laboratories in Oak Ridge. Wigner is the current president of the American Physical Society.

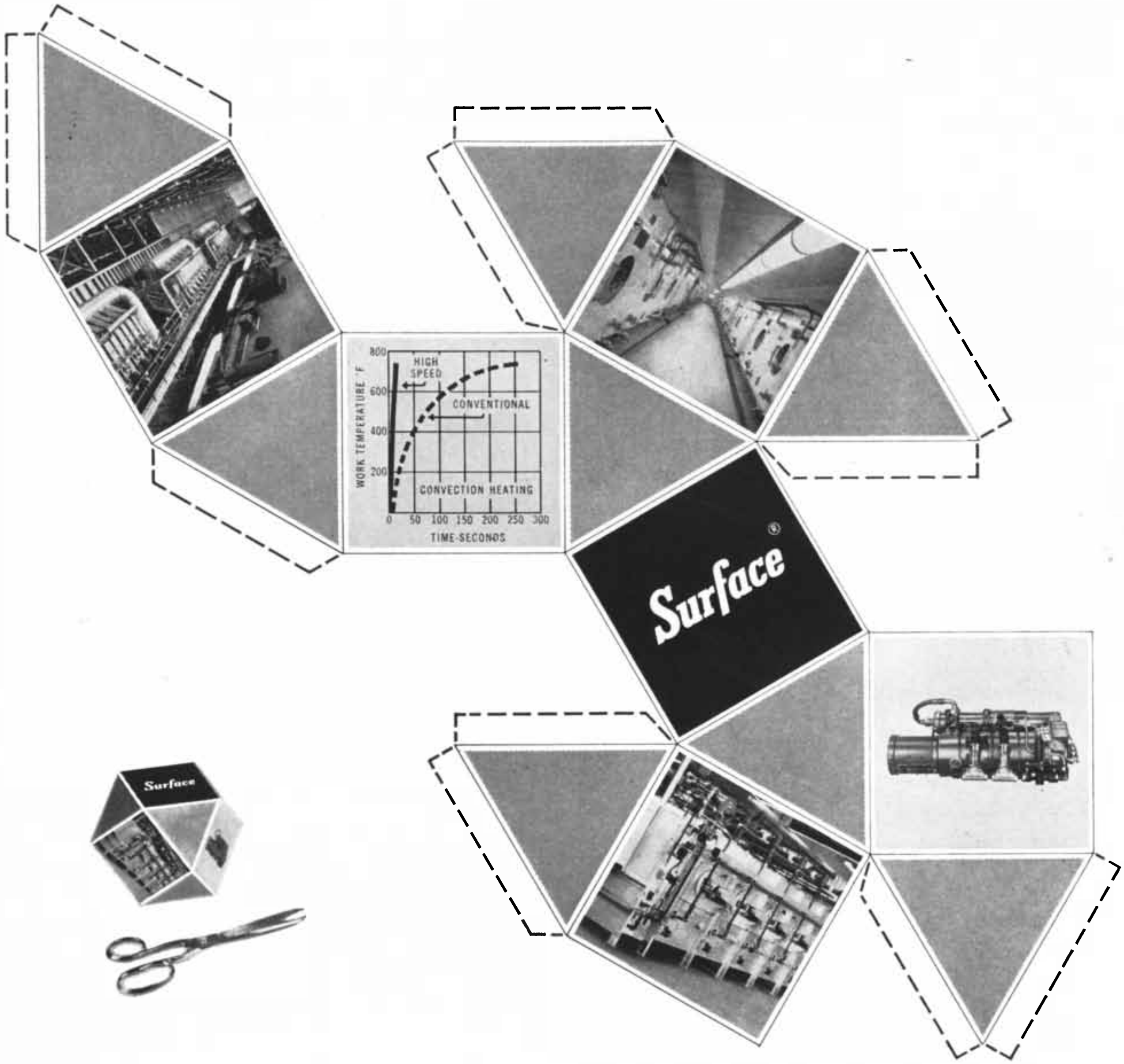
ANTHONY C. ALLISON ("Sickle Cells and Evolution") is a postgraduate fellow at the University of Oxford, where he is engaged in research on cell metabolism in the Medical Research Council Laboratories, directed by the famous biochemist H. A. Krebs. Allison was

brought up on an estate in Kenya and was fluent in two African languages before he could speak English. "It was inevitable in these circumstances that I should become interested in anthropology and natural history. After qualifying in medicine at Oxford I turned to research in human genetics, which helped to satisfy these interests." His field work has taken him on expeditions to Lapland, Syria and most parts of Africa. Two years ago he was a research fellow at the California Institute of Technology.

EDWARD A. STEINHAUS ("Living Insecticides") is director of the Laboratory of Insect Pathology at the University of California. As a student at North Dakota Agricultural College he vacillated between microbiology and entomology, "never dreaming that anyone would pay good money for scientific research in a combination of these two fields." He got his Ph.D. from the Ohio State University in both bacteriology and entomology, and during the war he worked for the U. S. Public Health Service on diseases transmitted by insects. In 1945 Harry S. Smith, head of the Department of Biological Control at California, persuaded him to come to Berkeley and set up the first laboratory devoted generally to the study of insect pathology.

JOHN M. BLATT ("Time Reversal") is a reader in physics at the University of Sydney in Australia. He was born in Vienna in 1921 and came to the U. S. as a refugee in 1939. Blatt went to the University of Cincinnati, did graduate work at Cornell and Princeton universities, became a U. S. citizen in 1944 and received his Ph.D. from Princeton in 1945. For three years he was at the Massachusetts Institute of Technology as a research associate of Victor F. Weisskopf, and they collaborated on *Theoretical Nuclear Physics*, now considered a standard text on the subject. Blatt later taught at the University of Illinois and went to Australia in 1953. At present his main field of interest is low-temperature physics.

JOHN R. PIERCE, who reviews *Automata Studies* in this issue, is director of research in electronic communications for the Bell Telephone Laboratories. He joined Bell Labs in 1936 after receiving his Ph.D. from the California Institute of Technology. He has specialized in the development of electronic tubes and in microwave research. He is currently concentrating on automatic switching, a field closely akin to the designing of computers and automatic control systems.



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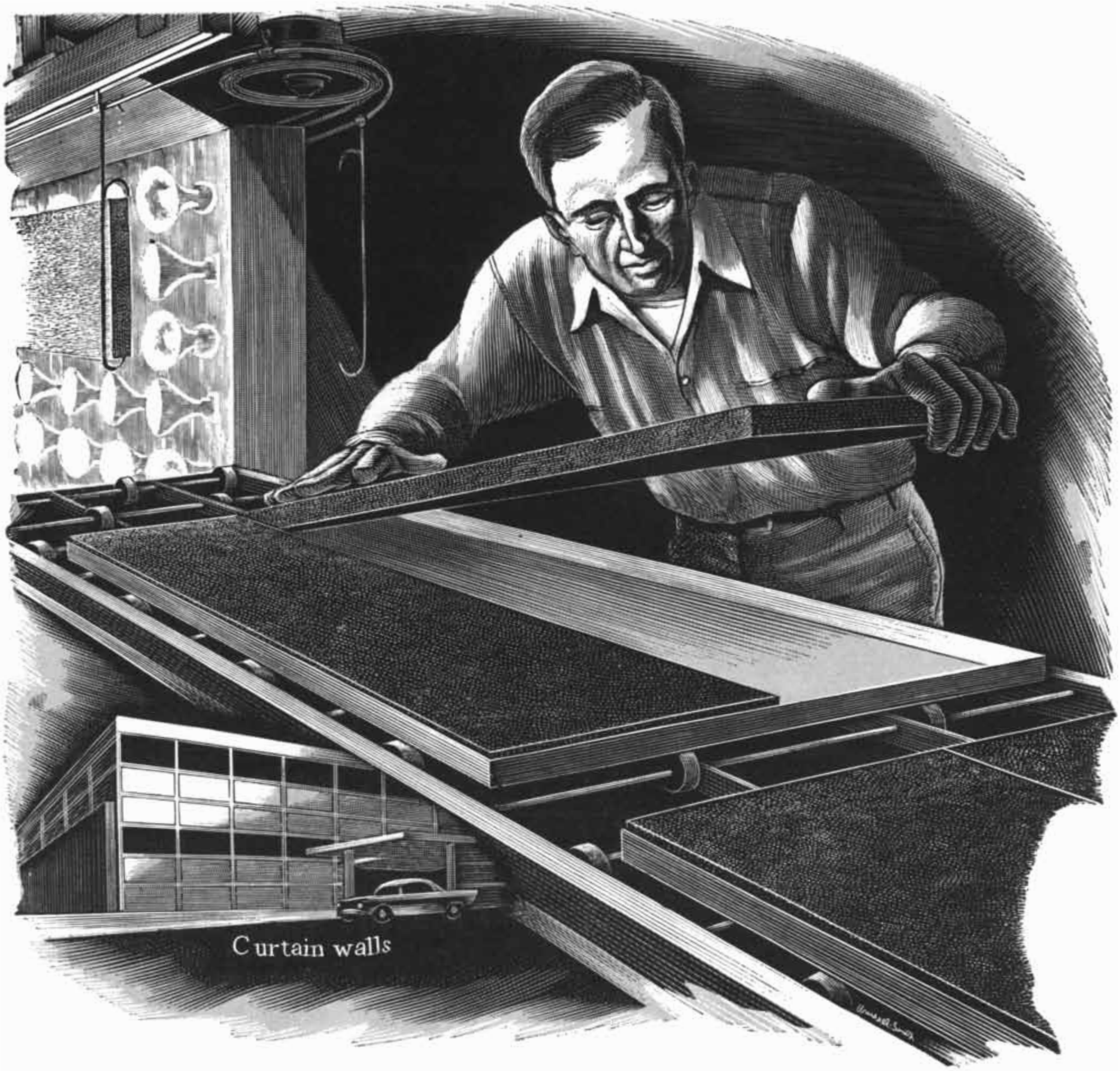

Curtain walls

Established 1845 SCIENTIFIC AMERICAN August, 1956 Volume 195 Number 2

Physics in the U.S.S.R.

An interview with Robert E. Marshak and Robert R. Wilson, two of the U. S. physicists who were invited to attend the recent meetings in Moscow and to visit Russian physical laboratories

by E. P. Rosenbaum

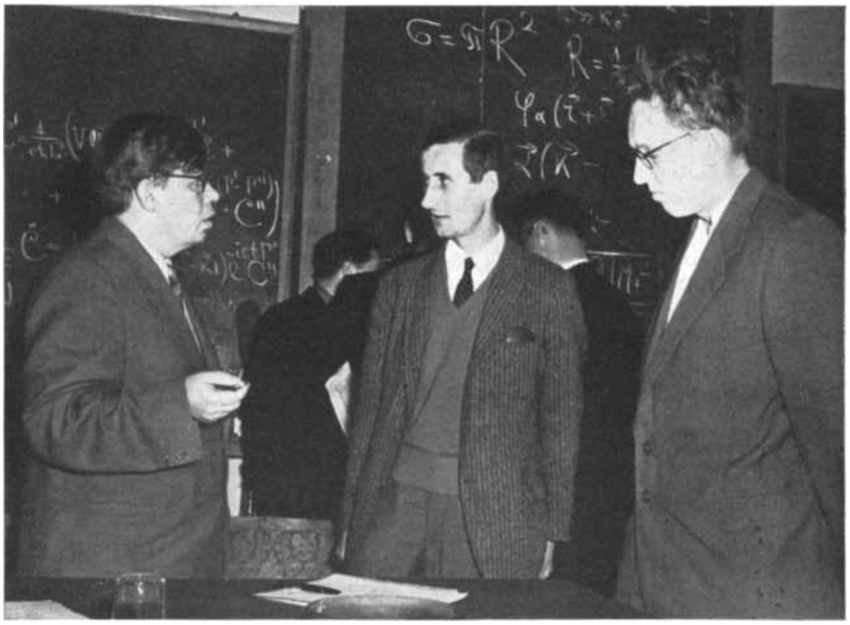
One morning last February a dozen U. S. physicists found waiting in their offices an unexpected cablegram from the president of the Academy of Sciences of the U.S.S.R. It invited them to attend a meeting on high-energy particle physics in Moscow in May. As it happened, invitations to a similar conference to be held at the University of Rochester in April were going out that very day to a number of Soviet physicists. Thus, simultaneously but without prearrangement, the seed of scientific communication planted at the 1955 Geneva conference on atomic energy had begun to sprout in both countries.

The Russian physicists who came to Rochester expanded the Moscow invitation list somewhat, and eventually 14 Americans went to Moscow. Together with physicists invited from many other countries, both Western and Eastern, they were in the Soviet Union from May 13 to May 28. After the conference in Moscow they visited the leading nuclear physics laboratories in the Moscow area and some of the experimental atomic power plants. Some of the guests also went to see laboratories in Leningrad, Kharkov and Kiev and a cosmic ray station in Soviet Armenia. Apparently the foreign scientists were freely shown practically everything worth seeing in connection with Soviet high-energy physics.

This article reports the impressions of two of the first Americans to return to the U. S.—Robert E. Marshak, a theoretical physicist who heads the physics department at the University of Rochester, and Robert R. Wilson, an experimentalist and expert on particle accelerators who directs the Laboratory of Nuclear Studies at Cornell University.

Marshak and Wilson flew to Moscow in the same plane. They got a dramatic foretaste of Soviet hospitality when their plane landed at the Vnukovo airport, 20 miles from the city, at two o'clock in the morning. Waiting to greet them was a delegation of prominent scientists, including L. D. Landau and I. E. Tamm, the best-known of the Soviet theoretical physicists, and V. I. Veksler, co-inventor of the synchrotron (or "phasotron," as it is called in the U.S.S.R.). These men were meeting every plane that brought in Western visitors to the conference!

The Soviet hosts provided all their guests with interpreters who served also as guides and social secretaries of a sort. Travel in Moscow was unrestricted, and the interpreters could be dismissed at any time. Limousine transportation was always available. As guests of the Soviet Academy of Sciences, the visitors were relieved of all money problems. Meals in public eating places, theater tickets and



SOVIET PHYSICISTS N. N. Bogolyubov (*left*) and D. V. Shirkov (*right*) chat with F. J. Dyson (*center*), theoretical physicist at the Institute for Advanced Study in Princeton, N.J.

E. Segrè (U. S.), R. E. Peierls (Great Britain) and M. S. Kozodayev (U.S.S.R.)

I. E. Tamm (U.S.S.R.)

the like were all free, arranged and paid for by the interpreters out of an apparently unlimited entertainment budget.

Among all the scientists easy and cordial relations were quickly established. Talk was not restricted to technical matters but ranged freely over many fields. The Soviet hosts entertained privately and at home, as well as officially. They seemed delighted at the opportunity to establish informal contact with their Western colleagues.

While the U.S.S.R. physicists were relaxed in their personal relationships, they showed that their attitude toward their work was much less so. One of the strongest impressions brought back by Marshak and Wilson is the urgency with which high-energy physics research is now being pursued in the Soviet Union. The atmosphere at the meetings and in the laboratories reminded them of Los Alamos in the Manhattan District days. There was the same personal dedication to the work, the same emphasis on speed rather than cost, the same lavish financial support for facilities. There was also, in the U.S.S.R., a strong sense of competition—of trying to outstrip a rival. When a Western visitor asked A. N. Nesmeyanov, president of the Soviet Academy of Sciences, why the U.S.S.R. was pushing the construction of accelerators so hard, he answered: "We owe it to the Americans." Inspecting the 680-million-electron-volt synchrocyclotron, the Russians' largest operating accelerator, the U. S. physicists were surprised to find that its copper coils were air-cooled rather than liquid-cooled—a sacrifice of cooling efficiency which cost an extra 800 tons of precious copper. The Russians explained that they had resorted to this because it had cut the construction time by nine months!

The scientific meetings in Moscow were attended by some 900 uninhibited, voluble scientists. Visitors heard the talks in simultaneous English translation through headphones. Vigorous discussion followed the reading of papers. Younger men were quick to pounce on anything they thought to be errors in the work of even the most prominent academicians. When a speaker on any topic (including members of the U. S. delegation who gave papers) stepped out of the meeting room after a session, he was at once surrounded by dozens of eager Russian questioners who were surprisingly well informed. In some cases they were better acquainted with the U. S. literature on a subject than the Americans themselves.

The visitors were strongly impressed by the Soviet equipment for high-energy research. Four accelerators in the U.S.S.R. are operating at energies of 100 Mev or higher [*see table on page 32*]. The most important of these are a 240-Mev electron synchrotron in Veksler's laboratory and the 680-Mev proton synchrocyclotron, which is under the direction of M. G. Mescheryakov at the Central Institute of Nuclear Research at Bolshoya Volga, about 80 miles north of Moscow on the Volga River. In a few months a 10-billion-electron-volt (Bev) proton synchrotron, built by Veksler, will go into operation at the Volga laboratories. For several years this will be the most energetic machine in the world. The "race" will not stop there, of course, for the U. S. and CERN, the European Organization for Nuclear Research, will have 25-Bev machines by 1960, and the U.S.S.R. hopes to have a 50-Bev version in operation a couple of years later. Aside from the giants, various other accelerators are being built or designed in the Soviet Union. Wilson found that the Russians are turning out "standard" 60-inch cyclotrons virtually on a mass-production basis. They are built in less than a year; it generally takes three years or more in the U. S.

Marshak and Wilson believe that the Soviet research in high-energy physics is just beginning to gather momentum. It is only about two years since this field was declassified and the leading investigators were released from military work in the U.S.S.R. Wilson and Marshak believe that there is a great, stored-up force now ready to break out. "A lot of people with a lot of power," as Wilson puts it.

The leading center of high-energy research is, of course, the "big Volga lab" at Bolshoya Volga. The laboratory has recently been converted into an in-

V. I. Veksler (U.S.S.R.)

Jack Steinberger (U. S.), L. Riddiford (Great Britain) and L. D. Landau (U.S.S.R.)

ternational research center for the Communist world—an "Eastern CERN," as the visitors termed it. Ten other Communist countries are cooperating with the U.S.S.R. in the support of this facility and in conducting research there. The director of the laboratory is D. I. Blokhintsev.

The laboratory's chief item of interest is its 680-Mev proton accelerator. This machine, though far below the energy capacities of some accelerators in the U. S. and England, is important because it produces an intense proton beam in an energy range which is particularly crucial for certain studies of mesons. The design of the accelerator itself is not unusual; it seems to be a scale-up of an earlier synchrocyclotron built at Berkeley. But the experimental arrangements and equipment surrounding it are another matter. "They knocked my eye out," Wilson says. He was impressed, first of all, with the great variety and number of particle beams—protons, neutrons and mesons—that the machine is set up to deliver [*see diagram on page 33*]. Secondly, the auxiliary equipment is elaborately made: the detectors, counters and electronic circuitry are not the homemade affairs typical of a U. S. laboratory but are beautifully engineered.

The visitors were in fact impressed by the generally close collaboration between physicists and engineers in the Soviet Union. Many of the papers on fundamental accelerator design, topics which in the U. S. are still the exclusive concern of physicists, were delivered at the Moscow meeting by engineers. A Soviet engineer apparently enjoys more prestige, and a higher rate of pay, in work supporting fundamental research than in an industrial job.

Although Russian equipment is better engineered than that in the U. S., there is not yet quite the variety and, in some areas, the quality that is available here. Electronic circuits, while well adapted to the purposes for which they are intended, are some five to ten times slower than their U. S. counterparts, Wilson estimates. Large plastic scintillators and Cerenkov counters are just coming into use. Photographic emulsion techniques for recording particle tracks are not as advanced as in the U. S. and Western Europe. Bubble chambers are being actively developed, but about a year later than in the U. S. The "solid cloud chamber" that received some publicity in the U. S. a couple of years ago does not appear to be in use.

The Soviet work with accelerators, like earlier work in the U. S., is focused largely on the nature of the mysterious force holding neutrons and protons ("nucleons") together in the nucleus of the atom, with particular attention to pi mesons, called "pions." Investigation of the nuclear force has been pursued in the U. S. by two lines of experiment: bombardment of nucleons with nucleons and with pions. Until recently the Soviet investigators concentrated mainly on nucleon-nucleon work. However, meson bombardment has turned out to be so rich a field of investigation that the Soviet physicists are giving increasing attention to pion-nucleon scattering.

Pion scattering patterns indicate that individual protons or neutrons have some sort of internal structure, as yet only dimly understood. A consequence of this is that a proton or neutron can have several different "states," analogous to the excited states of an atom or the nucleus as a whole. Presumably the different states of a nucleon involve different energy relationships among the parts of the particle.

An isolated nucleon in its ordinary state can have either of two possible charges (zero for a neutron, plus one for a proton) and it has a certain rate of spin around its own axis, conventionally stated as 1/2 unit. What the meson experiments show is that when a nucleon is hit hard enough, its spin and its charge may be momentarily greater than in the normal or ground state. Marshak says that the Soviet nucleon-nucleon experiments have helped to confirm this idea. These experiments involve careful and precise measurements of pion production by collisions of nucleons in the 400- to 700-Mev range. The new Soviet experiments in bombardment of nucleons with pions in the range of 150 to 400 Mev also have helped to throw light on the problem.

When nucleons collide at about 600

Mev, they produce two pions. A study of pion production in the neighborhood of this threshold should give important new information about the interaction of pions with nucleons and, perhaps, about the nuclear force. Soviet researchers are now making precise measurements in this interesting region.

The Russians are showing much originality and ingenuity in their plans for the new machines now in the design stage. The 50-Bev accelerator is to be a strong-focusing synchrotron, *i.e.*, one in which the particle beam is sharply narrowed by means of an alternating arrangement of converging and diverging magnetic fields. This system has a rather serious drawback: at a certain critical energy through which the particles pass as they are being speeded up the beam becomes unstable and tends to fly apart. Designers of the 25-Bev strong-focusing machines at Brookhaven and CERN have devised complex and elaborate methods for overcoming the difficulty. The Soviet designers elegantly sidestep it. They insert some "compensating" sections in their magnet ring—sections bent the wrong way (convex inward). The effect is to raise the unstable region above 50 Bev so that the particles do not encounter it.

A more radical departure is a "non-ferrous synchrotron" which is now being built by G. I. Budker at the Moscow Physical Institute. It does away with the iron core usually enclosed in the coils of the electromagnet and uses only the coils. In this way the field can be made much stronger and the diameter of the circular track can be reduced. A 200-Mev model now under construction will have less than a third the diameter of a

MOSCOW LEBEDEV PHYSICAL INSTITUTE	240-MEV ELECTRON SYNCHROTRON	OPERATING SINCE 1949
	600-MEV ELECTRON SYNCHROTRON	UNDER CONSTRUCTION
BOLSHOYA VOLGA CENTRAL INSTITUTE FOR NUCLEAR RESEARCH	680-MEV PROTON SYNCHROCYCLOTRON	OPERATING SINCE 1949 ENERGY IN 1952 WAS 480 MEV CONVERTED TO 680 MEV IN 1953
	10-BEV PROTON SYNCHROTRON	UNDER CONSTRUCTION TO BE FINISHED IN ABOUT SIX MONTHS
MOSCOW PHYSICAL INSTITUTE	1-BEV PROTON LINEAR ACCELERATOR	DESIGN STUDIES UNDER WAY 40-MEV PROTON LINEAR ACCELERATOR ALREADY OPERATING
	200-MEV NON-FERROUS ELECTRON SYNCHROTRON	UNDER CONSTRUCTION
	1-BEV NON-FERROUS ELECTRON SYNCHROTRON	DESIGN STUDIES UNDER WAY
MOSCOW INSTITUTE FOR THERMAL STUDIES	7-BEV STRONG-FOCUSING PROTON SYNCHROTRON	UNDER CONSTRUCTION THIS IS A MODEL FOR THE 50-BEV MACHINE LISTED BELOW
	50-BEV STRONG-FOCUSING PROTON SYNCHROTRON	CONSTRUCTION SCHEDULE OF PERHAPS FOUR TO SEVEN YEARS SITE NOT CHOSEN
KHARKOV UKRAINIAN TECHNICAL INSTITUTE	1-BEV ELECTRON LINEAR ACCELERATOR	DESIGN STUDIES UNDER WAY
TOMSK	100-MEV BETATRON	OPERATING
LENINGRAD	150-MEV ELECTRON SYNCHROTRON	OPERATING

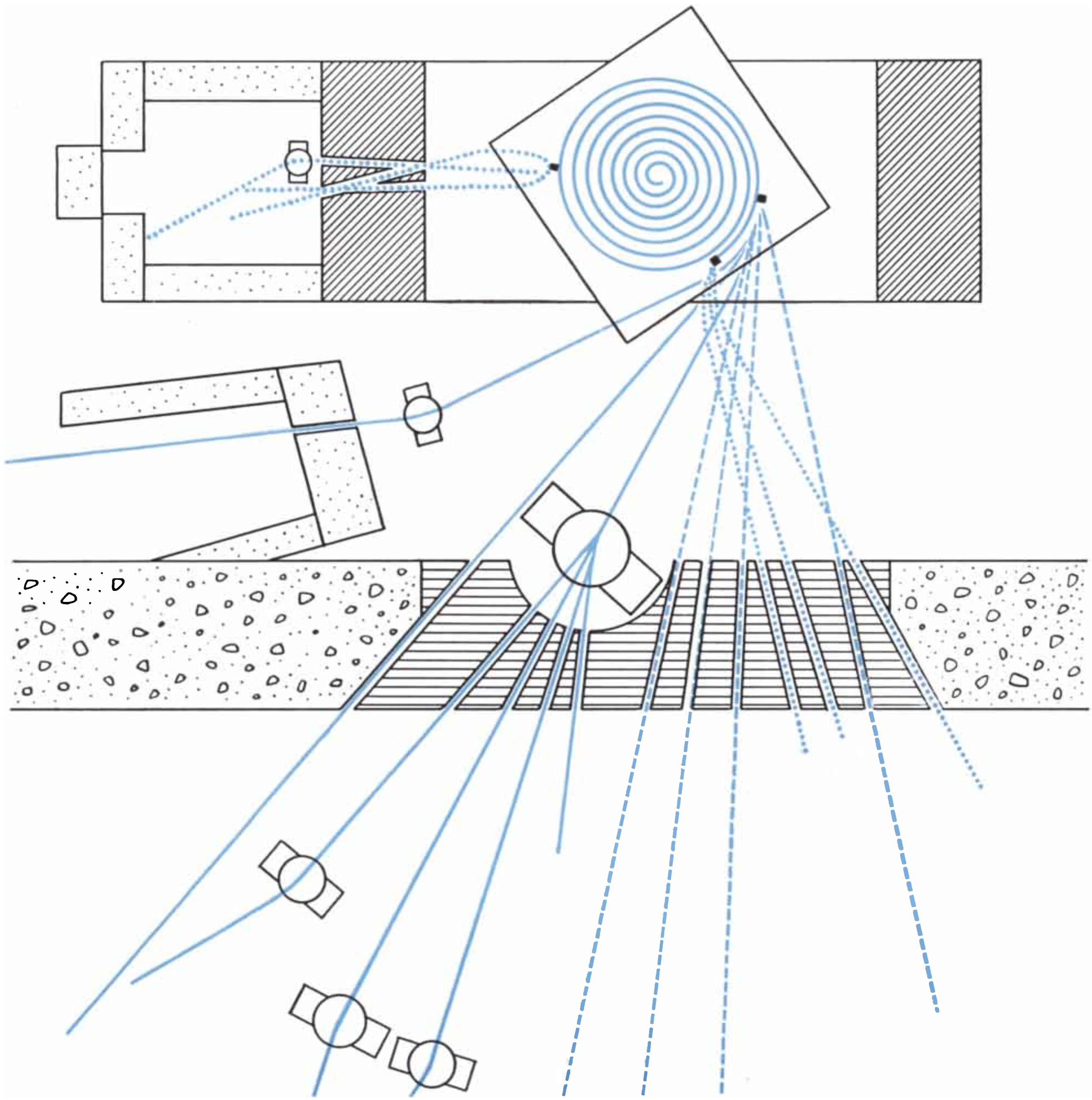
SOVIET ACCELERATORS with energies of 100 Mev (million electron volts) or more are listed above. The list is not official, but includes all the machines the visitors heard about. The 10-Bev (billion-electron-volt) proton synchrotron, when it is completed, will probably give leadership in high-energy physics to the U.S.S.R. The 50-Bev machine is the largest for which specific plans exist.

conventional machine of the same energy. A projected one-Bev version will be about a sixth the size of a comparable iron-cored device.

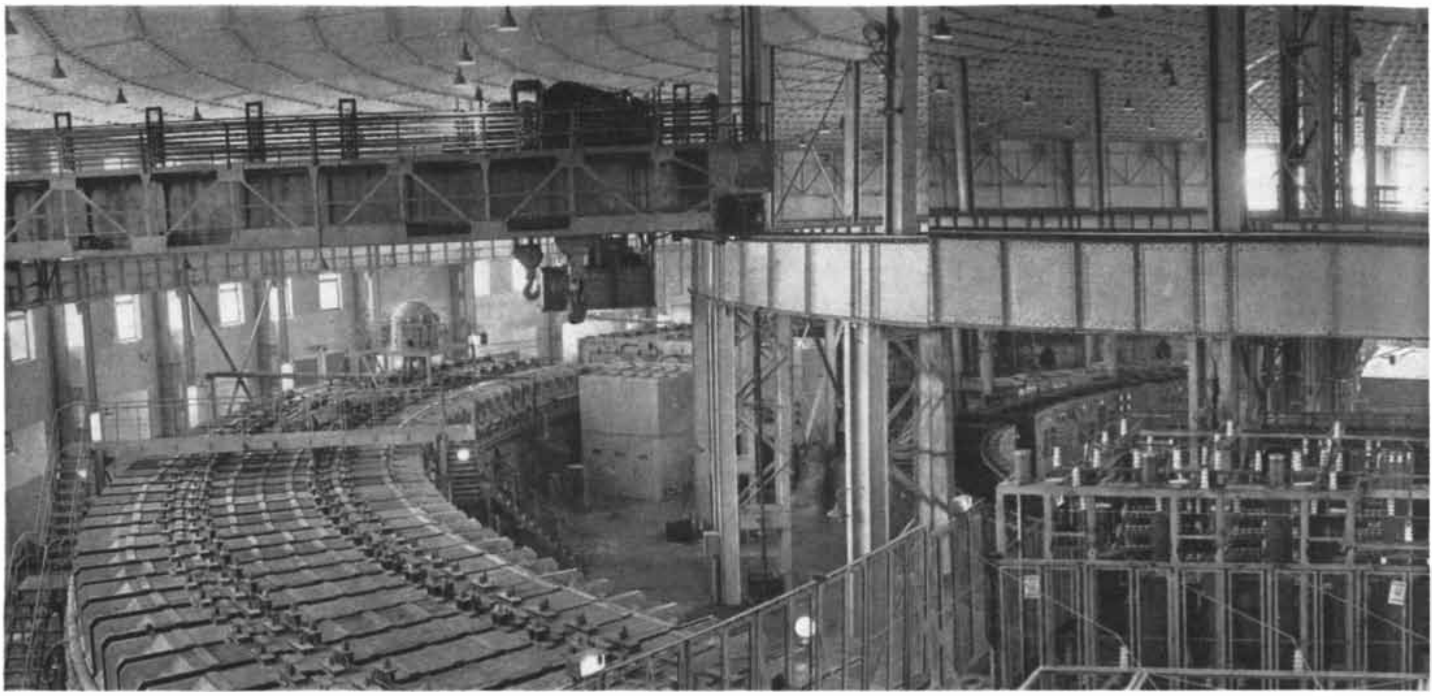
Another unorthodox scheme under consideration by Soviet physicists is a machine which will eliminate the large magnet altogether. When an intense current in an ionized gas travels in a circular path, it contracts into a very thin stream (a phenomenon related to the "pinch effect" that has been suggested as a possible method of containing a thermonuclear reaction). Associated with the narrow stream of current is a very powerful magnetic field. Soviet designers propose to use it as the guiding field for a circular accelerator, in place of an electromagnet.

In the field of theoretical physics the leading workers in the U.S.S.R. include Landau, Tamm, I. Pomeranchuk and a recruit to physics from pure mathematics, N. N. Bogolyubov. Landau and his co-workers reported to the conference a new view of quantum field theory. Applying the theory to calculate the interaction of a "Fermi particle" (*e.g.*, an electron or nucleon) with a "Bose particle" (*e.g.*, a photon or a pion), they discovered that if particles were considered as points, the interaction came out zero. Western theorists are now mulling over the Soviet results. If no flaws are found in the argument, a fundamental revision of modern field theory will be required, since much of it is based on the simplifying assumption of point particles.

The visiting physicists returned to the U. S. with admiration for the vigor of Soviet physics but also with some



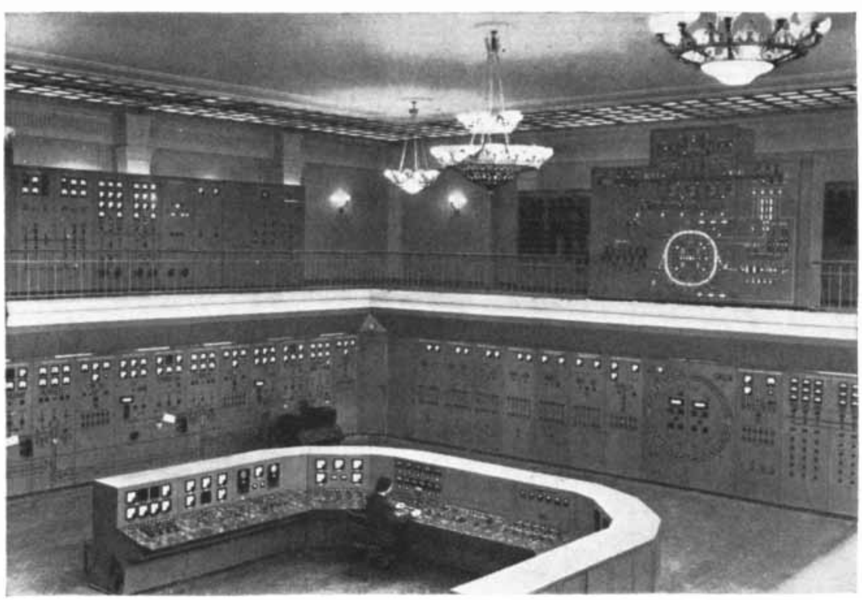
680-MEV SYNCHROCYCLOTRON is diagrammed schematically. The accelerator itself is the square at top, with the spiral line representing the beam of protons. External beams of protons (*solid lines*), neutrons (*broken lines*) and mesons (*dotted lines*), some bent by magnets, are directed through channels in the shield to experimental setups. The small blocks in accelerator are targets.



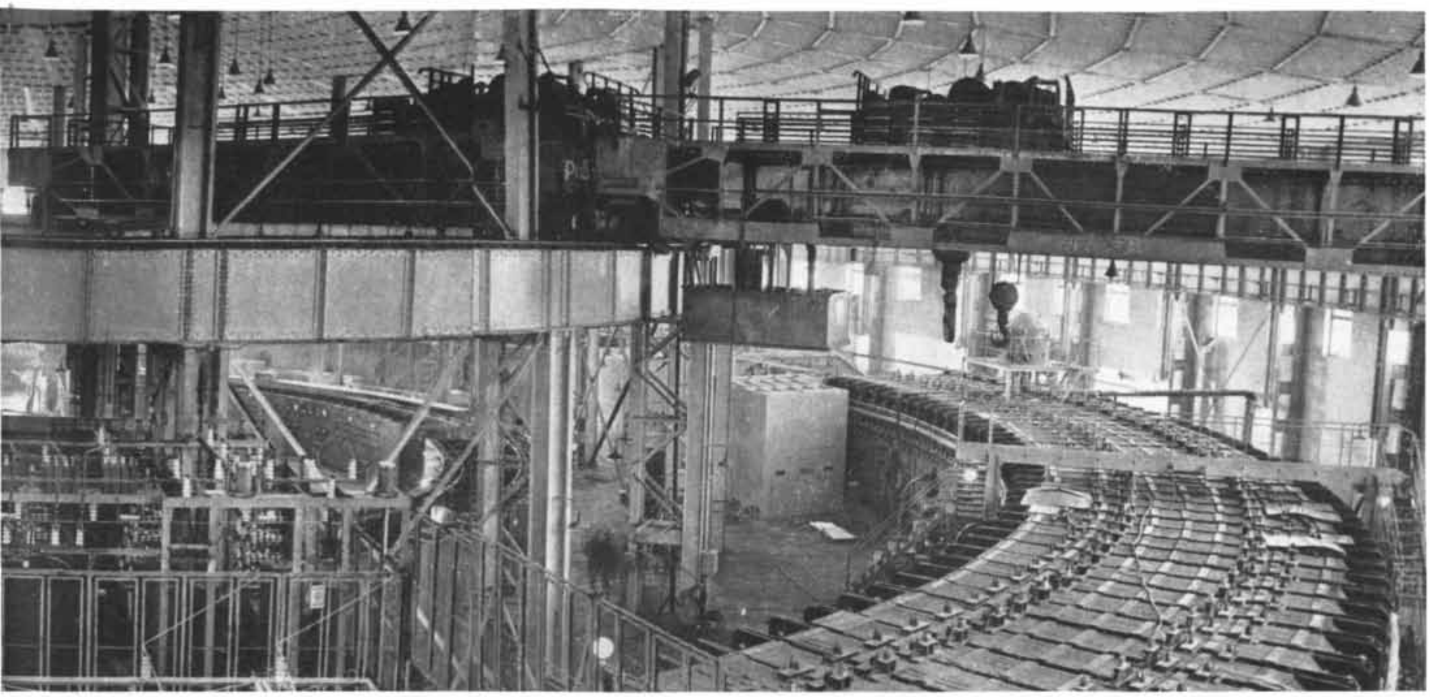
10-BEV PROTON SYNCHROTRON is nearing completion at the Central Institute of Nuclear Research at Bolshoya Volga near Moscow. This photograph shows the huge circular magnet. It weighs 36,000 tons and is about 200 feet in diameter. By contrast, the

troubling questions. They were disturbed by the competitive intensity of the Soviet effort. High-energy physics, depending on multimillion-dollar machines, is competitive in a way that is almost unprecedented for basic science. Marshak and Wilson report that Western European physicists associated with CERN seemed rather taken aback with what they saw in the U.S.S.R. CERN is now building a 600-Mev proton accelerator. By the time it is finished, the Soviet physicists may well have skimmed some of the experimental cream and excitement from this energy region. "If I were at CERN," Wilson says, "I would be busy trying to anticipate and to devise advanced experiments going deeper into the problems for which solutions are being sought."

Marshak and Wilson left the U.S.S.R. with the sense of a challenge that must be met. A few days back in familiar surroundings, however, led them to wonder whether they really want to "do physics" in this way. They found the idea of doing science *against* someone neither a



CENTRAL CONTROL PANELS of the 10-Bev accelerator is shown in the photograph at left. The center picture shows the building which houses the giant machine. At right is a view of a part of the installation, including the linear accelerator which injects particles

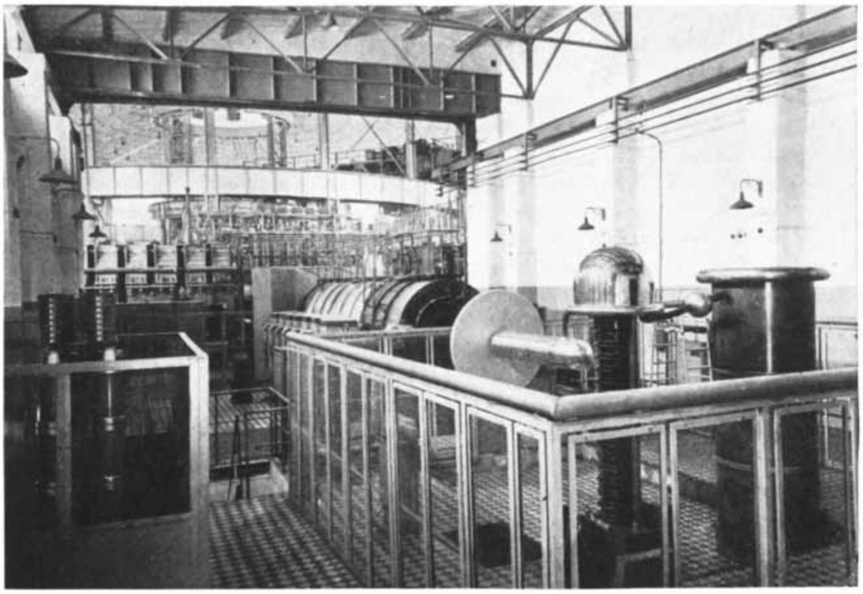


magnet of the 6-Bev machine at the University of California weighs 10,000 tons and has a diameter of 110 feet. Although impressed with the size of the Soviet machine and with the quality of its engineering, U. S. physicists did not find any new ideas in its design.

familiar nor a congenial prospect. Their hope is that the coming competition will take the traditional course of energetic but friendly rivalry among scientists.

They were left in some doubt as to why the Soviet Union is going in for basic research so intensively and on so big a scale. The high-energy work does not appear to promise any specific military or industrial applications. The physicists concluded that the leaders of the Soviet Government might be motivated in part by a conviction of the importance of basic research to technology and in part by a desire to lead the world in culture on as many fronts as possible. The Soviet physicists themselves, though imbued with some competitive spirit, seemed to be animated in the main by the same mixture of motives that is characteristic of scientists everywhere—curiosity, pleasure and pride in achievement, social responsibility and the more obscure personal reasons.

In any event, one thing seems certain: high-energy physics will be an increasingly active and exciting field.



into the doughnut-shaped chamber within the magnet. The laboratory at which the accelerator is located has recently been converted to an international research center. Physicists from 10 Communist countries other than the U.S.S.R. share in the use of its facilities.

THE ORIGIN OF SUBMARINE CANYONS

Many theories have been proposed to account for these rugged features of the earth's crust. It now seems that they are cut by streams of turbid water which flow along the ocean bottom

by Bruce C. Heezen

During the last 30 years or so the ocean bottom has become the main frontier of exploration on the surface of our planet. The vast area hidden in the darkness of the deep sea (nearly three quarters of the earth's surface) is slowly being explored and mapped for the first time, lately with the cogent help of the echo sounder. It has been an adventure full of surprises. We have "seen" enough to realize that if the oceans were somehow drained of water, they would expose a landscape as varied as the continents—mountains taller than Everest, plains as vast as the Russian steppes, gorges rivaling the Grand Canyon.

All this has brought a crowd of exciting questions. We know that the topography of the continents has been shaped in large part by river and wind erosion. What forces could have molded features so similar in the deep sea? Of all the enigmas, none has been more spiritedly debated than the mystery of the undersea canyons [see "Submarine Canyons," by Francis P. Shepard; SCIENTIFIC AMERICAN, April, 1949]. Off the shores of all the continents the underwater slopes are cut by great channels which look exactly like river canyons on land. They course through the sea bottom for hundreds of miles and invariably debouch onto a broad plain, like a river mouth opening to a delta. What process cut these gorges in the ocean? Many theories were proposed: all had a touch of the incredible. Now it seems that the question can at last be answered.

Two hypotheses have received foremost consideration. One suggested that the canyons were cut by actual rivers during ice ages when the oceans were lower than now and the continental shelves stood above sea level. This theory has always faced the formidable objection that it demanded the removal of a seemingly incredible amount of water from the oceans (by way of glacial ice piled on the continents). The hypothesis now seems to have been squelched by certain recent discoveries: namely, that some submarine canyons, notably the one extending from the mouth of the Hudson River, run out to deep ocean basins which could never have stood above water.

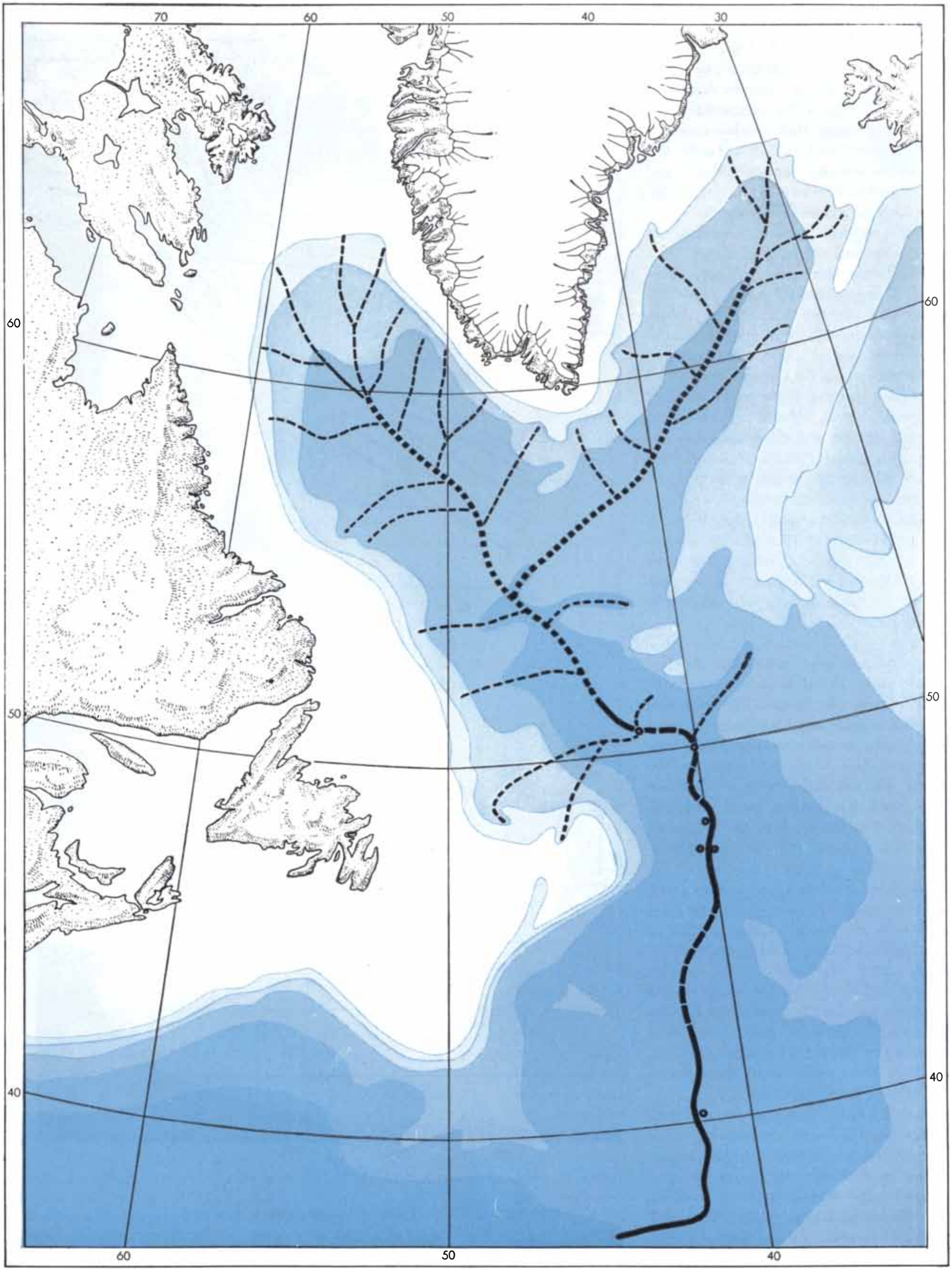
The other hypothesis is that the canyons were eroded by submarine flows, or avalanches, of silt-laden water, called "turbidity currents." This is an old theory with a checkered career. But the idea has been confirmed and built into a convincing picture by a series of rather dramatic discoveries and tests in the past decade.

More than three quarters of a century ago a Swiss engineer suggested that a canyon in the bed of Lake Léman might have been cut by heavy, silt-laden water flowing in along the bottom of the River Rhône. This suggestion received scant attention, but 20 years ago the Harvard University geologist Reginald A. Daly revived the idea as an explanation of the canyons in the oceans. His prestige encouraged several investigators to make experiments with models to test the possibility of turbidity currents. They obtained some evidence, though not conclusive, that such flows could occur. Moreover, engineers working on Boulder Dam observed some natural turbid underflows in the newly created Lake Mead behind the dam. Submarine geologists remained unconvinced, however, that this process could account for the huge canyons in the sea. It was difficult to believe that currents of muddy water along the ocean bottom could be powerful enough to erode these great gorges.

Then the matter was given an entirely new slant by discoveries from another quarter. In the summer of 1947 the research vessel *Atlantis* surveyed the deep-sea bottom between Bermuda and the Azores with two new instruments developed during the war: a continuously recording echo sounder which traces the profile of the ocean floor, and a corer which takes samples of the sea bed 40 to 60 feet thick. The *Atlantis* discovered a vast plain more than 200 miles wide in the deepest part of the western Atlantic. Cores extracted from this plain yielded a major surprise: whereas the deep-sea bed elsewhere consisted of thick deposits of fine oozes and clays, here the bed was mainly composed, down to the depth of the 15-foot core, of sand and silt very like the material on the beaches of New England!

The significance of these facts was not realized at first. But it became clearer after another exploration by the *Atlantis* in the summer of 1949. This voyage traced the Hudson submarine canyon for some 200 miles from the edge of the North American continental shelf to the western Atlantic plain mentioned above. Cores taken along this route showed that the canyon had been eroded through beds of clay many millions of years old, and that the floor of the canyon contained not only sand and gravel but also shells of clams which grow only in shallow waters near shore. The canyon's floor and walls, like the plain on which it debouched, were overlaid with only a thin layer of recent ooze.

All this strongly suggested that the canyon and the plain had been formed by a submarine river or currents of some kind. One could imagine that during the Ice Age streams of water from melting glaciers washed vast quantities of sand and gravel from the interior of



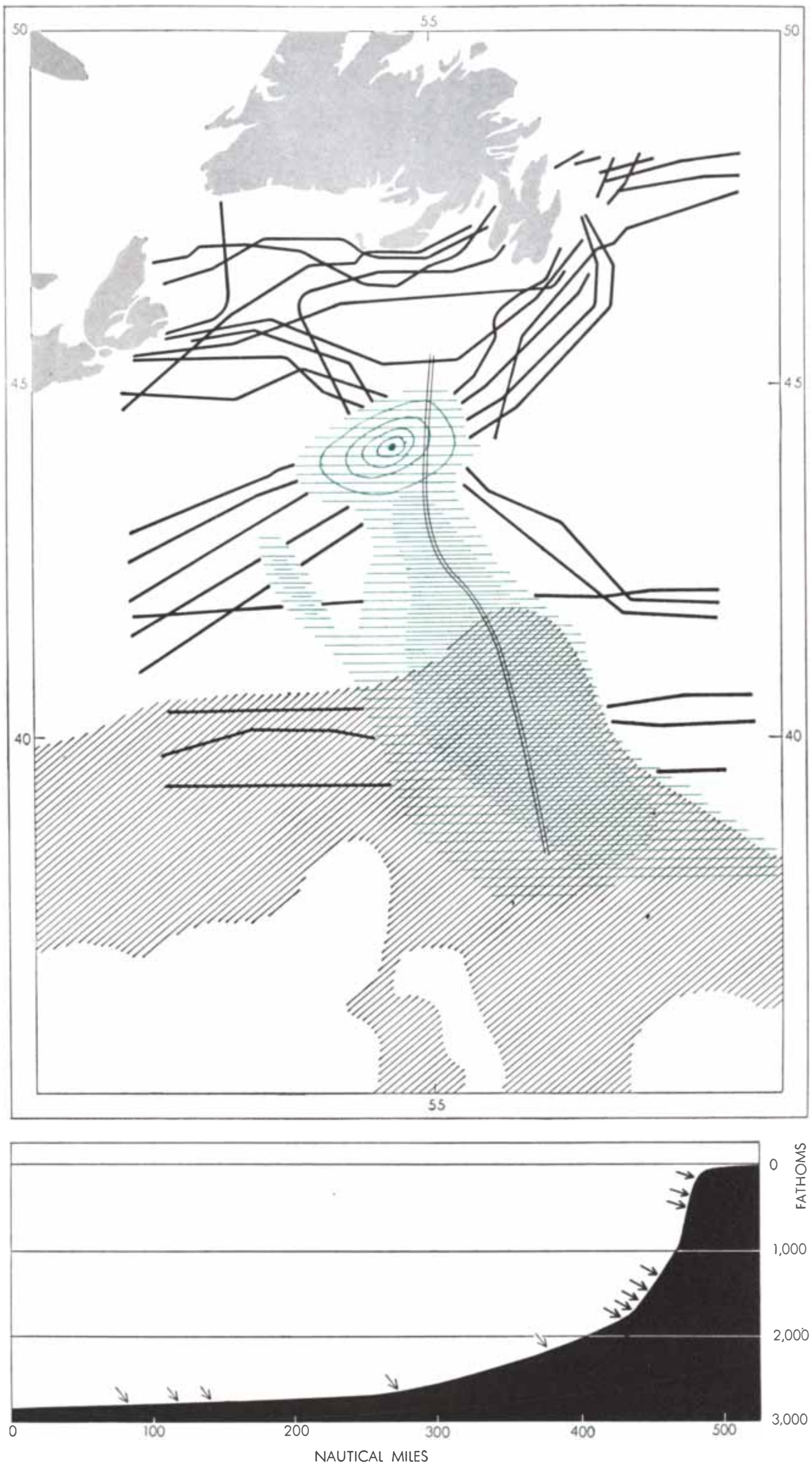
MID-OCEAN CANYON begins off Greenland and extends south to about the 38th parallel. The solid line traces sounded portions; the heavy broken line, unsounded connections between known sections. The heavy dotted lines represent the probable extension of the canyon; the light broken lines, possible tributaries. The small circles mark sites of breaks in transatlantic cables. The depth at various points is indicated by blue shading. The darkest tone represents a depth of about 2,500 fathoms; the lightest tone, about 500.

North America to the Atlantic coast, that masses of this material in the water flowed by gravity as currents down the slope at the edge of the continental shelf, that in so doing they eroded canyons in the slope, and that eventually the submarine streams deposited their sand and gravel in the deep-sea basins, building plains as a river builds a delta.

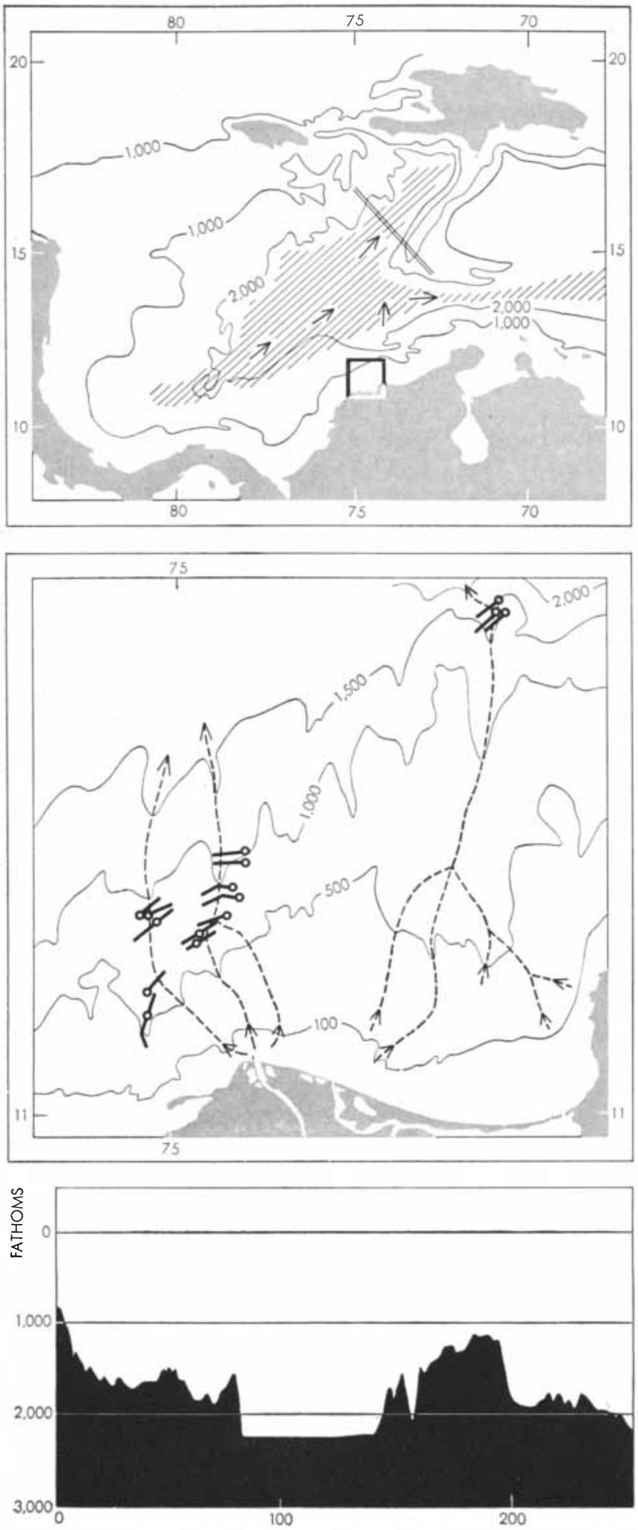
Such currents need not necessarily have been confined to glacial ages. On a smaller scale, one may suppose, occasional flows of turbid water may still take place on the sea bottom today. Sand and gravel accumulating on the steep continental slope, for example, might slide down the slope as avalanches from time to time. How could one find evidence of such a flow? It occurred to Maurice Ewing and the writer that the telegraph cables lying across the floor of the Atlantic might give a clue. Many of the transatlantic cables have been there for nearly a century. If strong submarine flows of the kind imagined do in fact occur, some of them may have broken the cables. An inspection of the record of cable breaks was obviously called for.

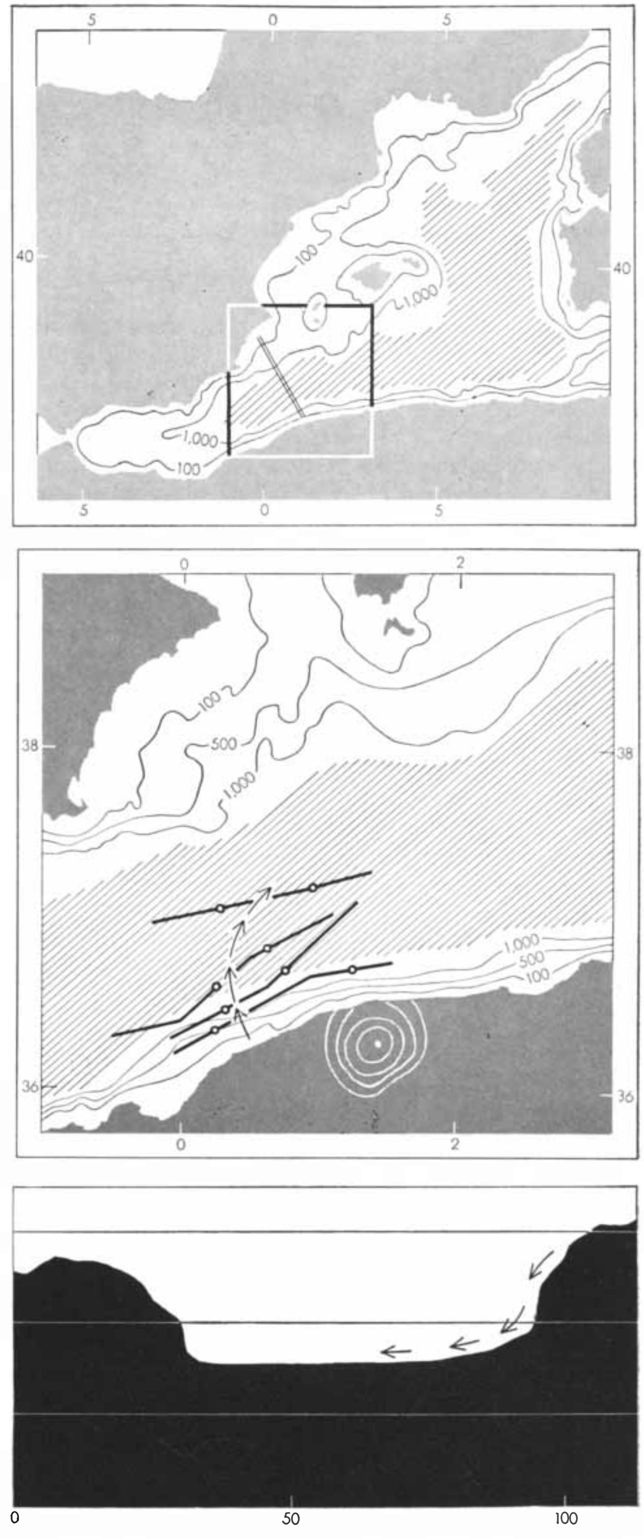
We did not have to look far. On November 18, 1929, a severe earthquake shook the Grand Banks in the Atlantic south of Newfoundland—an area which has a greater concentration of submarine cables than any other in the world. The cables broke on a wholesale scale, and the breaks were naturally attributed at the time to the quake itself. But a study of the timetable of the breaks discloses a remarkable fact. While the cables lying within 60 miles of the epicenter of the quake broke instantly, farther away the breaks came in a delayed sequence. For more than 13 hours after the earthquake, cables farther and farther to the south of the epicenter went on breaking one by one in regular succession. Each break was downslope from the one before, and the last took place in the deep ocean basin 300 miles from the epicenter.

It seems quite clear that this series of events must indicate a submarine flow: the quake set in motion a gigantic avalanche of sediment on the steep continental slope which broke the cables one after another as it rushed downslope and flowed onto the abyssal plain. Fortunately the automatic machines monitoring telegraph transmission recorded the precise time of the break in each cable, so that we can calculate the speed of the turbidity current that flowed down the slope. It ranged from about



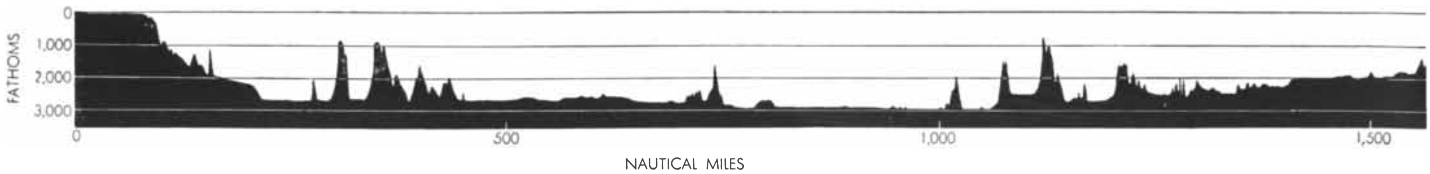
GRAND BANKS EARTHQUAKE, which occurred in 1929, caused a turbidity current that broke cables as far as 300 miles away from the epicenter of the disturbance. The epicenter is indicated on the map at the top of this page by the colored dot surrounded by circles. The turbidity current was strongest in the dark-colored portion and weaker in the lighter-colored peripheral areas. The region marked with diagonal black hatching is the abyssal plain. The solid black lines represent sections of the cables. The profile at the bottom follows the path marked by the two parallel lines on map. The short arrows show the points on the slope where the cables broke. On the profile the epicentral area is between the three arrows at upper right and the five arrows below them. The current reached a speed of 55 knots per hour.





CANYONS IN CARIBBEAN off the coast of Colombia have been coursed by numerous turbidity currents which have broken a submarine cable 17 times since it was laid in 1930. Upper map shows the general region, with area off the mouth of the Magdalena River in Colombia enclosed in small rectangle. Colombian Abyssal Plain is shaded. The arrows indicate former turbidity currents; the parallel lines, the path of profile at bottom. Lower map gives detail in the rectangle. The paths of turbidity currents are marked by broken lines. The breaks in the cable are indicated by the solid lines.

EARTHQUAKE IN ORLEANSVILLE in Algeria gave rise to a turbidity current which broke several cables in the Mediterranean. The upper map shows the western Mediterranean, with the region affected by the current enclosed in rectangle. The shaded area is the Balearic Abyssal Plain. Contour lines give depth in fathoms. Parallel lines show the path of the profile at bottom. Detail in the marked area is shown in the lower map. Lines represent cables, with breaks marked by open dots. Arrows show the probable path of the current. Epicenter of the quake is indicated by dot and circles.



FLOOR OF THE ATLANTIC from Martha's Vineyard (*left*) to Gibraltar (*right*) is traced in profile. The abyssal plain, which extends from about 750 miles to about 1,000 miles off the U. S. East Coast, is remarkable for its flatness and for the sand and silt deposits

50 miles per hour on the steep slope to about 15 miles per hour on the plain.

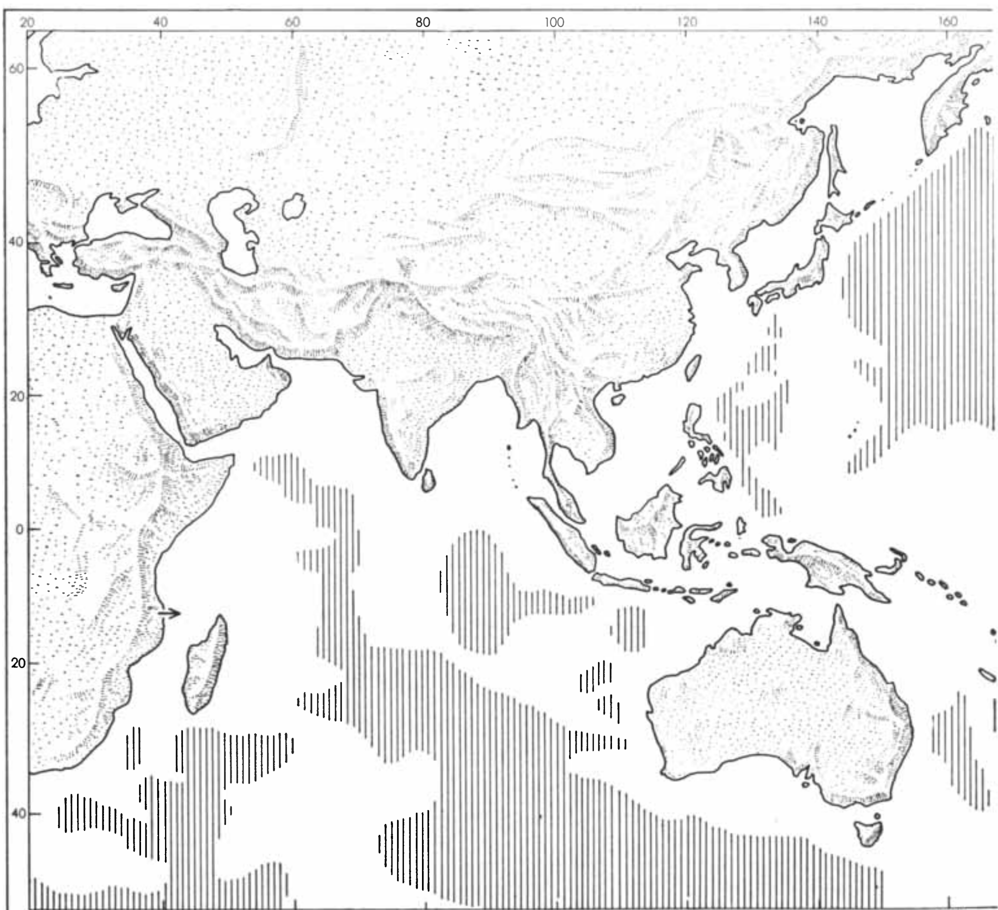
The deduction that such a current flowed over the cables is supported by reports of engineers on the cable repair ships, who had much difficulty finding the broken cables (presumably because they were deeply buried) and had to replace lost sections as much as 200 miles long. But for conclusive proof of our deduction, we decided to examine the scene itself. If our interpretation was correct, there should be a layer of silt of a certain thickness on the sea floor where the deepest cable break had occurred; Philip H. Kuenen of the Netherlands indeed calculated just how thick this layer should be. For several years hurricanes and instrument failures thwarted our efforts to get cores at this site, but we were finally able to obtain some in 1952, and much to our delight the thickness of the silt proved to be exactly as predicted.

In 1954 another earthquake in the Mediterranean yielded evidence almost as impressive as the case at Grand Banks. On September 9 of that year the disastrous quake centered at Orléansville in Algeria caused the breakage of five cables on the floor of the Mediterranean, lying at distances from 40 to 70 miles from the North African coast. The timing of the breaks showed that these, too, broke in succession according to their distance downslope in the sea; the presumed turbidity current traveled at from 40 to 5 miles per hour. Near the deepest break the repair crew found sand—apparently washed down from the coast.

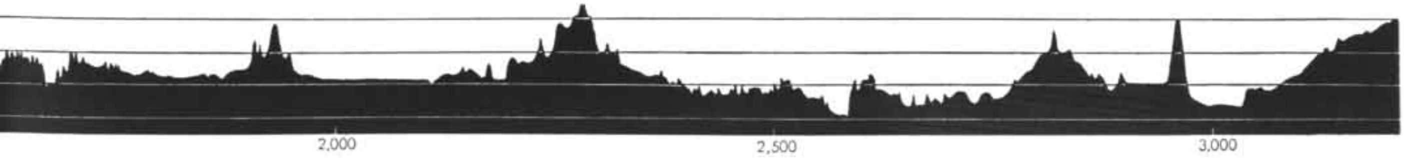
In the Caribbean off the mouth of the Magdalena River of Colombia there is a network of submarine canyons. A submarine cable which passes across these canyons has been broken 17 times since it was laid in 1930. On two of these occasions jetties flanking the river mouth slid into the sea. It can be concluded that the earth slides that carried away the jetties were transformed into turbidity currents which flowed down the canyon and deposited their load of sediments in the sea basin. Recent explorations have shown that this basin has an extremely smooth floor and contains sands, shallow-water shells and debris of land plants.

Evidence of the existence of turbidity currents has accumulated from many other sources. Several years ago the *Atlantis* took two cores from the bottom of the Puerto Rican Trench—the deepest place in the Atlantic Ocean. The deposit here included limy shells of shallow-water organisms, and, most important, it contained fragments of limy marine plants which require sunlight for life. This material, transported from the shore to the deepest part of the ocean, was striking proof that currents must flow over the sea floor. The flat floor of the Puerto Rican Trench, suggesting a plain formed by flow down its slopes, had led us to expect that material from shallow waters would be found there, but this expectation in no way diminished our joy in the discovery.

Not all the canyons in the sea stem from the mouths of land rivers. Indeed one of the longest is a mid-ocean canyon that runs from the area between Iceland and Greenland to a point south of Newfoundland. This canyon in the deep ocean basin, two to four miles wide and 25 to 100 fathoms deep, was discovered in



HISTORICAL TURBIDITY CURRENTS appear as arrows on this map of the oceans of the world. The shaded areas represent regions which are inaccessible to turbidity currents



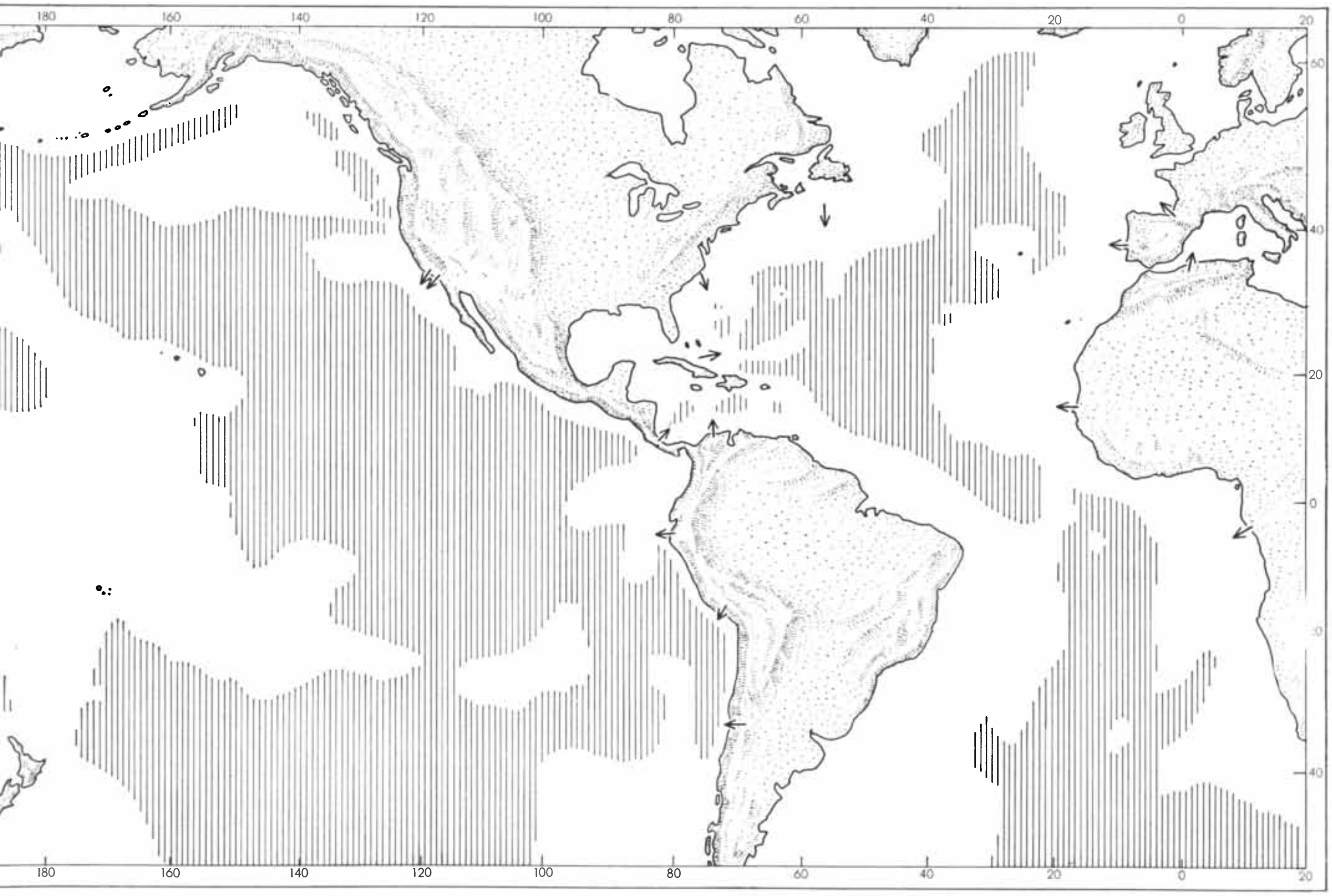
typical of shallow-water areas. These deposits were presumably washed out onto the plain by turbidity currents. The only one of the numerous seamounts to reach above the ocean surface is represented by the Azores. To the left of the Azores is Atlantis Seamount.

1949 and extensively explored in 1952. Its floor contains sand and possibly gravel. The canyon may have been eroded by periodic turbidity currents set into motion when freezing conditions in the Greenland area produced masses of turbid, heavy water—full of sediment, very salty and extremely cold.

There are many possible ways in which turbidity currents might be generated—freezing conditions, triggering by earthquakes, the piling up of deposits on steep ocean slopes by rivers, and so on. Granting the existence of such currents, it is not difficult to see how repeated flows, each originating from nearly the same spot atop a slope, could gradually erode a canyon in the ocean.

Aside from explaining the origin of the submarine canyons, the evidence for the existence of turbidity currents is interesting on several other counts. For one thing, it indicates a way in which organic material is transported from the continental coasts to feed fish and other organisms in the deep sea. For another, it suggests how organic sediments may accumulate in sea basins and eventually become petroleum. Much of the petroleum in the world is found in ancient sands which once were part of the sea floor. Turbidity currents therefore offer a clue concerning where to look for oil; the concept has in fact been applied successfully in exploration of the oil fields of southern California. Still another interesting aspect of these currents has to do with developments in the atomic age: for example, it is possible that an offshore atomic blast might trigger a turbidity current which would spread radioactive debris throughout an entire ocean basin.

The study of the sea floor is carried on primarily in the interest of pure science, but like many other basic studies, it is not without commercial, economic, military, social and political implications.



coming from shallow water. The height of these regions and the surrounding topography cut them off from the flows which have taken sand and marine organisms from the continental shelves and transported them to many of the deepest parts of the ocean floor.

Information and Memory

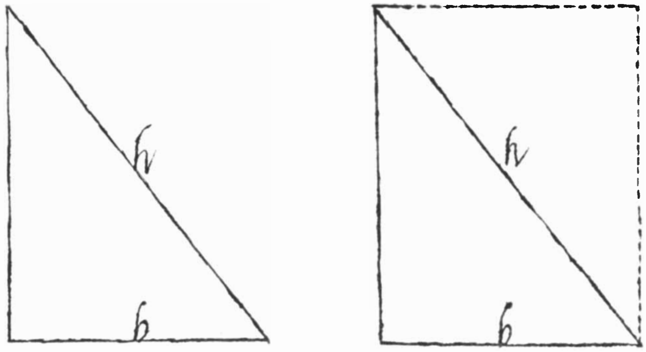
If a man sees six marbles, he can usually name their number without counting. With more marbles, he often makes mistakes. This indicates a limitation of perception that is overcome by resourceful stratagems

by George A. Miller

Some things are easy to remember. A short poem is easier to memorize than a long one; an interesting story is better recalled than a dull one. But brevity and wit are not all that is involved. Equally important is the way things fit together. If a new task meshes well with what we have previously learned, our earlier learning can be transferred with profit to the novel situation. If not, the task is much harder to master.

Imagine that you are teaching geometry to children. You have covered the business of calculating the length of the hypotenuse of a right-angled triangle when the base and the altitude are given. Now you are about to take up the problem of finding the *area* of a right triangle when the base and the hypotenuse are given. Suppose you were given your choice of the following two methods of teaching the children to solve the problem. In method A you would help them to discover that the area of a right triangle is half that of a rectangle with the same base and altitude, that the unknown altitude of the triangle in this case can be calculated from the given base and hypotenuse by use of the Pythagorean theorem, and that the area of the triangle can therefore be found by deriving the altitude, computing the area of the rectangle and then taking half of that. In method B you would simply tell the class to memorize six steps: (1) add the length of the base to the length of the hypotenuse; (2) subtract the length of the base from the length of the hypotenuse; (3) multiply the first result by the second; (4) extract the square root of this product; (5) multiply the positive root by the length of the base; (6) divide this product by 2.

Which method of teaching would you choose? Probably no one but an experimental psychologist would ever consider method B. Method A is productive and insightful; method B is stupid and ugly.



TWO METHODS may be used to teach children how to find the area of a right-angled triangle. The method associated with the triangle at left has the following algebraic steps: (1) $h + b = v$, (2) $h - b = w$, (3) $v \times w = x$, (4) $\sqrt{x} = \pm y$, (5) $+ y \times b = z$, (6) $z/2 =$ area. The method associated with the triangle at right proceeds: (1) find altitude by the Pythagorean theorem, (2) find area of rectangle from base and altitude, (3) area of triangle is half the area of rectangle. The first method is considered ugly and the second efficient. Why?

But just why do we find method B repulsive? What is repugnant about a procedure that is logically impeccable and that leads always to the correct answer? This question is raised by the psychologist Max Wertheimer in his provocative little book, *Productive Thinking*. An obvious answer is that a child taught by method A will understand better what he is doing. But until we can say what it means to understand what one is doing, or what profit there is in such understanding, we have not really answered Wertheimer's question.

It is helpful to consider the interesting fact that method B is the procedure we would use to instruct a computing machine of the present-day type. The machine is able to perform arithmetical operations such as addition, subtraction, multiplication, division and the extraction of roots. Instruction for the machine consists in writing a "program"—like the series of steps used in method B except that the computer's program must be even more explicit and detailed, with even less hint of the basic strategy. Computing machine engineers have their hearts set on some day designing machines which will construct programs for themselves: that is, given the strategy for handling a problem, the machine will understand the problem well enough to create all the appropriate operations or subroutines required to solve it. The desirability of such a development is obvious. In the first place, at present it takes many hours of drudgery to write the detailed instructions for all the steps a computer must take. Then, after the instructions have been written, they must be stored in the machine in some easily accessible form. In a large machine the number of subroutines may run into the thousands; it might actually be more economical to equip the machine with the ability to create them on demand rather than to build the necessary storage and access machinery. In other words, in a very elaborate computer it would be more efficient to store rules from which subroutines could be generated than to store the routines themselves.

It seems, therefore, that even the computing machine realizes that method B is ugly. Each subroutine is an isolated operation that must be stored in its proper place, and no attempt is made to tie these steps to other information available to the machine. So we can see that one superiority of method A lies in the fact that it makes more efficient use of the capacity for storing information. In the teaching of geometry to a child, method A highlights the relations of the new problem to things that the child has already learned, and thus it provides the rules by which the child can write his own subroutines for computation. In essence the ugly method is less efficient because it requires the child to master more new information.

The intimate relation between memory and the ability to reason is demonstrated every time we fail to solve a problem because we fail to recall the necessary information. Since our capacity to remember limits our intelligence, we should try to organize material to make the most efficient use of the memory available to us. We cannot think simultaneously about everything we know. When we attempt to pursue a long argument, it is difficult to hold each step in mind as we proceed to the next, and we are apt to lose our way in the sheer mass of detail. Three hundred years ago René Descartes, in an unfinished treatise called *Rules for the Direction of the Mind*, wrote:

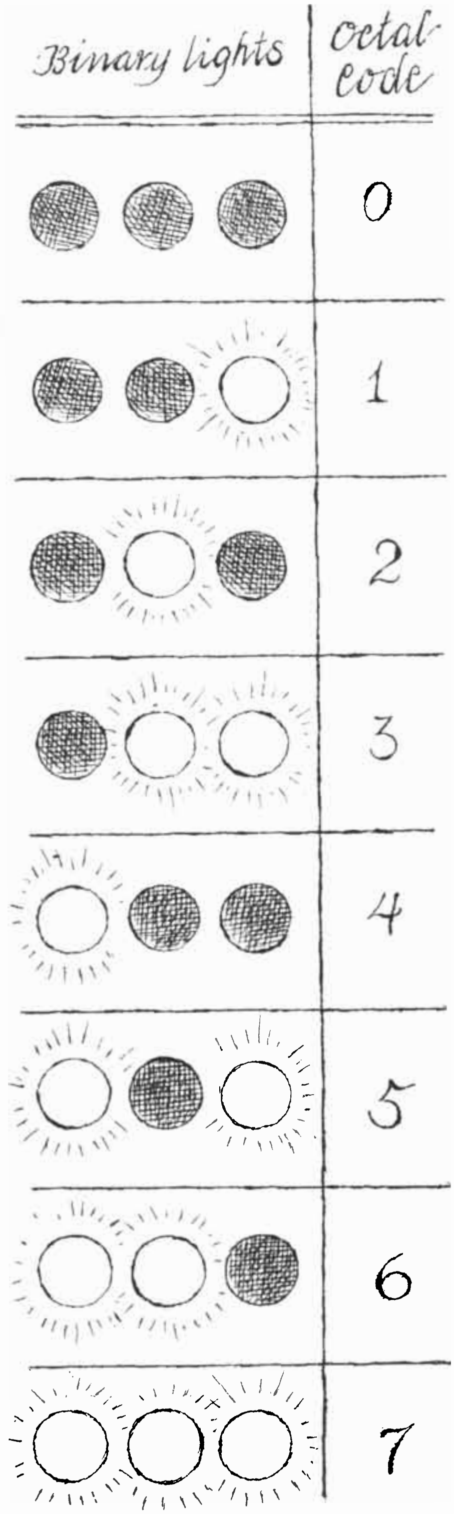
"If I have first found out by separate mental operations what the relation is between the magnitudes A and B, then that between B and C, between C and D, and finally between D and E, that does not entail my seeing what the relation is between A and E, nor can the truths previously learned give me a precise knowledge of it unless I recall them all. To remedy this I would run them over from time to time, keeping the imagination moving continuously in such a way that while it is intuitively perceiving each fact it simultaneously passes on to the next; and this I would do until I had learned to pass from the first to the last so quickly, that no stage in the process was left to the care of memory, but I seemed to have the whole in intuition before me at the same time. This method will relieve the memory, diminish the sluggishness of our thinking, and definitely enlarge our mental capacity."

Descartes's observation is familiar to anyone who has ever memorized a poem or a speech, or mastered a mathematical proof. Rehearsal or repetition has the very important effect of organizing many separate items into a single unit, thus reducing the load our memory must carry and leaving us free for further thinking. In terms of logic, the process is like the substitution of a single symbol for a longer expression which would be clumsy to write each time we wanted to use it.

The practical advantages of this unitizing process were vividly illustrated for me the first time I saw one of those digital computing machines that have small neon lights to show which relays are closed. There were 20 lights in a row, and I did not see how the men who ran the machine could grasp and remember a pattern involving so many elements. I quickly discovered that they did not try to deal with each light as an individual item of information. Instead, they translated the light pattern into a code. That is to say, they grouped the lights into successive triplets and gave each possible triplet pattern a number as its name, or symbol. The pattern all three lights off (000) was called 0; the pattern off-off-on (001) was called 1; off-on-off (010) was called 2, and so forth. Having memorized this simple translation, the engineers were able to look at a long string of lights such as 011000101001111 and break it down into triplets (011 000 101 001 111) which they immediately translated into 30517. It was much easier to remember these five digits than the string of 15 lit and unlit lights.

Reorganization enabled the engineers to reduce the original complexity to something easily apprehended and remembered without changing or discarding any of the original data. There is an analogy between this simple trick and the process described by Descartes. Each step in a complex argument is like a single light in the binary sequence. Rehearsal organizes the steps into larger units similar to the engineers' triplets. Repeated rehearsal patterns the long argument into larger and larger units which are then replaced in thought by simpler symbols.

The first person to propose an experimental test of the span of a man's instantaneous grasp seems to have been Sir William Hamilton, a 19th-century Scottish metaphysician. He wrote: "If you throw a handful of marbles on the floor, you will find it difficult to view at once more than six, or seven at most, without confusion." It is not clear whether Hamilton himself actually threw mar-



COMPUTER LIGHTS are quickly read by engineers using the code illustrated here.

bles on the floor, for he remarked that the experiment could be performed also by an act of imagination, but at least one reader took him literally. In 1871 the English economist and logician William Stanley Jevons reported that when he threw beans into a box, he never made a mistake when there were three or four, was sometimes wrong if the number was five, was right about half the time if the beans numbered 10 and was usually wrong when the number reached 15. Hamilton's experiment has been repeated many times with better instrumentation and control, but refined techniques serve only to confirm his original intuition. We are able to perceive up to about six dots accurately without counting; beyond this errors become frequent.

But estimating the number of beans or dots is a perceptual task, not necessarily related to concepts or thinking. Each step in the development of an argument is a particular thing with its own structure, different from the other steps and quite different from one anonymous bean in Jevons's box. A better test of "apprehension" would be the ability to remember various symbols in a given sequence. Another Englishman, Joseph Jacobs, first performed this experiment with digits in 1887. He would read aloud a haphazard sequence of numbers and ask his listeners to write down the sequence from memory after he finished. The maximum number of digits a normal adult could repeat without error was about seven or eight.

From the first it was obvious that this span of immediate memory was intimately related to general intelligence. Jacobs reported that the span increased between the ages of 8 and 19, and his test was later incorporated by Alfred Binet, and is still used, in the Binet intelligence test. It is valuable principally because an unusually short span is a reliable indicator of mental deficiency; a long span does not necessarily mean high intelligence.

A person who can grasp eight decimal digits can usually manage about seven letters of the alphabet or six monosyllabic words (taken at random, of course). Now the interesting point about this is that six words contain much more information, as defined by information theory, than do seven letters or eight digits. We are therefore in a position analogous to carrying a purse which will hold no more than seven coins—whether pennies or dollars. Obviously we will carry more wealth if we fill the purse with silver dollars rather than pennies. Similarly we can use our memory span most efficiently by stocking it with informationally rich symbols such as words, or perhaps images, rather than with poor coin such as digits.

SIR WILLIAM HAMILTON, a 19th-century Scottish philosopher (not to be confused with Sir William Rowan Hamilton, the mathematician), observed: "If you throw . . . marbles on the floor, you will find it difficult to view at once more than six . . . without confusion."

The mathematical theory of communication developed by Norbert Wiener and Claude Shannon provides a precise measure of the amount of information carried. In the situation we are considering, the amount of information per item is simply the logarithm (to the base two) of the number of possible choices. Thus the information carried by a binary digit, where there are two alternatives, is $\log_2 2 = 1$ bit. In the case of decimal digits the amount of information per digit is $\log_2 10 = 3.32$ bits. Each letter of the alphabet carries $\log_2 26 = 4.70$ bits of information. When we come to make the calculation for words, we must take into account the size of the dictionary from which the words were drawn. There are perhaps 1,000 common monosyllables in English, so a rough estimate of the informational value of a monosyllabic word selected at random might be about 10 bits.

A person who can repeat nine binary digits can usually repeat five words. The informational value of the nine binary digits is nine bits; of the five words, about 50 bits. Thus the Wiener-Shannon measure gives us a quantitative indication of how much we can improve the efficiency of memory by using informationally rich units. The computer engineers who group the relay lights by threes and translate the triplets into a code can remember almost three times as much information as they would otherwise.

It is impressive to watch a trained person look at 40 consecutive binary digits, presented at the rate of one each second, and then immediately repeat the sequence without error. Such feats are called "mnemonic tricks"—a name that reveals the suspicious nature of psychologists. The idea that trickery is involved, that there is something bogus about it, has discouraged serious study of the psychological principles underlying such phenomena. Actually some of the best "memory crutches" we have are called laws of nature. As for the common criticism that artificial memory crutches are quickly forgotten, it seems to be largely a question of whether we have used a stupid crutch or a smart one.

When I was a boy I had a teacher who told us that memory crutches were only

Binary (1 bit)	Decimal (3.3 bits)	Alphabetic (4.7 bits)	Syllabic (10 bits)
110100	4972	XJR	for, line
0100110	86515	AYCZ	nice, it, act
10010011	021942	EDLYG	time, who, to, air
101100010	3776380	QJPEVJ	by, west, cent, or, law
0010101110	28201394	DLXBAHC	bay, sea, ten, red, ask, mob
11010001011	918374512	HOKOMSFB	go, how, ice, save, hat, sue, way
101001110110	1038204665	FQGUJRZVM	odd, gas, call, at, ant, pay, get, was
0001010111011	57048621937	DNKSNWJUWT	by, game, log, free, so, you, car, big, why

SPAN OF IMMEDIATE MEMORY depends mainly on the number of items to be memorized and is relatively independent of the amount of information per item. In this table the amount of information is measured in "bits," or binary digits. A binary digit can be 1 or 0, and hence conveys a minimum amount of information. A person who can repeat nine binary digits can usually memorize seven decimal digits, six letters or five words (*row above broken line*). The other rows compare the span for other groups of items.

one grade better than cheating, and that we would never understand anything properly if we resorted to such underhanded tricks. She didn't stop us, of course, but she did make us conceal our method of learning. Our teacher, if her conscience had permitted it, no doubt could have shown us far more efficient systems than we were able to devise for ourselves. Another teacher who told me that the ordinate was vertical because my mouth went that way when I said it and that the abscissa was horizontal for the same reason saved me endless confusion, as did one who taught me to remember the number of days in each month by counting on my knuckles.

The course of our argument seems to lead to the conclusion that method A is superior to the ugly method B because it uses better mnemonic devices to represent exactly the same information. In method A the six apparently arbitrary steps of method B are organized around three aspects of the total problem so that each aspect can be represented by symbols which the student has already learned. The process is not essentially different from the engineers' method for recoding a sequence of binary lights.

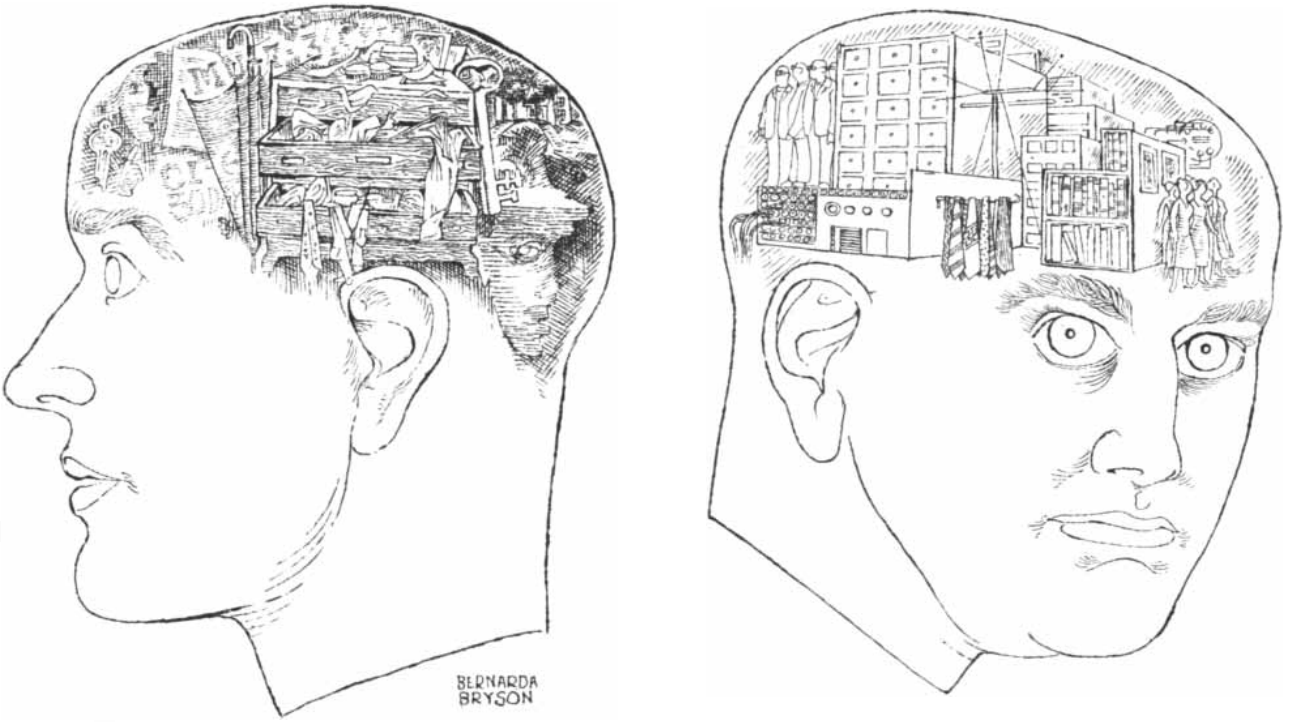
It is conceivable that all complex, symbolic learning proceeds in this way. The material is first organized into parts which, once they cohere, can be replaced by other symbols—abbreviations, initial letters, schematic images, names, or what have you—and eventually the whole scope of the argument is translated into a few symbols which can all be grasped at one time. In order to test this hypothesis we must look beyond experiments on the span of immediate memory.

Our question is: Does the amount of information per item (*i.e.*, the number of possible alternative choices per item) affect the number of items we can remember when there is a large amount of material to be mastered? For example, is it more difficult to memorize a random sequence of 100 monosyllabic words than 100 digits or 100 letters of the alphabet? The question is important because it has a bearing on how we can organize material most efficiently for learning.

In an exploratory study that S. L. Smith and I devised at the Harvard University Psychological Laboratories, the subjects were required to memorize three different kinds of lists of randomly chosen items. One list was constructed from a set of 32 alternatives (all the alphabet except Q plus the numerals 3, 4, 5, 6, 7, 8 and 9), another from a set of eight alternatives, and the third from just two alternatives. The subject read a test list at the rate of one item every second and then had to write down as much of the list as he could remember in the correct order. The lists ran to 10, 20, 30 or 50 items. If the subject failed to reproduce the list exactly, it was presented again. The number of presentations required before the first perfect reproduction measured the difficulty of the task.

We were not greatly surprised to find that the subjects did somewhat better (*i.e.*, needed about 20 per cent fewer trials) on the binary-choice lists than on the other types. After all, a run of, say, six zeros or six ones is easy to remember and therefore in effect shortens the list. But on the other two types of lists (eight alternatives and 32 alternatives) the subjects' performances were practically indistinguishable. In other words, it was just as easy to memorize a list containing a lot of information as one of the same length containing less information.

Very similar results have been obtained at the University of Wisconsin by W. J. Brogden and E. R. Schmidt, who did their experiments for other reasons and without knowledge of the hypothesis Smith and I were trying to test. They used verbal mazes with either 16 or 24 choice points and they varied the number of alternatives per choice point from two to 12. Here again the length of the list of points that had to be learned, and not the number of alternatives offered at each choice point, determined the difficulty of the test—with the same excep-



FANCIFUL HEADS were drawn by Bernarda Bryson to depict René Descartes's *Rules for the Direction of the Mind*, described in the text of the article. The individual at left has presumably not had the benefit of the rules, whereas the man at right has.

tion that we found, namely, that it was slightly easier to remember where only two choices were offered.

Tentatively, therefore, we are justified in assuming that our memories are limited by the number of units or symbols we must master, and not by the amount of information that these symbols represent. Thus it is helpful to organize material intelligently before we try to memorize it. The process of organization enables us to package the same total amount of information into far fewer symbols, and so eases the task of remembering.

How much unitizing and symbolizing must we do, and how can we decide what the units are? The science of linguistics may come to our aid here. Language has a hierarchical structure of units—sounds, words, phrases, sentences, narratives—and it is there that one should seek evidence for a similar hierarchy of cognitive units.

It has been estimated that English sentences are about 75 per cent redundant: that is, about four times as long as they would need to be if we used our alphabet with maximum efficiency. At first glance this fact seems paradoxical. If length is our major source of difficulty, why do we deliberately make our sentences longer than necessary? The paradox arises from a confusion about the definition of sentence length. Is a sentence 100 letters, or 25 words, or 6 phrases, or one proposition long? The fact that all our books contain 75 per cent more letters than necessary does not mean that 75 per cent of the ideas could be deleted. And it is those larger subjective units, loosely called ideas, that we must count to determine the psychological length of any text.

A sequence of 25 words in a sentence is easier to recall than a sequence of 25 words taken haphazardly from the dictionary. The sentence is easier because the words group themselves easily into familiar units. In terms of psychological units, a 25-word sentence is shorter than a sequence of 25 unrelated words. This means that the word is not the appropriate unit for measuring the psychological length of a sentence. Perhaps linguistic techniques for isolating larger units of verbal behavior will provide an objective basis for settling the question.

When we memorize a sentence, all our previous familiarity with the lexicon and grammar of the language comes to our aid. It is one of the clearest possible examples of the transfer of previous learning to a new task. And the transfer is profitable because it serves to reduce the effective length of the material to be remembered. By learning the language, we have already acquired automatic habits for unitizing those sequences that obey the rules of the language.

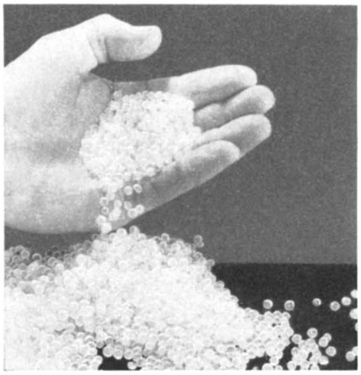
There are three stages in the unitizing process. All three were described in the 17th century by John Locke in his famous *Essay Concerning Human Understanding:* "Wherein the mind does these three things: first, it chooses a certain number [of specific ideas]; secondly, it gives them connexion, and makes them into one idea; thirdly, it ties them together by a name." Men form such complex ideas, Locke said, "for the convenience of communication," but the combination of ideas sometimes leads to confusion because it is "the workmanship of the mind, and not referred to the real existence of things." The development in the 20th century of a mathematical theory of communication enables us to see more clearly how this process serves the convenience of communication and, coupled with the fact that it is the length, not the variety of the material that limits our memories, gives us an important insight into the economics of cognitive organization.

Organizing and symbolizing are pervasive human activities. If we can learn to perform them more efficiently, perhaps we shall indeed be able, as Descartes promised, to "relieve the memory, diminish the sluggishness of our thinking, and definitely enlarge our mental capacity."

Kodak reports to laboratories on:

the plasticizerless plastic for the kitchen middens of tomorrow . . . how to draw a crowd into your tent . . . non-hygroscopic acetylcholine iodide

Beyond the squeeze bottle



Since we are stepping up the pace at Longview, Texas, to make 40,000,000 pounds annually of these *Tenite Polyethylene* pellets, it is desirable to look beyond squeeze bottles, sheet, pipe, wire covering, and housewares, much as our vast learning in dye chemistry is winning favor from a color-responsive populace who have known polyethylene only as the white, waxy one. No stone must be left unturned. From under one there might crawl out some triviality, colorful or otherwise, that within a twelvemonth *has* to go on every single ****** ******* in service. Likely as not, the gizmo's daddy turns out to be a guy better wooed with numbers than with warm, reassuring words. All right:

Average Properties of Tenite Polyethylene

Thermal coefficient of expansion	11×10^{-5} in/in/°F
Thermal conductivity	8×10^{-4} cal/cm²/sec/°C/cm
Specific heat	
solid (70-105F)	0.55
liquid (250-285F)	0.70
Brittleness temperature	<-70C
Tensile strength at fracture, 73F	2150 to 1100 psi (depending on formulation selected)
Dielectric strength (.030″ specimen at 60 cycles)	1000 v/mil (short time)
Volume resistivity	10^{19} ohms/cm
Surface resistivity	$>4 \times 10^{14}$ ohms
Dielectric constant	2.3
Dissipation factor	<0.0005

For more such, write to Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company), requesting the 16-page specification booklet on Tenite Polyethylene, *the plasticizerless plastic by which future antiquaries may date our kitchen middens. During the discussion of how the beads might get fabricated into the objects you need, we have every intention of making a friend out of you.*

Slowdown in color

In the heat of debate we once heard an advertising man cry out, "What's a product? Anybody can make a product. The real art is selling a product."

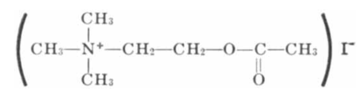
Though since moved on to fields where his artistry could more lushly flower, he wasn't entirely wrong, just too sweeping in his value judgements. In the market place—particularly in the industrial market place—many a wonderfully ingenious and efficient product of the engineering mind and hand fails to ring the bell as loud and clear as expected, simply because too few potential customers know how the thing works. One way to draw a crowd into the tent for educational purposes is to show them movies. Showmanship isn't all; some mechanisms can be seen at work in no other way than through movies which slow down the action fifty times or more. Sometimes recognition of this is all the showmanship needed.

There was a time when these high speed movies were used only for development and trouble-shooting. Long miles of high speed film still quite justify themselves in the form of black-and-white rush negatives shown once to taut little engineering groups, but more and more high speed shooting is done on *Kodachrome Film* and even on *Commercial Kodachrome Film*, which is chosen only with advance knowledge that numbers of full-color copies will be required for circulation.

"High Speed Motion Pictures," a new booklet obtainable from Eastman Kodak Company, Sensitized Goods Division, Rochester 4, N. Y., tells about the Kodak High Speed Camera *and about the films spooled for this kind of movie making.*

A delightful business

You sit one fine morning reading your mail and lo, there is a letter from a researcher at a medical school in the green hills of Vermont who wants to know why you don't put up acetylcholine as the



quaternary iodide. Somehow, possibly by reading it in a book, he seems to have learned that acetylcholine iodide is not hygroscopic at all, whereas that well known vasodilator acetylcholine itself and its well known bromide (Eastman 2117) absorb so much water from the air that to try to weigh them out accurately is a nuisance. There doesn't seem to be a blessed reason in the world why you can't put up acetylcholine iodide. You even think of a way to make it from starting material less costly than acetylcholine. You try it and it works and the iodide *is* non-hygroscopic. That particular researcher is pleased at what an agreeable fellow you are, and you are pleased at the prospect of all the acetylcholine iodide that all the other researchers are going to buy from you.

So now all you have to do is to advertise that Acetylcholine Iodide (*Eastman 7209*) *costs $2.60 for 10 g. and is one of some 3500 highly purified organic chemicals sold by Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y.* (*Division of Eastman Kodak Company*).

Price quoted is subject to change without notice.

This is one of a series of reports on the many products and services with which the Eastman Kodak Company and its divisions are . . . *serving laboratories everywhere*

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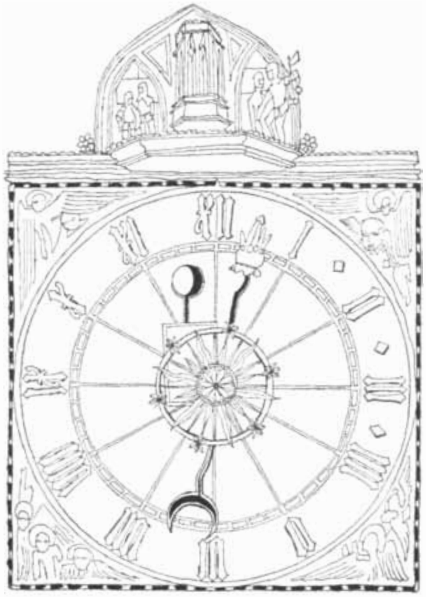
SCIENCE AND



Little Neutral One

A long and exciting adventure in physics has come to a triumphant end. The neutrino has been found. Frederick Reines and Clyde L. Cowan, Jr., of the Los Alamos Scientific Laboratory trapped the ghostly particle in an underground chamber near the Savannah River atomic pile.

In the article on this search by Philip Morrison, published in the January issue of SCIENTIFIC AMERICAN, Morrison compared the neutrino to the planet Neptune. The discovery of Neptune was a crowning achievement of classical physics: the motions of other planets showed it had to be there. The neutrino is a similar achievement of modern physics, and its discovery is a vindication of the law of the conservation of energy.

The existence of the particle was suggested by Wolfgang Pauli and Enrico Fermi to account for the puzzling phenomenon of beta-decay—the spontaneous conversion of a neutron into a proton and an electron. In this process a certain amount of mass is lost, which should turn up as energy of the product particles. However, the proton and electron almost never have enough energy to balance the account. Pauli and Fermi proposed that the missing energy is carried away by an uncharged, virtually weightless particle which Fermi named neutrino—"little neutral one."

A consequence of the theory is that the hypothetical particle should interact hardly at all with other forms of matter. The average neutrino would pass through 50 light-years of solid lead before reacting with another particle. Thus it is intrinsically almost undetectable. Reines and Cowan undertook to detect it by recording its extremely rare interactions. Their experiment, whose successful outcome was reported at a meeting of the American Physical Society in New Haven last month, depends on the reverse of beta-decay: a proton captures a neutrino and is converted into a neutron and a positron. Both of the products are easily detectable.

In order to get a measurable number of events the experimenters needed a strong source of neutrinos and an enormous number of target protons. Their neutrino source was the biggest nuclear reactor in the U. S.—the Savannah River pile. The target protons were the hydrogen nuclei in two tanks of water, each six feet 3 inches long, four and a half feet wide and three inches thick. These tanks were sandwiched triple-decker style among three detecting tanks, each containing about 50 cubic feet of a scintillating liquid.

Whenever a neutrino was captured, the resulting positron combined almost immediately with an electron. The two particles annihilated each other and gave rise to a pair of gamma rays which produced light flashes in the scintillator tanks. The flashes were picked up by some of the hundreds of photomultiplier tubes lining the tanks. The neutron formed with the positron was captured, after a few millionths of a second, by the nucleus of a cadmium atom (cadmium was dissolved in the target water). This capture also released gamma rays which caused scintillations.

To distinguish the telltale sequence from random flashes in the detectors caused by other nuclear events was the crux of the experiment. It was accomplished by selecting electronically only groups of flashes of just the right brightness, occurring in a certain definite spatial relationship to each other and within the proper time interval. Reines and Cowan had run their experiment for 1,371 hours at the time of their report. In a number of variations of the experimental setup they obtained average counts of from one-half to three neutrinos per hour. The ratio of these counts to unwanted background from cosmic rays and other radiation from the reactor was about 10 to one.

The experimenters devised a number of stratagems to give additional proof that they were actually counting neutrinos. To show that the radiation was coming from the reactor rather than from outside they varied the power level of the pile. Their counts went up and down with the power. To eliminate the possibility that they were counting neutrons or gamma rays from the pile, they inserted some tens of tons of wet sawdust between it and their apparatus. This material strongly absorbs neutrons and gamma rays. If they had been responsible for the counts, the rate should have been reduced tenfold by the sawdust. In fact, it was not reduced at all.

Reines and Cowan had earlier tried a similar but less rigorous experiment at the Hanford reactor. They believed that they had found the neutrino at that time, but the results were far less convincing than the ones at Savannah River.

The discovery is "of great importance," according to Atomic Energy Commissioner Willard F. Libby. He said it should help in understanding the mysterious force that holds atomic nuclei together. Libby also pointed out that part of the energy produced by stars is carried off by neutrinos. It would be interesting "to learn how much of the energy in the universe has been 'lost' into the neutrino state, and it is hoped that this can be estimated in experiments following up the work which led to the detection of the neutrino."

National Science Board Members

The U. S. Senate has confirmed the appointment of nine members of the National Science Board. Four of them are charter members appointed to a second term: Laurence M. Gould, geologist, Carleton College; Paul M. Gross, chemist and dean, Duke University; George D. Humphrey, president, University of Wyoming; Frederick A. Middlebush, president emeritus, University of Missouri.

The new members are: Edward J. McShane, mathematician, University of Virginia; Samuel M. Nabrit, president, Texas Southern University; Julius A. Stratton, vice president, Massachusetts Institute of Technology; Edward L. Tatum, biologist, Stanford University; Warren Weaver, director of natural sciences division, Rockefeller Foundation. All will serve six-year terms, except for Weaver, who has been appointed to fill a vacancy until 1960.

Modernizing High-School Math

The Carnegie Corporation of New York has given the University of Illinois $277,000 to revamp high-school mathematics teaching. A project headed by Max Beberman has during the last four years evolved a more sophisticated mathematics curriculum, which is already being tested in five Illinois and Wisconsin high schools. It is designed to give the student a more coherent view of mathematics and also to ground him in some of the ideas and techniques of higher mathematics.

The Illinois educators have discarded the conventional order of courses: elementary algebra for freshmen, plane geometry for sophomores, intermediate algebra and solid geometry for juniors and advanced algebra and trigonometry for seniors. Under the new program they are teaching algebra and analytic geometry in the freshman year. Sophomores get a new course called the theory of sets: set theory compares the properties of similar things, such as whole numbers. Juniors learn about complex numbers and elementary calculus. The mathematics course for seniors is still being planned.

Venus on the Air

Of all the celestial bodies showering the earth with radio waves, Venus seems to be the most vociferous. Last month the following signals were reported as coming from Earth's sister planet:

A steady hissing at 10,000 megacycles, which indicates that the surface of Venus is hotter than boiling water. This signal was detected by Cornell H. Mayer and co-workers at the Naval Research Laboratory.

An intermittent crackling, which resembles static from terrestrial thunderstorms. It was picked up by John D. Kraus at the Ohio State University.

A sound so much like wireless telegraph signals that it was at first thought to be interference from a radio telegraph station. Kraus, the receiver, said: "Whatever phenomenon is responsible for the signals must be of a rather complex type."

Ultraviolet Sky

As rockets and earth-circling satellites rise above the atmosphere, astronomers will be able for the first time to capture the ultraviolet light emitted by the stars. The atmosphere absorbs all but the longest ultraviolet wavelengths before they can reach the earth.

How will the sky appear in ultraviolet light? Robert J. Davis of Harvard Observatory has made a detailed prediction. According to his calculations, summarized in *Sky and Telescope*, the ultraviolet sky will seem as strange as the picture now being put together by radio astronomers [see "The Radio Sky," by John D. Kraus; SCIENTIFIC AMERICAN, July].

The brightest object in the ultraviolet sky will be the sun, but its magnitude will be minus 13.2—far less than its visual magnitude of minus 26.7. The next brightest will be the southern Wolf-Rayet stars, Zeta Puppis and Gamma Velorum, with ultraviolet magnitudes of about minus 3.

Generally speaking the ultraviolet sky will contain more extremely bright objects than the visual sky. No fewer than 23 stars will have ultraviolet magnitudes brighter than minus 1, whereas visually only Sirius, the moon, the sun and some planets are as prominent as this. On the other hand, few distant stars will be visible, because interstellar dust strongly absorbs ultraviolet light.

The moon will be among the least conspicuous objects in the ultraviolet sky. It reflects little ultraviolet light and will have a magnitude of only plus 5.

Glacial Cycles

The advances and retreats of polar ice that have punctuated man's existence on earth are rare events in the scale of geologic time. Prior to the Pleistocene Period, which began about one million years ago, there appear to have been few ice ages. Why did glaciers then suddenly start to form, and what has made them wax and wane? Maurice Ewing, director of the Columbia University Lamont Geological Observatory, and an associate, William L. Donn, recently published in *Science* a new theory to explain the glacial cycle.

At the beginning of the Pleistocene Period, they postulate, the earth changed its axis of rotation so that the North Pole shifted from somewhere in the North Pacific to its present location in the Arctic Ocean. The Arctic, then chilly but unfrozen, furnished moisture to the air, and the moisture fell as rain and snow on the land near the pole. This precipitation created glaciers, which for a time continued to grow and to spread southward. When so much water was locked in the glaciers that the sea level dropped per-

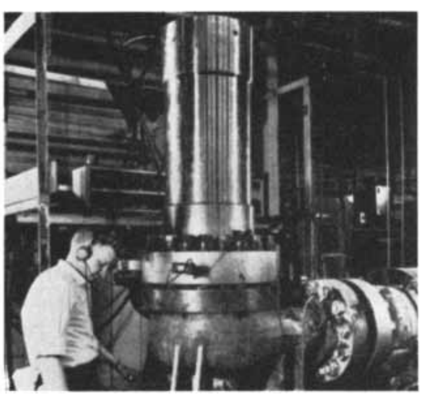
DOW CORNING

SILICONE NEWS

How Designers Plan for Tomorrow

- Silicone insulated motor-pump handles radio-active coolants
- Industry eyes liquid springs made more efficient with Silicone fluids
- New auto transmission seals of Silicone rubber are "boiled in oil"

HEART OF THE USS NAUTILUS— Heat energy of radioactive water from the nuclear reactor is circulated under pressure through the steam generators by canned motor-pumps. Water at temperatures up to 675°F circulates through the motor bearings, between the separately canned stator and rotor assemblies and around the stator. Silicone insulated stator windings are protected from the hot liquid by a stainless steel jacket; the rotor by a leak-tight cylinder of nickel alloy. **Canned motor-pumps** with capacities ranging from 5 to 17,000 gallons per minute are made by Westinghouse. Skillful engineering with silicone insulation enables these pumps to handle liquids at system pressures up to 2500 psi. Special units will even handle liquid metal at temperatures



up to 1000°F. Other applications: steam systems involving controlled or forced circulation and some process applications in the chemical and petroleum industries. No. 29

METHUSELAH AMONG MOTORS is a silicone insulated 10 hp motor in Dow Corning's motor test lab. It's still going after more than 58,000 hours at an average copper temperature of 465° F. That's equivalent to over 350 years' operation at regular Class H motor temperatures.

MIGHTY MITES — Liquid filled "Hydra Springs" by Wales Strippit Corporation provide forces 3 to 6 times greater than coil springs of the same size. Dow Corning silicone fluid is specified as the compressible medium for these springs because its compressibility is 9 to 10% at 20,000 psi compared to 6 or 6½% for mineral base oils.

Heat stability was another important consideration leading to the use of Dow Corning silicone fluid. Semi-inorganic, it retains nearly constant viscosity and does not break down despite high operating temperatures. Hydra Springs have already proved highly successful in metal working dies, perforating equipment, testing equipment, ordnance devices and specialized machinery. Other applications are in the offing. No. 30

SILICONE SURFACE —gives glass containers better "slip", reduces jam-ups on filling line, increases filling rates as much as 80%. Also imparts greater resistance to bruising and scratching—cuts line breakage as much as 50%. Leading glass makers now offer containers coated with Dow Corning Silicones at little or no extra cost. No. 31

BOILED IN OIL—Most advanced design in automatic transmissions for automobiles requires greater activity of the oil within the unit. This means more heat. Where old designs operated in the range of 150°F to 250°F, new models average 250°F with frequent highs of 325°F. Seals molded of Silastic*, Dow Corning's silicone rubber, prevent leakage of the hot oil and assure long maintenance-free service.

Amazing as it may seem, this sealing assignment is actually duck soup for a material that stays rubbery and

keeps its shape at temperatures far above and far below the limits of organic rubber. Silastic's range is from −130°F to 500°F. No. 32

*T.M. REG. U.S. PAT. OFF.

GOOD-BYE HEADACHES — Mold cleaning, a costly problem in the rubber industry, has been virtually eliminated by Dow Corning silicone mold lubricants. Here's a typical report from a leading rubber company: "With silicone mold lubricants we never have to clean molds except when we take them out for change or repair." No. 33

TOMORROW'S PRODUCTS — will come from imaginative use of new materials. That's why design, production and maintenance men need the new Reference Guide to Dow Corning Silicone Products. No. 34

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CANADA: DOW CORNING SILICONES LTD., TORONTO GREAT BRITAIN: MIDLAND SILICONES LTD., LONDON FRANCE: ST. GOBAIN, PARIS haps 50 fathoms, the Arctic Ocean was cut off from much of the warmer water it had been getting from the Atlantic. As a result the Arctic Ocean froze. The glaciers, without their source of moisture, could no longer grow. Gradually they melted, refilling the seas and restoring the warm currents to the Arctic. At this point the Arctic Ocean again became an open sea, and the stage was set for another glacial advance.

As long as the North Pole remains inside the Arctic Ocean, glacial periods will continue to come and go, Ewing and Donn said. Their theory, they pointed out, contradicts one common conception: that at the height of every glacial epoch ice covered the entire northern portion of the earth. Instead, they maintain, the Arctic Ocean is unfrozen when the glaciers are largest. When man migrated from Asia to America during the last Ice Age, according to Ewing and Donn, the Arctic Ocean had not yet frozen and the climate there was warmer than it is today.

Bird Semantics

Most birds speak a rudimentary language. A crow, for example, gathers its flock by uttering a distinctive "assembly call" and disperses it by squawking an "alarm call." The flock will respond to tape recordings of these calls just as it does to the cries of a live bird.

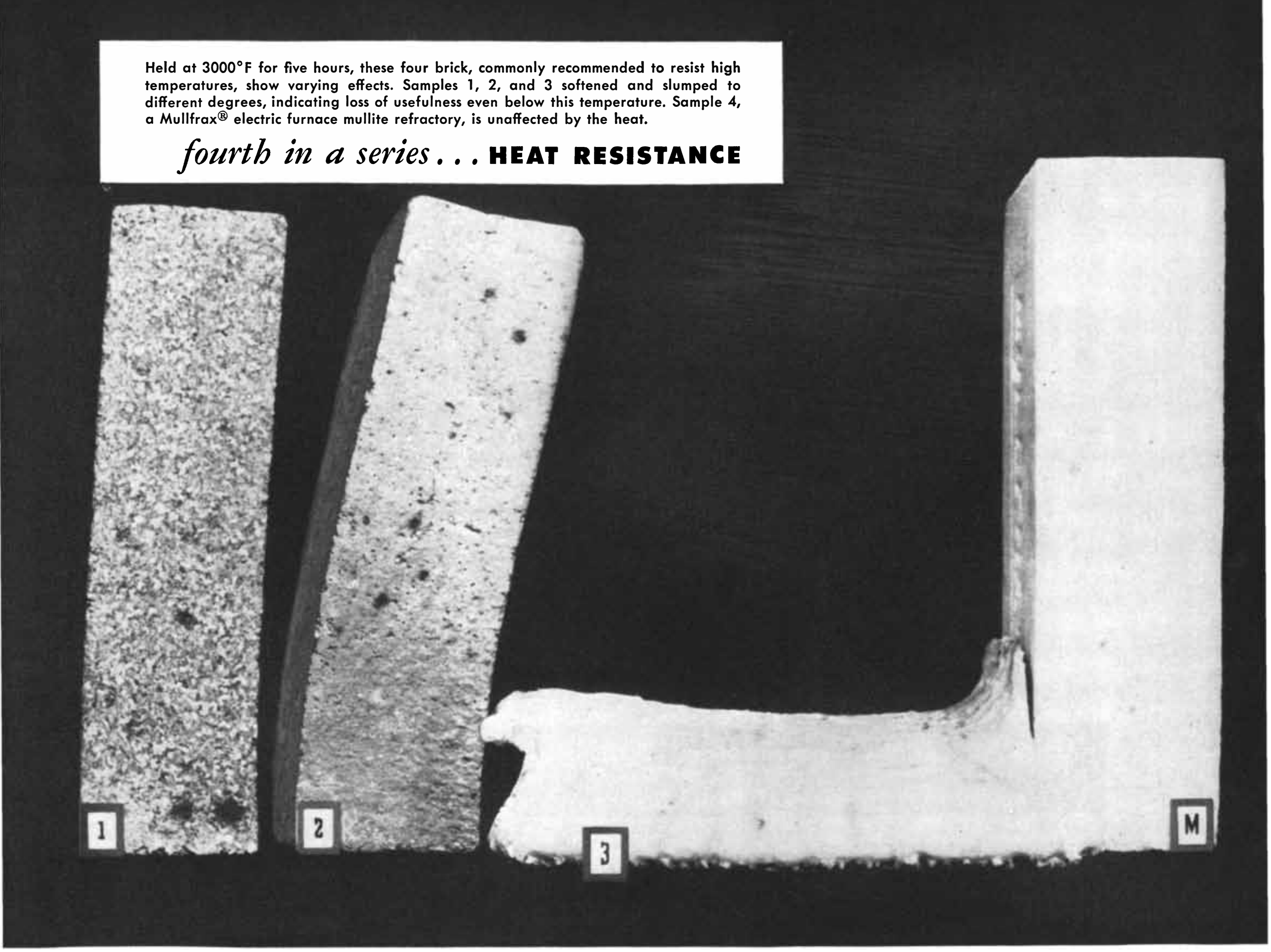
Two research groups, one in the U. S., the other in France, recently exchanged tapes on which they had recorded the calls of their native crows. Their object was to learn whether French crows (rooks, jackdaws and carrion crows) would understand the language of the American Eastern crow, and *vice versa*.

Roosting French crows consistently ignored the alarm call of American crows, but more than half of the French birds were aroused by the broadcast of an American assembly call. American crows were less knowing linguistically. They were wholly unmoved by the plaintive cries of nestling rooks or the strident assembly call of adult jackdaws —commands which all three species of French crow invariably obey.

In a further experiment the French investigators broadcast the food-finding and alarm calls of the American herring gull, a bird that also dwells on French coasts. The French gulls paid no heed to the American calls.

The scientists concluded from these experiments that birds learn the language of their kind from older birds of their own group.

The French group comprised R.-G.



Held at 3000°F for five hours, these four brick, commonly recommended to resist high temperatures, show varying effects. Samples 1, 2, and 3 softened and slumped to different degrees, indicating loss of usefulness even below this temperature. Sample 4, a Mullfrax® electric furnace mullite refractory, is unaffected by the heat.

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Busnel, J. Giban and Ph. Gramet of the National Institute for Agricultural Research. The Americans were Hubert and Mable Frings and J. Jumber of Pennsylvania State University and the Mount Desert Island Biological Laboratory. They reported their work at the Second International Congress on Acoustics held in June at the Massachusetts Institute of Technology.

Light Beer, Heavy Water

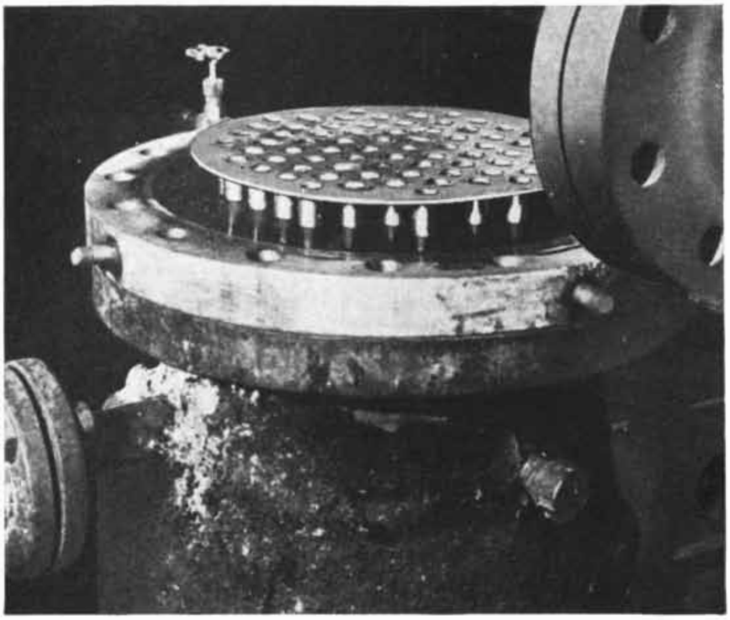
The first step in brewing beer is "malting," a procedure which partly converts barley starch into fermentable sugar. The grain is soaked in water so that it sprouts sugar-laden shoots. During the wetting a much subtler change also takes place in the water, three Swedish investigators have recently discovered. It becomes rich in heavy water. Barley absorbs relatively few of the scarce heavy-water molecules in ordinary water, so that water which has trickled through the grain has a concentration of the heavy variety.

Writing in *Nature*, L. Carlbom, R. Skjöldebrand and N. Nielsen report that by pouring water repeatedly through a bed of barley they have increased its heavy-water content more than fourfold. Although this raises the heavy-water concentration to less than .1 per cent, it indicates that waste water from breweries may prove commercially valuable. In the present process for extracting heavy water, the authors point out, the first stage is necessarily expensive because it involves processing huge volumes of liquid. If any of the several manufacturing methods could start with water slightly enriched with the heavy hydrogen isotope, the cost of heavy water (currently $28 per pound) would be greatly reduced.

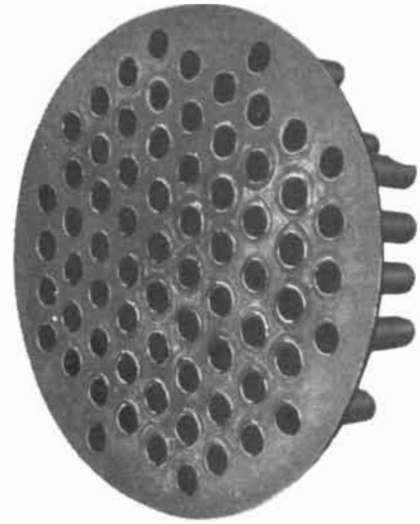
Bone Grafts

Bone from rats and cows has been successfully grafted into the legs of 10 dogs at the Naval Medical Research Institute, Bethesda, Md. It is a precedent-making experiment, because bone grafts even within the same species have been difficult up to now. The animal receiving the graft develops an antibody reaction to fats, protein and other organic matter in the bone. A new chemical treatment that rids bone of virtually all organic matter enabled the Bethesda dogs to incorporate the exotic bone into their bodies, Fred L. Losee and Lloyd A. Hurley report in *Nature*.

They soaked the bone in a solvent, ethylenediamine, and then in pure grain



'Top-hat' of REM-CRU titanium in service on condenser at E. I. duPont de Nemours, Inc.



Closeup of titanium 'top-hat'.

how TITANIUM 'top-hat' thwarts corrosion damage to DuPont condenser...

Problem: DuPont chemical engineers faced a particularly vexing problem in the frequent failure of a stainless steel condenser handling 60% nitric acid at 480F and 300 psi. Every five months or so, it became so badly corroded that replacement was necessary. Unit costs and downtime were serious.

Solution: Since failures always occurred at the condenser top, DuPont engineers decided to try protecting that area with a 'top-hat' insert of REM-CRU titanium. It consists of a titanium disc twelve inches in diameter, to which a cluster of 70 thin wall titanium tubes is welded. Fitting snugly into the top of the stainless steel condenser, the titanium protects the area where trouble started. *And it stopped failures completely*. The 'top-hatted' condenser has been in service for more than 16 months and still shows no sign of corrosion beyond a slight discoloration.

Dollars and Cents Facts About Titanium: It's true that titanium sheet and tubing cost more than stainless steel. But titanium's light weight (40% lighter than steel), means you must buy fewer pounds of *metal* for a given area. Furthermore, the cost of the metal is only a fraction of the cost of the finished assembly. Substituting titanium for stainless, therefore, increases the cost of a finished reactor, autoclave, valve or other piece of chemical equipment by only two or three times. Where titanium extends the service life of parts by such a factor, or eliminates costly maintenance and downtime, it's the obvious choice over cheaper but less corrosion-resistant metals.

At REM-CRU you can now get *prompt* delivery of this versatile metal in a wide variety of sizes, shapes and grades — including new high-strength, weldable alloys. REM-CRU engineers will be glad to help with selection, application or fabrication problems.

To keep abreast of the latest developments on this vital metal, write to Dept. S-8 for the Rem-Cru Review — a free periodical presenting the latest technical data on titanium alloys.

REM-CRU TITANIUM

REM-CRU TITANIUM, INC., MIDLAND, PENNSYLVANIA

alcohol. This dissolved out almost all the organic constituents without changing the mineral structure of the bone. After they had grafted the treated bone onto the tibia of the dogs, the investigators injected the animals with radioactive alizarin red S, a dye which has an affinity with fresh bone growth. Radiations given off by the dye showed that the grafts took hold promptly.

Sounds inside the Heart

A new kind of stethoscope which is inserted directly into the heart has been introduced at the Philadelphia General Hospital. Its inventor, David H. Lewis, explains that it has a tiny barium titanate crystal mounted on the tip of a heart catheter. The crystal, a piezoelectric material commonly used to pick up underwater sounds, converts the noise of the heart into a pulsing electric current, which flows through wires in the catheter tube and is then reconverted to sound. This instrument makes it possible for diagnosticians to listen to the heart unmuffled by intervening layers of fat, muscle, cartilage and bone.

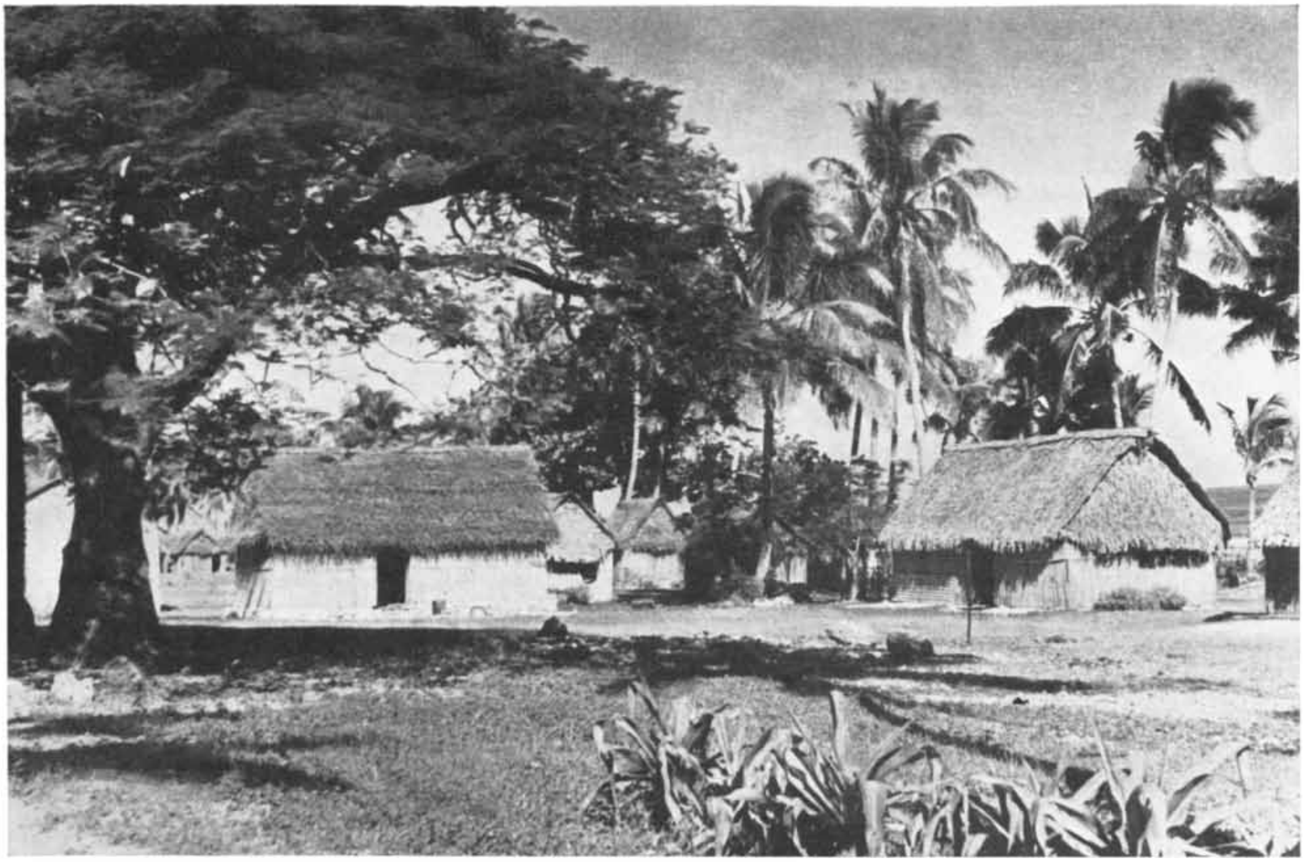
Abrupt Endings

The personality pattern of juvenile delinquents includes a characteristic impatience with life, according to experiments reported last month by Donald M. Johnson, a Michigan State University psychology professor. Johnson and a graduate student, Robert J. Barndt, are developing a verbal test to detect incipient delinquency in boys.

They selected 26 delinquents aged 15 to 17 from a vocational school in Lansing and matched them with 26 non-delinquents of similar age, intelligence, scholastic records and social backgrounds. Then they told each boy: "About 3 o'clock one bright, sunny afternoon in May two boys were walking down a street along the end of town. Now you start there and finish the story any way you want to."

The delinquent boys brought their tales to swift and often violent conclusions. Six of them told stories that ended within one hour of the 3 o'clock time, while none of the non-delinquent imagined such a quick ending. Conversely, six of the non-delinquents (but only one of the delinquents) prolonged their stories more than a week.

"Short-time perspective—living in the here and now, unconcerned about rewards and punishments in the future—appears to be part of the pattern of delinquency," concludes Johnson.



MANGAIA, one of the Cook Islands (*see map on pages 60 and 61*), is photographed in two aspects. At the top are houses roofed with pandanus leaves. At the bottom is the interior of the island, with houses where the Mangaians live while they cultivate their fields.

The Settlement of Polynesia

Where did the romantic inhabitants of these Pacific islands come from? The answer to the question begins to emerge from variations in their tools, their physique and, most important, their language

by Donald Stanley Marshall

Polynesia—that vast galaxy of islands in the mid-Pacific from New Zealand to Hawaii—was the last major area of the earth's surface to be discovered and occupied by man. It is the largest area ever occupied by a single people—possessing the same culture, speaking the same language and having much the same physical appearance. Its people have been intensively studied, and probably more written about than any other group in the world: they have fascinated painters and poets, novelists and feature writers, sea captains and musical comedy composers, archaeologists and anthropologists. And yet the Polynesians remain one of the great riddles of human history. Where did they come from, and how did they settle their huge oceanic realm?

Did they come from the west or the east—from Asia or America? Thor Heyerdahl is convinced that his celebrated voyage on the balsa raft *Kon-Tiki* proved the Polynesian islands could have been settled by ocean wanderers from Peru; professional scholars doubt that it proved anything about the actual origin of the Polynesians. Bystanders may well wonder what the tumult over Heyerdahl's book is all about—what difference does it make where Polynesian man came from? The answer is that the Polynesians and their culture have a particular interest for social scientists. Generations of investigators have hunted for clues to the origin of this people in their language, their customs, their religion, their tools and even their diseases. In so doing the scientists have discovered that Polynesia is a unique laboratory for studying why human beings behave the way they do.

Civilized populations are too complex for any total study of all the factors shaping their members' behavior; most "primitive" populations have too short a known history or afford only fragmentary information. In Polynesia we have an isolated people who have inhabited the region for more than 1,000 years. They have the same cultural background and speak the same language, so these variables are relatively constant. On the other hand, their groups live in a great variety of environments, from jungles to deserts, and we can see how different environments have modified their culture. We can compare Polynesians living in cities and on atolls, in the mountains and on the bosom of the sea. Further, we can see how the culture of the Polynesians has changed under various European administrations during the last two centuries. And finally, we have a continuous record of developments from the time they were "discovered" by explorers in the 18th century.

Islands of Paradise

Polynesia is one of the three major divisions of Oceania. It is distinguished from Melanesia (islands inhabited by dark-skinned people in the South Pacific) and Micronesia (small islands east of the Philippines, including the Marianas, Marshalls, etc.). The Polynesians are unmistakably related to the Melanesians and the Micronesians, but they form a distinct population with a history of their own. Polynesia (meaning many islands) embraces most of the immensity of the Pacific, from Easter Island on the east to a chain stretching toward Asia on the west, and from Hawaii on the north to New Zealand in the south [*see map on next two pages*].

It was in the 1760s and 1770s that Captain James Cook, Louis Bougainville and others discovered Polynesia. Their reports of the "Islands of Paradise" came to tired and war-torn Europe like balm from an exotic world. An avid reading public ate up everything the explorers (and their rehashers and interpreters) wrote. In France, Rousseau's philosophy of "natural man" took on flesh and substance. In England, high society lionized visiting natives from Polynesia. "Curiosities" (artifacts) from the islands became fashionable and brought fabulous prices. (They still come high today.) Funds were raised to send out missionaries and scholars. Soldiers brought back tales of the Polynesians' valor and chivalry: how on one occasion Maoris besieging a British camp sent in food so that the garrison might "fight on more even terms."

Accounts of the Polynesians have continued to pour forth in a steady stream to the present day. Robert Louis Stevenson, Nordhoff and Hall, Gauguin and many others contributed to their color and allure; the hula dance and pseudo-Hawaiian music took the entertainment world by storm; race horses named "Polynesian" and "Tahitian King" embellish the sports pages; *South Pacific* has broken box-office records throughout the Western world.

In the meantime hosts of scholars in many fields have compiled a mountain of solid information about the Polynesians and their culture. The devoted investigators include H. D. Skinner of New Zealand, the dean of Polynesian anthropologists; Henry W. Fowler of the Philadelphia Academy of Natural Sciences; and the staff of the Bishop Museum in Honolulu, notably the ethnologists J. Frank Stimson, Edward S. C. Hardy, Kenneth Emory and Polynesia's most distinguished son, Te Rangi Hiroa (Sir Peter Buck).

When the European explorers first saw the Polynesians in the 18th century, they were already long established in the islands, with a well-developed culture and resourceful methods of making a living in Oceania. Their islands were cultivated and landscaped: most were well-trimmed parklands covered with networks of roads and paths. The Polynesians had a remarkably detailed knowledge of their island history, preserved in stories, chants and traditions. But their history as a people before they came to the islands was lost to memory, except for the name of their unknown original homeland—"Hawaiki."

The clues we have suggest that the Polynesians colonized much of the Pacific at about the time the Scandinavian Vikings were sighting North America. Te Rangi Hiroa (a Maori) has labeled his ancestors "Vikings of the Sunrise"; Polynesians also like to call themselves "the Sea Kings." Their polished stone tools classify the original settlers of the islands as Neolithic men, but their civilization was no simple Stone Age culture.

The Vikings of the Pacific apparently arrived in the islands in fleets of deliberate migration. Legends passed down by Polynesian priests and bards speak of great double sailing canoes, embellished with feathers and statues, which carried priests, chiefs, warriors, commoners and their women. We do not know whether the voyagers had been driven to migrate by wars or population pressure at home or were urged on by the spirit of discovery. In any case their canoes were laden with coconuts, taro, banana and bread-

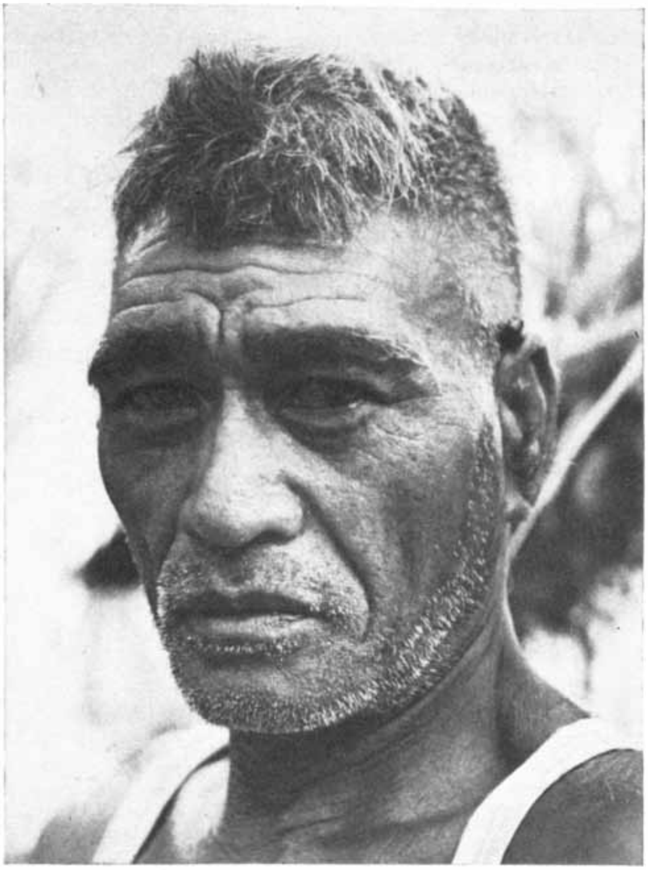
POLYNESIA is separated from Melanesia and Micronesia by this map. It is also subdivided into dialect areas. The area labeled "outliers" represents the route by which the Polynesians first entered Oceania. The "nuclear" area is where they settled for a time fruit plants, pigs, fowl—and the inevitable companions of man, the rat and the louse. The boats were held together with cords of coconut fiber and kept from sinking by constant bailing. The bold voyagers, roaming the immense, uncharted Pacific in an era when European sailors rarely ventured out of sight of land, moved from island to island until they had settled virtually every livable bit of soil over millions of square miles.

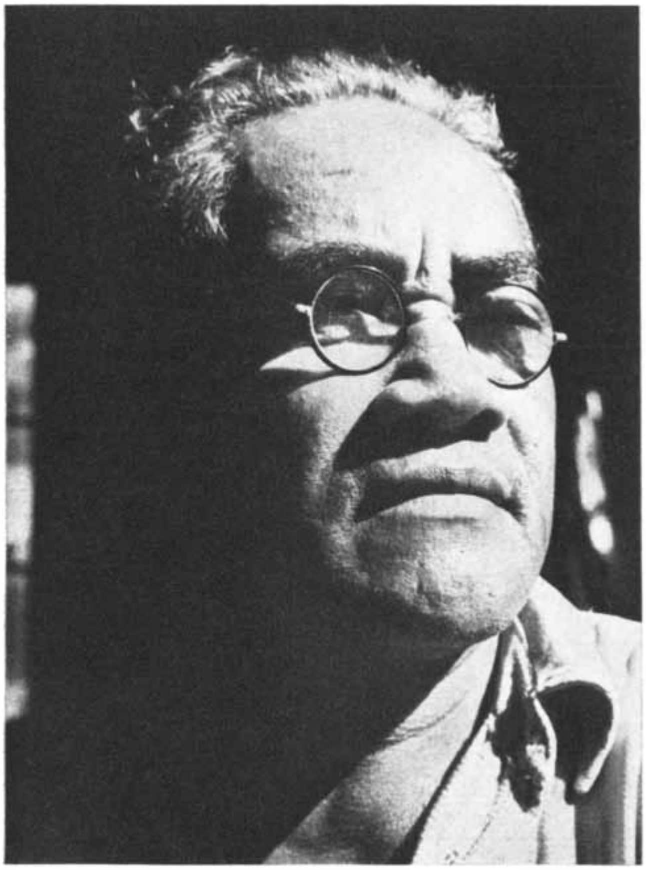
The home they found—and in which they remained—is as varied as it is hazardous. It includes naked atolls of coral sand and coconut trees, a mountainous subcontinent (New Zealand), tropical jungles, flowery Edens and wind-blown reefs in the sea. The sea is the all-pervasive denominator of the Polynesian's life. It is the source of his protein food and his travel highway. It is also a cruel destroyer, at times sweeping whole islands bare of population and vegetation. In spite of the danger the Polynesians choose to live on the shores of the islands whenever they can. Here is where the coconuts and fish are plentiful, and where a man can travel easily wherever he wishes.

Second only to the sea in importance is the wind, and the moisture it may—or may not—carry. Wind-swept rains may lash islands for weeks at a time, making fishing or agriculture impossible, so that bellies grow lean with waiting. They grow even leaner when hot winds suck

1 HAWAIIAN ISLANDS
2 JOHNSTON
3 MARQUESAS ISLANDS
4 TUAMOTU ISLANDS
5 SOCIETY ISLANDS
6 NORTH COOK ISLANDS
7 SOUTH COOK ISLANDS
8 AUSTRAL ISLANDS
9 RAPA
10 PITCAIRN
11 EASTER
12 SALA-Y-GOMEZ
13 KERMADEC ISLANDS
14 CHATHAM ISLANDS
15 NORFOLK ISLANDS
16 TONGA ISLANDS
17 NIUE
18 SAMOA ISLANDS
19 TOKELAU ISLANDS
20 PHOENIX ISLANDS
21 ELLICE ISLANDS
22 GILBERT ISLANDS
23 MARSHALL ISLANDS
24 WAKE
25 MARCUS
26 MARIANA ISLANDS
27 CAROLINE ISLANDS
28 BISMARCK ARCHIPELAGO
29 SOLOMON ISLANDS
30 NEW HEBRIDES ISLANDS
31 NEW CALEDONIA
32 LOYALTY ISLANDS
33 FIJI ISLANDS
34 MAPIA ISLANDS
35 COCOS ISLANDS
36 SUMATRA
37 BORNEO
38 JUAN FERNANDEZ

before new migrations. The "central" region is the later center of gravity of the Polynesian population. The "peripheral" areas are the limit of Polynesian migrations. The smaller divisions within these areas indicate the extent of island groups named at the right.





FOUR INHABITANTS of Mangaia in the Cook Islands illustrate the characteristic features of the modern Polynesian. At the upper left is one of the six governors of the island. At the upper right is a *mapu*, which may be translated as "young sower of wild oats." At the lower left is the Mangaian representative on the governing council of the Cook Islands. At the lower right is a young mother.

moisture from the land and plants wither and become like tinder. Then the islanders are reduced to hunting hardy but despised fruits—or to cannibalism.

Their Culture

This people, living an adventurous life on the edge of danger, developed a surprisingly sophisticated culture. In agriculture they showed a superb grasp of principles of irrigation and cultivation. With great labor they carried leaves and mold from high islands in their canoes to build soil on barren ones. They converted entire islands, such as Tongatabu, into gardens. Botanists are impressed with the fact that the Polynesians divided the plant world into monocotyledons and dicotyledons (plants with single-leaved and double-leaved seed embryos) long before the 17th-century English naturalist John Ray began the classification of plants in Europe. Their fishing skills were remarkable. They showed a knowledge of fine points of surgery. All their tools and other objects exhibited a love of beauty and a gift for esthetic expression: even their weapons were artistic—as is impressed upon anyone who has hefted the beautifully polished short clubs of the Maoris, the ironwood long clubs of the Marquesans or the shark-toothed clubs of the Hawaiians. The basic interest in sexuality and procreation also permeated every aspect of their life. Erotic symbols were carved everywhere: on house posts and burial chests, on weapons and stone images, on necklaces and household utensils.

For anthropologists the Polynesians' religion and social organization has been no less intriguing a study than their artifacts. Their religion was expressed in an intricate system of beliefs and practices; best known are their concepts of *Mana* (power) and *Tabu* (sanctity). Their social life was focused in a strikingly communal system of large families in which a child had many "mothers" and "fathers" besides his biological ones. Their political units were limited to single islands or valleys, ruled by chiefs whose position stemmed from individual personality as well as seniority of family descent.

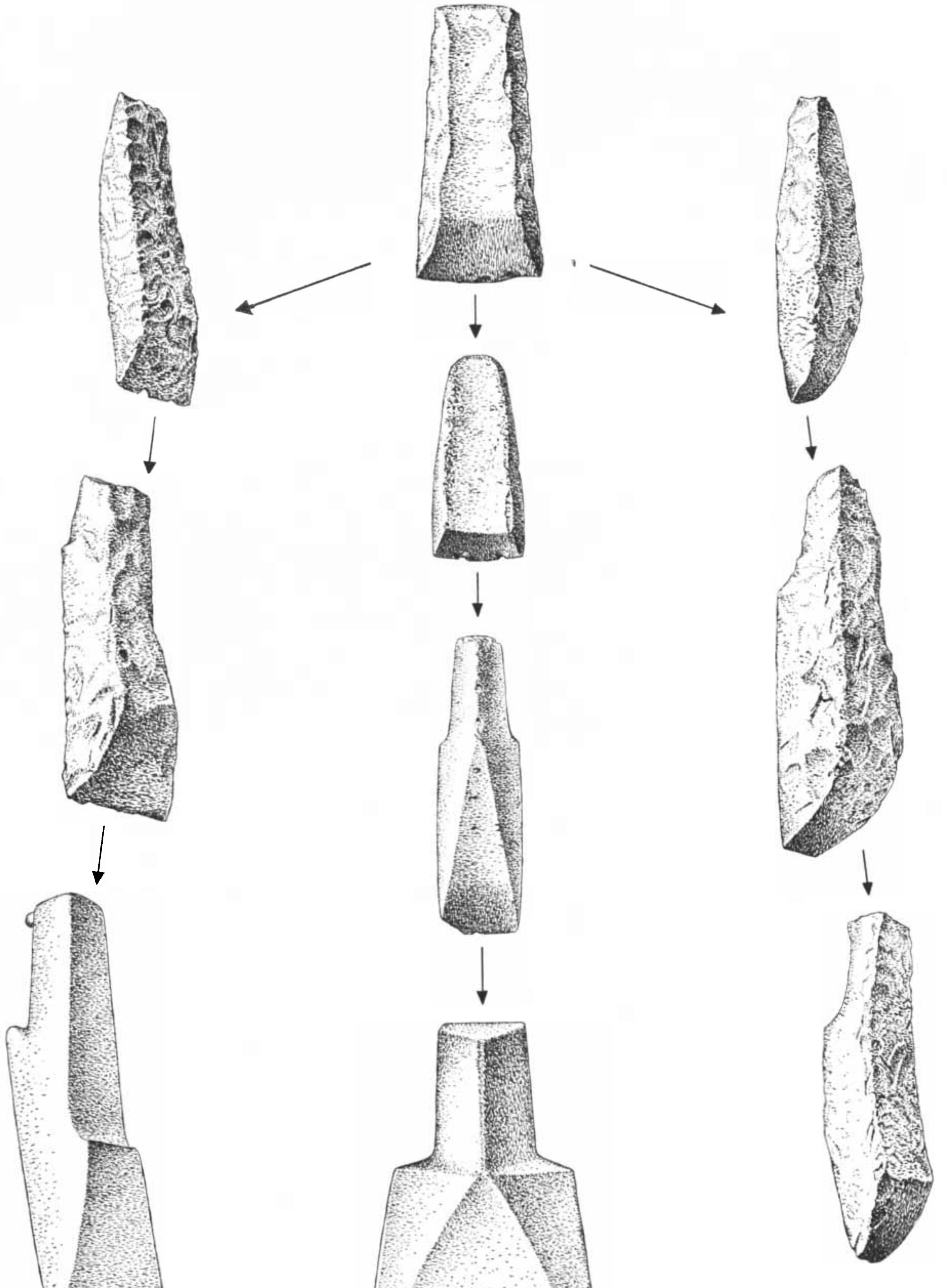
But perhaps the most noteworthy aspect of the Polynesians' culture was the beauty and richness of their language. To ears accustomed to Anglo-Saxon harshness, the cadences of the Polynesian tongue were enchanting. From the first contact Europeans developed a passion for taking down and translating the talk of the Polynesians. Among the islanders professional bards held dominant positions, and men talked and sang far into the night, incited by *kava* and the intoxicating cadence of their language. It was a gay language, with much play on and toying with words. And it played a most significant role in the life of the people. Individuals and families held, gained or lost land and power according to the extent of their knowledge of chants and genealogies, passed down from father to son. The language also reflected their philosophy and beliefs: it had no words for such Christian concepts as "sin" or "moral truth," but it had a wealth of terms describing the minutest variations of human behavior.

The Peabody Expedition

My purpose in this article is principally to report some conclusions about the Polynesians, particularly those gained through study of their language, that emerged from expeditions to the islands in 1951 and 1955 for the Peabody Museum of Salem, Mass., a famous center of collections from Oceania. The 1951 expedition, most of whose members were visiting the islands for the first time, worked from several different points of view.

Marianne L. Stoller (now with the Museum of the University of Pennsylvania) studied the arts and crafts of the New Zealand Maoris and the present ethnography of Tahiti. George M. Sheahan, Jr., of the University of Cambridge, compared the culture of the Marquesans today with that at the time of Captain Cook. Wallace P. Strauss of Columbia University studied historical documents in the great Mitchell Library in Sydney, Australia, and the equally famed Alexander Turnbull Library in Wellington, New Zealand. The Reverend Maru Check, an associate of the London Missionary Society, collected artifacts in the islands. J. Frank Stimson, who works in Tahiti, gave us a large collection of information, the results of a lifetime of scholarly toil. And the writer of this article made studies of the language, craniology and material culture of the Polynesians. The interpretations that follow are based upon his own investigations and reading.

One of the most useful keys in unlocking the gateway to the past in Polynesia is the evolution of the stone adze, which seems to have been the basic tool of this people even before they came to Oceania. Varieties of this tool have been dug up in many of the islands. It appears that the original settlers brought to Polynesia an adze of "quadrangular" (chisel-like)



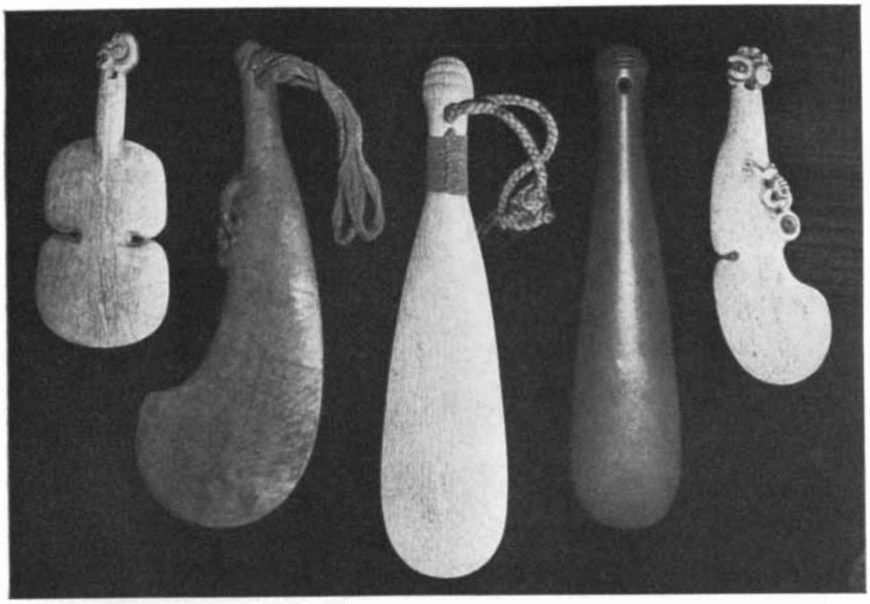
cross section. Specimens of this type have been found even on islands long uninhabited, such as Norfolk and Pitcairn. Also widespread in the islands is a "hogback" variation which is triangular rather than quadrangular in cross section and probably served other uses. From these basic types the inhabitants of different islands or regions developed refined and specialized versions; characteristically they chipped down one end of the stone blade to a *tang* (prong) for insertion into the adze handle [*see illustrations on opposite page*]. A fine example of the perfection they finally achieved is the magnificent ceremonial adze of Mangaia.

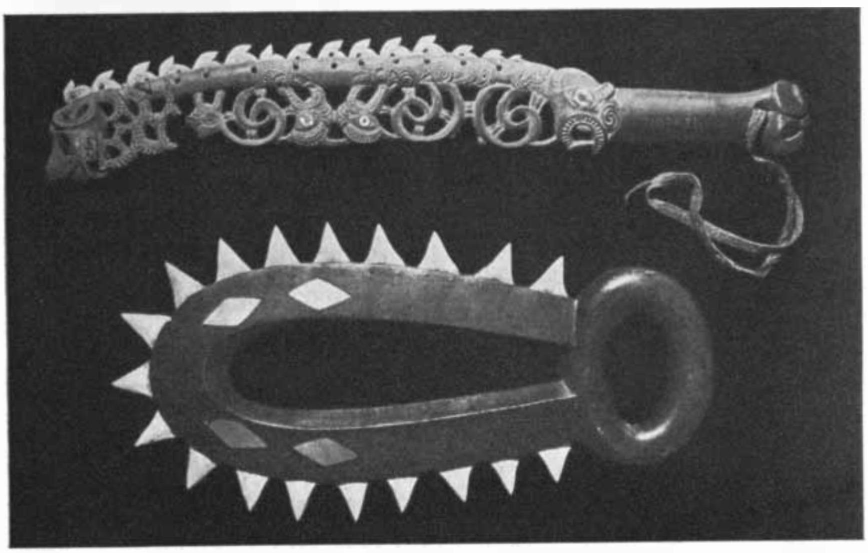
The adzes help us to retrace the ancient island-to-island migrations of the Polynesians. Adze types known to have originated in islands of eastern Polynesia have been unearthed in New Zealand; New Zealand adzes have turned up in the Fiji Islands; Melanesian adzes, in the Cook Islands and New Zealand; Cook Islands adzes, in Makatéa. With this evidence we can construct a pattern of the Polynesians' contacts or travels in the period before the Europeans discovered them.

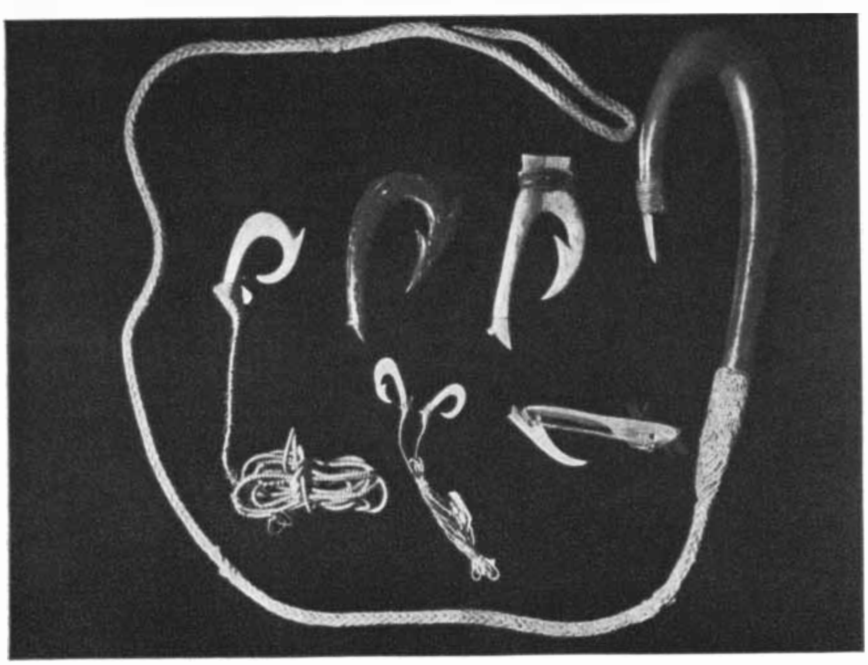
Studies of variations in the islanders' body build give us further clues along the same lines. The Polynesians, as we have noted, are a remarkably homogeneous people physically, but there are local differences, presumably due to isolation of groups since the people came to the islands. During the past three years Charles E. Snow of the University of Kentucky and the author have measured more than 1,000 skulls of Polynesians of past times. They are markedly narrower than the craniums of Polynesians of the present day. However, the trend to broadening of the cranium has proceeded at different rates in different places, and again we can find a pattern of relationships among the islanders. This pattern fits well with the groupings indicated by the stone tools and other items of material culture.

A particularly interesting aspect of the

STONE ADZES are a clue to the migrations of the Polynesians. At top center is an ancestral type of adze with a roughly quadrangular shape. At top left is a variant with a curved belly, which eventually gave rise to the type at bottom left. At top right is another variant with a curved back and a narrow blade, which gave rise to the type at bottom right. At bottom center is an intermediate type of adze with a broad blade and a triangular cross section.







OTHER POLYNESIAN TOOLS are clubs of stone, bone and wood from New Zealand (*top*), shark-toothed implements (*middle*) and fish hooks from Hawaii and New Zealand.

Polynesian skull is the unusual "rocker jaw"—a jaw curved on the lower side so that it rocks when laid on a table and pushed down at either end. This feature, presumably genetic, occurs in about half of all Polynesians, but it has not been observed among Micronesians and appears only rarely among Melanesians. It confirms other evidence that the Polynesians diverged rapidly from the other Pacific islanders.

The Language

Immeasurably more significant than either tools or bones, as a key to unlock the history of a culture, is language. For language is the basis of man's uniqueness, and the essence of his culture.

The literature on the Polynesian language is immense. It is fortunate that the earliest European explorers were so fascinated by the language that they wrote down lists of Polynesian words, for as a result we know what the words were before they were contaminated by foreign infiltration. During the past generation professional linguists have added their expert analyses to the earlier amateur observations. Consequently we now have a fairly thorough knowledge of the dialects and linguistic development of the Polynesian groups.

From the days of Captain Cook there has been no serious question about the linguistic identity of the Polynesians. A speaker of one of their dialects could make himself understood anywhere, whether in Tahiti, Easter Island, New Zealand or Tonga.

The Polynesian, Micronesian and Melanesian languages are all members of the family of languages known as Austronesian. It is related to Indonesian, including Malayan, and to languages used in Madagascar, but it does not "stem" from them; rather, all seem to be offshoots of some common ancestral language.

Comparing dialects over the centuries of time and the divisions of geography, the writer has been able to divide the Polynesian islands into certain major areas, which can be related to the history of the people. We can deduce (1) that a chain of islands in the western Pacific represents the route by which the Polynesians first entered Oceania and where they left "outliers"; (2) that the Polynesians settled down for a time in the mid-Pacific on islands which became the "nuclear" jumping-off place for further migrations; (3) that the center of population gravity later moved eastward to a "central" region; and (4) that islands in the South Pacific form a "peripheral" part of Polynesia [*see map on pages 60 and 61*]. These divisions based on language agree with those based on adze types and cranium measurements.

The instrument for tracing the evolution of the language is an analysis of changes in the sounds of given words [*see table on page 72*]. Now there is a new technique of analysis, developed by Morris Swadesh and Robert Lees, which makes it possible to give a rough estimate of when the Polynesians first came to the Pacific. The technique is called "glottochronology," and it rests on the finding that in general a basic segment of any language changes at the fairly constant rate of about 19 per cent in each 1,000 years. Our data indicate that the Polynesian dialects diverge from the other Austronesian languages by about 50 per cent. This suggests that the Polynesians had come to Oceania about 2,000 years before the European explorers arrived.

In the century and three quarters since then the language has changed rapidly, though irregularly, in part because of the European influence. The shift in a basic section of the Tahitian dialect is as high as 22 per cent. The new Tahitian dialect has become the common tongue of much of Central Polynesia.

Let no one suppose that the interest of scholars in the Polynesian language is confined to the reconstruction of history or the processes of cultural evolution. They are drawn to the language as much by esthetic delight as by scholarship. To illustrate, we need only cite a Polynesian prayer, as translated by Stimson:

O thou God, of the divine abide!
O thou God, the unnamable One!
O thou God, whose manifestations
are innumerable!
O thou God, creator of all!
I ask of thee—
—That the people dwelling in
the Third-heaven
of this world of now be most
well and fortunate;
—That the people dwelling in
the homeland be
untroubled by disaster;
Turn thy favor hither to these
people here
For thou art a kindly God
For thou art a God of good deeds.
O thou unnamable One—
Sacred, sacred thou art!

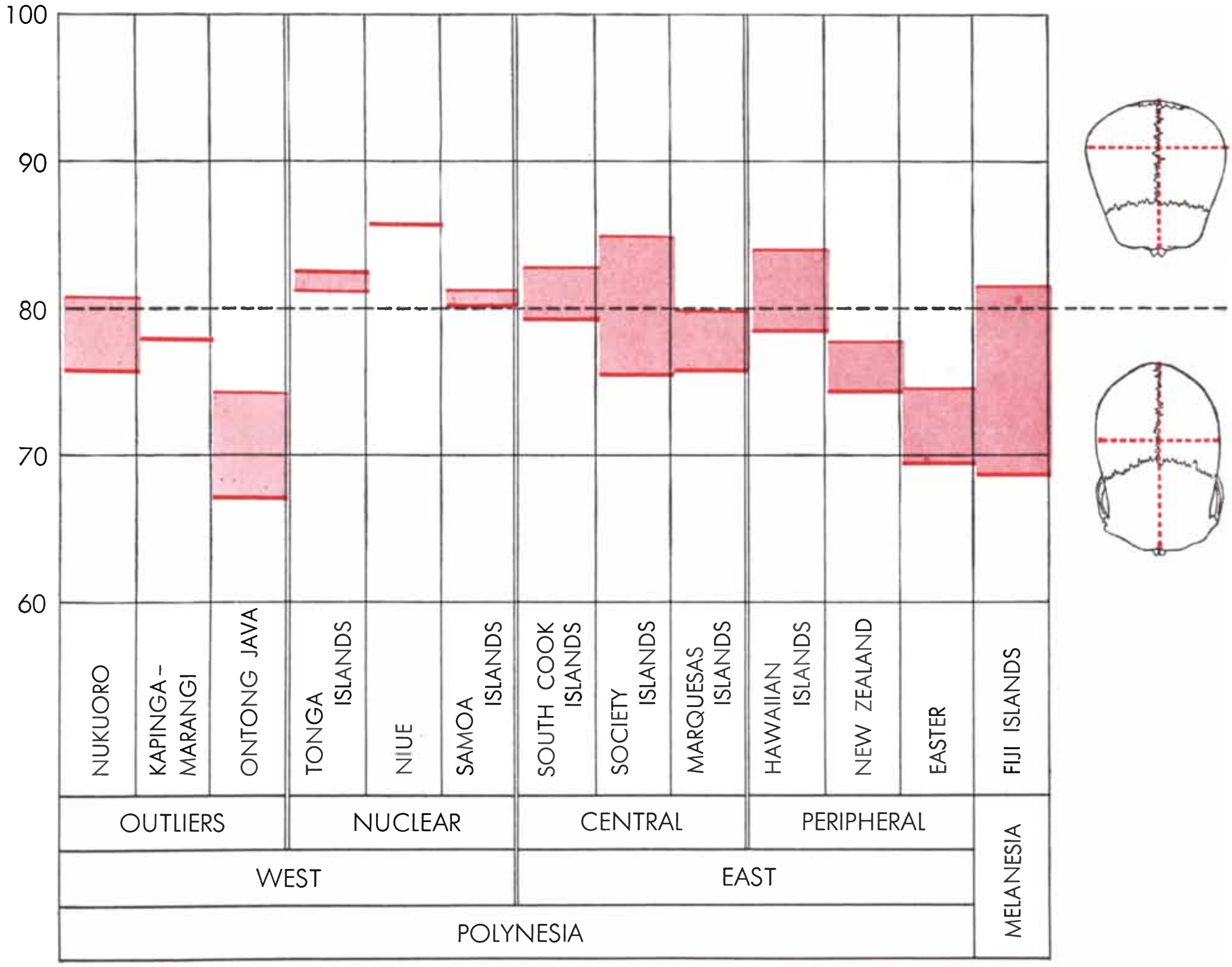
Whence the Bronze Vikings?

What conclusions can we draw from our study of the Polynesians? We can certainly reaffirm that they are a single, distinct people, with marked differences in language, physical type and material culture from their nearest Melanesian neighbors (in Fiji) or Micronesians (in the Gilbert Islands). Beneath the surface differences, however, the Polynesians are clearly related to their Oceanic neighbors to the west. It is important to realize that the relationship is one of pattern, rather than merely individual traits. Similarities of diet, for example, are not restricted to single foods but embrace a whole complex, made up of taro, yam, breadfruit, coconut, etc. The point is important because no relationship in general pattern has yet been found between the Polynesians and any ancient population in America. The possibility of sporadic contact with the Americas cannot be denied, but there is no evidence that Polynesian culture was significantly influenced from that direction.

As to the question, Where *did* the Polynesians come from?, the best we can do is to point vaguely to southern Asia. We do not yet know enough about ancient cultures in that part of the world to pinpoint the "Bronze Vikings' " origin. About the date of their migration we can say that a preliminary linguistic analysis seems to indicate it took place some 2,000 years ago, but we have no tangible evidence of their presence in Polynesia before about 1,000 years ago. More archaeological evidence, more studies of their language and folklore, measurements of many more craniums, more museum study of artifacts and more knowledge of the past climate and geography of Oceania will be required before problems of Polynesian origin can be solved. We cannot today go much beyond the statement of the great English scientist, Sir Joseph Banks, who accompanied Captain Cook:

"From the similarity of customs, the still greater one of traditions and the almost identical sameness of language between these people [of New Zealand] and those of the islands in the South Sea, there remains little doubt that they came originally from the same source, but where that source is, future experience may teach us. At present I can say no more than that I firmly believe that it is to the Westward and by no means to the East."

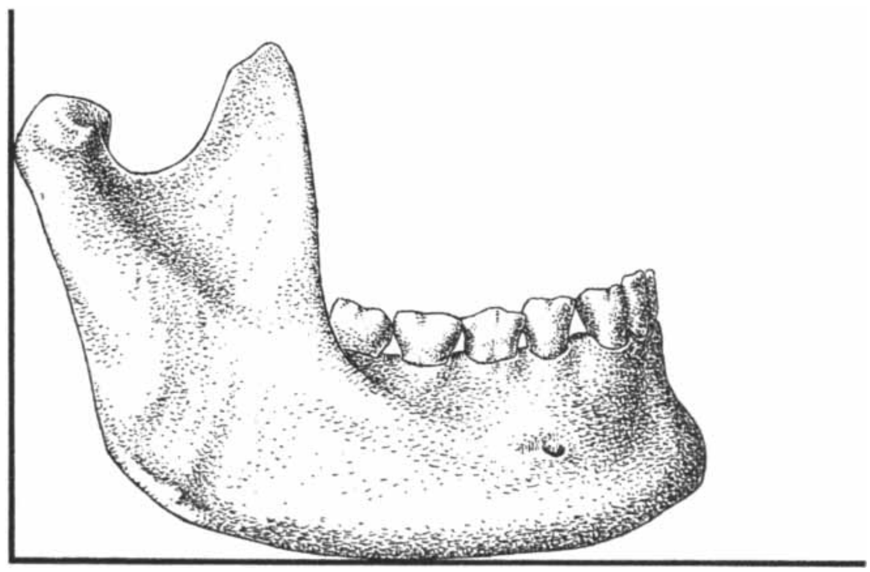
The writer will venture to offer the following theory as one that fits the known facts. It seems most likely that the Polynesians entered the Pacific from

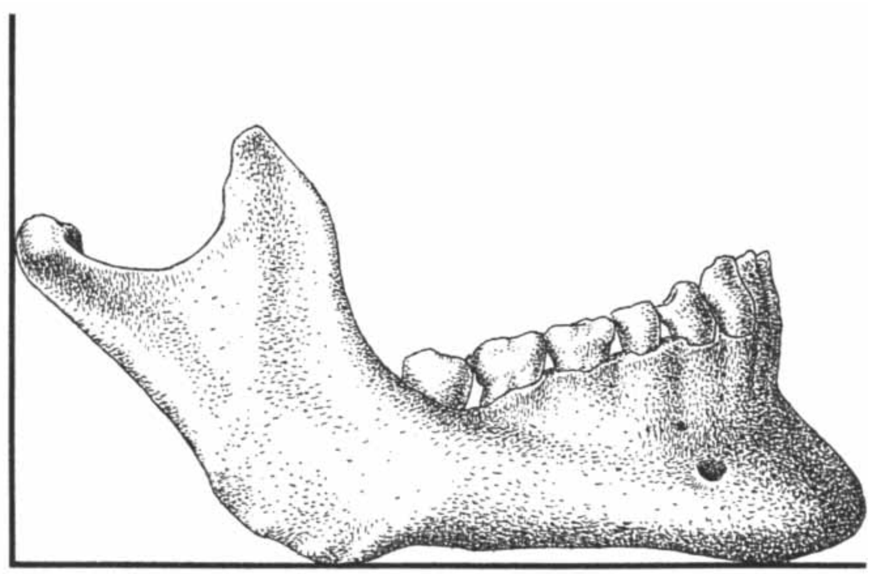


SHAPE OF CRANIUM of a given Polynesian is related to the time that has passed since his ancestors settled on his island. Over the generations there has been a tendency for the Polynesian cranium to change from a long, narrow type (*at right below dotted line*) to a short, broad type (*above dotted line*). The numbers at the left relate the breadth and length; a cranium at 80 on the scale, for example, would be .8 times as broad as it is long. The bottom line on each of the colored bands represents the average cranial shape of Polynesians who lived before Europeans came to the islands. The top line on each of the bands represents the average cranial shape today. On the island of Kapingamarangi only measurements of modern craniums were made; on Niue, only of pre-European craniums.

the west along the islands labeled "outliers" on the accompanying map. They stopped at the "nuclear" islands (Tonga, Samoa, *et al.*) and there developed Polynesian culture as we know it. The time of arrival at Tonga may have been slightly after the beginning of the Christian era. During this period the Polynesian physical type was genetically "set," and the Polynesian language, social structure and economy were stabilized.

As the population increased, voyagers again ventured out in great migration canoes—now into the vast ocean distances of "central" and "peripheral" Polynesia. It appears that this era of voyage and discovery was relatively short, but virtually every habitable island in the area was quickly discovered and settled. It is possible that climatic conditions were even more favorable to island culture then than now. Probably the Polynesians remained in fairly close touch with one another, and it was in this period that the legends of the great voyages between far-distant islands were established. This could have been the era of the Scandinavian Vikings, the Irish migrations and the great mass movements of wandering peoples across





ROCKER JAW of a Polynesian (*top*) is compared to the straight jaw of a non-Polynesian (*bottom*). The former rests on one point; the latter, on two points or on a flat lower edge.

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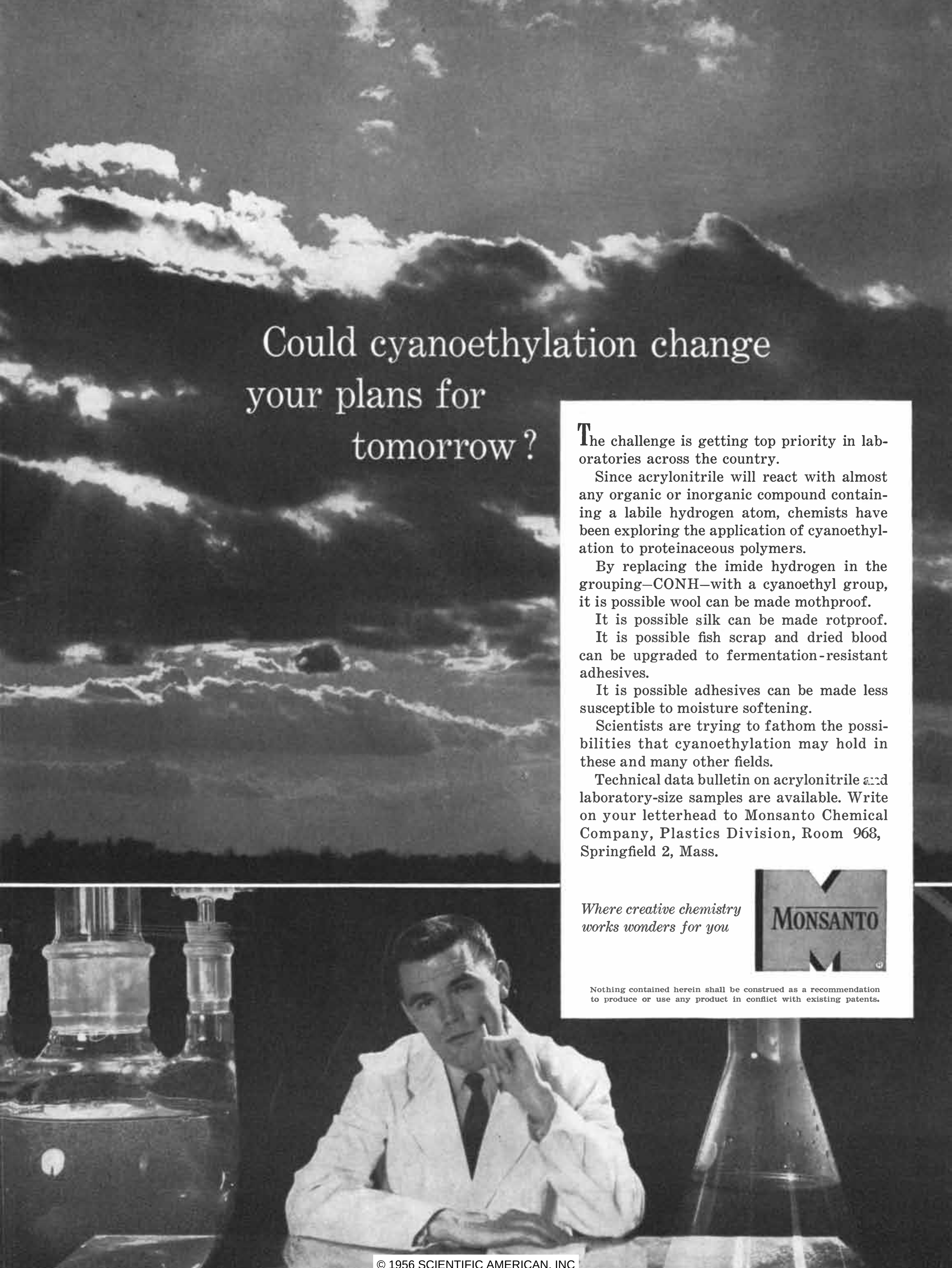
		OCEANIC CONSTANCY			POLYNESIAN CONSTANCY			POLYNESIAN VARIATION		
		BIRD	CANOE	FIRE	BLOOD	CHIEF	LAUGH	BANANA	BAMBOO	CHARCOAL
POLYNESIA · WESTERN · OUTLIER	NUKUORO	MANU-	VAKA	AHI	TOTO	ARIKI	KATA-	HUTI	*MATIRA*	
	KAPINGAMARANGI	MANU	WAKA	AHI	TOTO	ARIKI	KATA	HUTI	*MATIRA*	MARARA
	NUKURIA	MANU	VAKA	AFI	TOTO	ARIKI	KATA	HUTI	*MATIRA*	
	ONTONG JAVA	MAŊU	VAʼA	AHI	KOKO	*TUʼU*	ʼAKA	HUKI	*MAKILA*	
	SIKAIANA	MANU	WAKA	AFI	TOTO	ALIKI	KATA	FUTI		
	PILENI	MANU		AFI	TOTO	ALIKI	KATA	*TAVELI*	*MASILA*	*MATAPELO*
	RENNELL	MANU	VAKA	*VAKAI*	TOTO	AŊIKI		HUTI		
	TIKOPIA	MANU	VAKA	AFI	TOTO	ARIKI	KATA	FUTI		MARARA
POLYNESIA · WESTERN · NUCLEAR · NORTH	ELLICE (VAITUPU)	MANU	VAKA	AFI	TOTO	ALIKI	KATA	FUTI		
	TOKELAU (FAKAOFU)	MANU	VAKA	AFI	TOTO	ALIKI	KATA	FUTI		
	SAMOA (UPOLU)	MANU	VAʼA	AFI	TOTO	ALIʼI	ʼATA	FUTI	ʼOFE	MALALA
POLYNESIA · WESTERN · NUCLEAR · SOUTH	WALLIS (UVEA)	MANU-	VAKA	AFI	TOTO	ALIKI	KATA	FUSI	KOFE	MALALA
	TONGA (TONGATABU)	MANU	VAKA	AFI	TOTO	ʼEIKI	KATA	FUSI	KOFE	MALALA
	NIUE	MANU-	VAKA	AFI	TOTO	IKI	KATA	FUTI	K*AHO*	MALALA
POLYNESIA · WESTERN · NUCLEAR	PUKAPUKA	MANU	WAKA	AWI	TOTO	ALIKI		WUTI		
POLYNESIA · EASTERN · CENTRAL · WEST	NORTH COOK (MANIHIKI)	MANU	WAKA	AHI	TOTO	ARIKI	KATA			
	SOUTH COOK (RAROTONGA)	MANU	VAKA	AʼI	TOTO	ARIKI	KATA	*MEIKA*	KOʼE	*ŊARAʼU*
	AUSTRAL (RAIVAVAE)	MANU	VAʼA	AHI	TOTO	ARIʼI	ʼATA	*MEIʼA*	ʼOHE	*ŊARAHU*
	SOCIETY (TAHITI)	MANU	VAʼA	AHI	TOTO	ARIʼI	ʼATA	*MEIʼA*	ʼOFE	*ʼARAHU*
POLYNESIA · EASTERN · CENTRAL · EAST	TUAMOTU (ŊANĀ)	MANU	*HAVEKE*	AHI	*TIKAHIRI*	ARIKIʼ	KATA	*MEIKA*	KOFE	*ŊARAHU*
	MARQUESAS (HIVAOA)	MANU	VAKA	AHI	TOTO	AʼIKI	KATA	*MEIKA*	KOHE	*NANAHU*
	MANGAREVA	MANU	VAKA	AHI	TOTO	AKARIKI	KATA	*MEIKA*	KOHE	
	RAPA	MANU	VAKA	AʼI	TOTO	ARIKI		*TAUTAU*	KOʼE	
POLYNESIA · EASTERN · PERIPHERAL	HAWAII	MANU	WAʼA	AHI	KOKO	ALIʼI	ʼAKA	*ʻMAIʼA*	ʼOHE	*NANAHU*
	NEW ZEALAND	MANU	WAKA	AHI	TOTO	ARIKI	KATA			*ŊARAHU*
	CHATHAM	MANU	WAKA	AHI	TOTO	ERIKI	KATA			*ŊAREHU*
	EASTER	MANU	VAKA	AHI	TOTO	ARIKI	KATA	*MEIKA*		*ŊARAHU*
OTHER	MELANESIA (FIJI)	MANU-	VANKA	*BUKA*	DRĀ	*TURAGA*	*DREDRE*	VUDI	*BITU*	*GILAISO*
	MICRONESIA (GILBERT)	MAN	WA	AʼI	*RARA*	*TOKA*	*ŊARE*		*KAIBABA*	MARARA
	INDONESIA (SONSOROL)	MARI	WA	*API*	*SA*	*YOTIR*	*MERI*	*FADO*	*BABU*	

LANGUAGE VARIATIONS are the most important clue to the migrations of the Polynesians. At the left in this chart are the names of typical islands in the various linguistic divisions of Polynesia (*see map on pages 60 and 61*), together with those of islands from other parts of Oceania: Melanesia, Micronesia and Indonesia. In the first three columns to the right of these names are three sample words which are fairly constant throughout Oceania. In the second three columns are three more sample words which are fairly constant throughout Polynesia, but which differ from corresponding words in the rest of Oceania. In the third three columns are three sample words which are fairly constant throughout parts of Polynesia, but which differ from corresponding words in other parts. The words printed both in color and italics are those which have changed for various reasons. The symbols and Roman letters in color represent changes which are predictable for other words. The symbol resembling a script "n" stands for the sound "ng" in "going." The apostrophe stands for the "glottal stop," which may be defined as the "tt" sound of a Scotsman saying the word "bottle."

the continents of Asia and Europe about 1000 A.D.

Then something must have happened! Whether it was climatic change, epidemics, lack of trees for building canoes, or social upheaval we do not know. Whatever the reason, the Polynesians lost the viking spirit and settled down to a more stationary life. Gradually the culture of each island took a different turn. Slight differences in speech, local art styles and specializations appeared, and the emphasis on the greatness of individual gods and culture heroes shifted. Weapons began to vary. Eventually populations began to decline, and soon some islands were abandoned, with stone temple structures left as ghostly and enigmatic evidences of their former occupation.

This was the Polynesia that the Europeans found. The white man brought weakening influences to the Polynesians, but he also brought strengths: hospitals and doctors followed his dread diseases; the religion of the missionaries was flavored by the islanders to their own needs. There were new incentives to activity. From a low point a few decades ago the Polynesian has again commenced to breed above the rate of death. In New Zealand, Hawaii and elsewhere, able men of Polynesian ancestry have won high recognition for themselves and their people. Instead of being headed for extinction, as was thought until recently, the malleable culture of the "Vikings of the Sunrise" may still have an interesting future.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Theoretical Physics and Mathematics

In the field of theoretical physics, the Laboratory carries on studies of nuclear theory, equations of state, mathematical analysis methods, hydrodynamics problems and various aspects of applied mathematics. The Theoretical Division is also concerned with the conceptual design of nuclear weapons, and supports many non-weapons activities such as the nuclear reactor and propulsion programs. The equipment used includes the Los Alamos-developed Maniac, the Maniac II, two IBM 704's and an IBM 701.

Experimental Nuclear Physics

Much of the work in experimental physics is concerned with nuclear properties of various materials. Fundamental studies are made of nuclear forces, neutron and charged-particle reactions and cross sections. Experimentation in controlled thermonuclear reactions is assuming increasing importance. Among the facilities available are three Van de Graaffs, two Cockcroft-Walton machines and a variable energy cyclotron.

Electronics and Instrumentation

The Laboratory is engaged in the design and development of nuclear physics research instruments, scintillation counters, fast pulse amplifiers, multi-channel analyzers, fast oscilloscopes, radiation detection instruments, electronic controls and control systems, and high-speed cameras which operate at 15 million frames per second. Electronics specialists also assist in the design of digital computers and of instruments for studying nuclear and thermonuclear detonations.

Nuclear Reactor Research

In connection with the peacetime applications of nuclear energy, the Laboratory is currently developing several advanced power reactors of unusual design. In addition, two research reactors are available for experimental studies. The remotely controlled critical assembly machines, known as Topsy, Godiva and Jezebel, constitute neutron research tools of a unique character.

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The Laboratory is actively engaged in the application of nuclear energy to the new and challenging field of self-propelled mobile reactors. There are studies in progress relative to engine design, heat transfer, controls and instrumentation.

Chemistry

Research in chemistry is devoted largely to inorganic and physical studies, especially of materials such as uranium, plutonium, deuterium and tritium used in nuclear energy systems. Radiochemical methods are applied in various investigations. Much work is being done on reaction kinetics, the effects of radiation on chemical reactions, complex ion formation and the determination of heats of combustion and solution. Extensive analytical studies include the use of a great variety of instruments, as well as the techniques of microanalysis.

Metallurgy and Metallurgical Engineering

Research activity and development in this field includes investigation of the metallurgical properties of materials used in nuclear energy systems; studies of extremely refractory substances, ceramics, cermets and plastics; the behavior of materials under extremely high temperatures and high pressures; studies of the properties of plutonium and its alloys, with increasing reference to their use in reactors, and of uranium and its alloys; development of fabrication techniques for various metals and alloys; and the high temperature properties of refractory metals tungsten, molybdenum, columbium, etc.

Weapons Physics, Design and Testing

Still the nation's principal institution for nuclear and thermonuclear weapons research, the Laboratory takes nuclear weapons from the concept stage to proved performance as determined by field tests. Activities in weapons research and development include the mechanics and dynamics of initiating a nuclear energy release; the behavior of supercritical systems; the testing of nuclear devices and weapons assemblies in Nevada and in the Pacific; engineering design of tests and prototypes of nuclear systems; and the design and development of nuclear weapons components and the techniques for their manufacture.

Explosives Research and Development

Work in this field includes study of fabrication, storage and stability problems of explosives; making and evaluating novel organic chemical compounds of possible use as explosives; mechanics and dynamics of explosive phenomena; and physical and chemical properties of explosive material using mass spectrometer, infra-red spectrometer, X-ray equipment and other analytical techniques. High explosives are employed in research on equations of state and shock wave phenomena.

Mechanical Engineering

Design and development work is carried on in connection with weapons design, field test facilities, the power reactor and propulsion programs, servo-mechanisms and remote control systems. High explosives systems are designed and manufactured. Other types of work are estimating, cost analysis and liaison between architectural engineers and contractors.

Chemical Engineering

Chemical engineering work includes studies of heat transfer, fluid flow, solvent extraction, evaporation, distillation and systems at extreme temperatures and pressures. Problems supporting inorganic and physical chemistry research projects are also undertaken. Other activities are the remote control handling of radioactive materials and corrosion and erosion studies.

Electrical Engineering

Much effort is devoted to the design of induction heating systems for study of alloys at extremely high temperatures; of DC power supplies at currents up to 100,000 amperes; of servomechanism controls for nuclear reactors; and of high magnetic field systems. Work is done in planning, building and installing power distribution systems and their controls.

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The Effects of Radiation on Solids

The orderly atomic arrangement characteristic of metals and other crystals determines many of their properties. Energetic radiation disturbs the order and thus can drastically alter the properties

by Frederick Seitz and Eugene P. Wigner

In the anxious days when atomic scientists were building the first chain-reacting pile in the "Metallurgical Laboratory" at the University of Chicago, no problem was more worrisome than the question concerning how the pile would be affected by its own radiation after it became active. On most of the other problems—the critical requirements for the chain reaction, controls, shielding, cooling—the physicists felt fairly confident of their calculations. But the radiation question was full of uncertainties. It was known that exposure even to weak natural radioactivity could change the structure and properties of materials. What would happen to the uranium rods in the reactor under the disruptive forces of intense neutron radiation, nuclear fissions and so on? More serious still, what would happen to the graphite moderator? Graphite was a part of the actual structure of the pile; unlike the uranium, it was not to be removed or replaced from time to time; and it was known to be subject to damage by radiation.

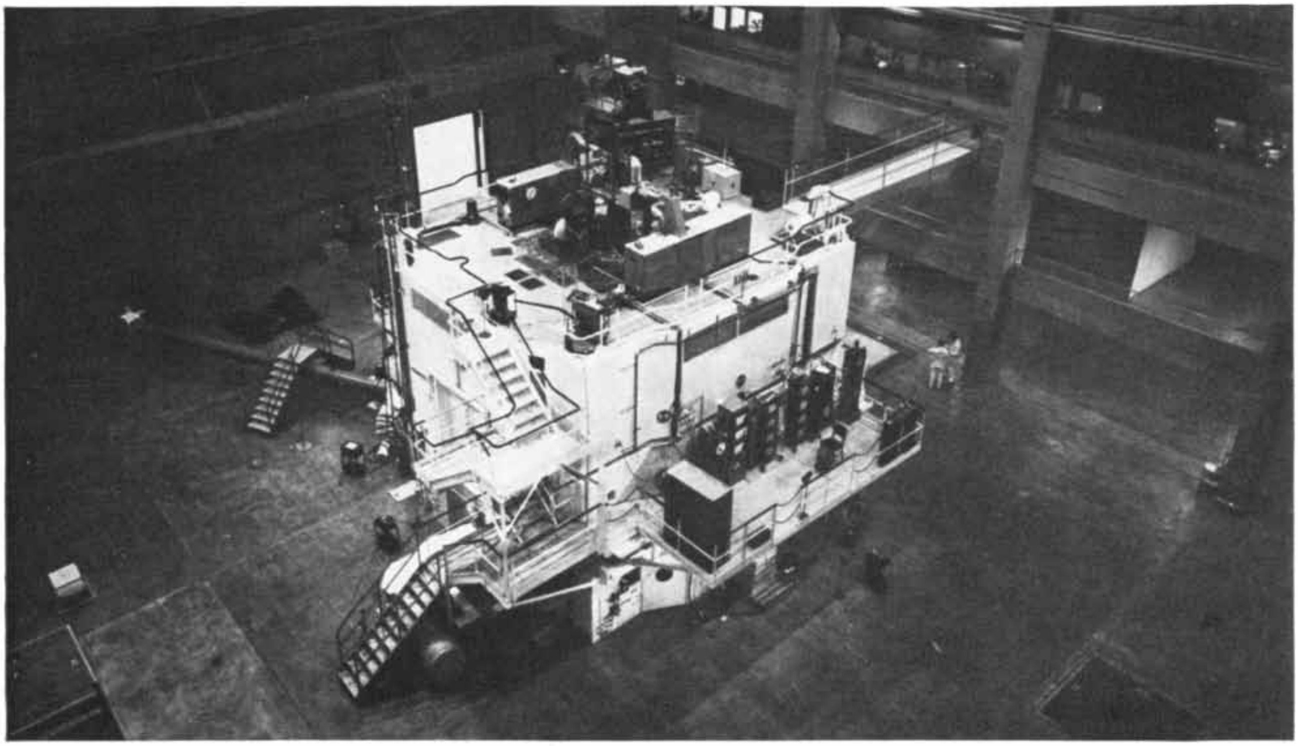
The group concerned with the future health of the new atomic "child" was so uncertain and pessimistic about the reactor's ability to survive radiation and other "diseases" that it reported: "It would be unscientific to claim a useful life longer than about 100 days." More than 50 times that period has now passed and nearly all the original reactors are still alive and operating. What we did not realize at the time was that graphite, as well as metal, has some ability to recover from radiation damage—to heal its wounds, so to speak. Nevertheless, the effect of radiation on solids remains an important and absorbing study. It is still a major practical problem in the construction of reactors; besides this, it has become a valuable tool for fundamental research into the properties of solids. Research on radiation damage is now being carried on not only in the national laboratories of the Atomic Energy Commission but also at a number of universities and industrial laboratories. The AEC recently announced eight such research contracts totaling well over $250,000 a year. The program of study of radiation effects on solids has steadily grown both in magnitude and in scope.

Let us try to describe some of the facts we have learned about radiation damage. Metals and nonmetals react differently; we shall consider first the effects on a nonmetal—the graphite (crystalline carbon) commonly used as the moderator in a reactor. The neutrons released by uranium fission in a reactor have a kinetic energy of about one million electron volts. When a fast neutron strikes the nucleus of a carbon atom in the moderator, it transfers a substantial fraction of its kinetic energy to the atom, and the latter recoils from the impact. Since the carbon atom's recoil energy is much greater than the binding energy holding it in the crystal lattice (which is less than 10 electron volts), the atom is thrown out of its normal position. This results in two defects in the lattice: the dislodged atom occupies an interstitial space in the lattice (like a marcher out of his row in a parade), and it leaves behind a vacant site in the regular order.

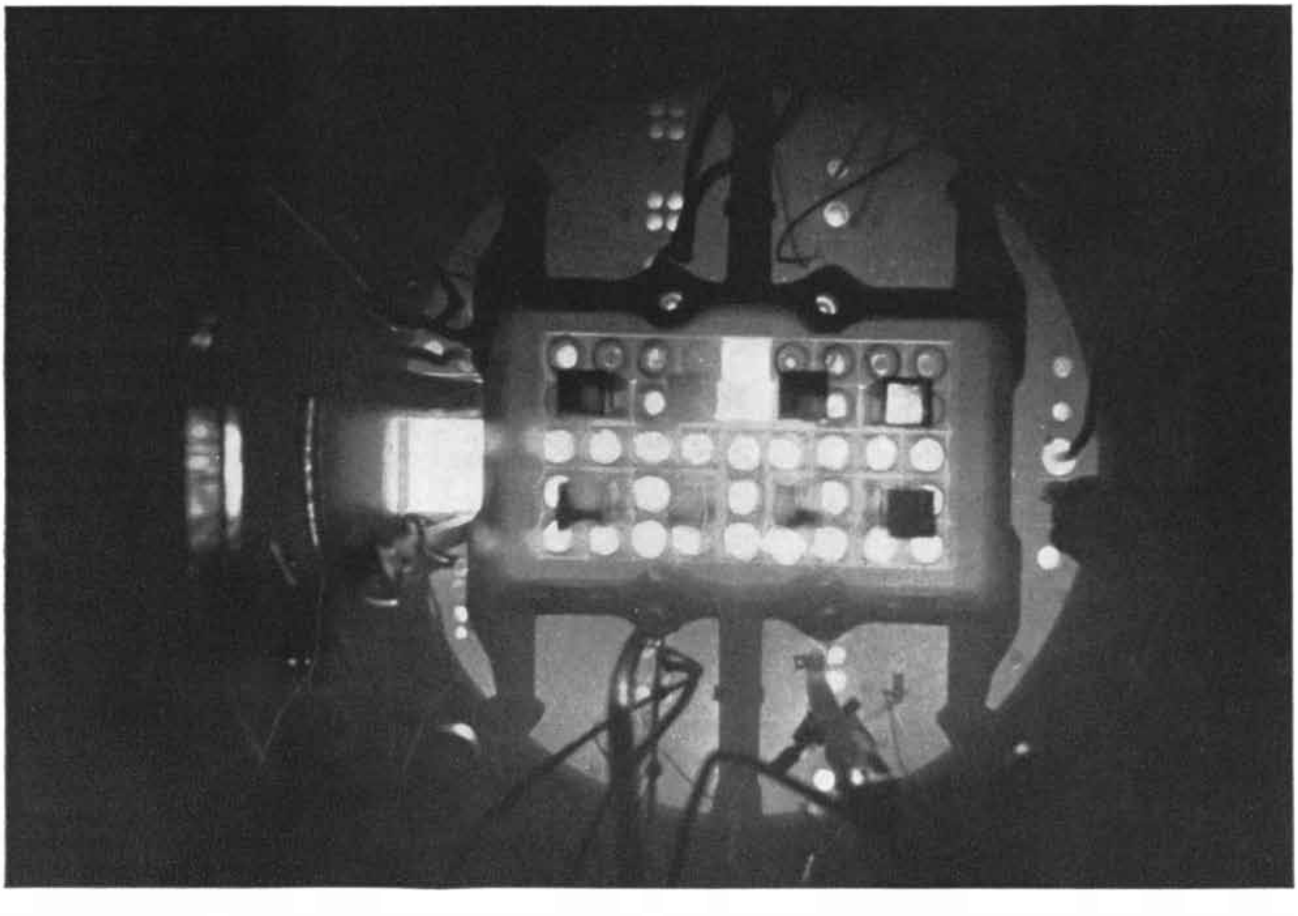
The foregoing describes the direct effect of collisions between fast neutrons and atoms in the lattice. These collisions in themselves account for only a small part of the damage actually produced. A fast neutron dislodges about 60 carbon atoms, at most, before it is slowed to a harmless speed. It is the recoiling carbon atoms that produce most of the damage in the lattice. They have bulk as well as speed. The first carbon atom hit by a million-volt neutron, for example, recoils with an energy of about 150,000 electron volts. In effect it acts like a strong and husky man who decides to get out of a very crowded subway rather suddenly. It throws the other atoms to right and left until it reaches the end of its range, that is, until its energy is exhausted.

Now it develops that in the atomic world this series of events takes a turn which is the opposite of what one might expect if he thinks in terms of mechanical collisions. The charging atom creates more havoc near the end of its rush than it does at the beginning. The reason is that we are dealing here with interatomic forces rather than what we usually think of as physical contact. As the fast-moving atom begins its dash through the crowd of surrounding atoms, its encounter with each one is too fleeting to permit much transfer of its momentum. It therefore dislodges only an occasional atom from its lattice position. But as the traveling atom slows down, the interatomic forces have more time to act, and it displaces more and more atoms. Finally, when it drops to a certain low velocity, it transfers its remaining energy to a local cluster of atoms. As a result the tiny local region suddenly heats up, sometimes to a temperature as high as 10,000 degrees centigrade. This phenomenon, called a "thermal spike" or "displacement spike," lasts only about one hundredth of a billionth of a second, but it may damage or deform the crystal.

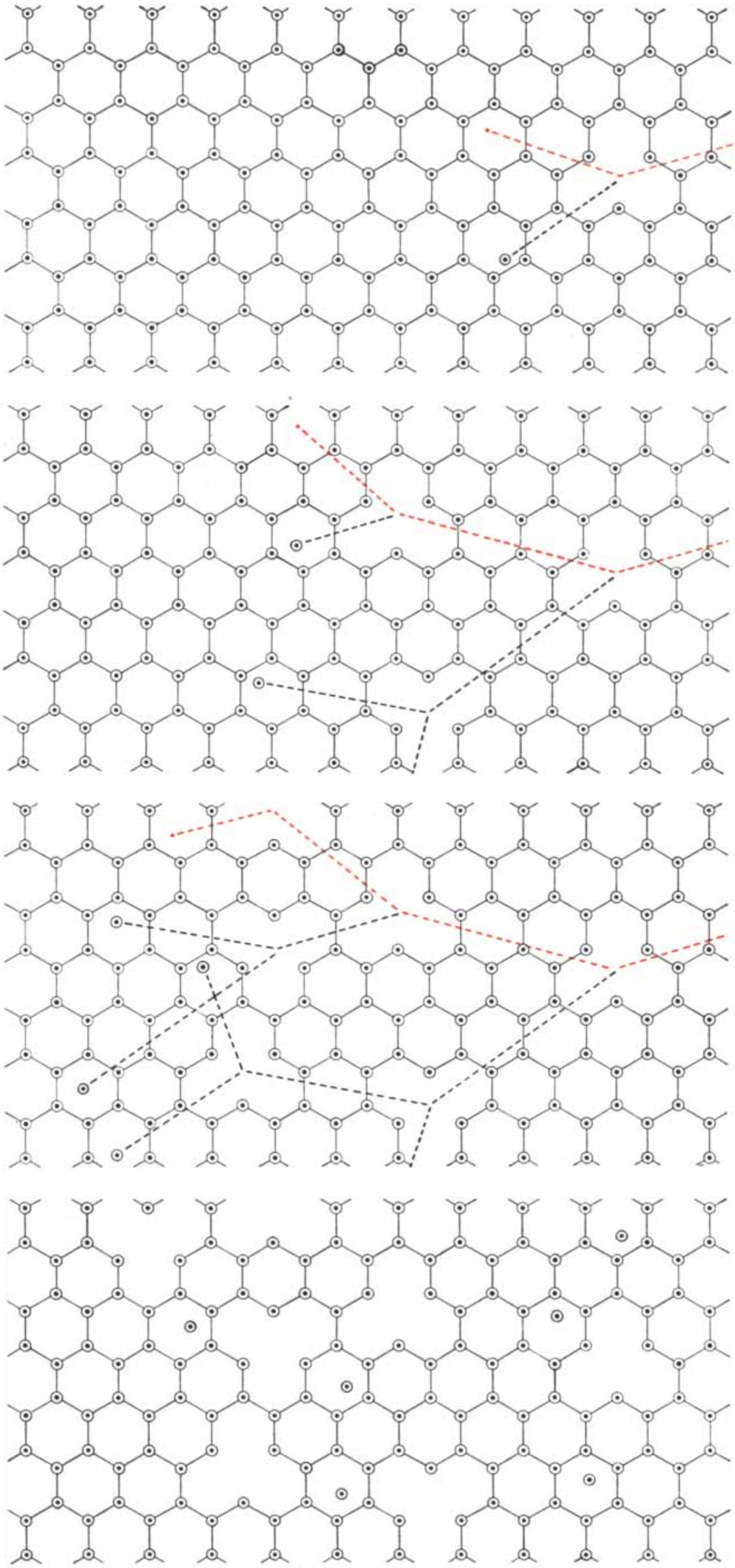
Its effects are fairly complicated and not yet well understood. It appears that the minute "spike" region melts. Evidence of this melting has been found in radiation experiments on a carefully prepared alloy of copper and zinc. The atoms were arranged in a regular lattice in which each copper atom was surrounded by eight zinc atoms and *vice*



MATERIALS TESTING REACTOR at the National Reactor Testing Station in Arco, Idaho, is used to study the effects of radiation on metals and other substances. This research is leading to improved radiation-resistant materials for use in future reactors.



IRRADIATED MATERIALS are photographed in the interior of the Materials Testing Reactor through 20 feet of water. Most of the glowing circles are fuel elements. The light comes from Cerenkov radiation, produced in transparent materials by very fast particles.



versa. Bombardment of this crystal with neutrons was done at very low temperatures, near the temperature of liquid helium, in order to "freeze in" any changes in the crystal. Analyses afterward showed that the atoms had become mixed in a disordered way, and that most of the disordering must have taken place in regions of thermal spikes.

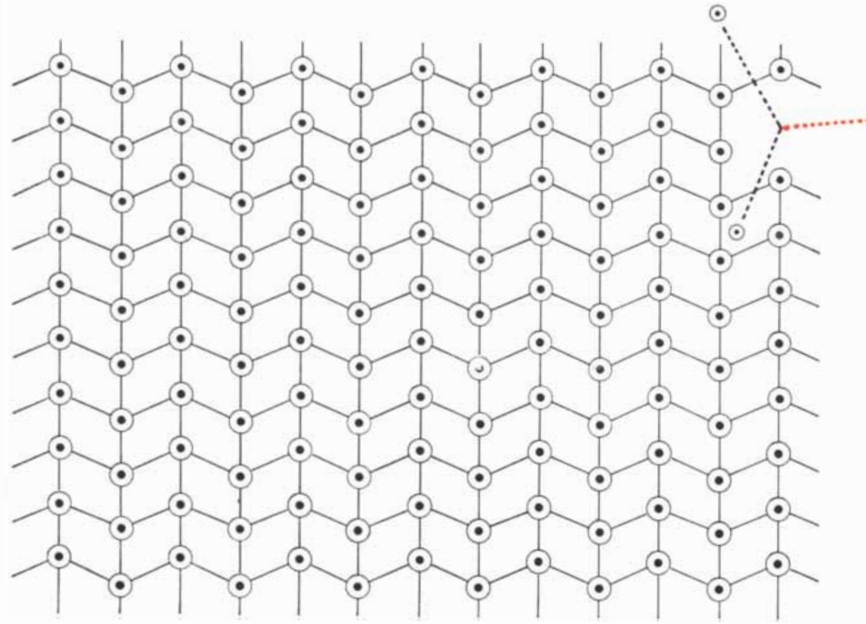
Besides melting, the heated regions expand. Such swelling causes deformations of the crystal, some of which presumably remain after the hot regions cool, so that the material around them is permanently distorted.

In a crystal damaged by radiation it is very difficult to distinguish how much of the damage is due to these spikes and how much to simple displacement of atoms. We can assume that spikes are a more important source of damage in metals than in graphite, because in the heavier elements recoiling atoms produce spikes at a higher energy level and therefore have a larger fraction of their energy left for producing them. In the case of graphite, the moving carbon atoms have used up most of their energy dislodging atoms before they drop to the low velocity at which they generate spikes. We can estimate that the most damaging part of the flight of recoil atoms in graphite is in the velocity range from 100,000 down to 10,000 electron volts.

It has become clear that radiation can produce a great variety of defects in the lattice, resulting in varying damage to the material.

In this account of the process that produces radiation damage in solids we have given most attention to graphite, but much of what we have said applies to the metal fuel in a reactor as well. The agent of damage is essentially the same: namely, flying particles. The principal difference is that in uranium the important bombarding particles are not neutrons but fission products. The heavy fission fragments hit atoms in the crystal lattice far harder than neutrons, and the atoms receive, on the average, about

LATTICE DEFECTS are produced when a neutron strikes a graphite crystal. The hexagonal crystal structure is represented diagrammatically in two dimensions. At top the neutron (*colored dot*) has struck and dislodged a single atom. The next two drawings show how the process builds up, with both neutron and recoiling atoms acting to dislodge further atoms (*neutron path is in color; atom paths are in black*). At bottom is the final result: a lattice with a number of vacant sites and "interstitial" atoms.



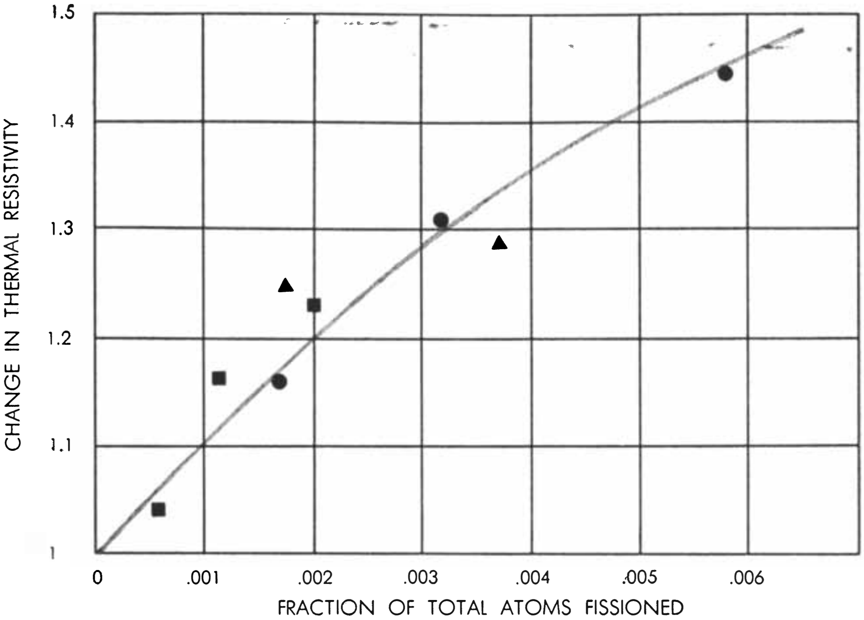
URANIUM LATTICE, also shown in two dimensions, suffers the same kind of damage as the carbon lattice, with an added complication. Sometimes the neutron is absorbed by the uranium nucleus, causing fission. The fission products may do more damage than neutrons.

1,000 times more energy. The damage is therefore much greater. In addition, the fission conversion of part of the uranium into other elements also weakens the metal. Fortunately metals are tough and can stand a lot, particularly if they do not have to stand it too long!

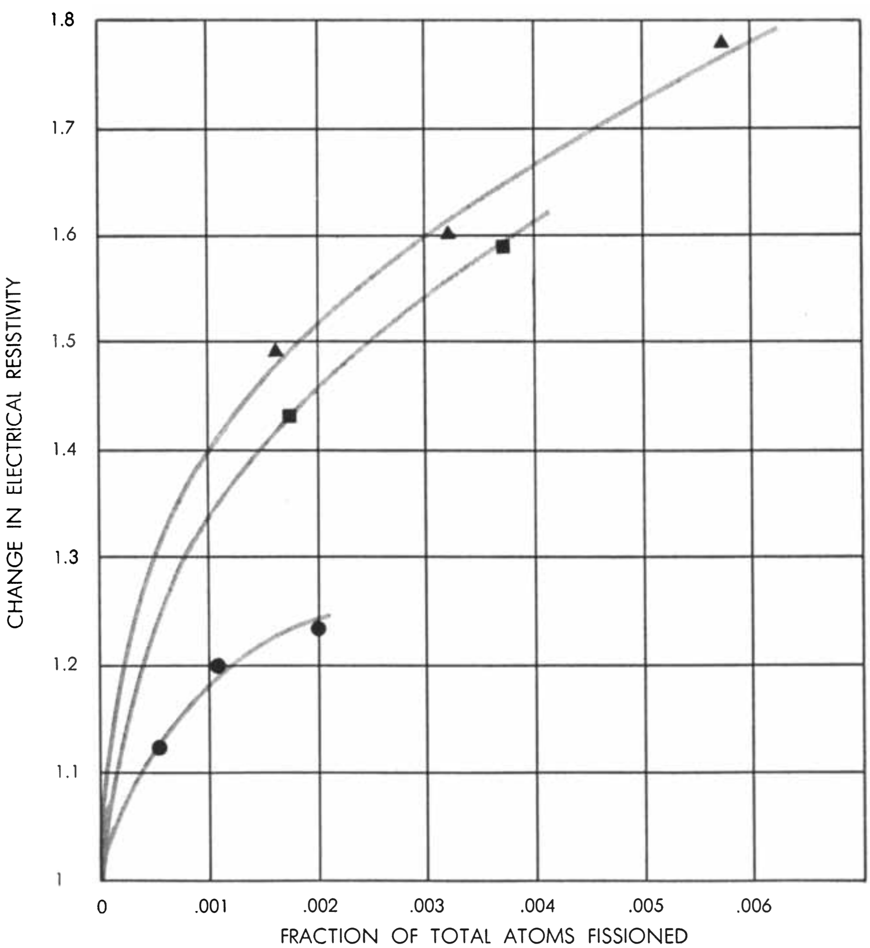
Let us consider now the recuperating powers of materials damaged by radiation. Usually dislodged atoms attempt to return to something resembling their original positions in the lattice and to restore their original properties. We can investigate the recovery process best at low temperatures. If the damaged material is held at a temperature where the atoms can move around a bit, the interstitial atoms and vacancies will begin to recombine and the lattice distortion will heal. The crystal's properties then tend to return to normal. This is well illustrated by a study of the recovery of copper after it was irradiated near the temperature of liquid helium. The property measured was its conduction of electricity. Copper, which is a nearly ideal metal, recovers very rapidly if it is irradiated near room temperature; to "freeze in" all the damage and prevent recovery during irradiation it must be kept not far above absolute zero. Now when the temperature of the irradiated specimen is raised to about 35 degrees Kelvin, its electrical conductivity increases sharply. It is not yet known whether this abrupt and irreversible change, common to copper and many other metals, is a result of the reunion of vacancies and interstitial atoms which are very close to one another or whether it is due to healing of some of the distortion produced by thermal spikes. This is one of the critical questions being investigated at several laboratories.

It is interesting to note that each increase in temperature permits a little more of the damage to heal. This shows that there is a spectrum of different types of defects, some of which are more resistant to correction than others. We know that small traces of impurity atoms can have a significant influence on the rate of recovery. Some of the defects produced are so stable that one must heat the metals to temperatures nearly halfway to the melting point in order to remove them.

On the whole, pure metals are the most resistant of all materials to radiation damage and recover most easily, presumably because the atoms in metals are most mobile. But reactions like those in metals have been found in valence compounds such as diamond, silicon and germanium, and in simple salts and oxides such as sodium chloride and beryllium oxide. On the other hand, organic materials, particularly polymers such as plastics, are exceedingly sensitive to radiation and suffer permanent and irreparable changes. In these cases the damage is associated with the breaking of chemical bonds which are diffi-



CHANGE IN PROPERTIES of uranium-aluminum alloys caused by fission of some of the uranium atoms was measured by D. S. Billington of Oak Ridge National Laboratory. The upper graph shows the increase in resistance to the flow of heat; the lower graph, the increase in resistance to electricity. Squares, circles and triangles represent observations on alloys containing respectively 5.7, 15 and 17.2 per cent uranium by weight. The vertical scales give the ratio of final to initial value. Thus the upper graph shows that when two thousandths of the atoms have split, the thermal resistivity is 1.2 times its normal value.



cult to rejoin in the original way. Most polymers lose their ductility when given even moderate exposures. In brief, they behave in a way almost opposite to that of the metals.

From the practical standpoint, what are the types of damage—and the possible benefits—produced by radiation? As we have seen, the microscopic result of irradiation is the formation of lattice defects. How do these defects alter the properties of the material? There are four important kinds of predictable changes.

First, we know that properties such as conduction of electricity and heat depend on a regular and undistorted lattice. We are not surprised to find, then, that the conductivity of materials for both electricity and heat falls sharply with increasing irradiation [*see charts at the left*]. Losses of conductivity up to 30-fold have been measured. Fortunately reactors do not rely too heavily on the heat conductivity of the moderator, and that of metals is less severely affected by radiation. Hence the decreases in conductivity do not cause real concern from the point of view of reactor operation. We must quickly add, however, that these changes do affect the instruments stuck into the reactor and must be taken into account in problems concerned with instrumentation.

The second type of radiation damage is represented by a loss of ductility. The lattice defects have the effect of blocking the glide planes of the crystals. Thus the materials behave as if work-hardened, and in fact may become brittle. This damage affects the handling of uranium fuel elements and is a major cause for concern. The changes in ductility can be spectacular. The effect was demonstrated in a U. S. atomic energy display at Geneva. Every few seconds a light ball was thrown alternately at two copper cylinders, which looked identical but differed in the fact that one had been exposed to the neutrons of the Oak Ridge reactor. The normal cylinder, when hit by the light ball, gave no sound. But the irradiated one sang like a tuning fork. We understand that no amount of normal cold-working could endow copper with as much rigidity as this irradiated specimen possessed.

These first two types of effects—on conductivity and ductility—are the most striking but not necessarily the most harmful changes caused by irradiation. From the point of view of reactor operation there are two others which have caused more anxiety.

One is a swelling of the material. The

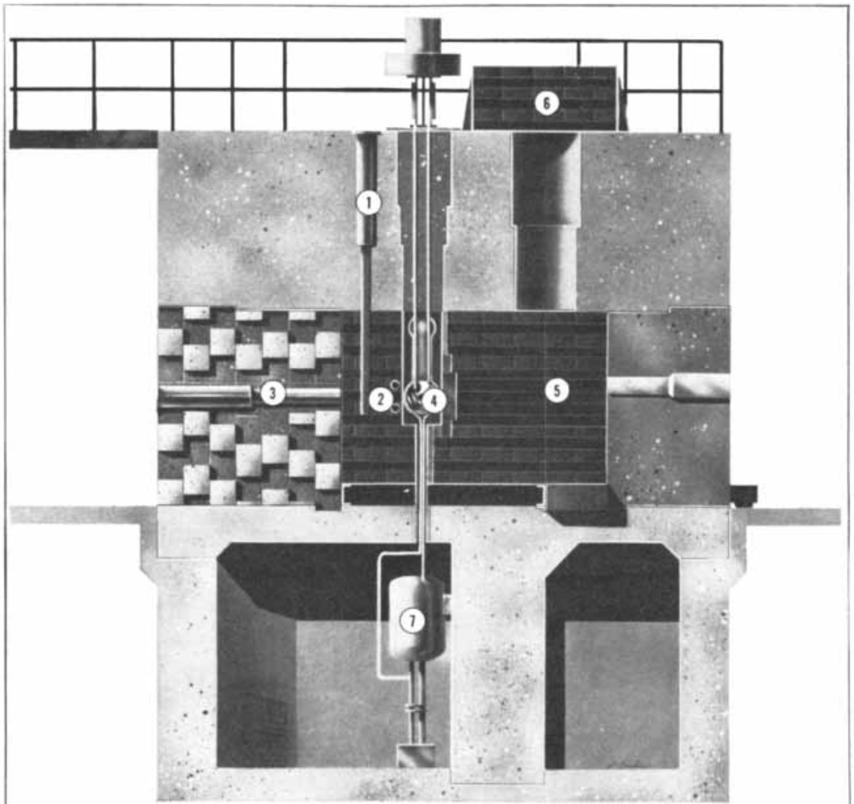
NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Aqueous, homogeneous type nuclear reactor being built for Japan

The first nuclear reactor for the Far East is being built by ATOMICS INTERNATIONAL for the Atomic Energy Research Institute of Japan. The reactor will be located near Tokyo. When the reactor starts operating early in 1957, a full program of research into the peaceful applications of nuclear energy will begin. This program includes the production of radioisotopes, studies in neutron activation, neutron diffraction, radiation effect on materials and training in reactor techniques.

At a rated power of 50 kilowatts, this solution type reactor will produce a peak thermal neutron flux of 1.7 x $10^{12}/cm^2$ sec. Equipped with a five foot graphite thermal column, it will provide an extensive source of slow neutrons. Additionally, the room beneath the reactor housing the gas handling system has been designed to provide neutron-free gamma irradiation. This facility, ideally suited for biological and chemical experiments, will provide 50,000 curies of radioactivity in Xenon and Krypton gases circulating in the system.

The core of the reactor is a stainless steel sphere with a diameter of approximately 12 inches, filled with a uranyl sulphate solution. The fuel investment is approximately 1000 grams of Uranium^{235}. The reflector around the core consists of graphite stacked in a rectangular steel tank 5 feet high, 5 feet wide and 8 feet long. Appropriate holes for experimental facilities and instrumentation are located in the graphite. Five feet of dense concrete provides a shield around the reflector tank.



Solution Type Research Reactor for Japan.

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2—Pneumatic tubes
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Instrumentation control is provided by two types of sensing elements which give neutron level information. In the power range up to approximately 1 watt, two fission chambers are employed. In the power range of approximately 0.1 to 50,000 watts, two gamma compensated ionization chambers are used. One of these chambers is fed into a shutdown channel and an electrometer which in turn sends a signal to the power level recorder. Power level is automatically maintained by feeding an error signal from the level recorder to a servo-amplifier which drives the regulating rod motor in the proper direction to correct error. The other ionization chamber feeds a logarithmic amplifier, and period shutdown circuit.

The core cooling system consists of a closed, recirculating system using demineralized light water. The core cooling loop includes about 90 feet of stainless steel tubing, the associated pump, valves and piping, and a heat exchanger to transfer the heat to a secondary cooling system.

ATOMICS INTERNATIONAL, a division of North American Aviation, Inc., is a major reactor builder—experienced in the design, construction and operation of nuclear reactors for research and the production of power. A reactor similar to the one scheduled for Japan has been installed for the Armour Research Foundation of the Illinois Institute of Technology in Chicago. It is one of several in-action nuclear reactors designed and built by ATOMICS INTERNATIONAL.

If you are interested in any phase of reactor technology, ATOMICS INTERNATIONAL is staffed and equipped to serve you. Please write: Director of Technical Sales, Department SA-N4, ATOMICS INTERNATIONAL, P.O. Box 309, Canoga Park, California. Cable address: ATOMICS.

ATOMICS INTERNATIONAL

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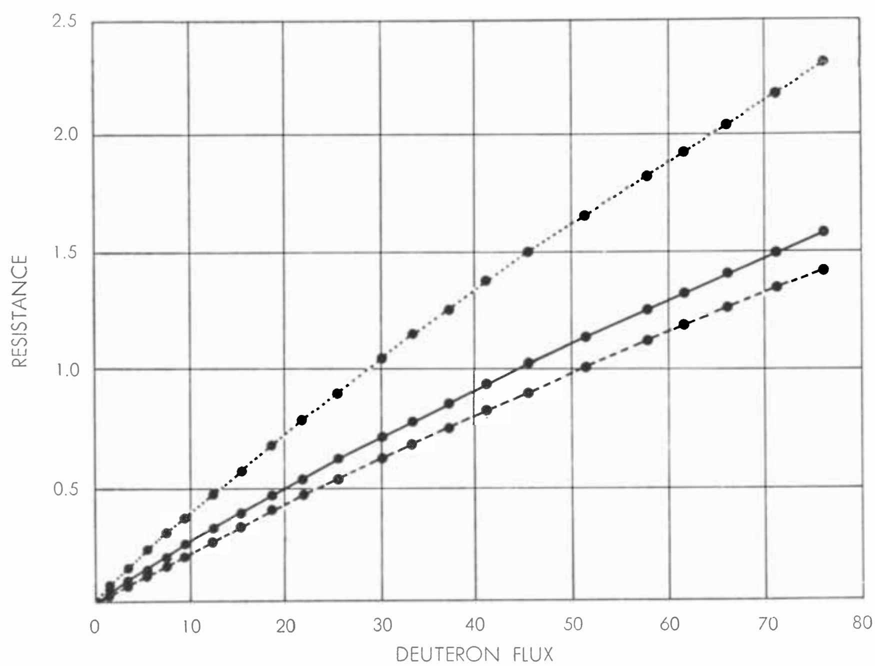
PIONEERS IN THE CREATIVE USE OF THE ATOM displacement of atoms to irregular positions in the lattice expands the crystals. Hence the volume of a block of material increases as the dosage of radiation increases. When the Materials Testing Reactor of the AEC in Idaho went into operation with its new beryllium oxide moderator, the moderator expanded about 1 per cent the first day. Fortunately this expansion did not proceed linearly with time: after 10 days it was much less than 10 per cent. Nevertheless, it can be very disconcerting to have to use as structural elements materials which change their dimensions after they are installed.

The other disquieting effect of radiation is an unstable energy situation. The interstitial atoms represent a considerable amount of stored energy. When they move back into vacancies in the lattice, they release this energy. The amount of sword-of-Damocles energy stored in this way can reach values up to hundreds of calories per mole (one gram multiplied by the molecular weight of the material). Obviously a sudden release of it could lead to unpleasant complications. On the other hand, this property also has constructive possibilities: some have suggested using irradiated graphite as a kind of storage battery.

We call the various effects mentioned "damage" because they change critical properties of materials that have been placed in reactors to perform definite functions based in part on these properties. The changes in properties are regarded as harmful not because they would not be useful under certain circumstances, but because they impair the behavior for which the material was selected. To minimize the effects of these changes in a reactor, it has been suggested that materials might be deliberately irradiated before they go into the reactor. This stratagem might yield materials with desired properties and stability against further irradiation.

Indeed, we can expect that irradiated materials will be put to more and more uses as understanding of their properties and potentialities grows. Graphite storage batteries and the superhardening of copper are only a beginning of the list of possibilities. We have scarcely scratched the surface of knowledge of the radiation-induced properties of materials.

Speaking as individuals who have been interested in radiation effects on solids since the conception of the first large reactors, we find it gratifying that a phenomenon which originated as a pure nuisance promises to provide us with useful information about the solid state in general and about many of the materials we use every day.



DEUTERON BOMBARDMENT of copper (*broken curve*), silver (*solid curve*) and gold (*dotted curve*) increases the electrical resistance of these metals. The horizontal scale gives the number of particles per second in each 10^{-15} square centimeters of cross section of the beam. The vertical scale shows the increase in resistance, measured in ten millionths of an ohm, of a one-centimeter cube. Measurements were made at 10 degrees above absolute zero.

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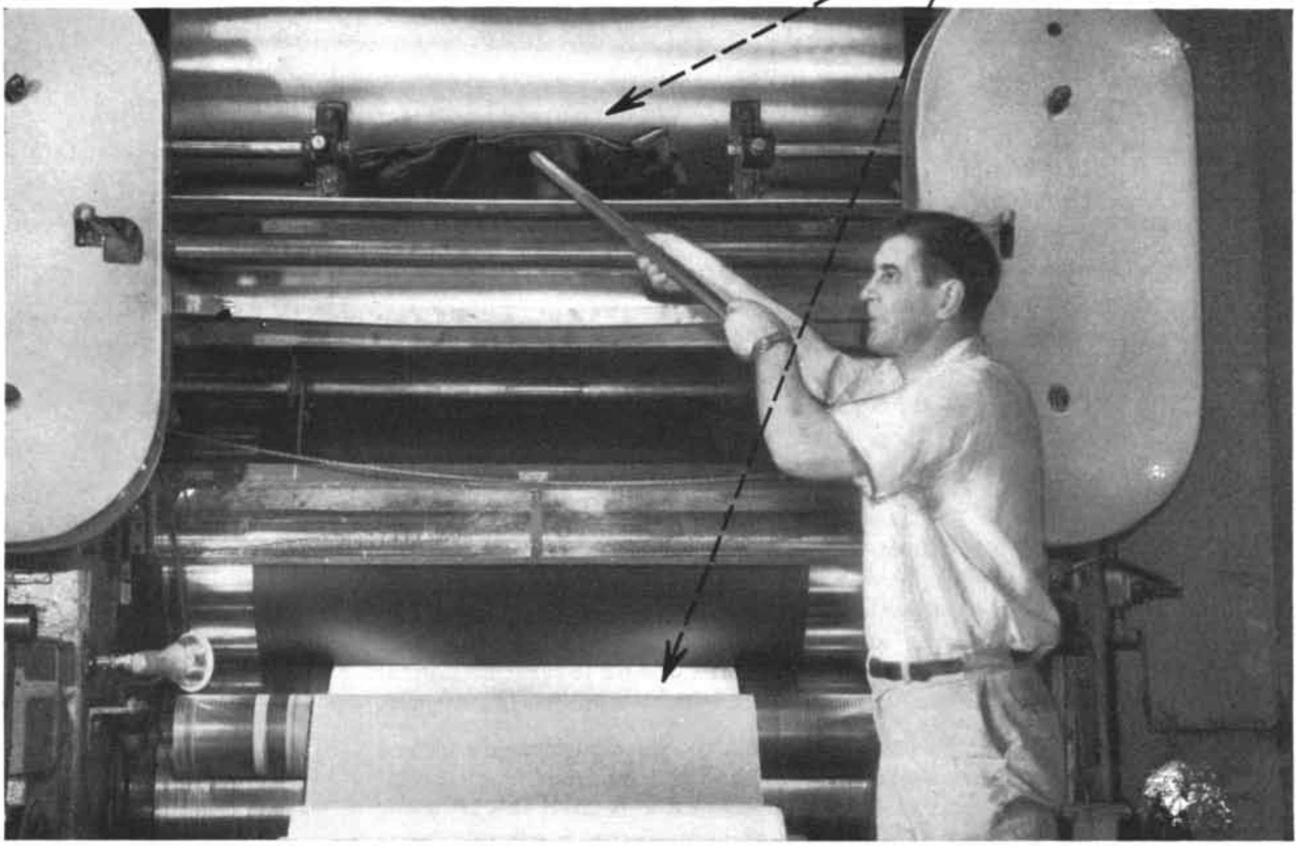

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SICKLE CELLS AND EVOLUTION

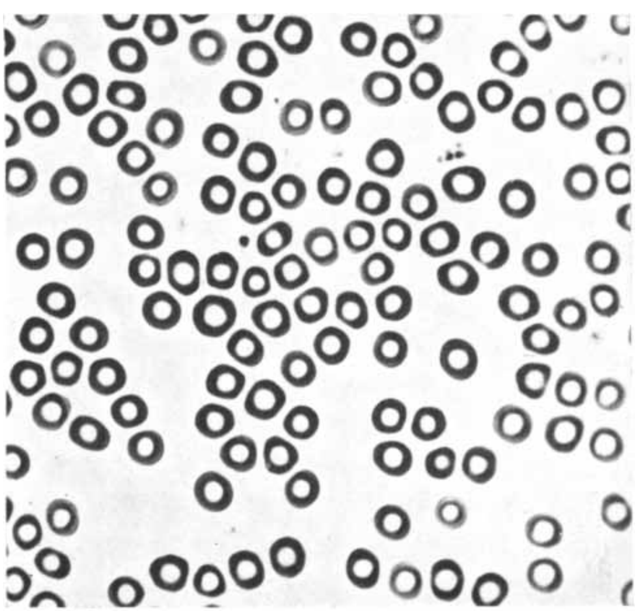
Why has the hereditary trait in which the red blood cells are sickle-shaped persisted for so many generations? The surprising answer is that under some conditions it is actually beneficial

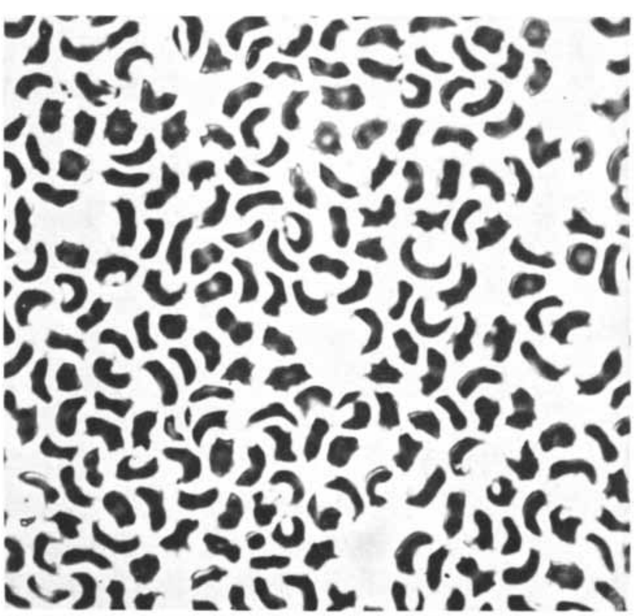
by Anthony C. Allison

Persevering study of small and seemingly insignificant phenomena sometimes yields surprising harvests of understanding. This article is an account of what has been learned from an oddly shaped red blood cell.

Forty-six years ago a Chicago physician named James B. Herrick, examining a Negro boy with a mysterious disease, found that many of his red blood cells were distorted into a crescent or sickle shape. After Herrick's report, doctors soon recognized many other cases of the same disease. They learned that it was hereditary and common in Negroes [see "Sickle-Cell Anemia," by George W. Gray; SCIENTIFIC AMERICAN, August, 1951]. The curious trait of the sickled blood cells gradually attracted the interest of physiologists, biochemists, physical chemists, geneticists, anthropologists and others. And their varied investigations of this quirk of nature led to enlightenment on many unexpected subjects: the behavior of the blood's hemoglobin, inherited resistance to disease, the movements of populations over the world and the nature of some of the agencies that influence human evolution.

Let us review first what has been learned about the sickle cell phenomenon itself. As every student of biology knows, the principal active molecule in the red blood cells is hemoglobin, which serves as the carrier of oxygen. It appears that an unusual form of hemoglobin, produced under the influence of an abnormal gene, is responsible for the sickling of red cells. This hemoglobin molecule differs only slightly from the normal variety, and when there is an ample supply of oxygen it behaves normally: *i.e.*, it takes on oxygen and preserves its usual form in the red cells. But when the sickle cell hemoglobin (known as hemoglobin S) loses oxygen, as in the capillaries where oxygen is delivered to the tissues, it becomes susceptible to a peculiar kind of reaction. It can attach itself to other hemoglobin S molecules, and they form long rods, which in turn attract one another and line up in parallel. These formations are rigid enough to distort the red cells from their normal disk shape into the shape of a sickle [*see photomicrographs below*]. Now the sickled cells may clog blood vessels; and they are soon destroyed by the body, so that the patient becomes anemic. The destruction of the hemoglobin converts it into bilirubin—





RED BLOOD CELLS of an individual with sickle cell trait, *i.e.*, a sickle cell gene from only one parent, are examined under the microscope. At the left are oxygenated red cells; they are disk-shaped. At the right are the same cells deoxygenated; they are sickle-shaped.

the yellow pigment responsible for the jaundiced appearance often characteristic of anemic patients.

Most sufferers from sickle cell anemia die in childhood. Those who survive have a chronic disease punctuated by painful crises when blood supply is cut off from various body organs. There is no effective treatment for the disease.

From the first, a great deal of interest focused on the genetic aspects of this peculiarity. It was soon found that some Negroes carried a sickling tendency without showing symptoms of the disease. This was eventually discovered to mean that the carrier inherits the sickle cell gene from only one parent. A child who receives sickle cell genes from both parents produces only hemoglobin S and therefore is prone to sickling and anemia. On the other hand, in a person who has a normal hemoglobin gene from one parent and a hemoglobin S from the other sickling is much less likely; such persons, known as carriers of the "sickle cell trait," become ill only under exceptional conditions—for example, at high altitudes, when their blood does not receive enough oxygen.

The sickle cell trait is, of course, much more common than the disease. Among Negroes in the U. S. some 9 per cent carry the trait, but less than one fourth of 1 per cent show sickle cell anemia. In some Negro tribes in Africa the trait is present in as much as 40 per cent of the population, while 4 per cent have sickle cell genes from both parents and are subject to the disease.

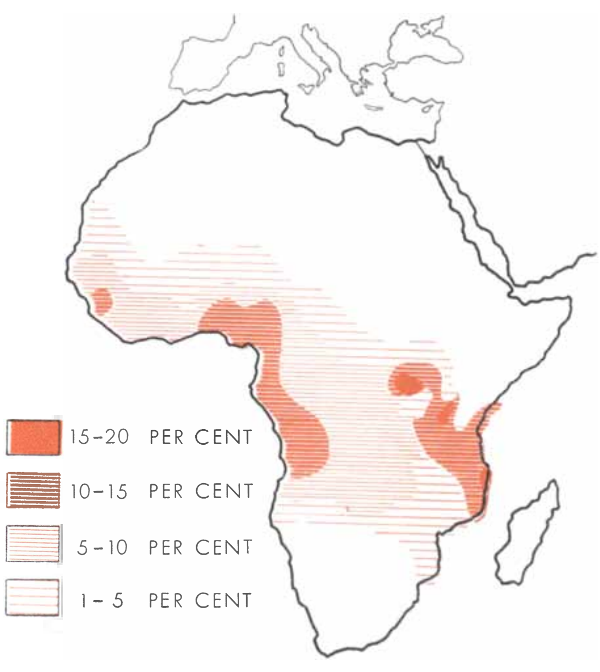
The high incidence of the sickle cell gene in these tribes raised a most interesting question. Why does the harmful gene persist? A child who inherits two sickle cell genes (*i.e.*, is homozygous for this gene) has only about one fifth as much chance as other children of surviving to reproductive age. Because of this mortality, about 16 per cent of the sickle cell genes must be removed from the population in every generation. And yet the general level remains high without any sign of declining. What can be the explanation? Carriers of the sickle cell trait do not produce more children than those who lack it, and natural mutation could not possibly replace the lost sickle cell genes at any such rate.

The laws of evolution suggested a possible answer. Carriers of the sickle cell trait (a sickle cell gene from one parent and a normal one from the other) might have some advantage in survival over those who lacked the trait. If people with the trait had a lower mortality rate, counterbalancing the high mortality of sufferers from sickle cell anemia, then the frequency of sickle cell genes in the population would remain at a constant level.

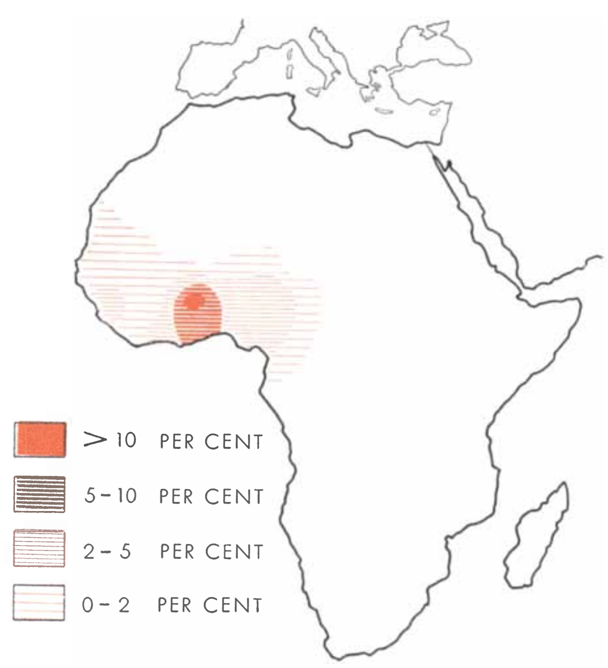
What advantage could the sickle cell trait confer? Perhaps it protected its carriers against some other fatal disease—say malaria. The writer looked into the situation in malarious areas of Africa and found that children with the sickle cell trait were indeed relatively resistant to malarial infection. In some places they had as much as a 25 per cent better chance of survival than children without the trait. Children in most of Central Africa are exposed to malaria nearly all year round and have repeated infections during their early years. If they survive, they build up a considerable immunity to the disease. In some unknown way the sickle cell trait apparently protects young children against the malaria parasite during the dangerous years until they acquire an immunity to malaria.

On the African continent the sickle cell gene has a high frequency among people along the central belt, near the Equator, where malaria is common and is transmitted by mosquitoes through most of the year. North and south of this belt, where malaria is less common and usually of the benign variety, the sickle cell gene is rare or absent. Moreover, even within the central belt, tribes in nonmalarious areas have few sickle cell genes.

Extension of the studies showed that similar situations exist in other areas of the world. In malarious parts of southern Italy and Sicily, Greece, Turkey and India, the sickle cell trait occurs in up to 30 per cent of the population. There is no reason to suppose that the peoples of all these areas have transmitted the gene to one another during recent times. The



FREQUENCY OF THE SICKLE CELL GENE is plotted in per cent on the map of Africa. High frequencies are confined to a broad belt in which malignant tertian malaria is an important cause of death.



FREQUENCY OF THE HEMOGLOBIN C GENE is similarly plotted. Unlike the sickle cell gene, which has a widespread distribution, this gene is confined to a single focus in West Africa.

U. S. Army Photo

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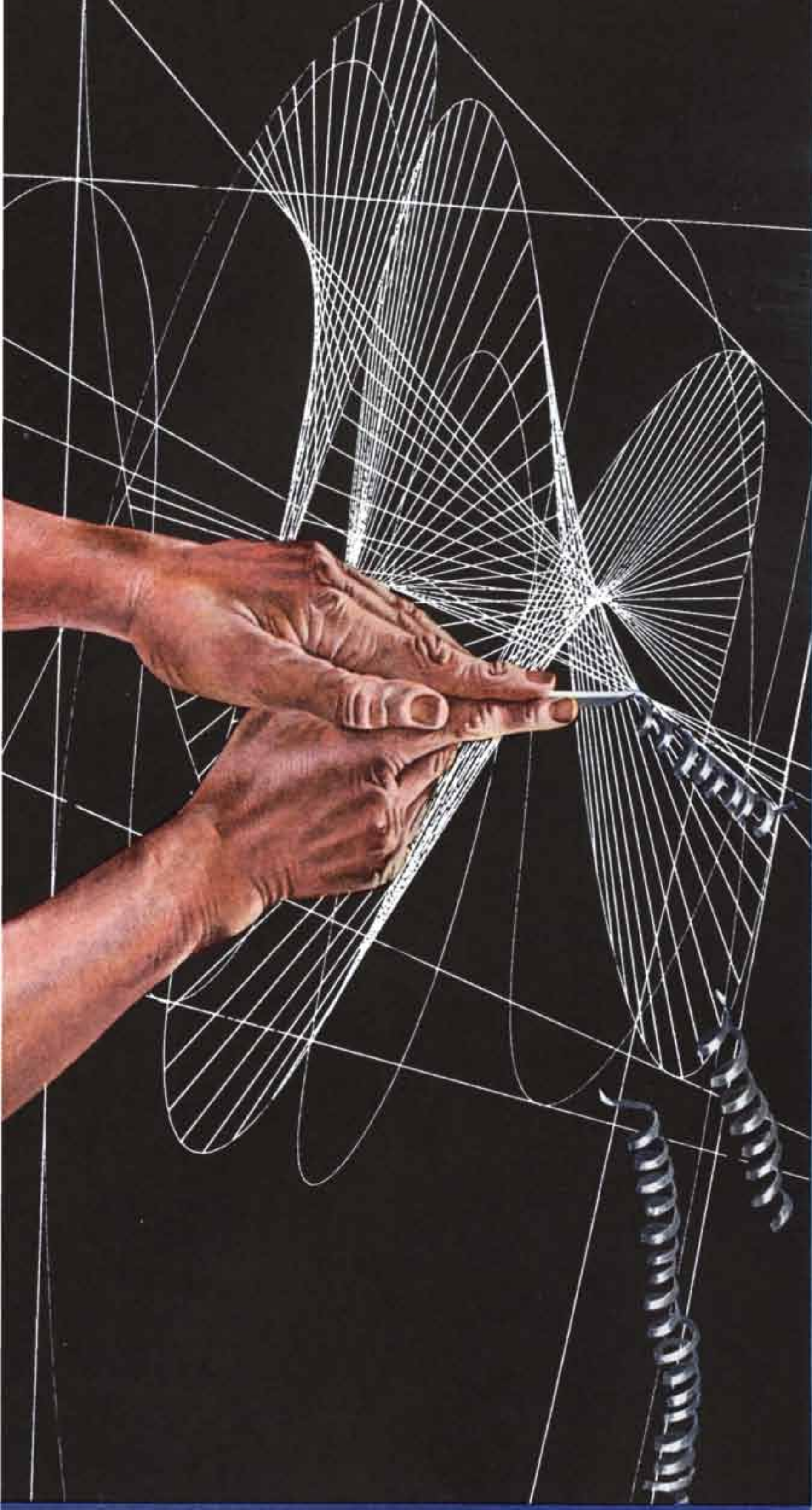

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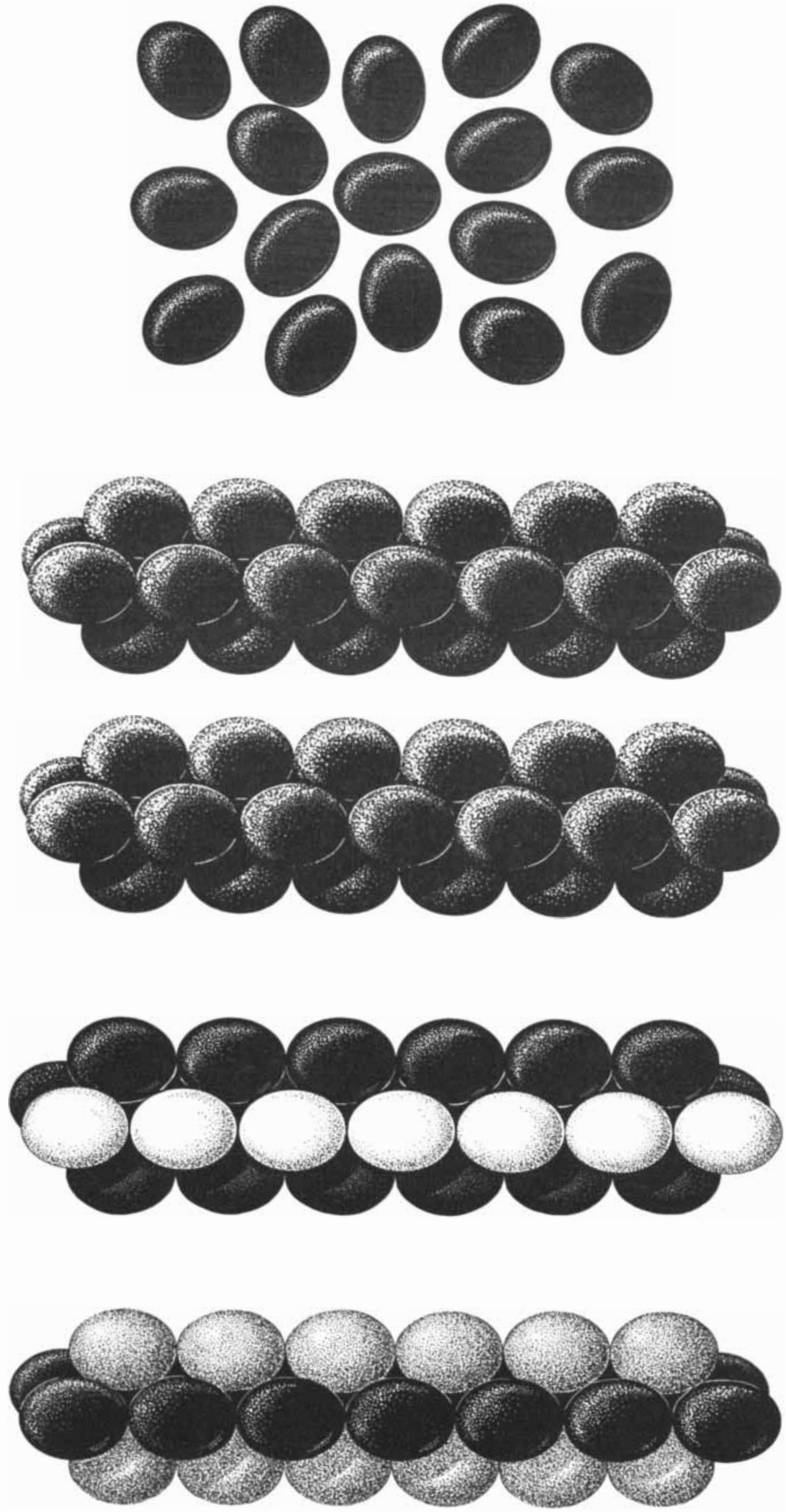
sickle cell gene may have originated independently in the several populations or may trace back to a few such genes passed along among them a thousand years ago. The high frequency of the gene in these populations today can be attributed mainly to the selective effect of malaria.

On the other hand, we should expect that when a population moves from a malarious region to one free of this disease, the frequency of the sickle cell gene will fall. The Negro population of the U. S. exemplifies such a development. When Negro slaves were first brought to North America from West Africa some 250 to 300 years ago, the frequency of the sickle cell trait among them was probably not less than 22 per cent. By mixed mating with Indian and white people this figure was probably reduced to about 15 per cent. In the absence of any appreciable mortality from malaria, the loss of sickle cell genes through deaths from anemia in 12 generations should have reduced the frequency of the sickle cell trait in the Negro population to about 9 per cent. This is, in fact, precisely the frequency found today.

Thus the Negroes of the U. S. show a clear case of evolutionary change. Within the space of a few hundred years this population, because of its transfer from Africa to North America, has undergone a definite alteration in genetic structure. This indicates how rapidly human evolution can take place under favorable circumstances.

Since the discovery of sickle cell hemoglobin (hemoglobin S), many other abnormal types of human hemoglobin have been found. (They are usually distinguished by electrophoresis, a separation method which depends on differences in the amount of the negative charge on the molecule.) One of the most common of these other varieties is called hemoglobin C. It, too, causes anemia in persons who have inherited the hemoglobin C gene from both parents. Moreover, the combination of hemoglobin S and hemoglobin C (one inherited from each parent) likewise leads to anemia. These two hemoglobins combine to form the rodlike structures that cause sickling of the red blood cells [*see drawings on this page*].

The hemoglobin C gene is largely confined to West Africa, notably among people in the northern section of the Gold Coast, where the frequency of the trait runs as high as 27 per cent. Whether hemoglobin C, like hemoglobin S, protects against malaria is not known. But



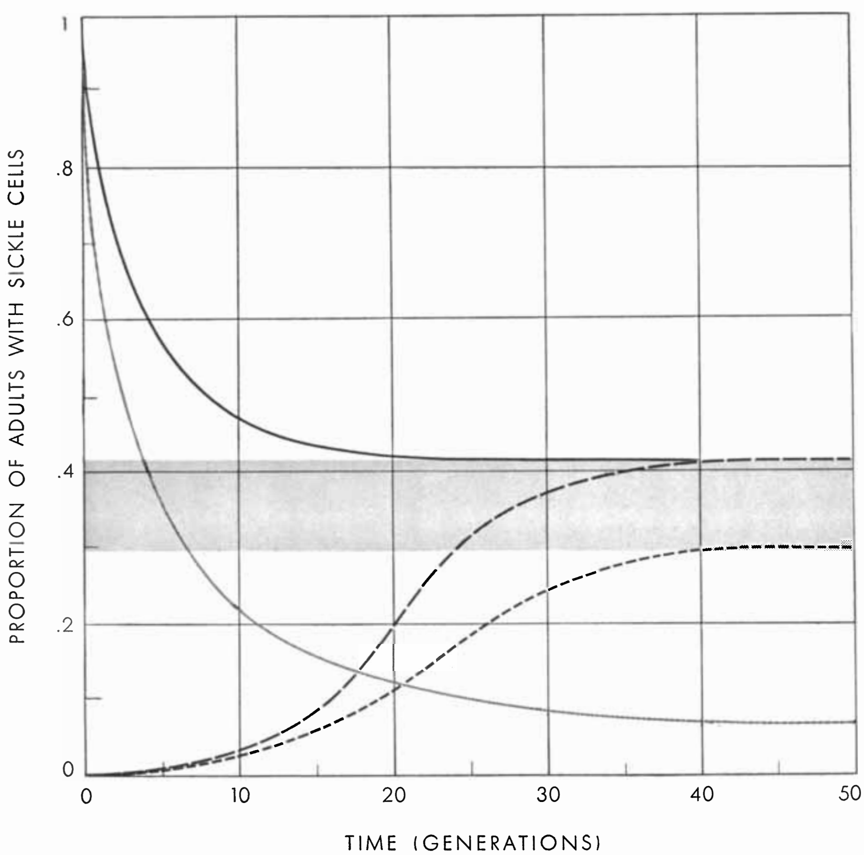
HEMOGLOBIN MOLECULES are represented as ellipsoids in these drawings. At the top are normal hemoglobin molecules, which are arranged almost at random in the red blood cell. Second and third from the top are sickle cell hemoglobin molecules, which form long helixes when they lose oxygen. Fourth is an aggregate of normal (*white*) and sickle cell molecules (*black*), in which every fourth molecule of the helix is normal. Fifth is an aggregate of hemoglobin C (*gray*) and sickle cell molecules; every other molecule is hemoglobin C.

the C gene must give some advantage, else it would not persist. Obviously inheritance of both C and S is a disadvantage, since it leads to anemia. As a consequence we should expect to find that where the C gene is present, the spread of the S gene is retarded. This does seem to be the case: in the northern Gold Coast the frequency of the S gene goes no higher than 5 per cent.

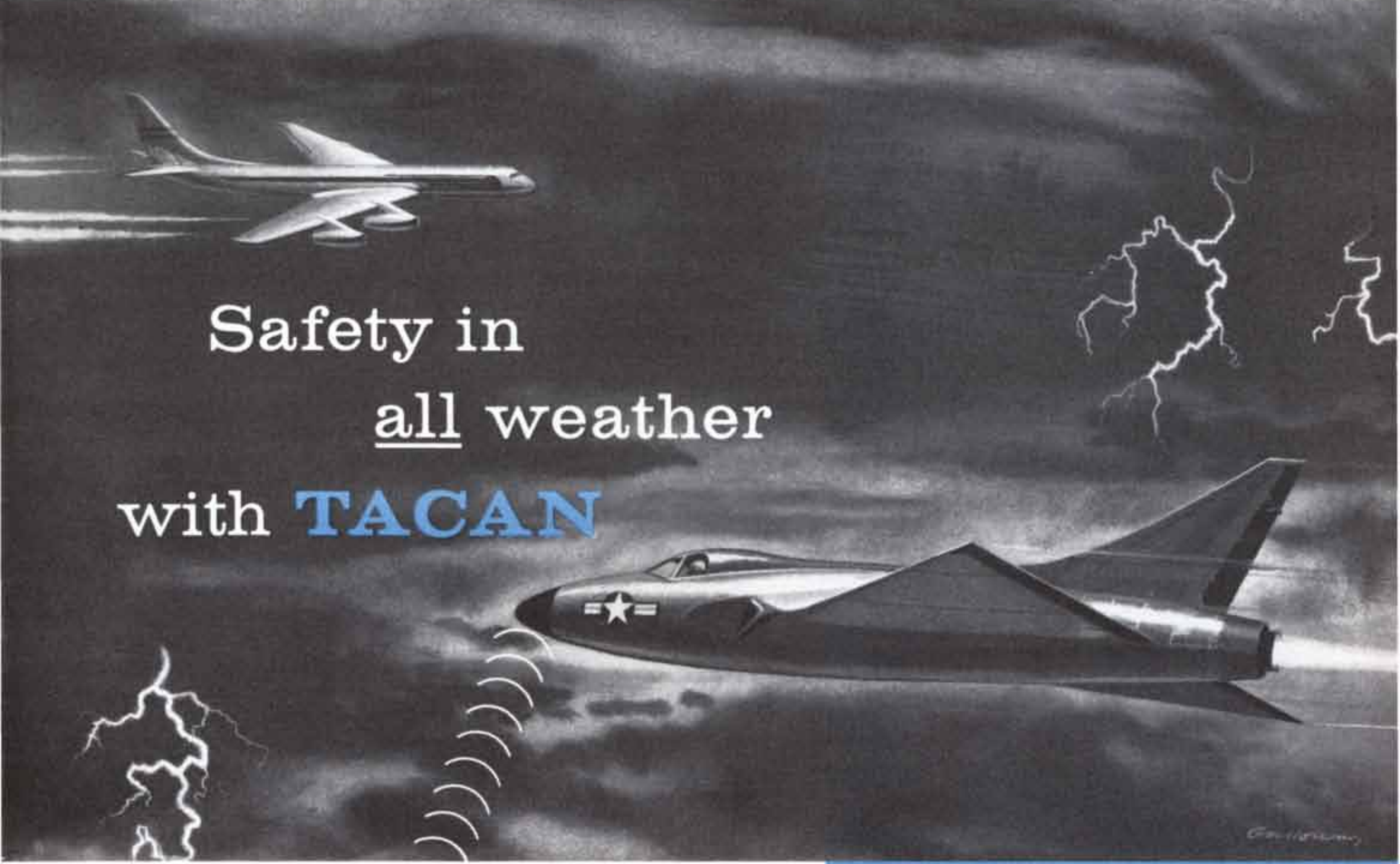
Another gene producing abnormal hemoglobin, known as the thalassemia gene, is common in Greece, Italy, Cyprus, Turkey and Thailand. The trait is most prevalent in certain areas (*e.g.*, lowlands of Sardinia) where malaria used to be serious, but there have not yet been any direct observations as to whether its carriers are resistant to malaria. The trait almost certainly has some compensating advantage, for it persists in spite of the fact that even persons who have inherited the gene from only one parent have a tendency to anemia. The same is probably true of another deviant gene, known as the hemoglobin E gene, which is common in Thailand, Burma and among some populations in Ceylon and Indonesia.

By now the identified hemoglobin types form a considerable alphabet: besides S, C, thalassemia and E there are D, G, H, I, J, K and M. But the latter are relatively rare, from which it can be inferred that they provide little or no advantage.

For anyone interested in population genetics and human evolution, the sickle cell story presents a remarkably clear demonstration of some of the principles at play. It affords, for one thing, a simple illustration of the principle of hybrid vigor. Hybrid vigor has been investigated by many breeding experiments with fruit flies and plants, but in most cases the crossbreeding involves so many genes that it is impossible to say what



RATE OF CHANGE IN FREQUENCY of adults with sickle cells under different conditions is shown in this chart. The horizontal gray band represents the equilibrium frequency in a region where individuals with the sickle cell trait have an evolutionary advantage of about 25 per cent over individuals without the sickle cell trait. If a population of individuals with a low sickle cell frequency enters the region, the frequency will increase to an equilibrium value (*long dashes*). If hemoglobin C is already established in the same population, the frequency will increase to a lower value (*short dashes*). If a population of individuals with a high sickle cell frequency enters the region, the frequency will decrease (*solid line*). If this population enters a nonmalarious region, the frequency will fall to a low value (*gray line*).



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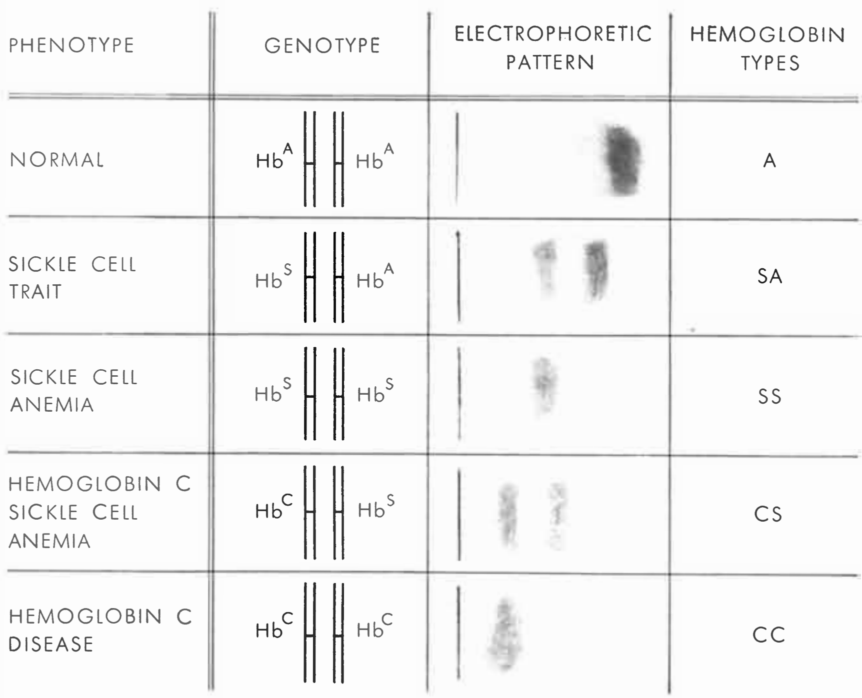
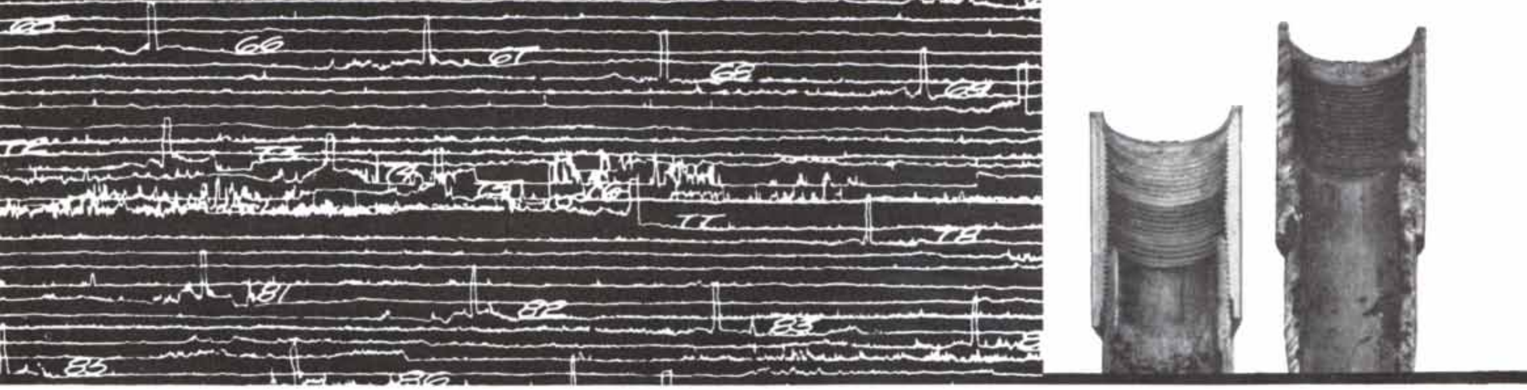
Secondly, we see a simple example of inherited resistance to disease. Resistance to infection (to say nothing of disorders such as cancer or heart disease) is generally complex and unexplainable, but in this case it is possible to identify a single gene (the sickle cell gene) which controls resistance to a specific disease (malaria). It is an unusually direct manifestation of the fact, now universally recognized but difficult to demonstrate, that inheritance plays a large role in controlling susceptibility or resistance to disease.

Thirdly, the sickle cell situation shows that mutation is not an unmixed bane to the human species. Most mutations are certainly disadvantageous, for our genetic constitution is so carefully balanced that any change is likely to be for the worse. To adapt an aphorism, all is best in this best of all possible bodies. Nonetheless, the sickle cell mutation, which at first sight looks altogether harmful, turns out to be a definite advantage in a malarious environment. Similarly other mutant genes that are bad in one situation may prove beneficial in another. Variability and mutation permit the human species, like other organisms, to adapt rapidly to new situations.

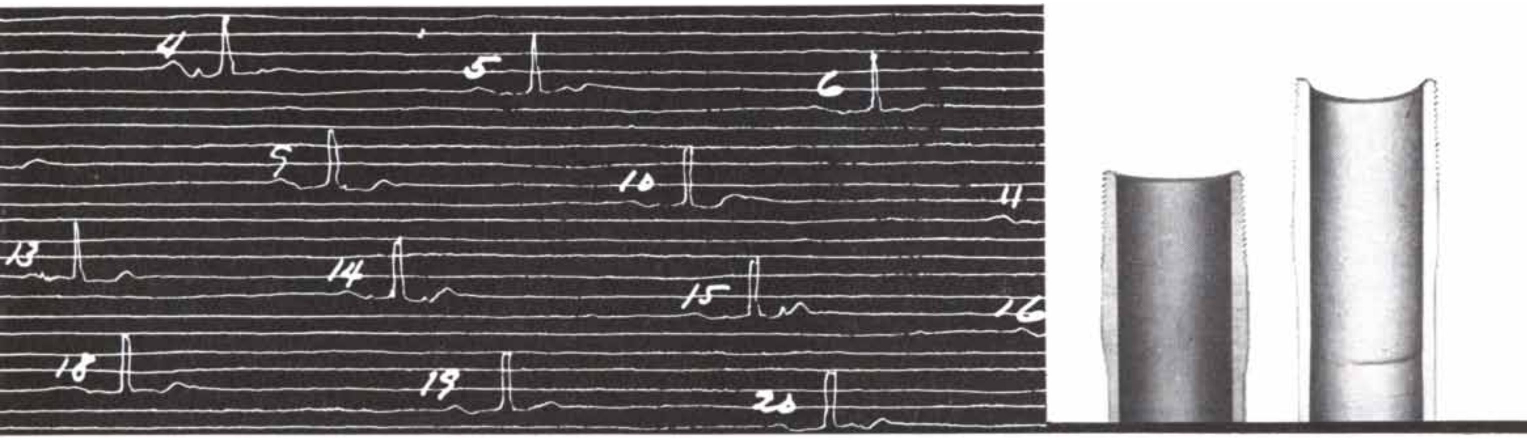
Finally, the sickle cell findings offer a cheering thought on the genetic future of civilized man. Eugenists often express alarm about the fact that civilized societies, through medical protection of the ill and weak, are accumulating harmful genes: *e.g.*, those responsible for diabetes and other hereditary diseases. The sickle cell history brings out the other side of the story: improving standards of hygiene may also *eliminate* harmful genes—not only the sickle cell but also others of which we are not yet aware.



HEMOGLOBIN SPECIMENS from various individuals are analyzed by electrophoresis. The phenotype is the outward expression of the genotype, which refers to the hereditary make-up of the individual. The H-shaped symbols in the genotype column are schematic representations of sections of human chromosomes, one from each parent. The horizontal line of the H represents a gene for hemoglobin type. Hb^A is normal hemoglobin; Hb^S, sickle cell hemoglobin; Hb^C, hemoglobin C. This kind of electrophoretic pattern is made on a strip of wet paper between a positive and a negative electrode. The specimen of hemoglobin is placed on the line at the left side of each strip. In this experiment hemoglobin A migrates faster toward the positive electrode than sickle cell hemoglobin, which migrates faster than hemoglobin C. Thus the pattern for individuals with two types of hemoglobin is double.



A caliper survey was made to detect corrosion of oil-well tubing. Erratic "blips" on the survey chart indicate corrosion in well using ordinary inhibitor. Parts of two corroded tubes are shown at right.



Evenly spaced "blips" in this chart show no corrosion, merely indicate tubing joints in well using inhibitor containing Sunaptic acid. The tubes look like new. Both surveys taken after one year.

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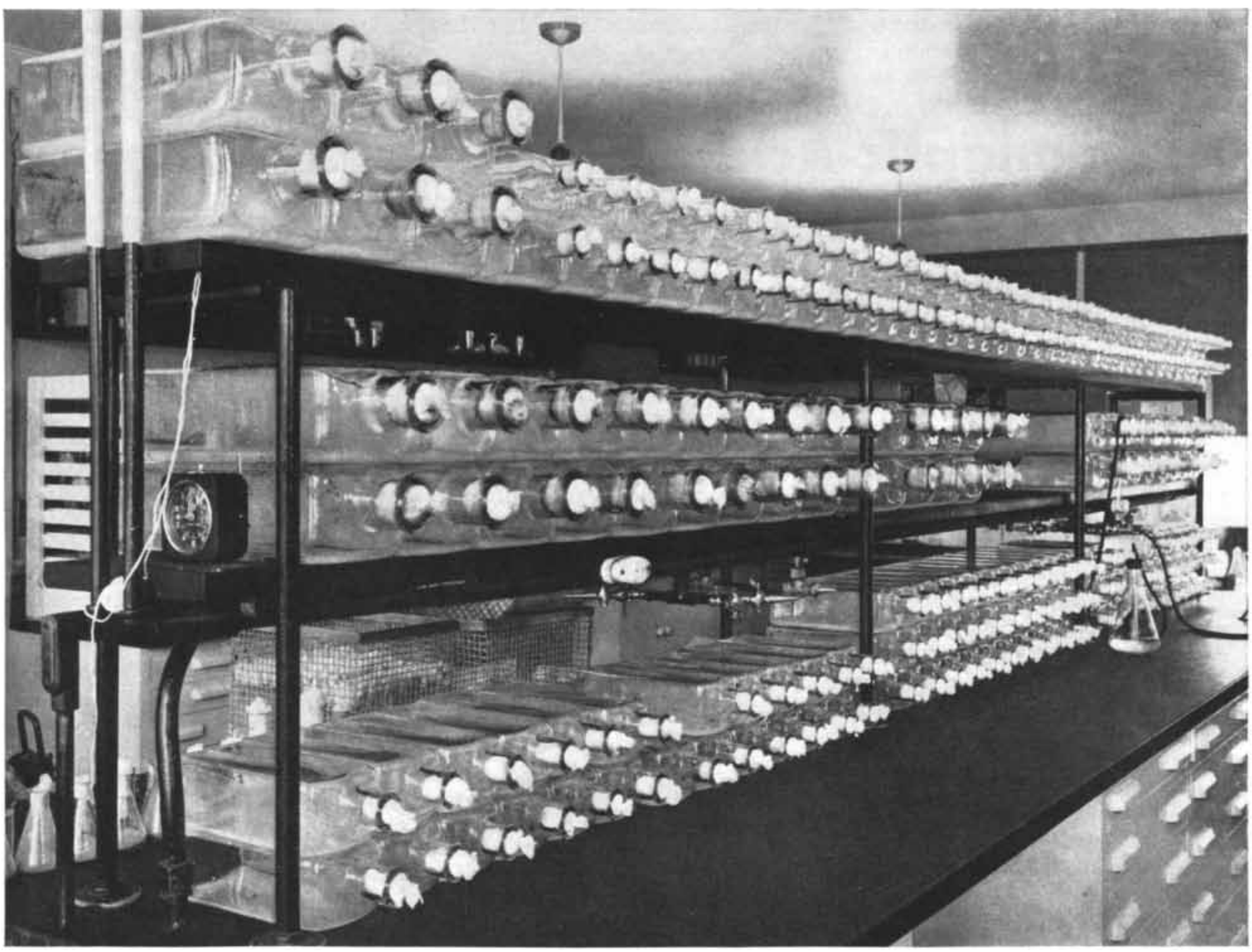
Living Insecticides

For almost a century entomology has sought to control harmful insects with their own infectious diseases. This dream is now being realized, notably in the artificial infection of a caterpillar that eats alfalfa leaves

by Edward A. Steinhaus

This summer in the Central Valley of California the green caterpillars that chew the tender new leaves of alfalfa have been coming to an untimely end. Some have been dying of a bacterial infection their species has never suffered before. Others have been sickened by a virus which young caterpillars do not usually encounter on tender new leaves. The virus and the bacterium are insecticides newly enlisted by farmers. They are spread on the plants like other insecticides by crop-spraying aircraft. Since they are relatively inexpensive to use and are nontoxic to plants and other animals, their success gives promise that microbes may become an effective addition to man's arsenal for protecting his health and his crops from insect pests.

Insects, like human beings, are subject to infection by a whole battery of



INCUBATION OF BACTERIA for use as insecticide can be conducted inexpensively on a large scale, as shown in this laboratory at the University of California. The 210 bottles here provide 70 square feet of agar surface. Cultures may be harvested in a week.

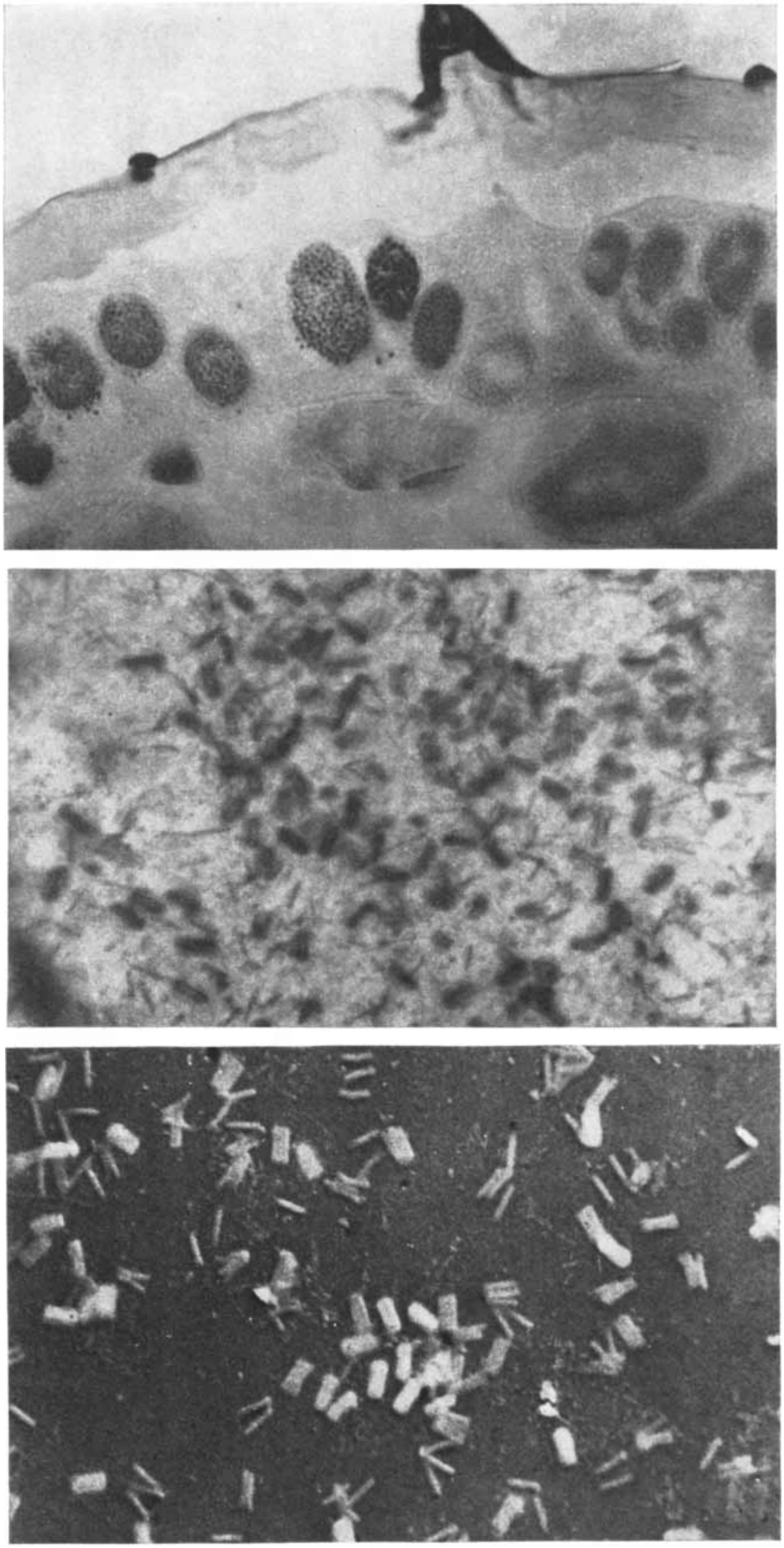
microorganisms—bacteria, fungi, viruses, protozoa and so on. Some of their diseases, notably those that attack the honeybee and the silkworm, were familiar before the time of Aristotle. In efforts to protect these beneficial insects man gained some comprehension of the nature of infectious disease in general. Investigating a fungus disease of the silkworm, Agostino Bassi in 1834 proved for the first time that disease could be caused by a microorganism. It was a study of diseases of the silkworm that started Louis Pasteur on the road to founding the science of bacteriology. Modern medical science owes an everlasting debt not only to these two men but to the diseases of the lowly silkworm that attracted their attention.

From the very first, students of the infections of insects were intrigued by the notion of using diseases to kill insect pests. In 1879 Elie Metchnikoff, who was later to be Pasteur's successor as head of the Pasteur Institute and winner of one of the first Nobel prizes, made a significant experiment along this line. He was able to infect larvae of the wheat cockchafer by inoculating a pot of soil containing insects with a pathogenic fungus. This success inspired I. M. Krasilshchik of the University of Odessa to establish a special laboratory in 1884 for the purpose of producing spores of the fungus on a large scale.

Just what became of the Odessa laboratory is not clear. Apparently it was abandoned because of practical difficulties, which have continued to dog the efforts of workers in this field. Until recently these difficulties made the prospect of microbial control of insects almost as hopeless as it was intriguing. Typically experimenters would report initial success with a fungus or a bacterium against the chinch bug on cereal crops in the U. S., against grasshoppers in Latin America and Africa or against the European corn borer in Europe. But workers who followed up were never able to obtain results as effective as those reported by the original experimenters.

In the early trials they would inevitably discover that success depended too heavily upon the weather: that is, a particular combination of humidity and temperature. In the case of bacteria, knowledge and techniques were not far enough advanced as a practical matter to insure the identity of the cultures used, to maintain their virulence and apply them with success under all the varying conditions of the field. Investigators would finally come to the discouraged conclusion that since these

ALFALFA CATERPILLARS crawl on an alfalfa plant in the Imperial Valley of California. The insect (*Colias philodice eurytheme*) is one of California's most destructive pests.



POLYHEDROSIS VIRUS is so called because it forms polyhedral inclusion bodies in the cells of its host; these can be seen as black dots in the photomicrograph of alfalfa caterpillar tissue at the top. The electron micrograph in the middle shows virus particles in a cell nucleus. Some of them form bundles. The individual and bundled particles, dried and shadowed with palladium, are shown at higher magnification in the electron micrograph at the bottom.

pathogens abound in nature anyway, there was little value in disseminating more of the same. Farmers and foresters were often overjoyed to see impending plagues of insect pests halted by natural outbreaks of disease which would virtually eliminate the insects for the season and frequently for years afterward. But in spite of Nature's spectacular successes, there seemed to be no way to put such diseases to work under control.

Interest was rekindled in the 1930s, however, by the famous success against the destructive Japanese beetle. Samson R. Dutky and Ralph T. White of the U. S. Department of Agriculture investigated the so-called milky diseases of this beetle. They identified the bacteria responsible for the diseases, learned how to produce spores in sufficient quantity for field distribution and applied the spores to the soil in order to infect the grubs of the beetle. One of these bacteria, *Bacillus popilliae*, proved especially effective. Just before World War II the Department of Agriculture and several state agencies began extensive distribution of this enemy of the Japanese beetle, and by now, with the additional help of new chemical insecticides, the beetle has been brought under control in many areas where it was once an unstoppable pest.

The Japanese beetle success did not, however, clear away the doubts that had been engendered by the previous history of failure. The milky disease is a special case in many respects. The disease fell as a new infection upon a dense and unresisting population. Furthermore, the beetle grub was attacked by the spores of the bacillus underground, where moisture is always present. Many still felt that microbial insecticides would work only in exceptional circumstances where humidity and other conditions met exacting specifications.

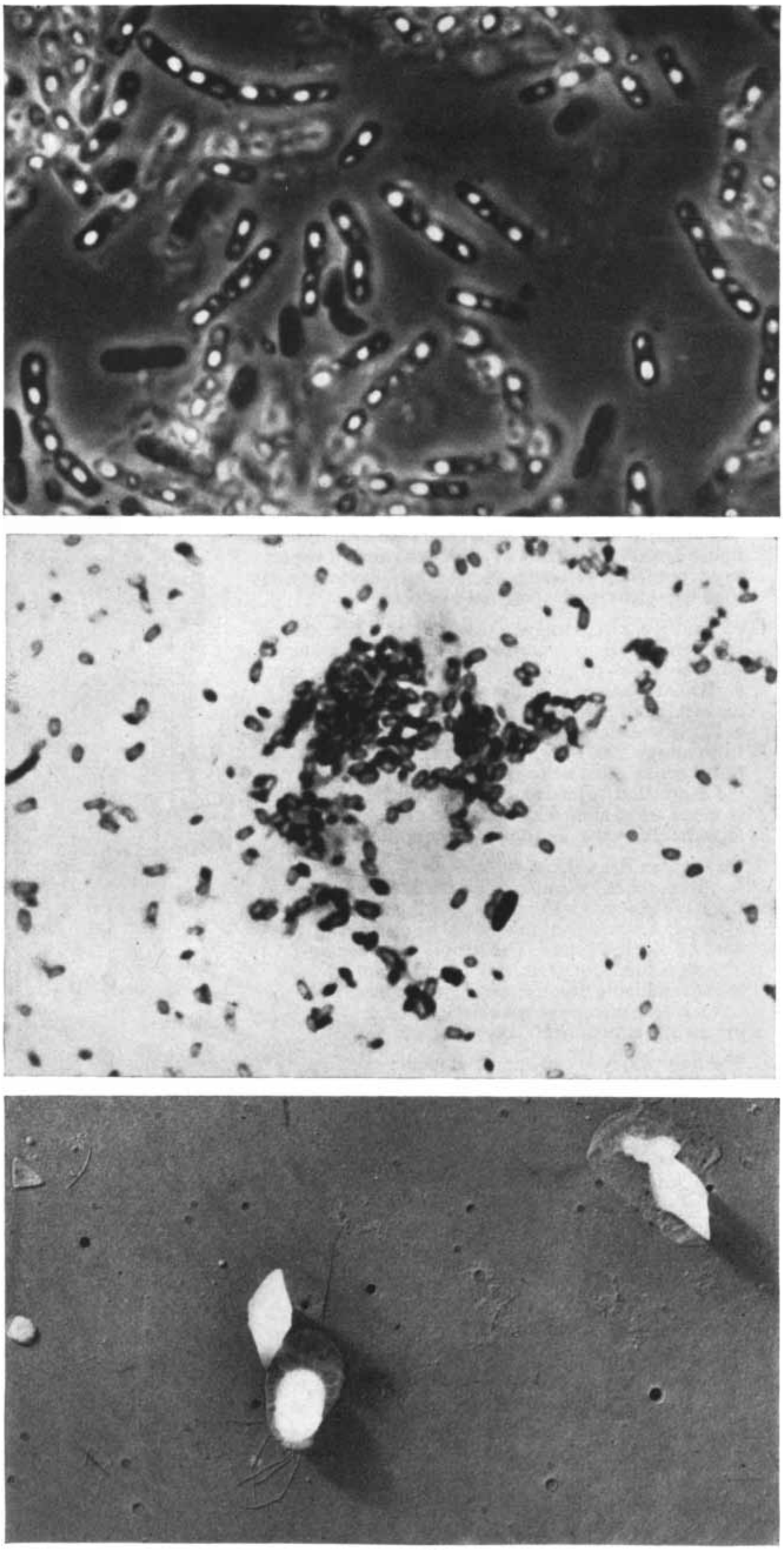
But some of us were led to wonder whether moisture in the environment was really as necessary as was generally supposed. This assumption had developed from the early work with fungi. It seemed to us that an important general distinction could be made between fungi and other pathogens, such as bacteria and viruses. Fungi are dependent upon moisture in the environment because they usually invade their hosts through the body wall. A fungus spore lands on an insect; if conditions are just right, it sends out a threadlike hypha that penetrates the body cavity. On the other hand, bacteria and viruses ordinarily find their way inside the bodies of their hosts via their food. The moisture required for their development is then provided automatically by the insect's internal environment. There seemed to be reason to hope that the requirements for successful microbial attack on insects were not as critical as had been thought.

So it was that in 1945, at the newly organized Laboratory of Insect Pathology in the Department of Biological Control of the University of California, we undertook to investigate the possibility of microbial control of the alfalfa caterpillar. This insect, *Colias philodice eurytheme*, is one of California's most destructive pests [see "Insect Control and the Balance of Nature," by Ray F. Smith and William W. Allen; SCIENTIFIC AMERICAN, June, 1954]. We chose as our first disease agent a virus which forms large numbers of polyhedral bodies in the tissue cells of the infected insect. In the basic phase of our investigation we had the advantage of the work of earlier investigators on similar virus diseases of the silkworm, the gypsy-moth caterpillar and the nun-moth caterpillar. They had established the viral origin of these diseases and thus facilitated our isolation and identification of the caterpillar virus. The next phase was the practical one of working out methods for artificial application of the virus.

In nature this disease does not attack the alfalfa caterpillar until too late. While the newly hatched caterpillars are feeding on the tender new leaves of the alfalfa plant in spring and early summer, the leaves are free of virus. It is only late in the season that the virus, lurking in the soil and surface debris, becomes widely disseminated among the plants, usually by gusts of wind and by water. By then the caterpillars have done their worst; even if the disease kills them off, they die on a ravaged crop.

Our first step was to see whether we could get the virus placed artificially on the plants by means of a spray or dust. C. G. Thompson, a graduate student in our laboratory (he is now in charge of the U. S. Department of Agriculture insect pathology program) undertook this field work. He prepared virus suspensions by mashing up the bodies of virus-killed caterpillars, and this material was sprayed on the plants. The results were immediately encouraging. The caterpillars were so susceptible to the spray that ingestion of a minute amount caused them to sicken and die in about a week. Even populations of low density could be destroyed, for spread of the disease did not depend on dissemination by sick caterpillars.

The test showed, then, that a caterpil-



INSECTICIDAL BACTERIA (*Bacillus thuringiensis*) **are shown in the photomicrograph at the top. The brightest spots within the bacteria are their spores. The slightly dimmer spots are crystals of a toxin that is lethal to insects. The photomicrograph in the middle shows the spores and toxin crystals. To the left and below the center of the electron micrograph at the bottom is a spore of the bacterium with a diamond-shaped toxin crystal beside it.**

lar population could be checked in time by spraying the leaves with the virus early in the season. It appeared also that there was no danger of the alfalfa caterpillar becoming resistant to the virus. Indeed, there is no evidence that resistant strains of the insect have developed in California in spite of the fact that it has been attacked by this virus for more than 50 years.

But what about humidity and temperature? This question was neatly answered by Thompson. He placed 20 caterpillars in small screen cages in a jar in which the relative humidity was so low that five of the test larvae died of desiccation. The food of the caterpillars was dusted with dried virus material. All of the caterpillars that survived desiccation died of the virus disease at the end of a week. By similar experiments Thompson showed that, within the temperature range in which the insects are active, susceptibility is independent of temperature. These were simple experiments, to be sure, but they were important in settling doubts that had been raised by earlier experiments with fungus diseases.

By 1950 we were able to report that epizootics of the disease can be induced in the field virtually at will even in the absence of high humidity and high population densities. We found that the bodies of approximately five diseased caterpillars provide enough virus to cover an acre of alfalfa. The virus keeps its virulence throughout indefinite periods of storage. When the time comes for application, the dried-up caterpillar bodies are simply stirred into solution in water. One caterpillar per gallon yields a standard concentration of approximately five million polyhedrons per quarter of a teaspoon, each polyhedron containing several hundred virus particles. This suspension is sown over the fields by aircraft.

To achieve economically significant results, it is necessary to apply the virus early enough in the life of the caterpillar to allow for the five- to seven-day incubation period of the disease. If the virus is applied after the caterpillars have grown large, the insects have time to devour the crop before the virus kills them. Practical use of the virus also requires the eye of a trained entomologist to determine whether the caterpillar population in a particular alfalfa field is likely to become big enough to warrant the expense of treatment.

With this limitation on the usefulness of the virus in mind, we kept on the lookout for other possible disease agents. One turned up with the discovery that

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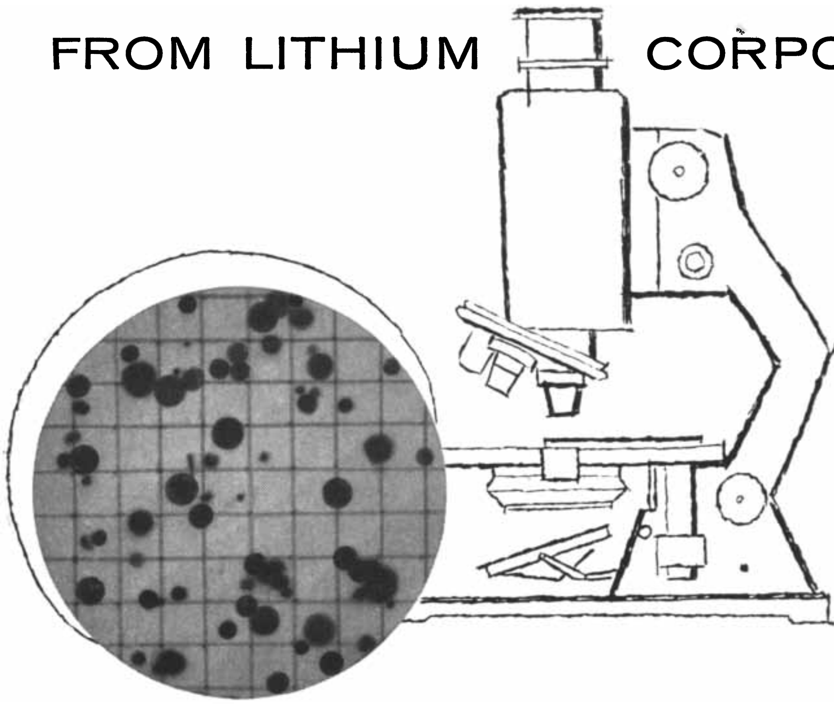

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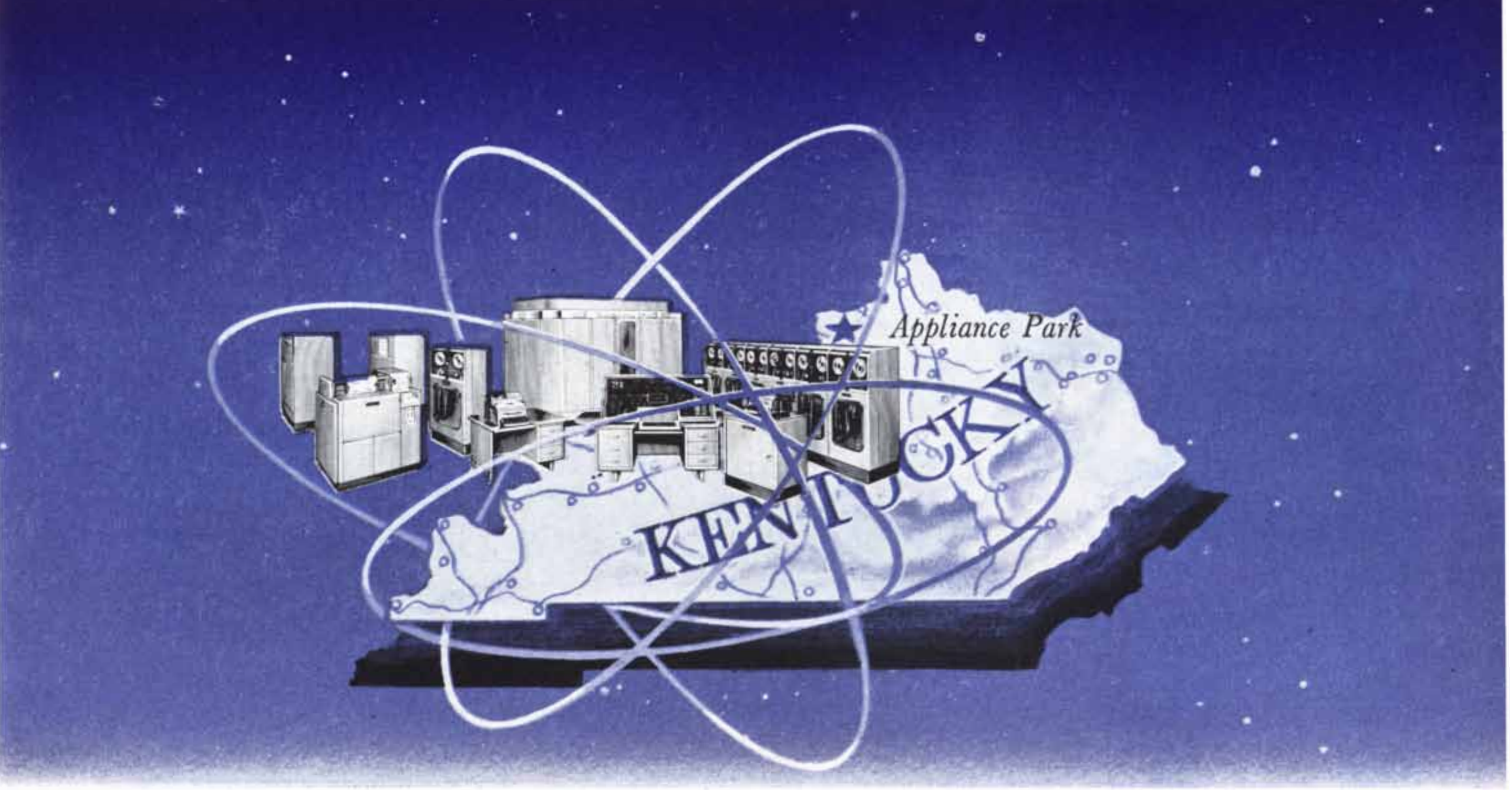
We set up nine test plots with corresponding control plots in separate alfalfa fields and applied varying concentrations of spores. Within 24 to 48 hours after the spray applications, the caterpillars showed the symptoms typical of most bacterial infections—sluggishness, diarrhea, discoloration and flaccidity. After death the bodies of the insects darkened, softened, putrefied and gradually dried down to a brittle scale. In seven of the nine test plots the caterpillar population was brought below economically harmful levels—about 20 larvae for each two sweeps of an entomological net. Meanwhile in the control plots the population remained at a destructive level of 60 to 90 larvae. Later field tests showed that artificial dissemination of this bacillus can cause epizootics not only among alfalfa caterpillars but also among a number of other species of insects.

Besides its faster action, the bacillus disease has another distinction which may or may not give it superiority over the virus. Caterpillars killed by the virus frequently leave a smear of putrid tissue on the hay, because their body wall breaks down; those killed by the bacillus, on the other hand, still have an intact skin and simply drop off the plant. Thus the hay is sweeter for animals and men. Of course this may carry a disadvantage from the standpoint of killing caterpillars, for the virus disease causes the dead insects to leave viruses on the plant to kill later comers.

Investigation of this bacillus has opened up the possibility of a new type of chemical insecticide. The killing power of the bacillus appears to reside mainly in a markedly toxic crystal formed in the bacillus. The crystal retains its toxicity for years. Its presence probably explains why this bacillus, unlike most bacteria, keeps its virulence through many years of artificial culture. Further studies may show that we have here a substance which kills certain insects but is harmless to other life.

While we have proceeded with our work on control of agricultural pests, investigators in Canada have been developing microbial agents for the protection of forests. In 1944 R. E. Balch and F. T. Bird began work with a virus that infects the European spruce sawfly. By a

BACTERIAL SPORES are harvested after separation from culture. For use in the field they are mixed with water and sprayed on the plants in the same way as a chemical insecticide.



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AIRPLANE SPRAYS an alfalfa field in California with insecticide. The flat expanses of the Central and Imperial valleys are particularly well-suited to this kind of operation.

combination of this virus and certain other parasites the spruce sawfly has been brought under control, at least in certain areas. More recently Bird has reported the successful introduction into Canada of another virus specific for the European pine sawfly. Limited applications of this virus, brought over from Sweden, have killed off sawflies on a large scale in infested forest lands.

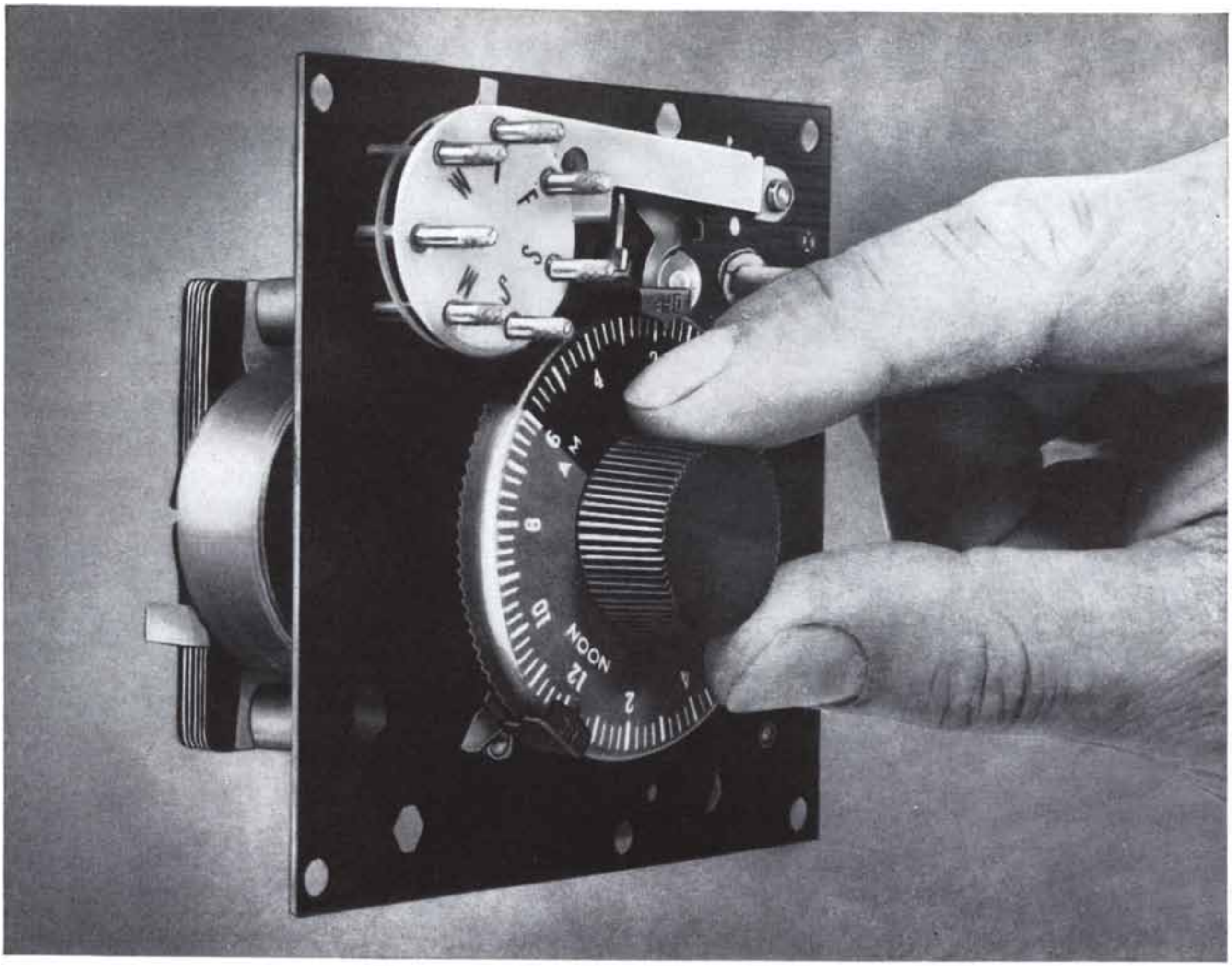
Progress with the viruses and bacteria has encouraged the investigations of other agents. There are indications that good results will eventually be obtained with protozoa and possibly even with parasitic worms. And fungi are by no means out of the picture as possibilities. They are the microorganisms that offer most hope for microbial control of nonchewing insects that feed by sucking plant juices. We need to discover strains of fungi which do not require high humidity to invade their insect hosts; it may then be possible to find ways of applying the moderate amount of moisture needed for infection by the fungi.

Economical large-scale production of the living insecticides remains a problem. Most bacteria and fungi can be produced with comparative ease on artificial culture media. But the viruses and the protozoa are a different story. Some of them can be bred satisfactorily in quantity on insects in an insectary, but some of the potentially useful ones have not yet been grown successfully under artificial conditions. Microbial control of insects would be materially advanced if convenient and inexpensive culture methods could be developed.

Applied insect pathology must contend with a number of other problems calling for research to enhance the reliability and flexibility of operations in the field. One concern is the difficulty of finding exactly the right time to apply each insecticide. Another is the long incubation period of some of the diseases.

In a few cases in which problems of this kind have been solved, the advantages of microbial control stand out. Compared with chemical insecticides, microorganisms are relatively inexpensive to produce. They leave no dangerous or toxic residues. They are harmless to plants and higher animals, including man, and indeed most of them are specific to their hosts, sparing beneficial insects. Furthermore, microbial agents can be used in various ways: in direct sprays or dusts, in combination with chemical insecticides, in conjunction with other insect parasites and predators. Some of them offer the unique advantage of becoming established in insect populations and providing lasting control.

Insect pathology is still a young science. From the few experiences recounted in this article, it would appear that the skepticism engendered by the highly publicized failures of the early pioneers is no longer justified. But, equally, no one should claim that pathogenic microorganisms are a panacea or that they will replace chemical insecticides. It is sufficiently satisfying that groups of scientists in a dozen different countries are bringing this intriguing idea to realization and adding a powerful new weapon in man's fight against the insects.



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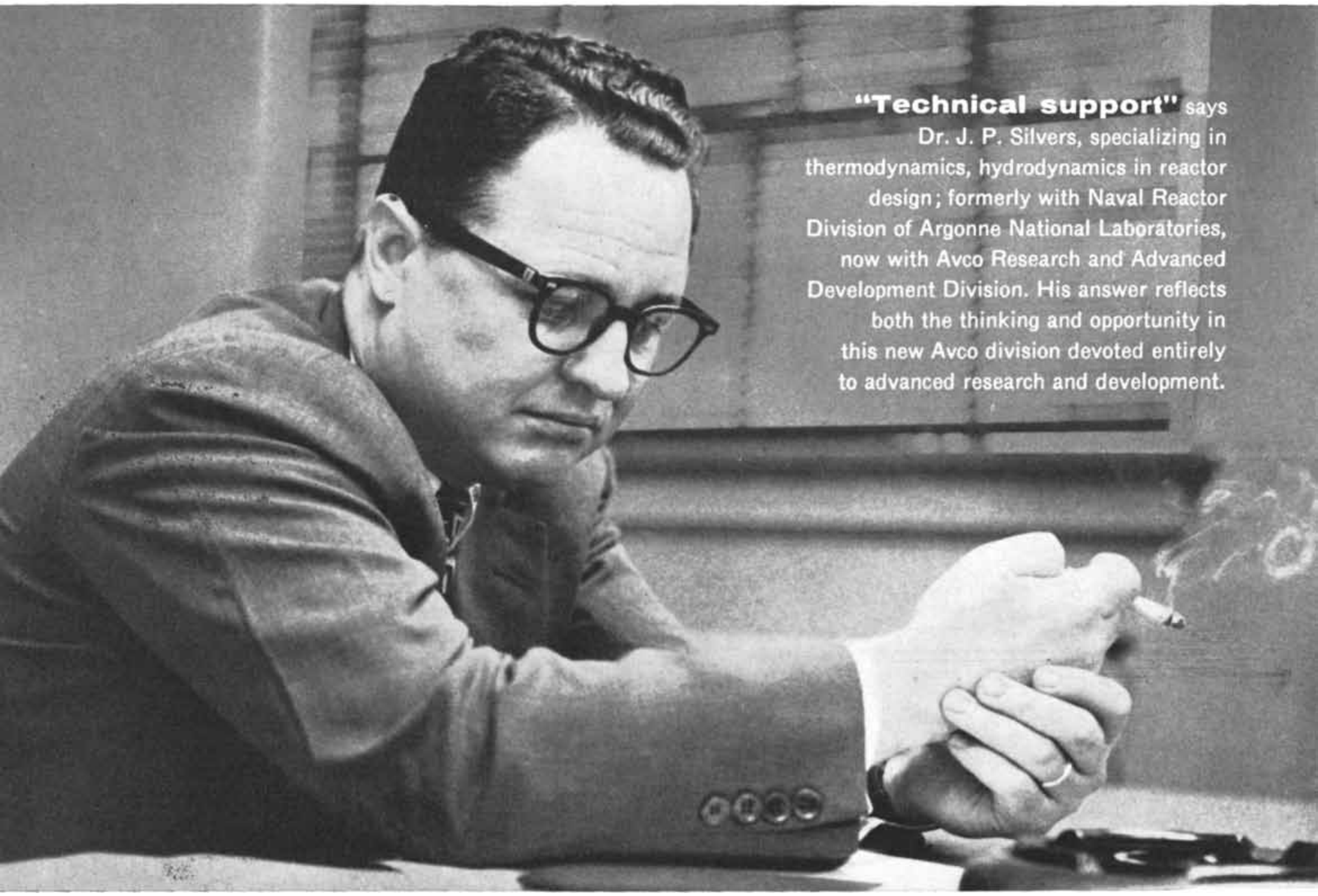

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TIME REVERSAL

Nothing in the laws of physics prevents time from running backward as well as forward, in microscopic events. But the law of averages is against it in the macroscopic world

by John M. Blatt

"Backward, turn backward, O Time, in your flight!" pleads the common song—but time flows ever onward, oblivious of our desires. What law of nature makes time so irreversible? The answer, for anyone who gives systematic thought to the matter, is rather unexpected. It turns out to be by no means easy to understand why time *is* irreversible!

Consider a collision between two billiard balls on a billiard table. If we make a movie of the collision and play the film backwards, we see the motions of the balls reversed in time [*see illustration below*]. Newton's laws of motion say that, assuming the collision is perfectly elastic and the effects of friction can be ignored, the forward and backward motions will be absolutely symmetrical. That is to say, there is nothing in the fundamental laws of motion to forbid time reversal.

But you properly object that frictional effects do exist. Let us take friction into account. In the forward sequence the balls lose speed by friction with the billiard table until eventually they stop moving. The energy of motion has been converted into heat: *i.e.*, the surface of the billiard table and the billiard balls themselves are slightly warmer than they were at the beginning of the motion. Now on every practical count a time reversal of this sequence is preposterous: the two balls would have to start moving for no apparent reason, would accelerate more and more, gaining energy from slight cooling of the table and balls, and would continue to accelerate after the collision until they reached the original state. Such a happening would violate all our intuition as well as the second law of thermodynamics, which says that with the system in temperature equilibrium, as the balls and table are at rest, the heat energy in the system could not be converted into energy of motion to move the balls. Hence it seems that as soon as we become realistic and take frictional forces into account, we find that time reversal is actually impossible.

But let us look a little more closely. What, after all, is the cause of friction? Friction is the result of innumerable little collisions between irregularities on

COLLIDING BILLIARD BALLS represent a phenomenon which is, making certain assumptions, reversible. In the drawing at left the balls are seen at rest. The center drawing shows their collision and final position. The drawing at right shows the episode reversed.

REVERSIBLE REACTION involves hydrogen atoms (*open circles*) and oxygen atoms (*black circles*). They combine to form water, which can dissociate into hydrogen and oxygen.

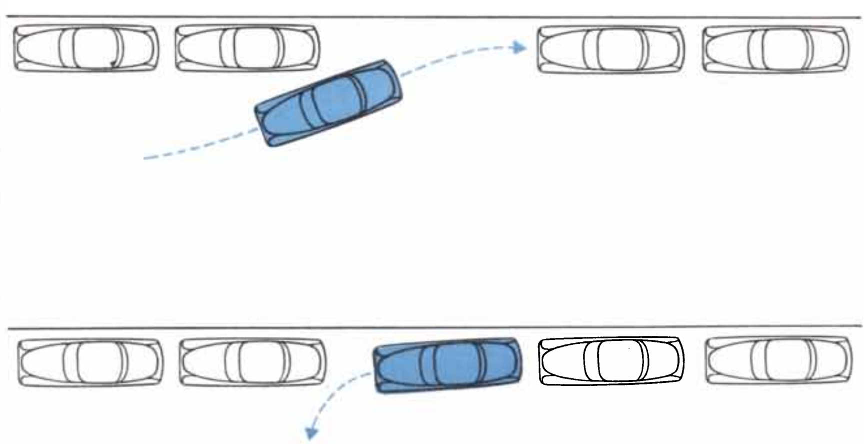
the surface of the billiard ball and the surface of the billiard table. Each of these elementary collisions obeys Newton's laws of motion—or, more accurately, the laws of quantum mechanics, which likewise allow time reversal. Thus the laws of motion still do not rule out time reversal at the microscopic level.

At this point one may begin to ask whether there is something wrong with the laws themselves. However, it is possible to show that the laws of motion and time-reversal symmetry both stand up when their consequences are examined and checked by experiments. The proof involves the so-called "reciprocity law."

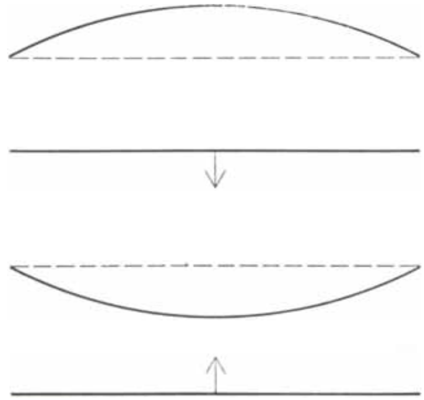
Consider two radio "hams"—Abraham in New York and Becker in Los Angeles. Each has a short-wave transmitter-receiver set, using a single antenna both for transmitting and receiving signals (though the antennas of Abraham and Becker may be very different). Abraham starts to transmit. His antenna is energized by a current of a certain strength and proceeds to emit radio waves. These waves are eventually intercepted by Becker's antenna, where they produce a certain voltage which is amplified by his receiving set. Becker then replies to Abraham's message by actuating his own antenna to transmit. The reciprocity law asserts that if he uses an exciting current of exactly the same strength as Abraham did, Abraham's set will receive a voltage precisely equal to that received by Becker. In general, even though the exciting current is different in the two cases, the reciprocity law says that the *ratio* of the received voltage to the transmitting current is always the same at the two antennas, regardless of differences in the antenna designs, of atmospheric conditions, of topography, of the locations of the two sets on the earth's surface, and so on. This reciprocity law has been confirmed experimentally and has been found to hold true in many branches of physics.

Now it seems demonstrable that the reciprocity law holds true if the basic processes occurring in the system under consideration allow time reversal. In other words, time reversal implies reciprocity. Thus an experimental proof of the reciprocity theorem gives strong support to the possibility of time reversal. Frictional effects do not matter here. Lars Onsager, the noted physical chemist (now at Yale University), showed in 1931 that the reciprocity laws are direct consequences of time-reversal symmetry in elementary collisions—often called "microscopic reversibility." This symmetry holds true on the microscopic scale even when the macroscopic phenomenon in question seems irreversible.

Basic work on reciprocity or reversibility at the atomic level, in the realm of quantum mechanics, was done in 1932 by the mathematical physicist Eugene P. Wigner, now at Princeton University. He showed how the reciprocity theorem



PRACTICAL IRREVERSIBILITY of a theoretically reversible operation is illustrated by the fact that it is much harder to get a car into a tight parking space than out of one.



VIBRATING STRING shows reversible action. Parts of string are "in phase," *i.e.*, reach their maximum displacement together.

can be applied to atomic collisions. Consider the combination of oxygen and hydrogen molecules to form water, and the reverse reaction—decomposition of water into oxygen and hydrogen. The reciprocity law of quantum mechanics asserts that, apart from certain statistical factors, both reactions have equal probabilities if the system has the same total energy in each case. The "if" is important. When two hydrogen molecules react with an oxygen molecule, forming two molecules of water ($2H_2 + O_2 \rightarrow 2H_2O$), the reaction liberates energy which appears in the form of kinetic energy of the two water molecules, flying apart from each other at great speed. The exactly inverse reaction ($2H_2O \rightarrow 2H_2 + O_2$) can occur only if two water molecules approach each other with precisely this speed. A similar reciprocity law holds for nuclear collisions.

Some physicists maintain that while the equations of quantum mechanics seem to allow time reversal, there is a fundamental consideration which explains why it is ruled out in the real world. Observation or measurement of any system disturbs the system irreversibly. This, they argue, accounts for the obvious irreversibility of time.

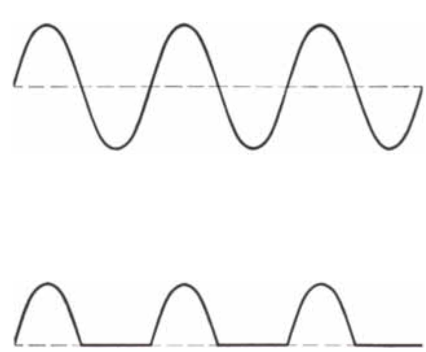
In my opinion the argument is a false trail. It says in essence that time reversal is possible as long as no one looks at the system but becomes impossible as soon as anyone observes it. Surely the irreversibility of time does not depend on such an accident as human observation of its effects! Are we to suppose that time was completely reversible before living observers arrived on the earth? Would it become reversible if all life were extinguished by superbombs?

We come back to the problem with which we started. If all elementary processes allow time reversal, why is time so patently irreversible on the macroscopic scale—*i.e.*, in the world as we see it? Why cannot an organism, for example, retrace its growth and become younger in the process?

The best and most fruitful answer we can find is that statistics, or probability, is against it. As a crude illustration of what this means we may consider an inexperienced driver trying to get his car into a tight parking space. The process is apt to cost him much time and mental anguish. Yet the same driver has little trouble getting his car *out* of the same parking space. Getting in and getting out are time-reversed motions. If the driver followed exactly the same sequence of moves and turns, in reverse order, parking the car would be as easy as getting out of the parking space. But we know it isn't. Why is one so much harder than the other?

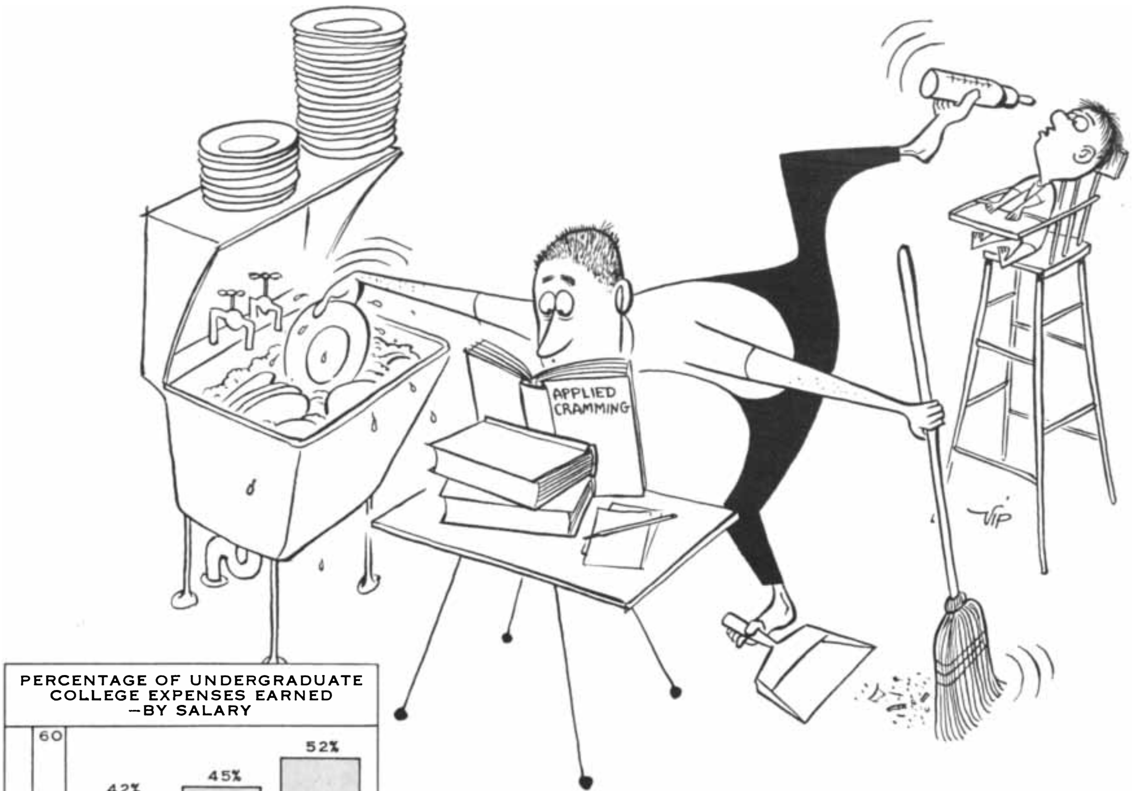
The answer lies in a careful analysis of what we mean by being "in" and "out" of the parking space. Because the space is tight, there is practically only one "in" position. But there are very many ways in which the car can be "out." A small alteration in the getting-out procedure leads to a different final position of the car, but the car is still "out." On the other hand, a small alteration of the getting-in procedure leads to damage claims against the driver, not to another "in" position!

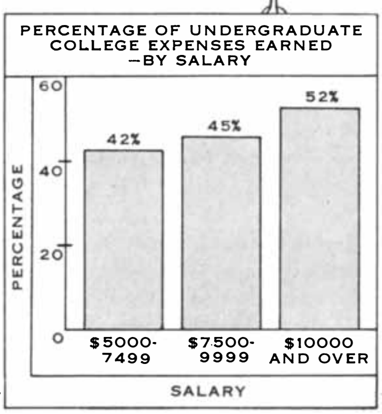
We conclude that time reversal is possible but the odds are against it. The idea becomes clearer when we consider a more elementary example. A gastight vessel is divided into two equal com-



DISTORTION by a rectifier is not reversible. Sending output (*below*) back through rectifier would not restore input (*above*).

SIDELIGHTS ON THE SCIENTISTS *number* **5** *of a series*





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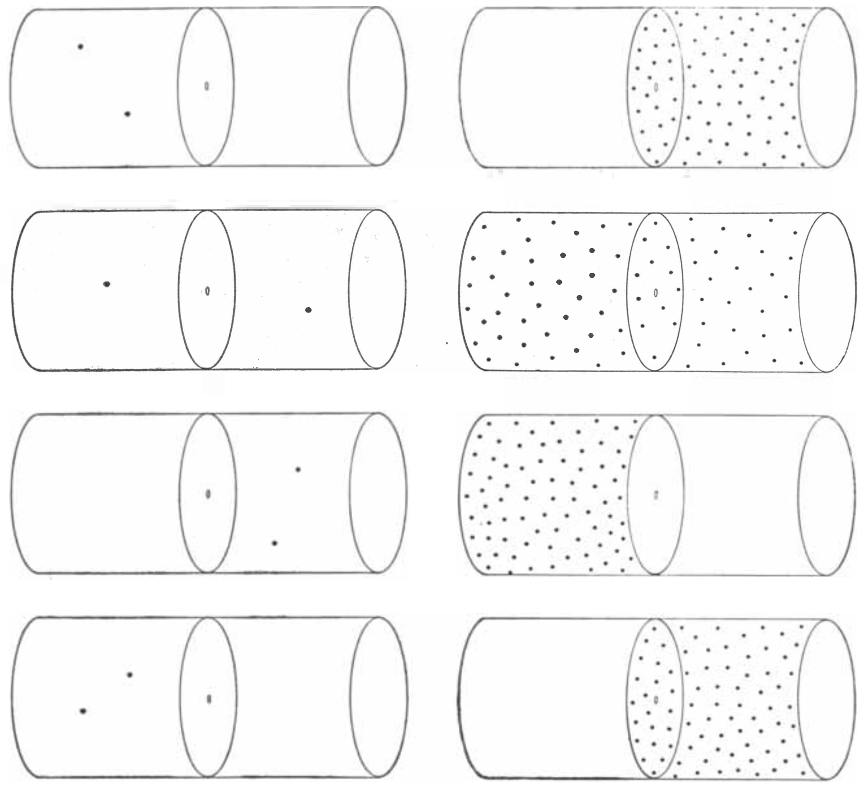

IMPORTANCE OF NUMBER in determining reversibility is illustrated above. Two gas molecules that start in one part of a divided container can easily return there by diffusion (*left*). When many molecules are involved, such an occurrence (*right*) is highly unlikely.

partments. One compartment is filled with gas; the other is evacuated. We now punch a hole in the partition between the compartments. The gas proceeds to diffuse through the hole into the other compartment, and after a certain time the gas will be distributed evenly between the two halves. Since the motion of the gas molecules is time-reversible, it is theoretically possible for all the gas molecules to diffuse back again into the initial compartment, leaving the other side a vacuum again. Yet we are pretty sure this will never happen.

The point is that we would feel fairly sure it *would* happen at some time if there were only two gas molecules in the first compartment to start with. We would then expect that, after the two molecules had had an opportunity to move about in their random motions, at any given instant there would be a probability of 1/4 for finding both gas molecules in the left-hand compartment, 1/4 for finding both in the right-hand compartment, and 1/2 for finding one in each compartment. Thus our "gas" would have a fairly high probability of diffusing back into its initial state.

This probability diminishes, of course, as we deal with more molecules. For a gas with three molecules the probability of finding it back in its initial state is 1/8; for a gas with four molecules, it is 1/16; with 10 molecules it becomes 1/1024; and already for 100 molecules (still much more dilute than the best "vacuum" we can achieve in the laboratory) the probability of return to the initial state is as small as one part in 10^{30}. This is so small that, assuming the mean time of diffusion of a molecule from one compartment to the other were one millionth of a second, the return of the 100 molecules to their initial compartment would take, on the average, more than 30 million billion years—far longer than the entire history of the earth. The situation is similar to that of the driver parking his car: there is only one way in which all the molecules can be in the same compartment, but many many ways in which they can be distributed approximately equally between the two compartments.

In an actual gas, or in the human body, the number of molecules is so large that the probability of an observable time reversal is inconceivably minute. The probability of your body returning to the state in which it was a minute ago is so tiny that your expected

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at 8 second intervals

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lifetime is nowhere near long enough even to *say* the number of million million . . . million years it would take for such a thing to happen.

In short, we conclude that while an observable reversal of time is not excluded, the chances are overwhelmingly against it.

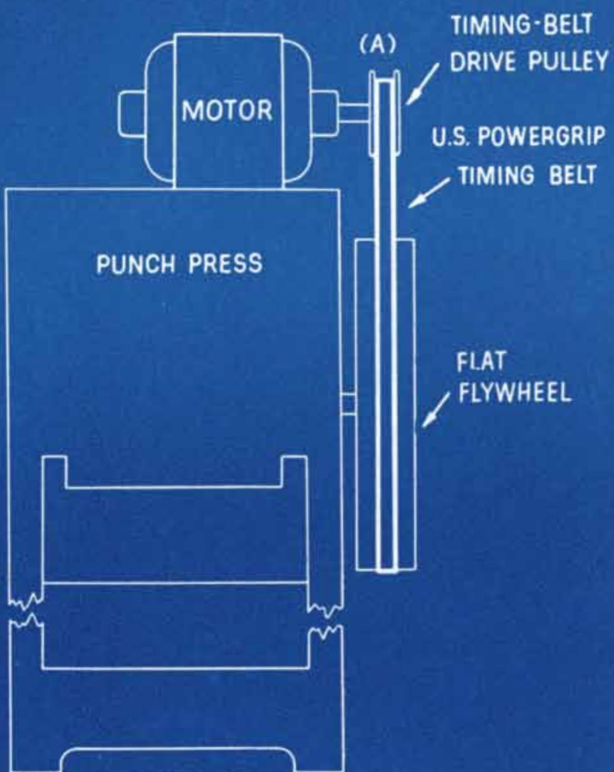
Suppose we unshackle ourselves from mundane conceptions of the duration of time and give ourselves all the time in the universe, stretching on for endless eons into the future. What is the possibility that the universe as a whole will repeat itself? There is a generally accepted principle in mathematical physics, known as the "ergodic theorem" (referring to energy), which says that in a closed, isolated system every elementary state is as likely to occur as every other. Therefore if the universe is a closed, isolated system, there is a finite chance of its returning to precisely the same state in which it stands today, and eventually (after an unimaginably long time, of course) it will do so. This would not be time reversal in the literal sense of a backward retracing of the path; rather, as the universe journeyed on, it would arrive again at a state exactly like the present, just as an airplane flying around the earth may come back to its starting point.

Experts differ about this possibility. The crux of the question, it seems to me, lies in whether the universe is a closed and isolated system. In the view of most cosmologists, the universe is isolated by definition (though this idea is disputed by the school of Fred Hoyle and Hermann Bondi, who assume that new matter is continually being created out of nothing). But whether or not the universe is closed is more debatable.

To our intuitive minds the expanding universe seems "obviously" an open system, extending through an infinity of space. The general theory of relativity, however, has thrown some doubt on this notion. Some of the solutions allowed by the equations of general relativity picture a curved-space universe of finite volume closed on itself, like the surface of a sphere. Such a universe would presumably return eventually to its present position.

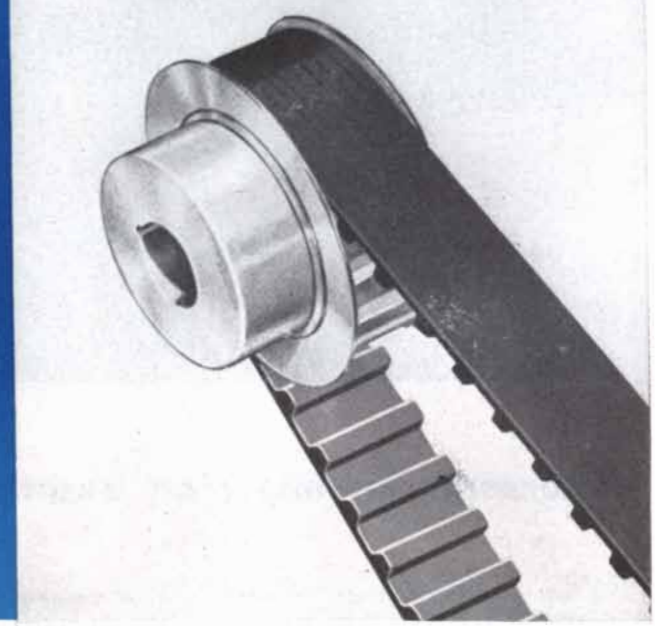
There is no proof, not even a strong likelihood, that the universe is in fact closed in on itself in this (or any other) sense. At the present stage of our knowledge of the universe, it seems to me most reasonable to suppose that the universe we know will never return to its state as of 1956, no matter how long our very very very distant progeny wait.

PowerGrip "Timing" Belts



To eliminate severe belt slippage and consequent burning of belt (at point A) when 5 h.p. motor was started, the conventional pulley and belt drive from the motor shaft were replaced with a grooved pulley and a U.S. PowerGrip "Timing" Belt driving the flat flywheel. The positive engagement of the "Timing" Belt eliminated slippage on the motor pulley completely. The slight remaining slippage is now dissipated over the much greater area of the flywheel. Result: Flywheel gets up to speed *without burning the belt*, thereby reducing maintenance and downtime costs.

How a plant engineer made this press deliver a better punch



This is one more example of the U.S. PowerGrip "Timing"® Belt's ability to simplify and improve a power transmission unit . . . one of the reasons why the invention of this belt was recently awarded the Franklin Institute's Edward Longstreth Medal for "Invention of High Order."

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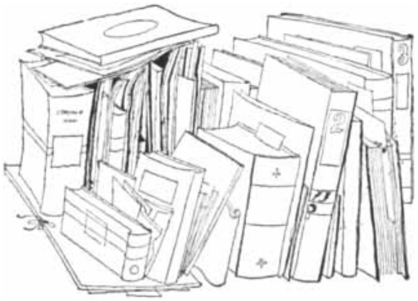


BOOKS

The philosophers of automation speculate about future machines

by John R. Pierce

AUTOMATA STUDIES, edited by C. E. Shannon and J. McCarthy. Princeton University Press ($4.00).

If robots dwelt, or were said to dwell, in some far land; if we had as different accounts of them as Marco Polo and Sir John Mandeville wrote of the unknown Asiatics, one could understand the strange mixture of gross credulity, blasé acceptance, horrified distaste and invincible ignorance that marks some present-day writing concerning them. Most writers of science fiction regard robots and thinking machines simply as good clean fun—amusing subjects for speculation. But there are philosophers and pundits who view automata with hot alarm. One respected author asserts, as nearly as I can tell, that had the Victorians nipped the notion of mechanical "brains" in the bud, using as a weapon "the stubborn fact of consciousness" rather than the existence of the soul, men of today would not think of themselves as machines, and we might have been spared our "age of anxiety." Other alarmists are moved not by moral fervor but simply by the fear that automata threaten unemployment.

All this seems to me a little like fear of the dark. Automatic machines are not demons in the dismal woods of never-never land; they are here among us today. Simple species of them in our homes regulate the furnace, change records and wash our clothes. Factories and offices display more complex kinds. And when you pick up your telephone and dial a long distance number, you put at your service by far the largest and most complex, if not the most subtle, automaton ever constructed by man. Yet few people are particularly astounded by this fact, and I know of no one who dislikes or fears the telephone for this reason. Also, the roster of telephone employees goes up and up.

These automata of everyday experience have largely been designed by clever engineers and tinkerers intent on getting some immediate job done. In like manner men built the first steam engines long before theorists explained thermodynamics. Now we are beginning to hear from theorists and philosophers of automation. The authors of this book, *Automata Studies*, are such men. They write about automatic machines from a realistic outlook on their possibilities and limitations.

The common measure of complexity in the hierarchy of automatic machines is the amount of information that can be stored in the machine's memory. This is usually reckoned in terms of the number of "bits"—a bit representing a binary digit (1 or 0), *yes* or *no*, *on* or *off*, *open* or *closed*. As the index of complexity the machine's bit capacity is usually compared with the number of cells in the human brain—some 10 billion.

The automatic switching system of the Bell System, as used in long-distance dialing, stands at the top of the hierarchy. It is estimated to have a total capacity of billions of bits, but this total is split up among thousands of cooperating machines. Thus the system is a highly cooperative colony of limited creatures rather than one entity.

Next in order of complexity come the large-scale electronic computers such as the IBM 704 and the Univac II. Such machines may have a fast memory of as much as a million bits, from which the machine can extract a given piece of data or an instruction (called a "word") in about 10 millionths of a second. This fast memory is ordinarily backed up by a slower memory of perhaps 10 million bits capacity, stored on magnetic drums or magnetic tapes. Stacks of cards may add a still slower memory of almost unlimited magnitude.

These large-scale computers, though less complex than the telephone switching system, are about 1,000 times faster (because largely electronic) and of course a great deal more versatile. They can solve problems ranging from investigating the stability of an airplane in flight to indexing the words in the Revised Standard Version of the Bible. They have been programmed to play a fair game of checkers, and presumably could play a fair game of chess. But such noncommercial uses are rare, for the rental of these computers ranges from $20,000 to $40,000 a month, and all their time and more is in demand.

The machines are versatile because only a moderate (but sufficient) number of fundamental operations is built into them: such as the ability to add, to subtract, to multiply, to divide, to compare the size of a pair of numbers, to put numbers into or take them out of various positions in the memory, to read into the machine and to print out from the machine. Their great complexity lies in the size of the memory, which stores not only the data concerning the problem and the results of intermediate computations but the instructions for working the problem as well.

Because the operations are sufficient and the memory is used very flexibly, a modern computer can be programmed to imitate any machine sufficiently less complicated than itself. Indeed, such a computer can imitate itself, examining and reporting the contents of its memory and following and reporting every action it performs. Such operation has been resorted to both for program trouble-shooting and as a stunt.

Below these universal, general-purpose electronic computers come various closely related business machines, many of them less speedy and more specialized. There are also many sorts of special machines, ranging in complexity from Claude Shannon's maze-solving mouse and W. Ross Ashby's Homeostat to sets of printed tables for playing ticktacktoe which one can buy in stationery stores. We have Edmund Berkeley's Squee, which picks up nuts; W. Grey Walter's turtles, which can learn and go to a box to be fed; machines for playing certain games; machines for designing relay circuits; machines for solving syllogisms. These special-purpose machines sometimes involve clever inventions which may later be incorporated into larger machines, and they often use clever strategies which might well be used in connection with a general-purpose computer. But the latter could be programmed to imitate the behavior of any of the special machines, though perhaps at a greater cost.

These, then, are the automata of today. The men who build the highest form of machines, general-purpose computers, are continually making them larger, faster and more reliable. The men who use them are continually finding new ways of using them to solve new problems.

The authors of *Automata Studies* include workers who have contributed directly to the computer art, notably Shannon and John von Neumann, but most of them are scientists (chiefly mathematicians) in other fields. They bring a variety of talents to bear on the problems discussed.

The resulting book is not to be read at a rate of 300 words per minute. I don't believe that many people will read it all the way through with complete understanding. The subject is difficult, and the material is new. Yet happily there is material in this book which is fully accessible to any inquiring mind. Something of the meaning of the results of the more difficult work can be gained even if the proofs are taken on faith. Certainly this is a book worth having and tackling. Fully reading and thoroughly understanding it, however, would take a long time and much help.

Aside from the clear and engaging preface by the editors, perhaps the most readable material in the book is a paper by the philosopher J. T. Culbertson entitled "Some Uneconomical Robots." Culbertson engagingly gives us (in principle) a way of "constructing a robot with behavioral properties just like John Jones or Henry Smith or in constructing a robot with any desired behavioral improvements over Jones or Smith." Culbertson starts out with a supply of elements which he calls "receptor neurons," "central neurons" and "effector neurons." In a straightforward way he tells how to build out of these neurons the most general possible memoryless robot. Such a creature could be made to perform some particular one among many possible acts (*e.g.*, to destroy a man), on receiving a particular stimulus (*e.g.*, seeing a man). Going on from this point, Culbertson shows how to synthesize a robot with "any specified behavioral properties whatsoever." Its behavior would depend on its entire experience.

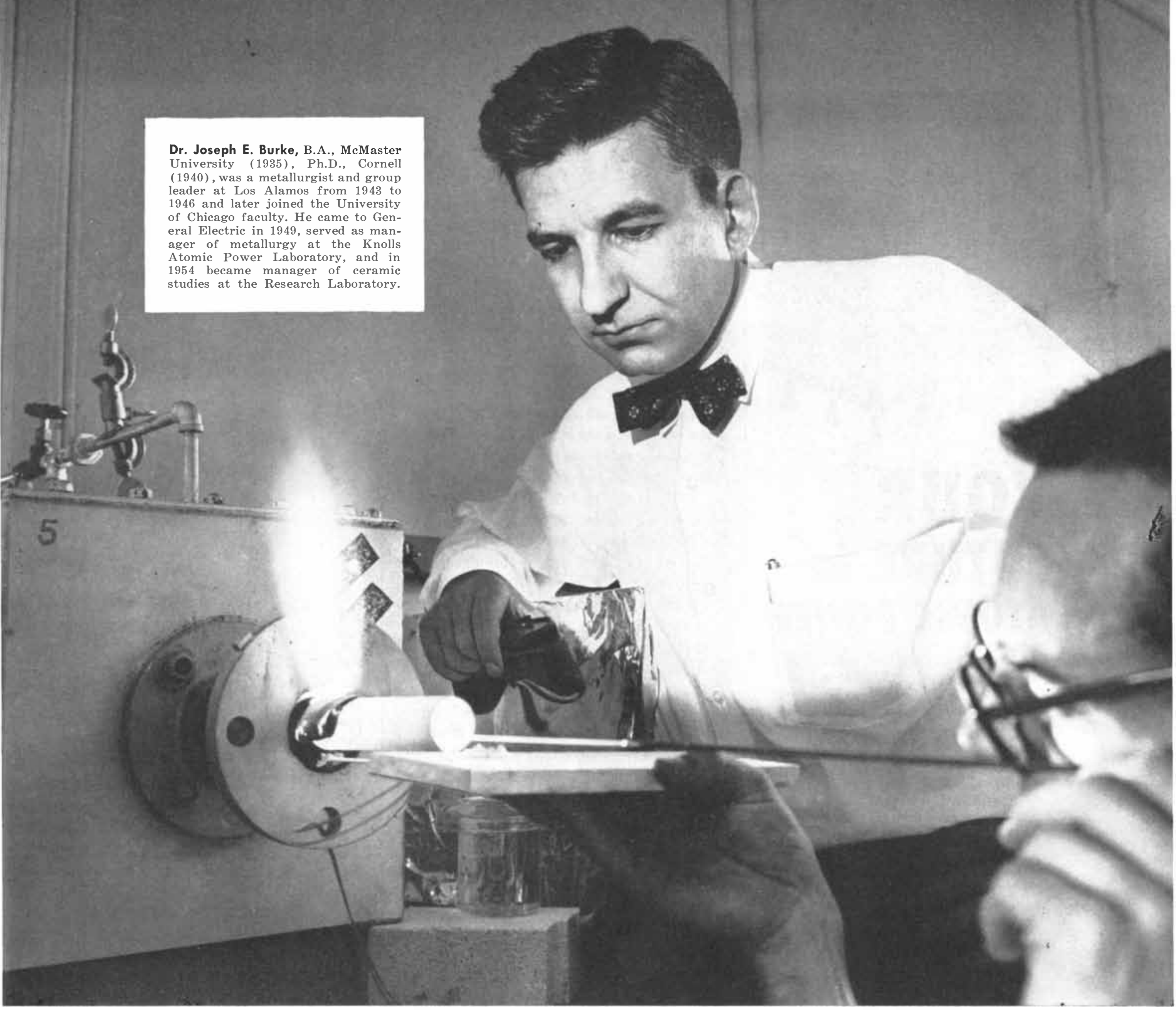
Culbertson realizes as well as anyone that the robots he discusses would be impossibly complex to build. Consider, for example, a very simple robot which would be called upon for just 10 successive exhibitions of behavior, each time choosing one among eight possible acts on the basis of receiving one among eight pieces of information. This robot, constructed according to Culbertson's method, would require about a billion neurons. Moreover, the number of different robots of this size that could be built is 1 followed by a billion zeros!

As Culbertson points out, the difficult problem is: "What sort of design can the brain have to accomplish human behavior with only 10^{10} cells? It is certainly not any relay design ingeniously fitted into a neurological straitjacket."

Edward F. Moore treats a different problem. Given an automaton which will respond to a sequence of input symbols by producing a set of output symbols, what can we learn of the nature of the machine without lifting the lid and looking inside? The paper explains sequential machines, in the terms of a certain number of internal states and of a table or diagram showing what the output symbol is for each state and what new state the machine will assume if a particular input symbol is received when the machine is in a particular state. All of this is fundamental to other work in the book. One interesting outcome of Moore's work is somewhat analogous to Heisenberg's uncertainty principle in physics. He points out that if we perform an experiment to answer the question: "Was A [a certain sequential machine] in state q_2 at the beginning of the experiment?", the performance of the experiment so changes the state of the system that it is impossible to find the answer to the question: "Was A in state q_3 at the beginning of the experiment?"

A paper by von Neumann shows clearly that general finite sequential machines can be built up from various sets of standard pieces or organs. He gives a clear and interesting example of a machine which could be said to learn by induction. He also shows how reliable machines can be made from unreliable organs which have a certain probability of giving the wrong output.

The first section of the book deals with "finite automata," the second with Turing machines—machines which can compute any computable number. The late A. M. Turing invented this imaginary machine in order to study certain difficult problems of logic. Shannon establishes rather simply that such a universal machine need have only two internal states, provided that it can print, read and erase a sufficiently large number of different characters on an infi-



Dr. Joseph E. Burke, B.A., McMaster University (1935), Ph.D., Cornell (1940), was a metallurgist and group leader at Los Alamos from 1943 to 1946 and later joined the University of Chicago faculty. He came to General Electric in 1949, served as manager of metallurgy at the Knolls Atomic Power Laboratory, and in 1954 became manager of ceramic studies at the Research Laboratory.

Ceramics for the jet age

General Electric's Dr. J. E. Burke seeks better ceramic materials by studying their microscopic structure

During a decade as a "practicing metallurgist," Dr. Joseph Burke contributed to the knowledge of structure and kinetics in metals. He also developed an interest in the crystalline cousins of metals: ceramics. Recognizing the potential of ceramic materials, Joe Burke turned his talents toward increasing and exchanging the mutually useful information produced by research in both ceramics and metallurgy. Now he is leading an intensive effort at the General Electric Research Laboratory to learn more about the *structure* of ceramics — and the effects of structure on mechanical, electrical and magnetic properties.

At General Electric, ceramics research already has created unique insulators for vacuum tubes, new ferrites for electronic uses, and transducers whose applications range from hi-fi to ultrasonics. As the day of "non-brittle" ceramics comes ever nearer, Joe Burke and his associates expect their non-metals may be the answer to many high-temperature problems of the jet age.

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nitely long tape. It is interesting to note, by the way, that Turing did not agree with those who interpreted Kurt Gödel's famous proof to mean that a machine could not equal the human brain [see "Gödel's Proof," by Ernest Nagel and James R. Newman; SCIENTIFIC AMERICAN, June].

The last section of this book, called "Synthesis of Automata," contains what is probably the most newsworthy paper: Ashby's "Design for an Intelligence-Amplifier." Ashby's prescription for a machine to amplify intelligence is not as clear, however, as Culbertson's for uneconomical robots. As nearly as I can make out, one proceeds about as follows. You ask the machine for, say, a description of a social organization which will be stable under certain specified conditions, to wit: family incomes of no less than $1,500 per year, fewer than 100,000 persons unemployed and fewer than 10 crimes of violence per week. The machine then goes over various possibilities, perhaps by acting as an analogue of trial organizations, and discards those that don't fit the requirements.

Since I have never designed a complicated social organization and can't imagine what the description of one would look like, I decided to consider Ashby's work in connection with a problem I have tried to solve, that of writing a sonnet. Let us specify concerning a sonnet that it must have the Petrarchan rhyme scheme, that it must be on the topic of the possibility of building a sonnet-writing machine and that it must be optimistic in tone. The machine might start out by writing down all the possible sequences of words of about the right length. The number of possible sequences is something like 1 followed by 4,000 zeros. This approach dismays even Ashby. I can imagine the machine starting out with various randomly chosen combinations of rhyme words and then placing randomly before these only such words as scan, to get the meter right in each line. I feel, however, that this process would still produce too many protosonnets for sorting over.

Ashby proposes a lower bound to the number of operations needed to arrive at the solution. As nearly as I can make out, in this case the lower bound would be attained if the machine wrote down a satisfactory sonnet straight off, but we don't know how to make the machine do this.

To be sure, the English language imposes certain constraints on the allowable order of words in a sonnet, and if we could formulate these constraints in a program which would assure that the machine would write only grammatical and idiomatic English, then by adding to this program the easier constraints of rhyme and meter we might be well on our way to success. Indeed, why ask for more? If we used as a title "An Optimistic Sonnet on the Possibility of a Sonnet-Writing Machine," who in these days would dare say we had not succeeded with even less than I have proposed?

The trouble is that no one has yet solved the difficult problem of making a machine produce grammatical and idiomatic English, with or without sense, and I suspect that there would be similar problems in any particular intelligence amplifier that Ashby might propose. All praise for any who solve such problems, and due meed for Ashby, too!

It seems unlikely, however, that we are threatened, or will be blessed, with completely machine-made sonnets, or social systems, in the near future. Nor will we be blessed (or threatened) with the expensive but gaudy uneconomical robots that Culbertson discusses. Nevertheless, thinking about such matters is a form of mental exercise which fits well with the perhaps harder thought required to understand all the limitations and possibilities of Turing machines and finite automata made up of certain universal elements, reliable or unreliable.

Such mental exercise is invigorating. I believe that it tends to chase away gloomy feelings akin to superstition. It need not make either human beings or complex automata seem less wonderful; on the contrary, it can make them seem more wonderful in many ways that one could not otherwise appreciate.

Short Reviews

BRITTEN'S OLD CLOCKS AND WATCHES AND THEIR MAKERS, revised and edited by G. H. Baillie, C. Clutton and C. A. Ilbert. E. P. Dutton & Co., Inc. ($25.00). F. J. Britten's standard horological history is an account of different styles of timepieces from the earliest specimens up to 1830. His book, first published in 1899, has been out of print for nearly 20 years; it is now republished in a thoroughly revised form. The editors have succeeded in maintaining the position of Britten's work, in the face of more recent competitors, as a book which "presents the picture as a whole with all its parts in perspective." The historical record, embellished with magnificent illustrations, is of absorbing interest. It begins with ancient water clocks and the first mechanical timekeepers of the 13th century. St. Paul's Cathedral in London had a clock of some kind in 1286, for whose care Bartholomew the Orologius received a loaf of bread a day and an allowance of beer. The earliest known "alarum clock" was made in Italy in the 14th century. What is thought to be the oldest surviving complete clock, located in Salisbury Cathedral, was made in 1386. It has an iron movement and apparatus for striking the hours, but never had a dial. House clocks were quite common by the end of the 16th century. They were driven by weights, had bells and were held together with pins or wedges, screws being unknown in clocks before 1550. Spring clocks came on the scene near the end of the 15th century. Their emergence depended on the invention of the fusee, a device (credited to Leonardo da Vinci) which enables the timekeeper to "change gear" as the spring runs down, thus preserving a more or less constant torque on the train (*i.e.*, wheels and pinions) throughout its running time. With this advance the mechanism could be reduced in size, and watches came into being. For a century and a half the emphasis of craftsmen was on decoration rather than on accuracy. Specimens of extraordinary beauty were achieved, but a clock in 1650 did well to keep time within five minutes a day. The invention of the pendulum and balance spring—first applied in practical form by Christian Huygens—brought about a tremendous improvement in accuracy within a few years. William Clement and Robert Hooke advanced the art by inventing escapement systems allowing the train to escape by equal amounts at regular intervals. By the mid-18th century the longitude problem was well in hand when John Harrison, after many trials and tribulations, won a prize of 20,000 pounds for his marvelous chronometer, which, after an extremely rough five-month sea voyage from England to Jamaica and back, showed a total error of less than two minutes. Included in this volume are many biographical records of famous makers and an excellent glossary which explains what is meant by such terms as beetle hand, cycloidal cheeks, grasshopper escapement, poker hand, remontoire, semi-dead-beat escapement, skeleton dial, tipsy key, stackfreed, surprise piece, wandering hour dial. An indispensable volume for the collector; for anyone else who can afford it, a joy.

ON THE TRACK OF PREHISTORIC MAN, by Herbert Kühn. Random House ($3.95). In 1864 the archaeologist Edouard Lartet discovered in La Madeleine cave in France a piece of mammoth bone engraved with the figure of a mammoth. Thereafter in further excavations small art objects of stone or bone, evidently made by paleolithic men, were found in increasing number. The great prehistoric picture gallery of Altamira was uncovered in 1879 but, curiously, forgotten for several decades; then, during the half-century from 1903 to 1953, no fewer than 107 caverns yielded Ice Age paintings and engravings. Much has been learned about prehistory from these sources. This book by a scholar at the University of Mainz is a popular survey of the principal centers of paleolithic art, all of which the author has visited and in some of which he has made his own discoveries. His book is informal and anecdotal, knowledgeable and easy to read. With its many illustrations it provides a good introduction to an exciting chapter in man's development.

GEOMETRY IN EGYPTIAN ART, by Else Christie Kielland. Transatlantic Arts, Inc. ($7.25). Miss Kielland's profusely illustrated essay, based on 12 years of study in Cairo and elsewhere, argues the intriguing thesis that Egyptian art, which maintained a striking uniformity of style over a period of several thousand years, was ruled by a clearly formulated method in which geometric principles played a leading part—the ultimate purpose being to express an "immutable equilibrium" of opposing cosmic forces. The plates, she says, "constitute the evidence of my book."

GENETICS IN THE ATOMIC AGE, by Charlotte Auerbach. Essential Books, Inc. ($2.00). In this brilliant little book Dr. Auerbach, of the University of Edinburgh's Institute of Animal Genetics, puts the radiation danger in perspective. To enable the reader to weigh the various factors for himself, she devotes most of her essay to explaining the fundamentals of genetics. She achieves a *tour de force:* a hundred-page exposition of the nature of mutations, their effect on the organism, the shuffling and reassortment of genes, the "dance of the chromosomes," the detection and transmission of a new mutation, the role of mutation in evolution, the production of mutations by X-rays, the "genetically permissible" dose of radiation. There is not one checkerboard diagram in the book, nor a Mendelian ratio, but the concepts are lucidly described in everyday words and the author's sister provides a charming and unusually enlightening set of illustrations. Dr. Auerbach's conclusions run something like this. Recessive gene mutations are more frequent

than dominant ones, lethals more frequent than mutations with visible effect, and harmful mutations without visible effect most frequent of all. It is therefore "not in the least surprising" that no significant increase in freaks or monstrosities has been found among children of persons who survived Hiroshima and Nagasaki, for in general there is simply no effect on the immediate offspring of a person who has received a fairly high dose of radiation in a short exposure. This, however, is no evidence that the radiation has caused no genetic damage. The danger "lies in the fact that mankind already carries a vast number of harmful recessive genes and that radiation adds to this store of potential death, disability and unhappiness." Every one of us, it has been estimated, carries at least eight harmful genes which, "on the road from mutation to extinction, cause a host of minor complaints of body and mind." Since the overwhelming majority of mutations are bad, their effect being comparable to what would happen to a fine watch if one tinkered with it haphazardly, the mutations that man himself adds to this store must sooner or later be paid for by an increase in the sum of genetic deaths and genetically caused ills. How much radiation the individual can take over a long period is in dispute. Dr. Auerbach is of the opinion that the "safe" tolerance has been overestimated.

THE LAWS OF NATURE, by R. E. Peierls. Charles Scribner's Sons ($4.50). Dr. Peierls describes his book as an attempt to set out the principles of modern physics "in simple language and without assuming any previous knowledge." With very little mathematics he escorts the reader through classical physics, relativity, quantum theory, the behavior of electron shells and ionic molecules, the exclusion principle, high-speed electrons, the atomic nucleus, wave mechanics, shell models, mesons and other new particles. A moderately well-informed student can gain from his book a remarkable insight into the logic and unity of physics, how the separate ideas fit together to make a wonderfully coherent structure. No similar treatment in recent years so effectively combines the abstract and intellectual aspects of the science with its real and descriptive parts. But it would be misleading to suggest that this survey is "popular." Peierls does not ease the reader's burden with felicitous metaphors or analogies; the diagrams are few and bare to the point of austerity. It is doubtful whether nonspecialists will be able without intense concentration to follow through to the end the chapter on relativity. The discussion is elegant and concise, but so much is packed into a single sentence or paragraph, and the diagrams are so ungraciously economical, that one has to read the same passages over and over again to break through to the heart of the matter. Even more formidable are the accounts of Maxwell's equations, electron theory, quantum mechanics and other abstractions. The author is determined to tell a primarily mathematical story without mathematics, which is almost as difficult as explaining the game of chess to a beginner without pieces or a board. Nevertheless this is a splendid book for any mature reader interested in the laws of nature. For scientists it affords a broad view and enlightenment on many specific points; for a layman it offers a rich adventure in the upper reaches of modern thought—an adventure he will not regret even when it bewilders him.

MAN'S NATURE AND NATURE'S MAN, by Lee R. Dice. The University of Michigan Press ($5.00). This book deals with the interaction between man, plants and animals living together in natural communities. Man forms partnerships in an ecological system with everything from algae and Brussels sprouts to trout and donkeys. He enriches his surroundings and impoverishes them; he depends on his partners, acts upon them and they act upon him. Members of the system that are not his partners are no less important in his life. Mosquitoes nibble at him from outside, bacteria and parasites from inside; against these and other assaults he must defend himself to survive. Thus again he alters and is altered by his environment. In a human community the ecological interrelationships are made even more complex by social, economic and political factors. Dice considers many of the strands of this vast network. He discusses the dynamics of human populations, the evolution of human heredity. He surveys the regulatory mechanisms that keep the individual organism adjusted to the frequent fluctuations in its environment, and the regulatory mechanisms of human communities, ranging from starvation, disease, war and migration to public opinion, penal sanctions, supply and demand. A long chapter is devoted to the evolution of human communities, another to their deterioration, yet another to interrelations among communities. The style of the book is painfully didactic; Dice is rarely content to say anything less than thrice. All the same his survey is a remarkable synthesis of knowledge, immensely enlightening and stimulating.

THE STORY OF MEDICINE, by Kenneth Walker. Oxford University Press ($6.00). Dr. Walker's popular survey of medicine runs from prehistoric trephining to prefrontal lobotomies. The author, a well-known British surgeon, writes ably about his fascinating subject, touching upon all its major developments. It is an entertaining and instructive book, but it spans so vast a territory in less than 350 pages that it leaves a reader feeling he has hopped, jumped and skipped through the field.

THE CONQUEST OF MT. MCKINLEY, by Belmore Browne. Houghton Mifflin Company ($6.00). In 1906 the late Belmore Browne, a noted explorer and mountain artist, went on an Alaskan climbing expedition with Dr. Frederick Cook, of questionable memory. The party divided, and some time later Cook claimed to have climbed McKinley—a claim which Browne would not credit and was able on a later expedition in 1910 to demolish. Neither on that occasion, nor on his final attempt in 1912 did Browne himself succeed in getting to the true summit of McKinley, but he got heartbreakingly close—within a few hundred yards of the 20,269 foot peak. The thrilling story of the three attempts is the subject of this engrossing book, first published in 1913 and now reissued.

THE HERO, by Lord Raglan. Vintage Books (95 cents). This is a witty and admirably irreverent work of scholarship. Lord Raglan, an enemy of the cliché that where there is smoke there must be fire, holds that myths are myths—not history. His theory is that all folk tales, and their heroes, must be considered completely fictitious unless proved to be based on fact; that is, he takes issue with the common belief that fables must have a factual basis else they would not have originated, much less survived. Raglan is as formidable a slayer of mythical heroes as they were of their mythical enemies. He revokes the credentials of, among others, Achilles, Moses, Elijah, Oedipus, Helen of Troy, Falstaff, Robin Hood, Sigurd, King Arthur, Leif Ericson. The latter, says Raglan, comes right out of Irish mythology. His delightful book, first published many years ago, is now available again in a reissue.

Notes

THE WORLD OF PLANT LIFE, by Clarence J. Hylander. The Macmillan Company ($8.95). This is the second, revised edition of a solid, well-illustrated survey of common American plants.

The Code of Maimonides: Sanctification of the New Moon, translated from the Hebrew by Solomon Gandz. Yale University Press ($3.75). The first English translation of an important document in the history of astronomy and the fixed calendar.

Essays in Biochemistry, edited by Samuel Graff. John Wiley & Sons, Inc. ($6.50). Twenty-seven essays in honor of the biochemist Hans Thacher Clarke on his retirement from Columbia University.

Electronics, by A. W. Keen. The Philosophical Library ($7.50). An introduction by a British engineer.

Meteors, edited by T. R. Kaiser. Pergamon Press Inc. ($8.50). Proceedings of a 1954 University of Manchester international symposium on meteor physics.

The Story of Man and the Stars, by Patrick Moore. W. W. Norton & Company, Inc. ($3.95). A sound, easily assimilable, illustrated short history of astronomy for grown-ups.

The Third Dimension in Chemistry, by A. F. Wells. Oxford University Press ($3.40). An introduction to structural chemistry. The author devotes half of his book to the geometry and packing of polyhedra, repeating patterns and the symmetry and shape of crystals; the second half applies these principles to molecular and crystal structures. Good illustrations.

Non-Euclidean Geometry. Dover Publications, Inc. (Paperbound $1.95). This is an attractive package of reprints containing classics on the subject by the Italian mathematician Robert Bonola, János Bolyai and Nikolai Lobachevski.

The Spirit of Modern Philosophy, by Josiah Royce. George Braziller, Inc. ($5.00). A reprint of the most lively of Royce's works. His book sketches the systems of the principal philosophers from Spinoza through Schopenhauer and Schelling.

Diffusion and Heat Exchange in Chemical Kinetics, by D. A. Frank-Kamenetskii. Princeton University Press ($6.00). Translation of a Russian work giving "a detailed systematic exposition of all chapters of macroscopic kinetics."

THE AMATEUR SCIENTIST

Concerning the professional study of an amateur sport: sailing boats

Ever since *Ranger* met and vanquished *Endeavor II* in the $11,000-per-minute America's Cup competition of 1937, the big yacht races have all been meticulously planned events. Their outcome is more or less decided, in a sense, months and sometimes years in advance of the starting gun in a low brick building that borders the campus of Stevens Institute of Technology in Hoboken, N. J. There, under the critical eye of Randolph Ashton and other specialists in the aerodynamics of sails and the hydrodynamics of hulls, the fleetest racing sloops on earth first demonstrate their prowess as models in an experimental towing tank without benefit of fanfare, crew, wind or wave.

The initial design of a championship hull, according to Ashton, is still largely an art based on long experience. But when experience has been milked dry, a test of a model of the proposed design in an experimental tank can show the designer where he stands and suggest improvements. A bit of planking is then shaved off here or built up there to achieve the optimum hull shape. In the Experimental Towing Tank at Stevens a racing yacht, however appealing esthetically, is viewed coldly as a pattern of force vectors.

A testing setup like that at Stevens is about as far beyond the financial reach of amateur sailors as the 200-inch Hale telescope is beyond amateur astronomers. Ashton does not hold out much encouragement to amateurs who may be tempted to build their own towing tanks for testing sailboat designs. He does believe, however, that any sailing enthusiast who plans to build a boat can profit from knowledge of the dynamics of sailing craft.

"The days of commercial sailing ships of course are gone forever," writes Ashton, "but sailing for pleasure and adventure has probably never been more popular. This year, in particular, with the sailboat competition a prominent feature of the Olympic games to be held in Australia, enthusiasm for racing is at a high pitch. And such a stimulus may account in part for increased interest in the whole realm of sailing.

"At the Experimental Towing Tank we have seen an unusual demand for sailboat model tests during the past year. Most of this demand has come from individuals and syndicates patriotically eager to build contenders for the Olympic races. We have tested many models of designs for the 5½-meter class. One or more of these boats, it is hoped, will be a winner—just as *Llanoria* was in the 1952 Olympics. A model of that boat—a 6-meter craft designed by Sparkman & Stephens, Inc., of New York City—was tested in our tank, and a number of beneficial design changes were suggested. The same testing procedure has been applied to the 5½-meter designs—by the Luders Marine Construction Company of Stamford, Conn.—being prepared for this year's Olympics. Incidentally, the 5½-meter racing boat, though familiar in Europe for some time, is practically new to American waters. It is nearly as long on the waterline as the 6-meter—about 22 feet as against 24 feet—but has a displacement of only about 5,000 pounds, as against 9,900 pounds for the 6-meter. The 5½-meter boat is accordingly less costly to build and handle. As to speed, it is expected from our tests that the '5½' will closely approach the '6' over all, and may even surpass it when sailing at substantially a right angle to the wind—an attitude known as broad reaching.

"Even when a sailboat is not strictly a racing design, its owner usually wants it to go as fast as possible consistent with reasonable comfort. Many an eastern U. S. yachtsman who ordinarily sails principally for pleasure aspires to win the Newport–Bermuda race and shorter ones. In this year's Newport–Bermuda event (June 17 to 20) the first three boats across the finish line had been tested and developed in the Stevens tank. *Bolero* crossed the line first despite the fact that her mainsail had been carried away in a 50-knot wind and she was forced to finish the race on her spinnaker. All three of the boats are from the Sparkman & Stevens yard.

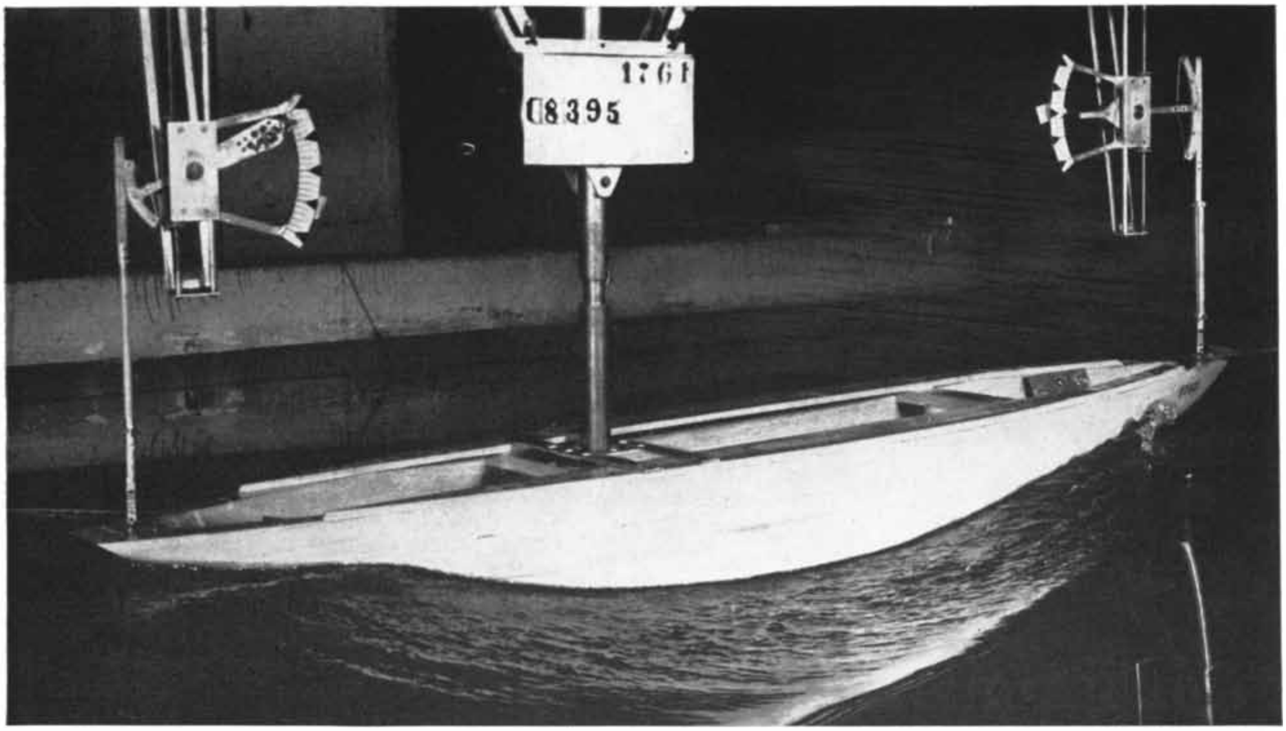
"Good performance is a primary requirement of almost every sailboat design; in fact, *better* performance than that attained by previous boats is what the designer and owner really want. Can this performance be predicted from a given design? If so, what are the theories and methods used?

"Accurate predictions of sailboat performance have been made at the Experimental Towing Tank for the past 20 years. The work was made possible by the fundamental analysis and research described in 1936 by K. S. M. Davidson, director of the laboratory.

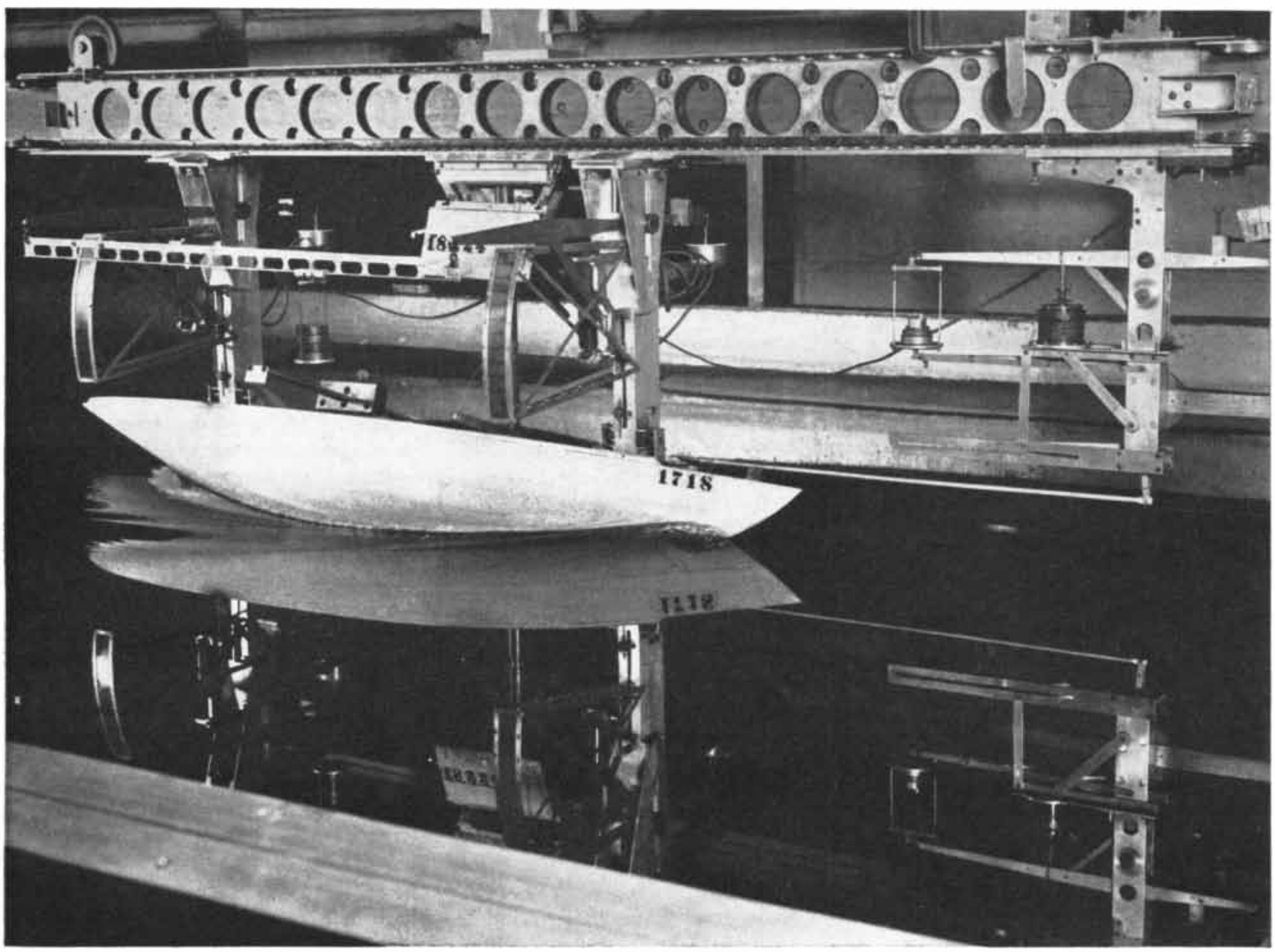
"A boat moving under sail is subjected to a fairly complicated set of wind and water forces. We can simplify the problem, without losing sight of basic principles, by dealing with a model driven by a steady wind in smooth water, ignoring the complications that arise when rough water causes the boat to roll, pitch and heave.

"Broadly considered, a boat responds to three principal systems of forces—those of gravity (weight), air and water. Since the gravity forces all act straight down, the vectors representing them are all in the same direction and can simply be added together to give a single vector acting downward at the center of gravity of the boat. The wind forces on sails, on the other hand, have various magnitudes and directions, so that they cannot be represented by a single vector. The same is true of local water forces acting on various parts of the hull. Further, there are combinations of opposed water, air and gravity forces—called 'couples'—which tend to turn or twist the boat, like the opposing forces applied by a rider's hands to the handle bars of a bicycle. Such couples occur, indeed, whenever the forces set up by the wind and gravity lie in planes different from those created by the water. Equilibrium results only when the water-force system offsets the combined resultant of the separate air and gravity forces.

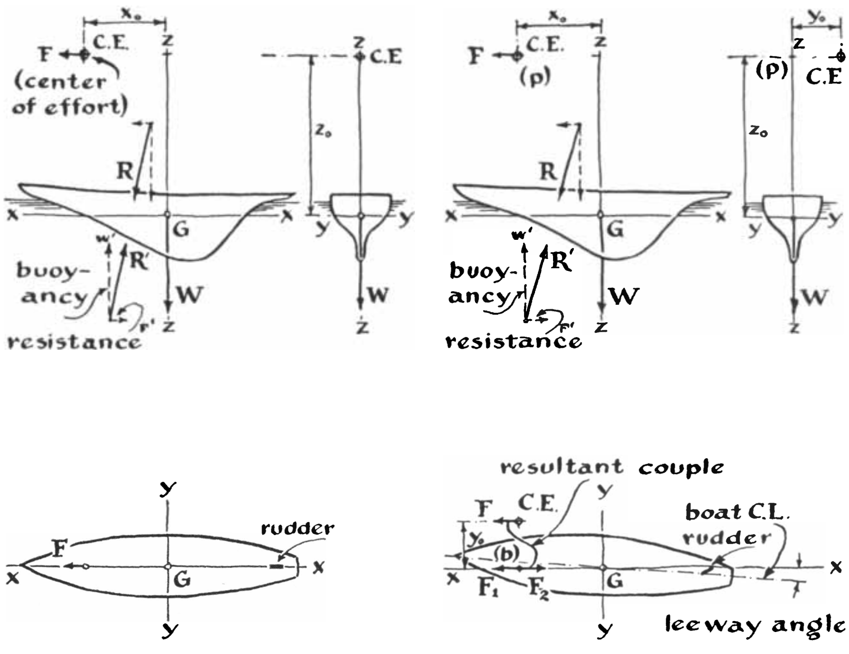
"The general nature of the three basic



A model sailboat "runs before the wind" in the Experimental Towing Tank at the Stevens Institute of Technology



Another model is towed "on the windward leg" in the Stevens tank



(a) Running Free with Spinnaker **(b) Running Free without Spinnaker**

Forces acting on a sailboat running before the wind

systems of forces is illustrated by the simple case of a sailboat with spinnaker running free before the wind. The magnitudes and spatial relationships of the forces are measured relative to the vertical, horizontal and longitudinal axes that pass through the boat's center of gravity; on a diagram these axes are represented by the conventional x, y and z [*see drawings on this page*]. The air force in this simple case is solely horizontal. The air force (F) and the gravity force (W) can both be considered to lie in the same plane and can therefore be combined in a single force vector (R). Hence no couple, or turning force, results. Equilibrium is established when R is precisely opposed by the combined effects of the boat's buoyancy and of the resistance met by the hull's motion through the water. To attain this precise balance of forces, the magnitude of the resistance encountered by the hull must match that of the opposing air force. This means that the boat must attain a specific 'equilibrium' speed, because the resistance increases with the velocity. In addition, if the directions of the opposing forces are to coincide, the hull must be free to alter its trim (bow up or down). In this simple case the center of the spinnaker's effort lies in the vertical plane that divides the boat into two symmetrical halves. It is assumed that the rudder is centered and that the boat is sailing on a straight course.

"A slight complication arises if the same yacht runs free before the wind without a spinnaker. She is then driven by her mainsail, which is carried to leeward. This shifts the center of the driving force to leeward by the distance y_0 [*drawing at upper right on this page*]. The air and gravity forces accordingly lie in different planes and cannot be combined as a single force. A couple results. To clarify the picture and make the case analogous to that of running with the spinnaker, it is possible to resort to the simple expedient of introducing two equal but opposite forces, F_1 and F_2 [*drawing at lower right on this page*]. This device leaves the system unchanged as a whole, but F_1 then corresponds to the air force in the spinnaker case and combines with the gravity force. The air force then combines with F_2 and forms the horizontal 'resultant couple.' Equilibrium is established by giving the boat a leeway angle through the action of the rudder.

"The speed of the boat will not necessarily be the same in the two cases, even assuming the same wind force, because the flow of water past the hull is asymmetrical in the second case. Sailors would say the boat 'yaws.' This increases the effective resistance encountered by the hull.

"Sailboats must sail into the wind far more frequently than they sail before it. Yacht races are usually won or lost on the windward leg. Therefore the designer of a sailboat is concerned mostly with its windward ability. The essential problem is to provide useful floating volume for the passengers together with the least development of water resistance consistent with adequate sail-carrying ability. The ability to carry sail is of special importance. Occasionally it happens that a change in design which improves this characteristic of the boat will actually injure its ability to run before the wind while providing the increased speed to windward so likely to lead to success in racing. Naturally the latter gets the preference.

"When sailing to windward, a yacht is spoken of as 'close-hauled.' Now it is theoretically necessary for a close-hauled boat to heel over [*see top drawing on page 132*] and to make some 'leeway'—*i.e.*, turn a little from the strictly windward direction. Obviously the sails must 'stand up' to the wind if it is to create a force against them. The wind force must then be resisted by the water force, equal and opposite in direction. These forces, with their components and resultants, are shown in the bottom drawing on page 132. The lateral wind and water forces produce a couple which tends to make the boat capsize; but in the equilibrium situation this couple is opposed by another righting couple of equal magnitude and opposite direction comprised of the buoyancy and gravity forces. The righting couple can be created only if the boat heels over, and the lateral water force will develop only if the keel advances through the water *at an angle*—like the close-hauled sails or like the wing of an airplane. For the keel to have this angle of attack the hull must make leeway. Incidentally, while the keel itself has a shape reasonably analogous to an airfoil, its 'lift' tends to increase the heel of the boat and thus to decrease the effective wind pressure.

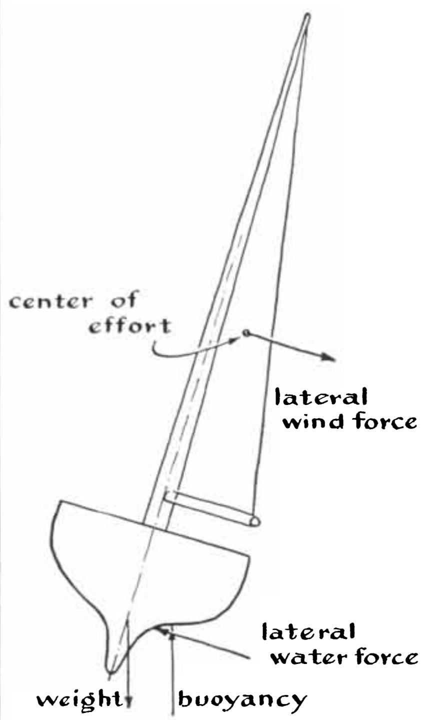
"The center of effort exerted by the close-hauled sail lies to leeward of the boat's centerline, of course, as in the case when the boat runs before the wind without spinnaker. In addition, the center of effort of the sail is displaced further from the boat's center of gravity by the angle of heel. The resultant air force can be resolved into components, one of which acts in the direction of the boat's motion (F_r), another in the transverse direction ($F_h \cos \Theta$) and the third downward ($F_h \sin \Theta$), the angle Θ being the angle of heel [*see drawings on page 134*]. These components act parallel to the longitudinal, lateral and vertical axes, respectively. They lie in planes which pass through points 1, 2 and 3 in the diagrams. The water couple required for equilibrium is formed by inequalities in the lateral components of the water forces acting on the hull. As a general rule these component forces must be greater on the lee side than on the weather side to balance the lateral wind force components—which means that the hull must make leeway.

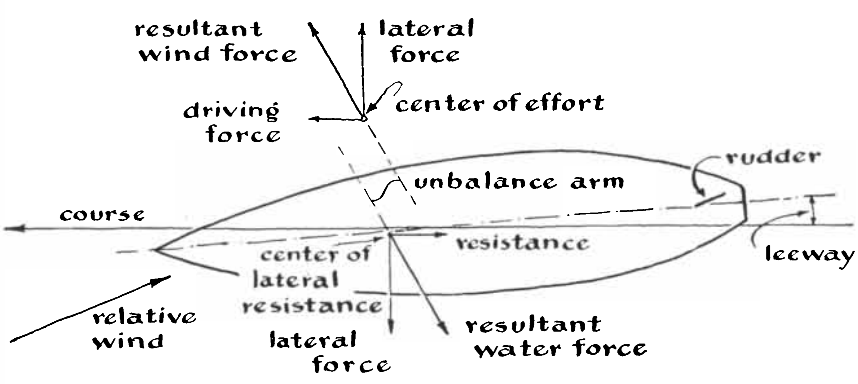
"One important air-water couple always investigated at Stevens produces an effect we call the 'unbalance arm': the tendency of a close-hauled boat either to nose into the wind or to fall off. An unbalance arm exists when the center of effort of the sail lies either fore or aft of the center of the hull's lateral resistance. When the center of effort lies aft of the center of resistance, the boat tends to nose into the wind and is said to have a 'weather arm.' It behaves like a weather vane, and for the same reason, the sail being analogous to the weather vane's tail, and the center of lateral resistance to the pivot on which the vane turns. If the two forces were perfectly aligned in opposition, the boat would have no unbalance arm and would accordingly sail a straight course when close-hauled without attention from the helmsman. In practice such balance is rarely achieved or even desired. Some rudder action is practically always required. Actually the rudder angle necessary to compensate for a small weather arm increases the drag of the boat little if at all; indeed, because of the flow pattern of the water around the hull it may even decrease the drag up to about two degrees of rudder angle. The yacht designer has a good measure of control over the unbalance arm, by moving the mast or altering the sail arrangement so as to shift the center of effort forward or aft as required. He can learn what change promises improvement in his original design either by a model test or by full-size trials.

"So far we have considered only the forces—the pushes and pulls—acting on the boat. What about their effects in terms of the boat's movement through the water—its speed? In effect, the angle at which the sails are rigged with respect to the center line of the hull and its keel causes the sail-hull combination to act as a kind of aerodynamic-hydrodynamic wedge. Wind force acts against one face of the wedge and water force against the other. The yacht tends to escape from between the opposing forces—much as a slick watermelon seed shoots out from between your finger and thumb when you squeeze it.

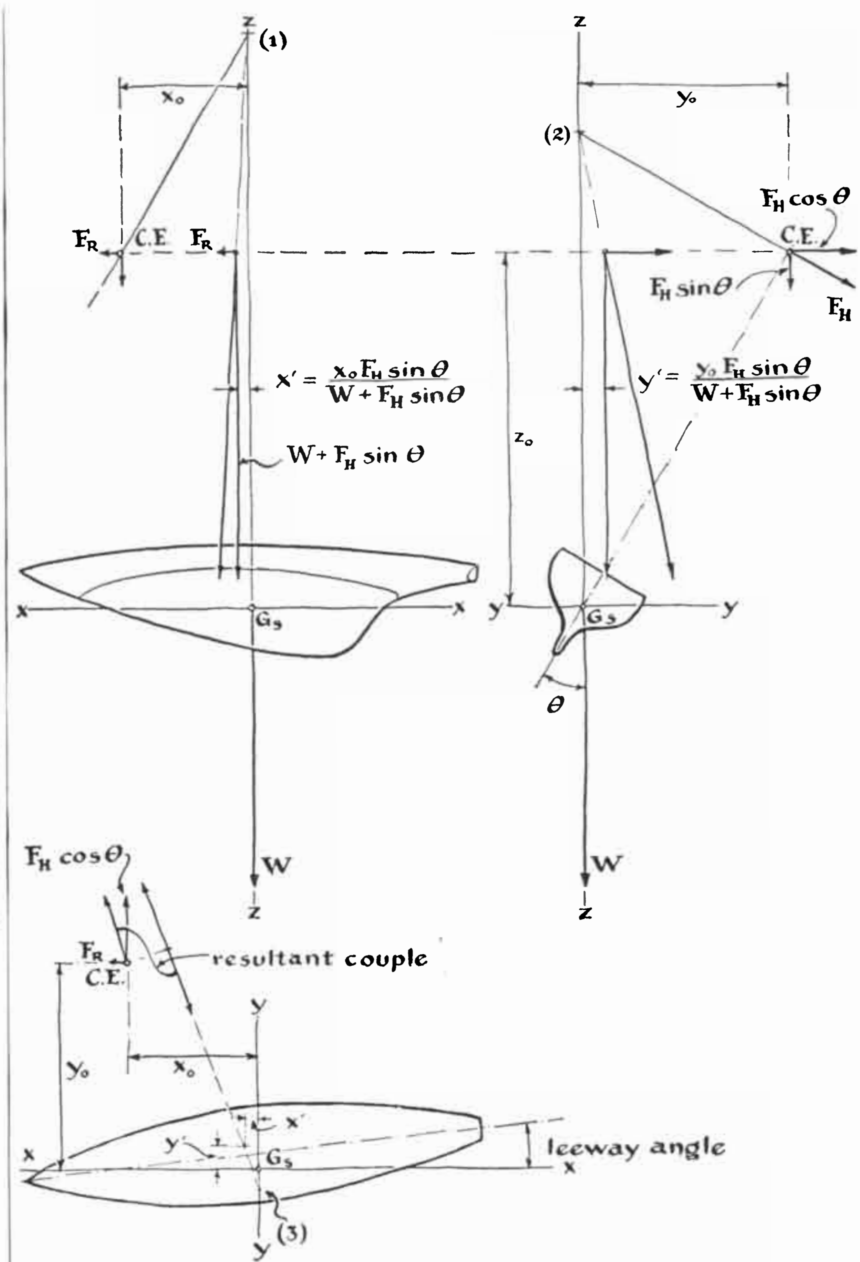
"The velocity analysis of a boat sailing to windward is shown in the diagram on page 136. The boat is headed at a slight angle with respect to its course and makes leeway as indicated. The 'sailing speed' on course (*i.e.*, rate of progress in the direction of its goal) is a vector resultant of the wind speed and the sailing angle. To a person aboard the sailboat the wind has a certain apparent velocity arising from the boat's motion; this velocity differs in direction and magnitude from the wind's true speed. Now the boat's sailing speed toward the goal will be at a maximum when the sailing angle is so increased that the vector of apparent wind speed is brought approximately abeam—the sailing tactic known as broad reaching. Conversely, the sailing speed will be a minimum when the sailing angle is decreased as much as possible—that is, when the boat is sailed as close to the wind as practicable. Somewhere between these extremes (nearer the minimum than the maximum) there is a sailing angle which results in the best compromise—*i.e.*, the best 'speed-made-good.'

"This speed-made-good directly into the wind, when considered in conjunction with the calculated true wind speed, is the final criterion of windward ability in the Stevens model tests. Speed-made-good is a function of the combined hull and rig characteristics; therefore it cannot be determined from model tests of the hull alone. Model tests of the hull determine the magnitude and direction of the force that must be provided by the sails in the actual boat when the hull moves on course at the speed and angle of heel for which the test was made. The designer must also have reliable knowledge of the lift-drag ratio of the rig and of the relationship between the apparent





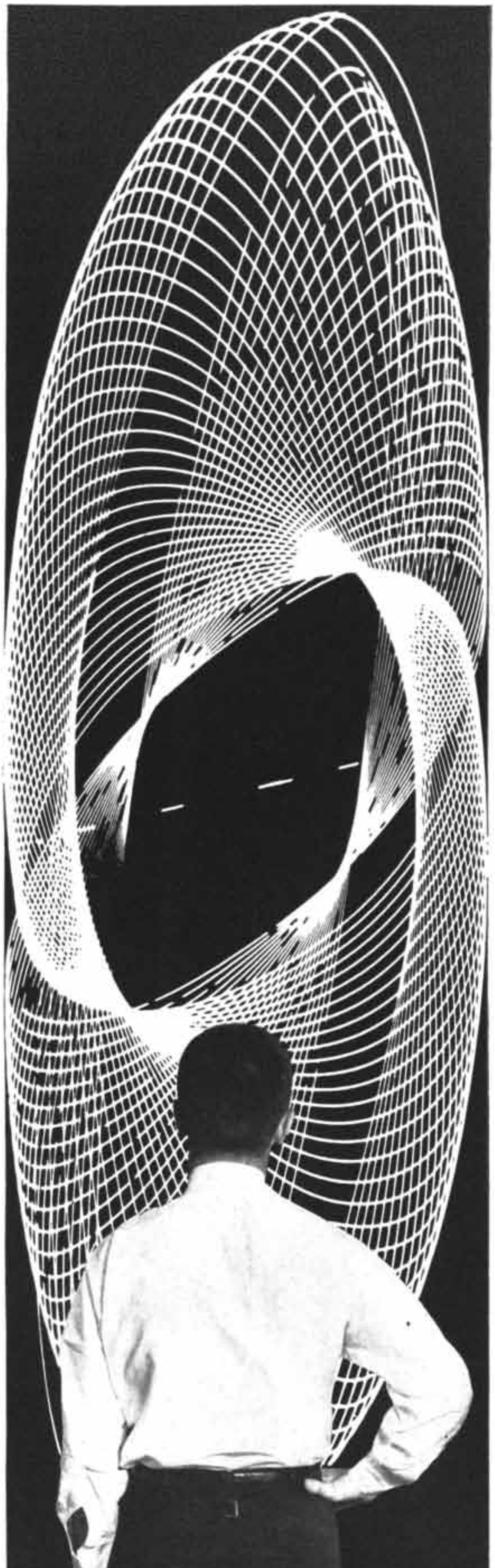
Forces acting on a boat sailing into the wind



A further analysis of forces acting on a boat sailing into the wind

speed and the corresponding total wind force exerted on the sails of the boat. Both the true and apparent speeds can then be calculated. When the test procedure is carried out for a number of values of the sailing speed at the same heel angle, it is found that the calculated speed-made-good increases at first as the sailing speed increases and then falls off. Accordingly there is always found a best speed-made-good, with its corresponding true and apparent velocities; and such findings agree with actual sailing experiences. Obviously, though, the accuracy with which the true speed can be calculated depends on the values used for the constants of full-sized rigs.

"At the Stevens tank these rig-constant values were originally derived by combining the hull data for a particular boat, as determined by model tests, with the results of a long, careful series of tests on the full-sized boat itself sailing to windward. This boat had a well-designed rig, a good set of sails and an expert helmsman. Measurements were made simultaneously of sailing speed and angle, relative wind velocity and angle of heel. The final analysis of data resulting from these tests indicated that the lift-drag ratio and the wind-force coefficient both varied primarily with the heel angle. Accordingly this angle has become a most important independent



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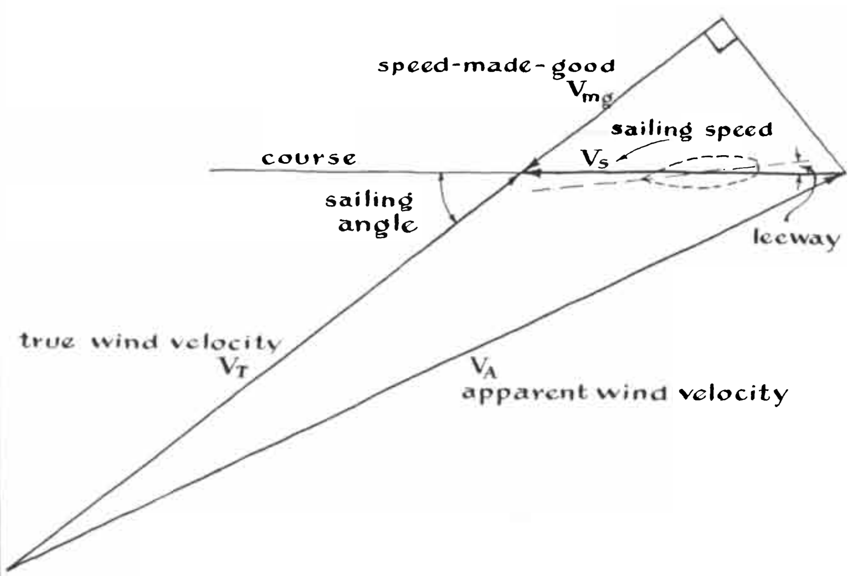
AUTOMATIC CONTROLS MAN HAS NEVER BUILT BEFORE variable in our tests. By measuring the water forces that act on the hull at various angles of heel—while holding other quantities constant—such as the speed of the model through the water, we can anticipate the magnitudes of the opposing aerodynamic forces that will be required for equilibrium at that angle.

"In the last analysis, we are interested in values of speed-made-good of various boats for the same true wind speed. A series of measurements made with respect to heel angle leads us directly to this desired information.

"The standard test procedure for a sailboat model at Stevens comprises (1) 'upright' tests and (2) 'close-hauled' or 'heeled' tests. Usually the upright tests are run first. They simulate the condition of a boat sailing before the wind. The model is made of a western sugar pine, varnished and very carefully rubbed down to a uniform finish, with a deck parallel to the designed load water line and a standard distance above it. The model is towed the length of the tank by a motor-driven carriage which rides on the underside of a monorail suspended above the center of the tank. The attitude of the model with respect to the water is determined by a set of adjustable mechanical linkages which connect it to the carriage. It is pulled by a horizontal tow-bar fastened to its foredeck and to a resistance dynamometer ahead of it [*see photograph at top of page 129*]. The model is accelerated to any one of a long series of test speeds by a post which extends down from the carriage. When the desired speed is attained, the post is disengaged from the model. Equilibrium is then established for the given speed by adjusting the force exerted by the dynamometer so that it just balances the opposing force of the water on the model. From the test data, predictions are made of the resistance of the full-sized sailboat over the whole speed range. From these predictions the designer can immediately compare his design with others in the preliminary and rather inconclusive case of sailing before the wind.

"Another consideration of special importance in both upright and heeled tests is that of establishing turbulent, as opposed to laminar, flow in the boundary friction layer of the model. Without turbulent flow the model tests would be useless. Now small models, particularly models of sailboats, with their extremely 'easy' bow characteristics, require close attention as to turbulent flow. We have developed a method of inducing the essential turbulence by applying a strip of coarse sand along the stem from the water line to the bottom of the keel.

"When a sailboat is close-hauled, the fundamental variables are speed of advance, angle of heel and leeway. If each of these variables remained independent, a veritable network of tests would be required for each model, and the interpretation of the test data would be extremely difficult. As a primary simplification, therefore, the model rudder is kept in its central position. The leeway is then fixed by the values of the other variables. At a particular speed of advance and angle of heel, the leeway must be such that the lateral water force will establish equilibrium precisely between the overturn-



True and apparent velocities of a boat sailing into the wind

THE UNIVERSE

Cluster of distant galaxies photographed by 200-inch Palomar Mountain telescope. The galaxies are the blurry or fuzzy, noncircular objects. The picture takes in less than one-fifth of a degree of sky.

ing and righting couples. The magnitude of the righting couple depends solely on the angle of heel. At Stevens tests are made over a range of speeds at heel angles of 10, 20 and 30 degrees, with the leeway adjusted at each speed to produce the lateral force corresponding to the heel angle. The 10-degree heel simulates close-hauled sailing in a light wind; the 20-degree heel represents average windward sailing, and the 30-degree heel simulates sailing into a strong wind with the lee rail almost awash but with full sail. Normally three speeds of advance are tested for each angle of heel, and three values of a mechanically applied lateral force corresponding to that developed by the wind are used for each speed. Two lateral dynamometers apply this lateral force at a height considerably below that of the normal center of effort, but the test technique allows for this, in part, by moving a standard sliding weight laterally above the model deck. This, together with the leeway adjustment, balances the applied force at the particular angle of heel. Other components of the wind force are compensated for by similar techniques.

"The ultimate objective of these heeled tests, as previously mentioned, is to predict the best speed-made-good to windward for the hull and rig under consideration at each of the three angles of heel. Values of speed-made-good are then plotted against true speed and the resulting curve becomes one of the designer's guides in making modifications and improvements. The designer is also supplied with charts showing the characteristics of resistance, leeway, center of lateral resistance and unbalance arm, so that he can compare the predicted performance of the model with that of other designs.

"Although each sailboat design will exhibit its special characteristics, the test and calculation techniques are carefully standardized to afford, as far as possible, rigorous comparisons between designs. In this way the designer learns quickly just how his boat is likely to perform.

"If any reader is by now stimulated to try some experiments of his own, it is recommended that he use full-sized sailing craft rather than models. Accurate construction of models and experimental equipment is difficult to the point of being impracticable. Moreover, data on full-sized boats are scarce at present and would be of great interest. Experiments to test sail coefficients, centerboard designs and locations and racing strategy—to mention only a few of the problems—offer challenging opportunities for ingenious and enthusiastic amateurs."

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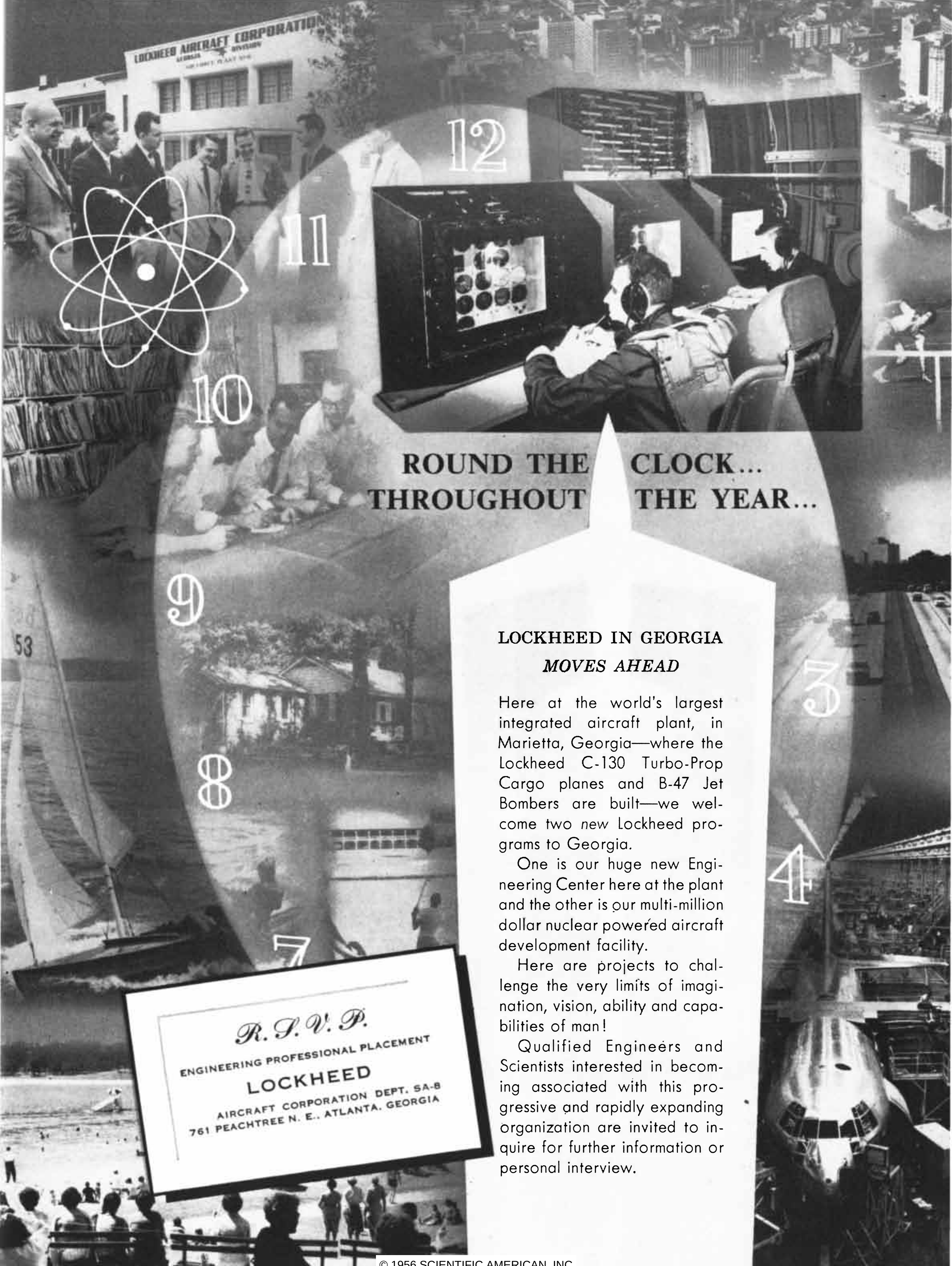
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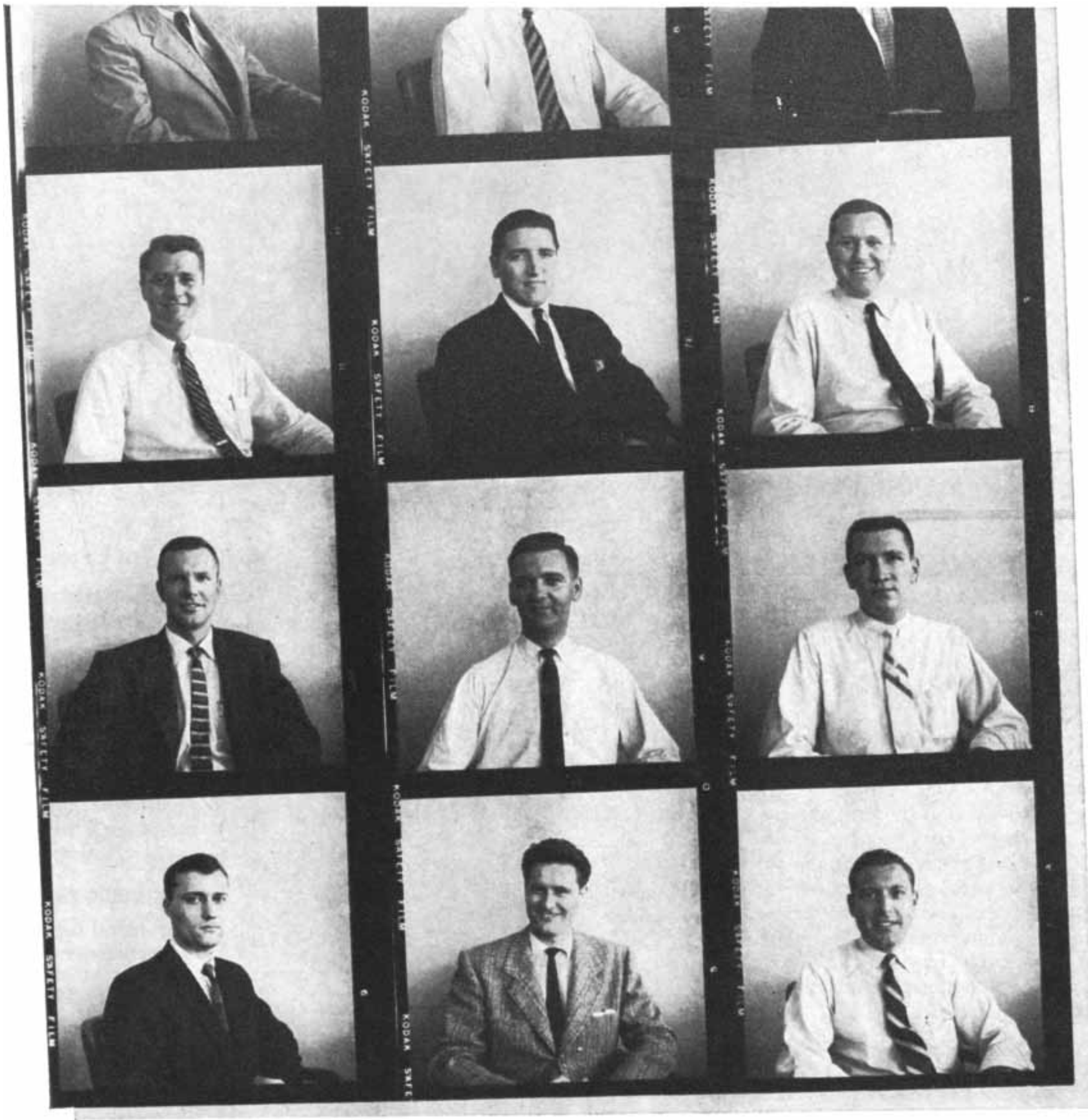

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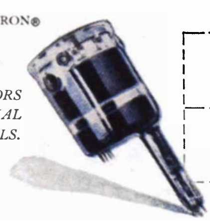

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