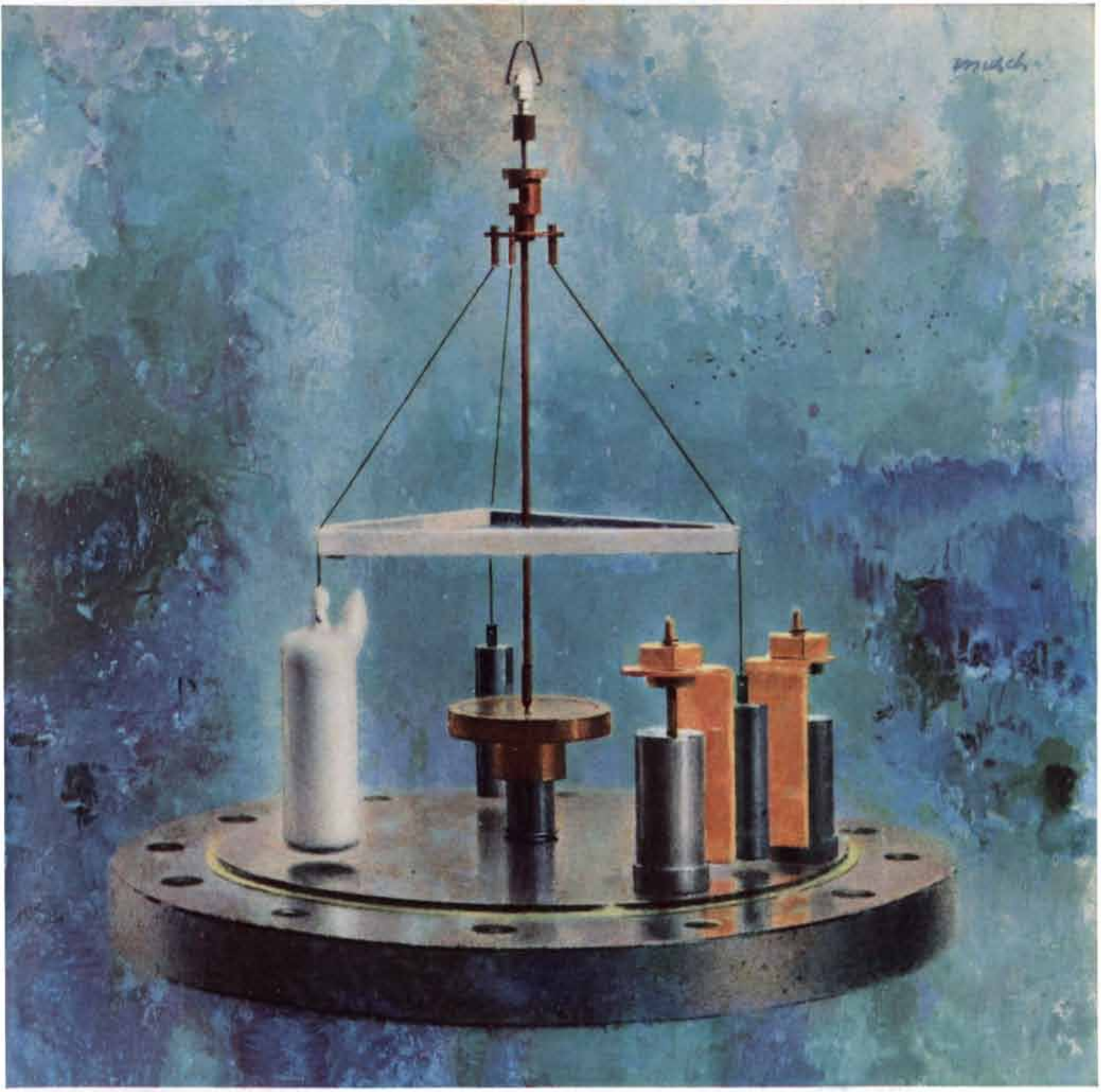
SCIENTIFIC AMERICAN

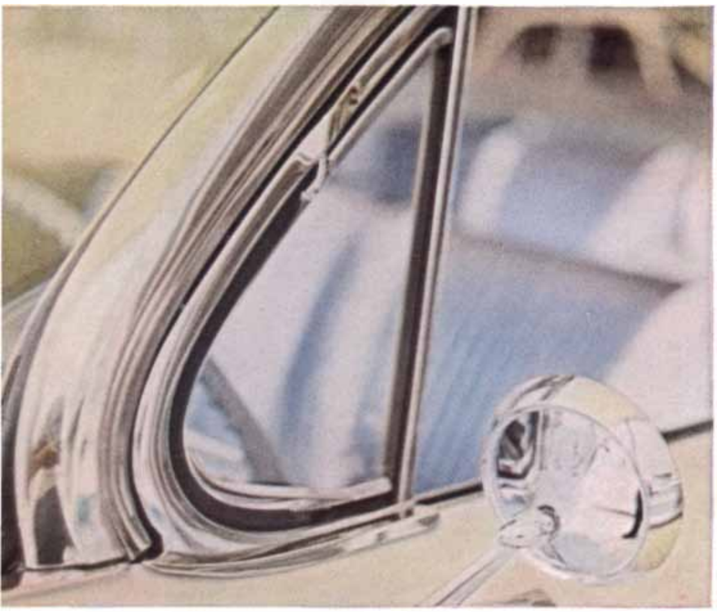


GRAVITY EXPERIMENT

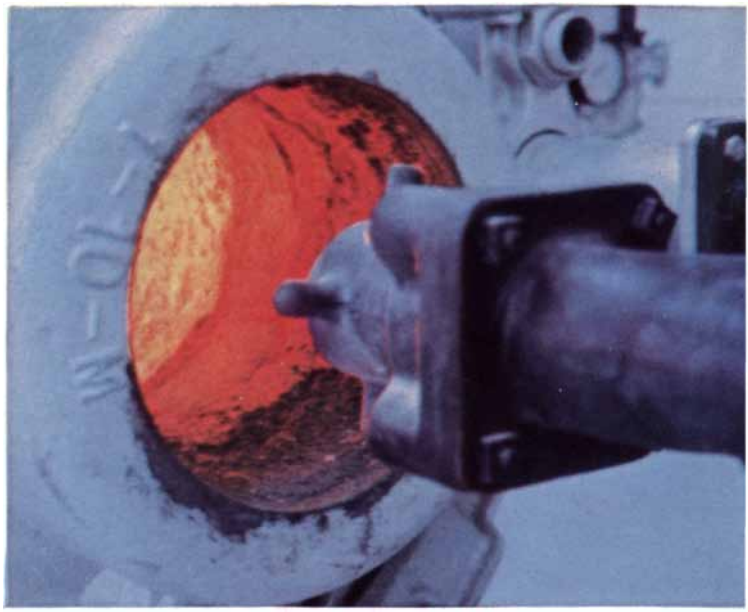
FIFTY CENTS

December 1961

ORGANOTINS BEAT BARNACLES: New anti-fouling marine paints demonstrate the broad spectrum biocidal activity of M&T's TBTO® (tributyltin oxide). Added to the paint, TBTO keeps boat bottoms free of barnacle type growths much longer . . . and adds new resistance against algae-like plant growth. TBTO is one more of the unique compounds in the "mushrooming" family of M&T organometallics . . . proves potent, too, in wood preservation, textile purification, hospital sanitation, water treatment.



NEW LONG LIFE FOR CHROMIUM PLATE: When plated thicker than usual specifications from previous processes, chromium cracks from internal stress. Galvanic action starts up causing pitting and rusting. Plating a thicker deposit with an ultra-fine crack pattern radically reduces such corrosion cell activity, assures optimum outdoor life for brightwork—as proved by M&T MICRO-CRACK CHROMIUM.



MODERN TECHNICAL SERVICE IN AGE-OLD ART: A new M&T ceramics laboratory probes the role of M&T's antimony chemicals, zircon and other minerals in frits and glazes via precision sampling and test runs on glass and enamel melts. This extensive, high temperature facility augments the technical service offered by M&T — one of the major producers of opacifiers for ceramic enamels and glazes.

New successes from Chemistry at M&T...When metals meet chemistry at M&T, the union brings you a better anti-fouling paint; develops a longer-lasting plated finish for automobiles; searches out the best ingredients for ceramics. In every case, there is a distinct benefit to an M&T customer and to his customers. METAL & THERMIT CORPORATION

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Established 1845 **SCIENTIFIC AMERICAN** December 1961 Volume 205 Number 6

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK 17, N.Y. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. SUBSCRIPTION RATE: $6 PER YEAR.

THE COVER

The painting on the cover depicts a sensitive torsion balance built at Princeton University to carry out a new test of the constancy of gravitational acceleration (*see page 84*).

THE ILLUSTRATIONS

Cover by Walter Murch

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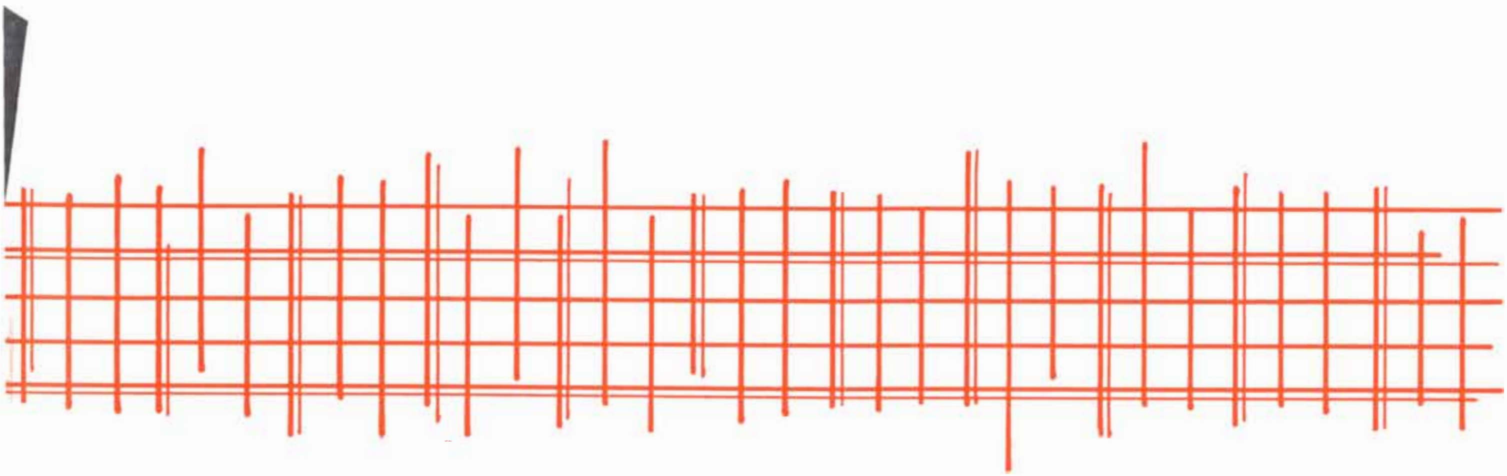
IMPACT

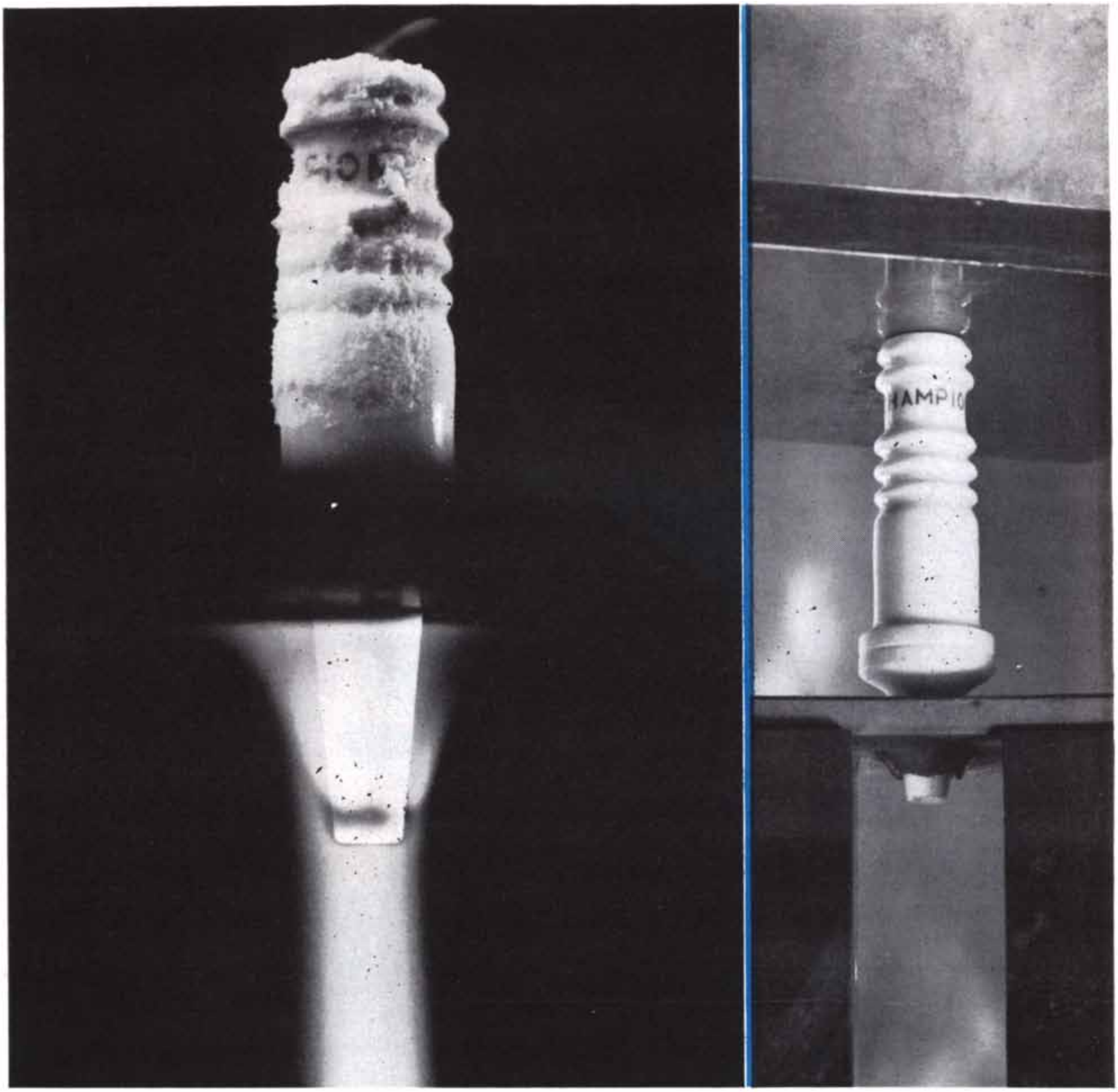
The impact of electronics on military technology is seen in the enormous growth of our defensive/offensive missile capabilities. As a manufacturer of the basic components that makes electronics happen, Tung-Sol numbers among its customers many companies who produce the vital firing, guidance and tracking elements essential to our missile program.

Reliability is a prerequisite of all components and in the missile program the performance standards are exceedingly critical. The ability to meet tight specifications in high volume production of electron tubes, transistors and diodes is a capability that distinguishes Tung-Sol. This is the reason why designers of the most sophisticated circuitry have found at Tung-Sol the answer to their components problem. Tung-Sol Electric Inc., Newark 4, New Jersey.

TUNG-SOL®

MIL-SPEC ELECTRON TUBES AND SEMICONDUCTORS—INDUSTRIAL AND AUTOMOTIVE LAMPS





Insulators with terrific resistance to thermal and mechanical shock! This spark plug insulator was cooled to minus 100°F. One end was suddenly brought to a white heat while the other end remained covered with frost. Another insulator was forced to pierce a ¼-in. steel plate—and remained undamaged.

From a frosty minus 100°F to white heat in seconds! . . . because ceramic engineers at Champion *mixed imagination with Alcoa Aluminas*

These Champion Spark Plug Company tests are more severe than any spark plug service requirements. But what better way to prove the almost unbelievable thermal and mechanical shock resistance of high-alumina ceramics?

Ceramics today do things undreamed of until Alcoa® Aluminas made them possible. Alumina refractories withstand inferno heats, yet remain strong and stable under load. Ceramic parts composed principally of Alcoa Aluminas meet many of the toughest demands of high-powered, high-frequency electronic equipment. Alumina ceramic cutting tools outperform tools of other materials. Mechanical ceramics, textile ceramics, even missile nose cones—all are better than ever because they're made with Alcoa Aluminas.

Why don't *you* mix imagination with Alcoa Aluminas to make your old product better or a new product possible? Send for our booklet, *Ceramics—Unlimited Horizons.* Aluminum Company of America, 701-M Alcoa Building, Pittsburgh 19, Pa.

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URGENT:

GIVE A COMMANDER A MOVING VISUAL OF BATTLE!

Keeping surveillance display in tempo with high speed weapons is a critical challenge we accept at Sylvania Electronic Systems.

For example, our pioneering and progress in electroluminescence—a new source of light—promises to be strikingly beneficial to top military personnel. By combining the exceptional reliability of such techniques with advanced communication and data processing systems, a commander can now have a graphic and *moving* picture of the course of action *as it happens!*

The key to such a picture is an advanced use of electroluminescence by GT&E engineers. When data communications control the excitation of the electroluminescent phosphors, letters, numbers, symbols—even areas for tactical display—can be illuminated on wall-size panels with definition of up to 2500 spots of controlled light per square inch! Thus it is possible to recreate patterns of troop, fleet and aerospace movements the moment they occur. What's more, since such a display uses little power and is not subject to catastrophic failure, it is ideally suited to the mobility requirements of the military.

Progress in electroluminescent display typifies the work being done by the scientists and engineers of the General Telephone & Electronics corporate family. The vast communications and electronic capabilities of GT&E, directed through Sylvania Electronic Systems, can research, design, produce, install, and service complete electronic systems. These systems cover the entire range from detection and tracking, electronic warfare, air traffic control, intelligence and reconnaissance through communications, data processing and display.

That is why we say—the many worlds of defense electronics meet at Sylvania Electronic Systems, a Division of Sylvania Electric Products Inc., 40 Sylvan Road, Waltham 54, Mass.

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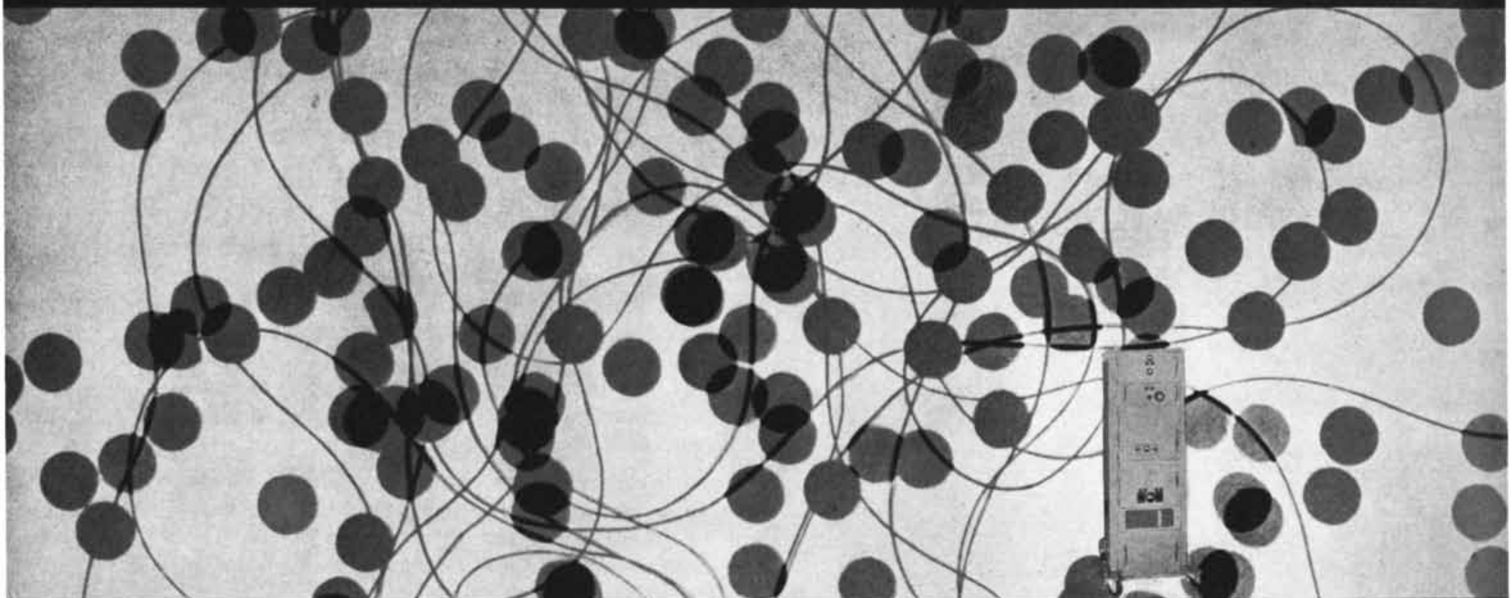
THE Primary Frequency Standard, used by the United States Naval Observatory to maintain A.1 Time



The U. S. Naval Observatory maintains Atomic Time (A.1) by using the Atomichron* as a frequency standard and utilizing reports from other laboratories in various countries which operate cesium-beam frequency standards. Ephemeris time, a most useful scientific tool, is defined in terms of Atomichron seconds, thus Atomichrons make Ephemeris seconds continuously available.

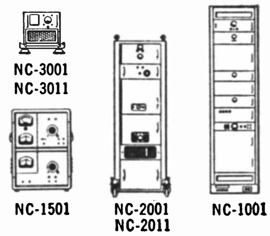
The Atomichron derives the invarient resonant frequency of the cesium atom from an evacuated cesium beam tube and uses its frequency stabilizing system to provide constant outputs with stabilities of parts in 10^{11} forever.

Atomichrons provide invarient outputs forever! Atomichrons are insensitive to dimensional changes; they are self-calibrating, fail-safe, resettable, and reproducible.

Atomichron Primary Frequency Standard models are available for field use and for application in those areas of advanced research or development technology requiring extremely precise control of timing and frequency: narrow band and secure communications; precision measurements required in tracking, guidance, control and navigation of satellites, missiles, and other general aerospace systems.

We invite your specific inquiry for further technical details on these or other time and frequency control problems.

ATOMICHRONS



NATIONAL COMPANY, INC. Dept. A. Malden 48, Massachusetts

*Reg. U. S. Trademark

LETTERS

Sirs:

In the concluding paragraph of his article introducing your issue on the living cell [SCIENTIFIC AMERICAN, September] Jean Brachet states: "This dissection of cells into their constituents does not, therefore, throw much light on the questions posed by philosophy." Quite the contrary is true; the probings of biophysicists and biochemists have shown that the living cell obeys causality, and that this is the answer to the questions posed by philosophy. If we could assemble a cell out of its constituent molecules, it would be no less alive than a cell that has evolved naturally; a cell does not possess "free will"; the response of a cell to its internal and external environment is uniquely determined by that environment.

The principle of causality implies that living organisms are complicated electrochemical structures that are subject only to the laws of gravitation, conservation of energy and so on. Effect predictably follows cause—predictably in the sense that the present and future state of the universe is completely determined by its past state, so that a supercomputer one billion years ago could have predicted that the living-cell issue of *Scientific American* would be a stimulus for all scientific disciplines.

"Free will" is an illusion; a choice made of our own free will is a choice made by elementary particles responding to physical laws, oblivious whether or not man commits atomic suicide. Human creativity is also an illusion in so far as it violates causality. Consciousness, on the other hand, has a real physical basis, probably in the form of electric currents that represent sensory and thought patterns.

Perhaps our imaginary computer could predict that scientists, circa 1962, will at long last recognize that living organisms obey causality. There is a slim chance that this could stop man's race toward self-destruction.

SID DEUTSCH

Polytechnic Institute of Brooklyn
Brooklyn, N.Y.

The Rockefeller Institute
New York, N.Y.

Sirs:

The article by John R. Pierce on communication satellites [SCIENTIFIC AMERICAN, October] was extremely interesting and timely. In his discussion Dr. Pierce might have mentioned that the first communication satellite was the earth's natural passive satellite—the moon.

The U.S. Army Signal Research and Development Laboratory first bounced radar signals off the moon as early as 1946 as part of Project Diana. The U.S. Naval Research Laboratory in 1951 demonstrated the feasibility of using moon reflection for communications and actually transmitted the first voice message over the earth-moon-earth path in July, 1954. The world's first (and still the only) *operational* space telecommunication system is operated by the Navy to carry traffic in one bounce between the Hawaiian Islands and Washington, D.C. This link has been fully operational since January, 1960, and now carries 16 channels of 60-word-per-minute UHF teletype for periods of from about four to seven hours each day, depending on the moon's declination.

Because of the exceptional reliability of its character and orbit and its absence of launching costs, the moon has served as a very economical communication satellite. Unfortunately there is only one in orbit.

B. I. EDELSON

Lieutenant Commander
Department of the Navy
Washington, D.C.

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Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Coherent Electromagnetic Sources: LASER and IRASER (Light and Infrared Amplification by Stimulated Emission of Radiation).

The development of the maser in 1954 opened the microwave region of the spectrum to many new uses. Now these same principles have been extended to the visible and infrared portions of the spectrum suggesting a wide variety of important applications.

Successful practical operation of a laser (light amplification by stimulated emission of radiation) would make possible the use of light in ways never before thought possible. For instance, one important application would open the optical range of the spectrum for communications use. Laboratory lasers have been operated but many problems remain to be solved before practical operation is possible.

Conventional light sources are fundamentally noise generators and the emerging light is a jumble of separate waves that reinforce or cancel each other in random fashion. In order to be useful for communication purposes (as radio waves are used) light waves would have to be generated so that they have:

1. Directionality—produce a beam of light with a small divergence.
2. Coherence—be coherent in time and space so that the waves at various points in space act in unison.
3. Monochromaticity—have a narrow line width or a very narrow frequency range.

The maser achieves the three requirements stated above. The principle is based on the fact that electrons have discrete orbits corresponding to fixed energy levels.

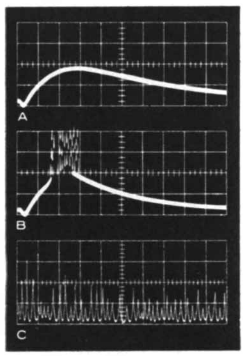
The first practical demonstration of this principle in the optical range of the spectrum was accomplished in 1960 using a ruby crystal. A flash of light is used to invert the normal electron population distribution within the ruby. The electrons in the chromium atoms of the ruby are raised by this flash of light to an excited state with two steps required to carry them back to ground. In the first step they give up some of their energy to the crystal lattice and fall to a metastable level from which they can fall to ground level emitting fluorescent light at 6943 A°. When a population inversion exists between the metastable level and the ground state the first few photons released will stimulate the still excited electrons to give up photons which stimulate still further emission in a cascading effect resulting in an intense burst of red light at 6943 A°. This light has the three properties suggested earlier: directionality—a spreading angle of a fraction of one degree; coherence—demonstrated in interference experiments; and monochromaticity—line width 0.1A°.

Other lasers have been operated including helium-neon gas giving off photons at 1.153 microns in the infrared, samarium doped calcium fluoride emitting at 7082A° and uranium doped calcium fluoride emitting at 2.1 to 2.5 microns.

Although sources are available for certain frequencies, problems remain. It is desirable to be able to develop sources that can be tuned or varied in frequency. More coverage of the infrared and visible spectrums is highly desirable. A modulating mechanism must be found to impress useful information onto the beam of light. Material must be found that will work at lower powers and at higher temperatures.

It is interesting to note the extent to which communication channels would be expanded beyond the present crowded electromagnetic spectrum if the visible spectrum were used. One angstrom unit in the visible spectrum is about 100,000 megacycles wide. Thus a coherent beam of light of frequency spread of 1A° could carry the same information as 25,000 television channels.

Honeywell scientists are presently operating lasers to study the fundamental phenomena that occur. For example the emission from the ruby laser occurs as a series of sharp spikes (see illustration at right.) The top trace (A) shows the natural fluorescent emission of the ruby when the exciting light is not sufficiently intense to cause the population inversion. The middle trace (B) shows the onset of stimulated emission at a slightly higher pumping level. The bottom trace (C) shows an expanded portion of the stimulated emission and indicates the spiked nature of the output.



Honeywell scientists have developed a mathematical model that seems to explain why pulses occur, the way they are spaced and the way they will vary. They are presently working with solid state materials that seem to have the potential of operating at normal temperatures and with low power requirements. Another device under development at Honeywell's Research Center will utilize cesium vapor and will operate in the infrared portion of the spectrum. Work is underway on methods of modulating the light beam using techniques similar to those used in radio.

The possibilities of opening the infrared and visible spectrums to communications, the practicality of optical radar, new possibilities in extremely high resolution photography, new developments in photo chemistry all add further emphasis to continuing work on lasers at Honeywell and other laboratories. If you would like to know more about Honeywell's work in this field and are engaged in scientific work involving lasers, you are invited to correspond with Mr. John Ready, Honeywell Research Center, Hopkins 8, Minnesota.

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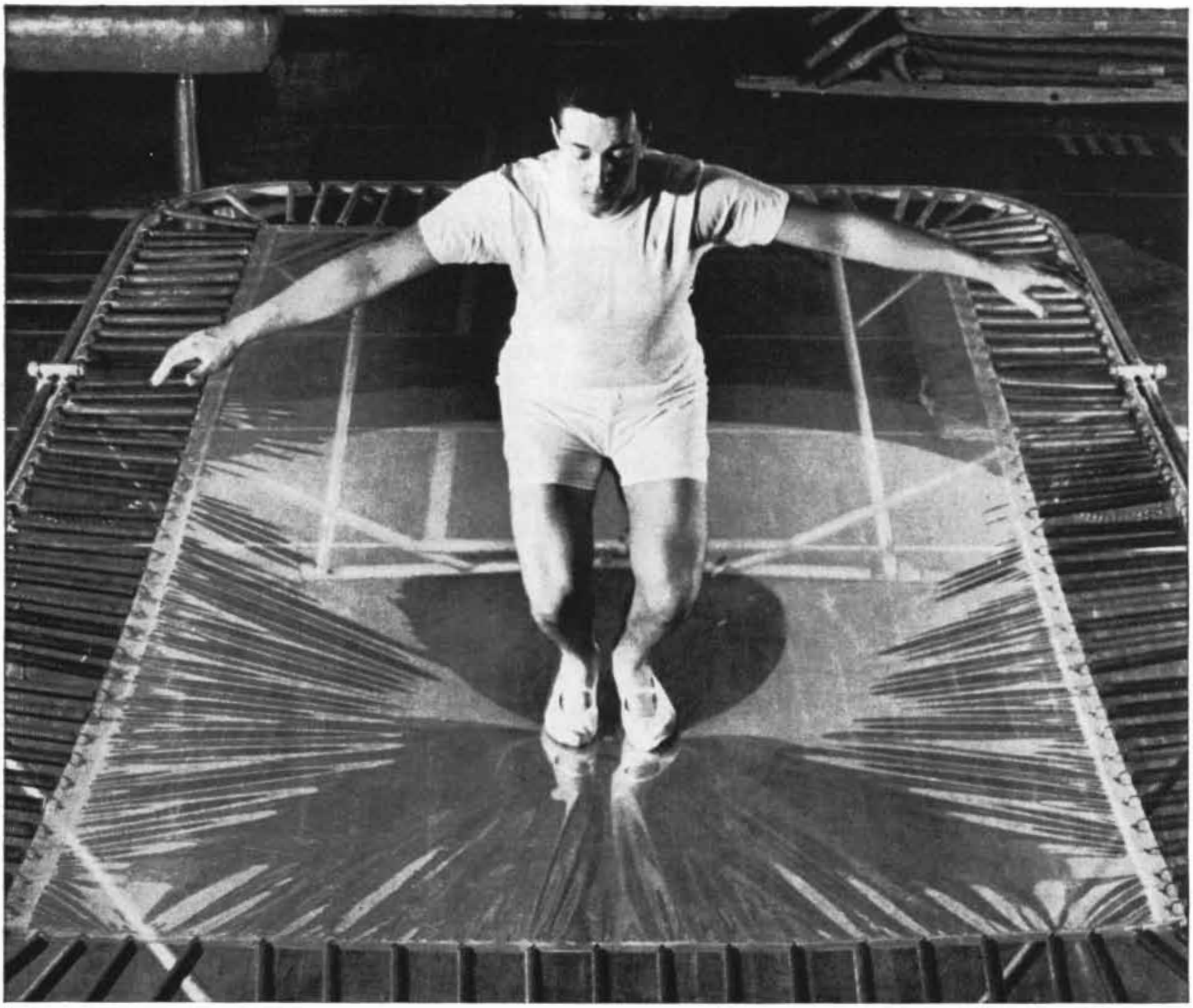
First in Control



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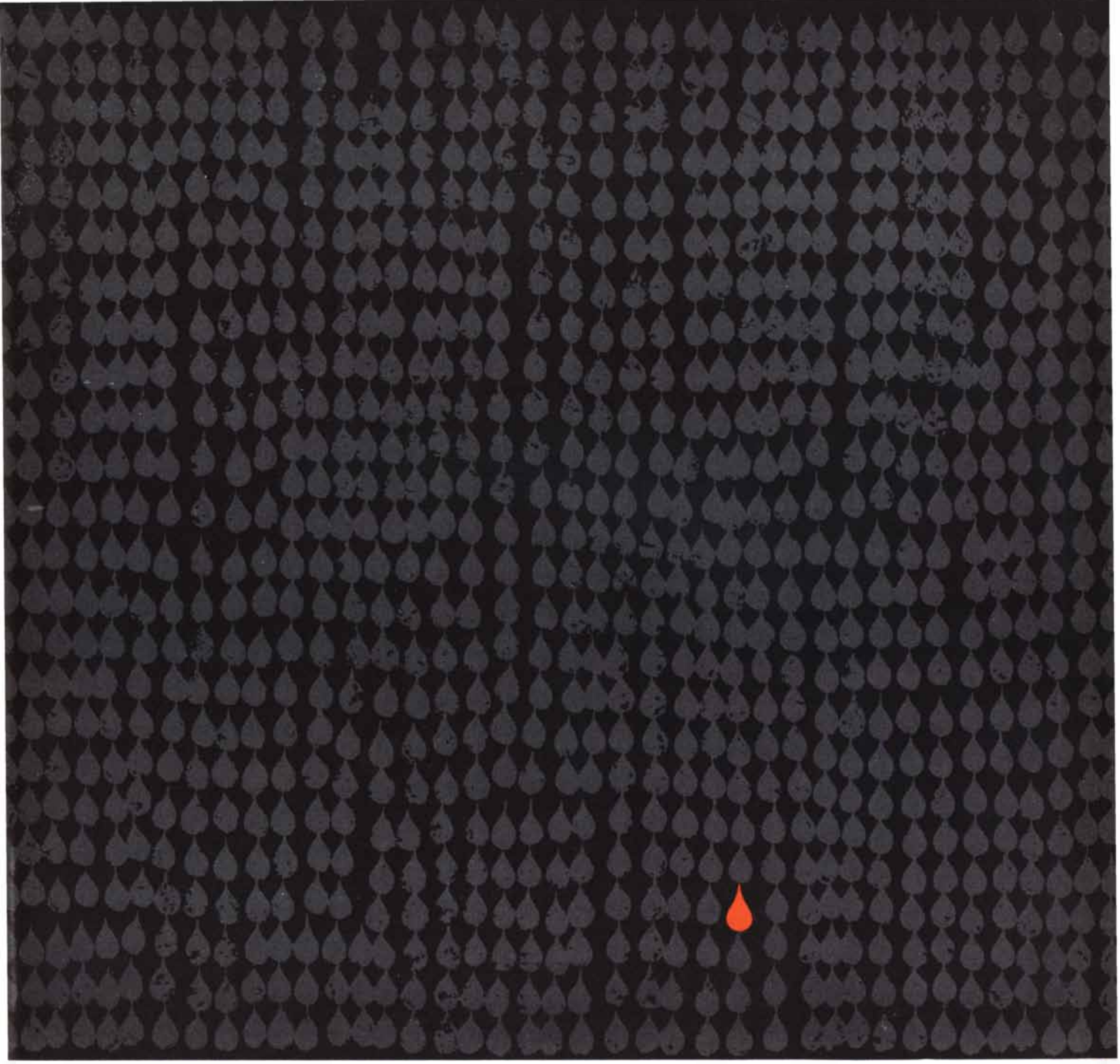
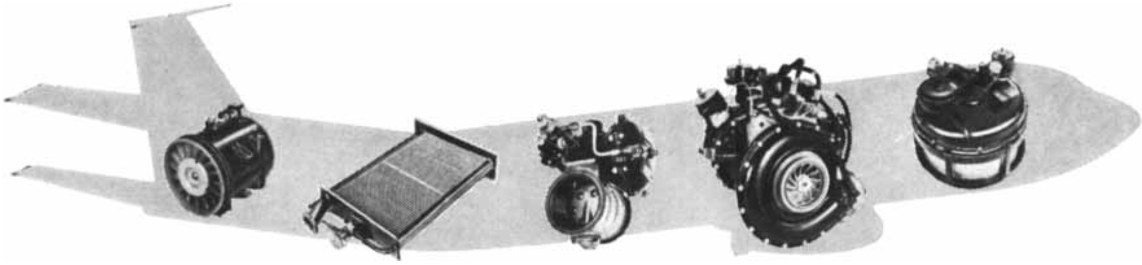
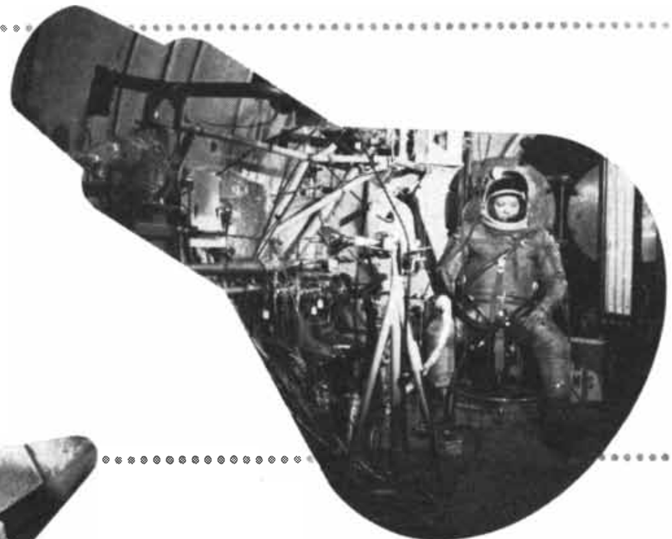
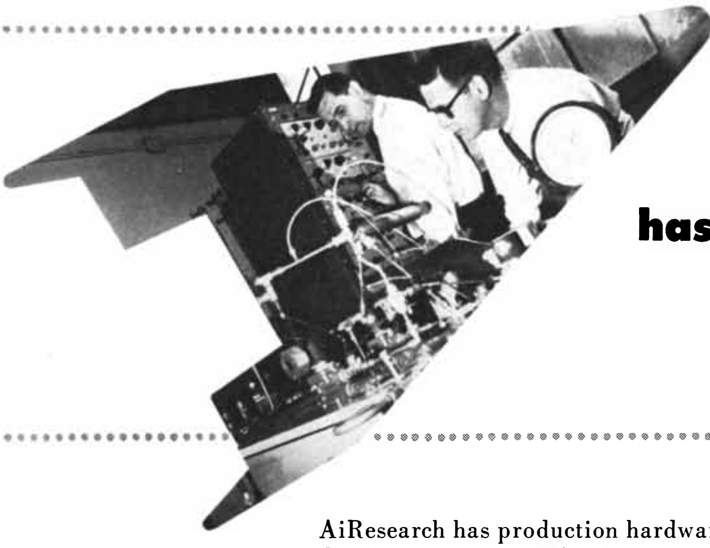




Only AiResearch has 2 million components in aircraft environmental systems*



Only AiResearch has life support systems for America's astronauts



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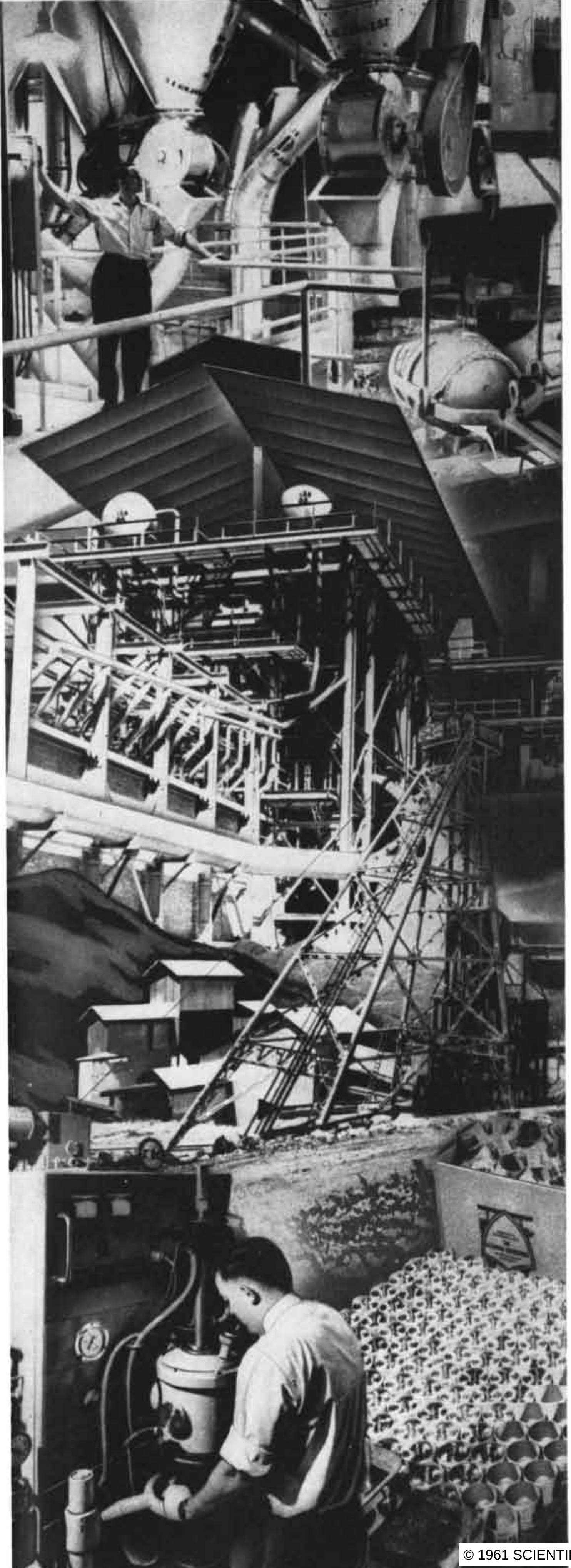

NEW YORK, Dec. 1 -- IN THE 10-DAY PERIOD ENDED NOVEMBER 28, ASARCO FILLED ORDERS FOR 22 BASIC COMMODITIES. THEY RANGED FROM 25 GRAMS OF HIGH PURITY ARSENIC TO 5,000,000 POUNDS OF LEAD. ASARCO ALONE AMONG WORLD PRODUCERS HAS ABILITIES AND FACILITIES TO EXTRACT, REFINE AND DELIVER SO MANY BASIC MATERIALS.

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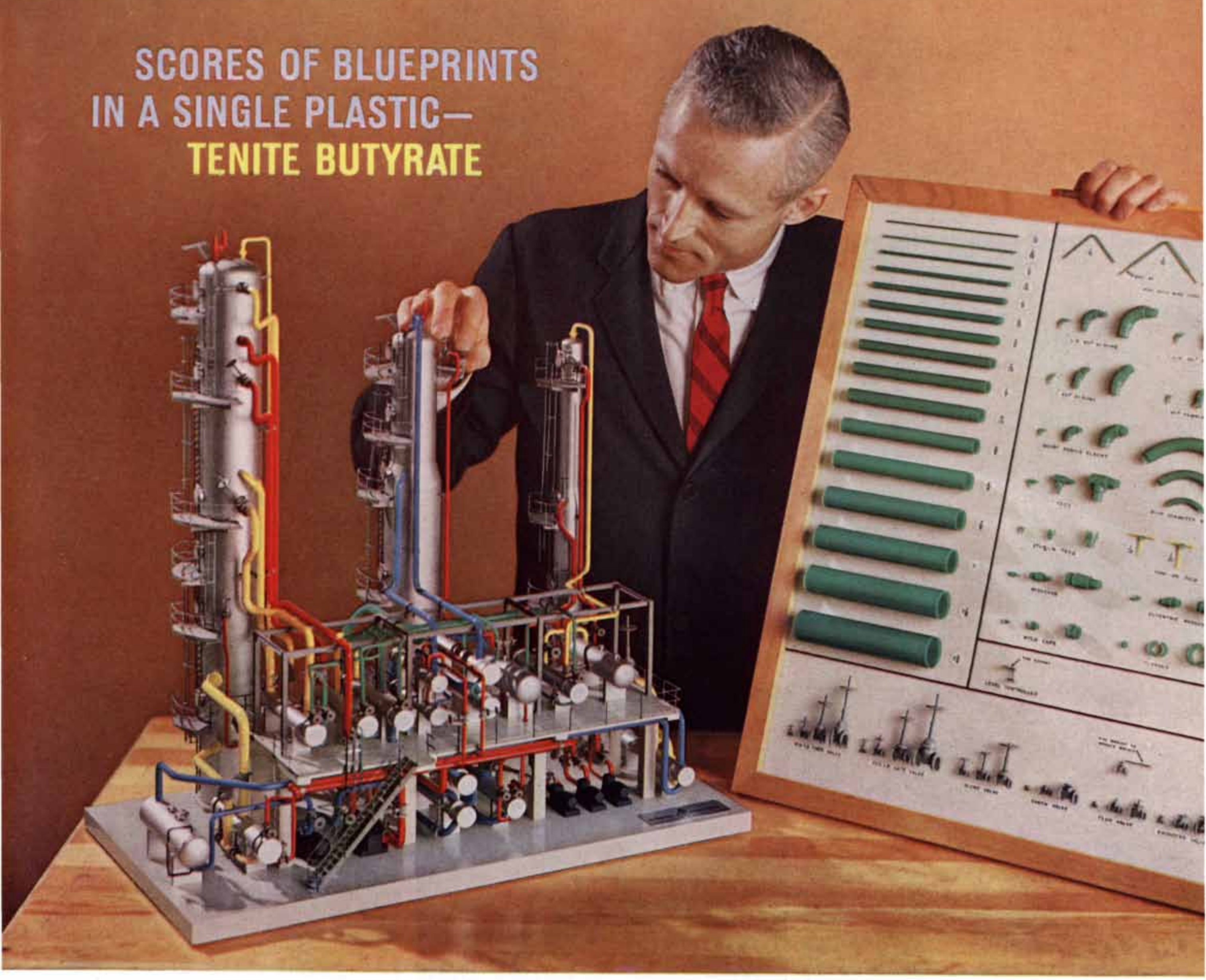

Built from stock components made of tough Tenite Butyrate, a model like this short-cuts the designing of a chemical processing plant or oil refinery. In effect, it provides a three-dimensional set of plans.

The number of required drawings is reduced, and photographs of the model can be of real use in actual construction, for the Butyrate pieces are molded or extruded to scale with extreme accuracy. Since Butyrate plastic is strong and tough, the parts can be joined by push-fit, and complex models are quickly put together. The plastic colors aid in coding the process flow. And the light weight and strength of Tenite Butyrate permit the model to be shipped abroad economically, where it overcomes many problems formerly caused by differences in language and drafting technique, and saves valuable time in personnel training.

The advantages of Butyrate—toughness, formability, colors (more than 42,000 formulated by the Tenite Color Laboratory), gloss, light weight, and economy—are the basis for scores of successful products. End-uses range from molded fishing lures to huge outdoor signs of thermoformed sheet.

In fact, Tenite Butyrate is formulated with so many useful combinations of properties that your own planning may benefit from knowing more about this versatile plastic. Qualified technical representatives will help. For information, write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

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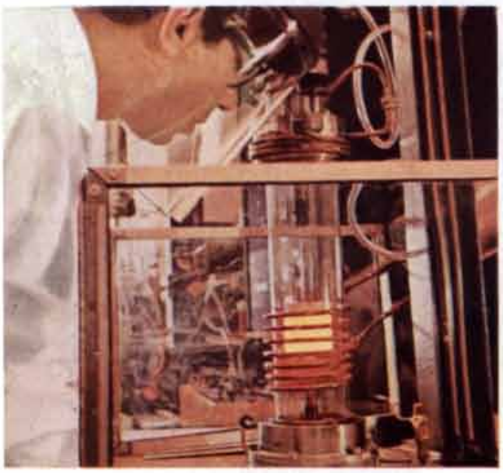
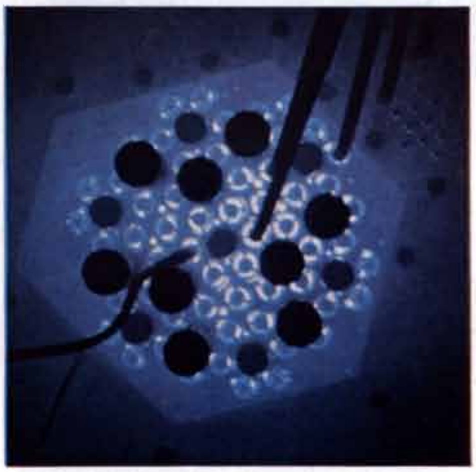


RESEARCH LABORATORIES. Westinghouse research has led to many important developments in nuclear science. Research is conducted by nuclear experts using advanced research facilities.



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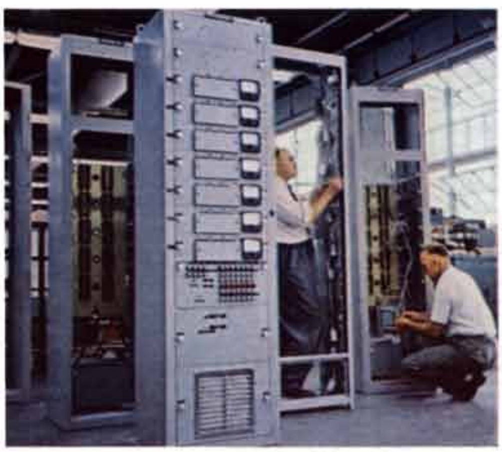
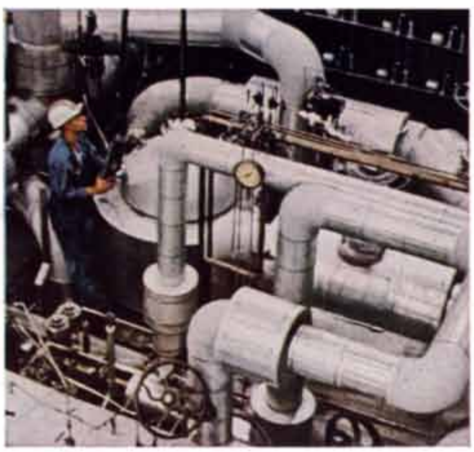


NUCLEAR CONTROL DEPARTMENT. Westinghouse control and instrumentation systems insure complete electrical compatibility in all phases of the nuclear power producing process.



ATOMIC POWER DEPARTMENT. Here the work of thousands of Westinghouse employees is coordinated in the design and development of complete nuclear power plants.

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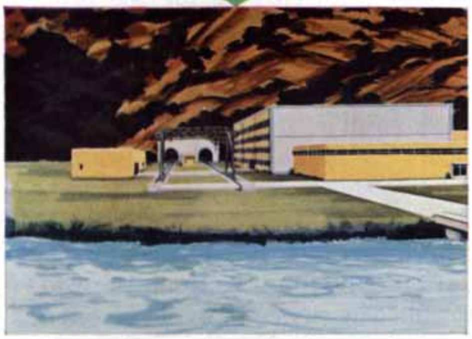
and has designed or is developing the reactors for all these atomic power plants

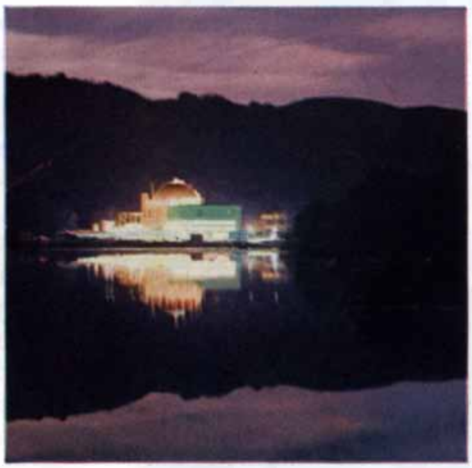


SENA, FRANCE. A 259-megawatt plant in Chooze, France, near the Belgian border (Artist's concept).

SAXTON, PA. An experimental water reactor to be used with an existing turbine-generator of the Pennsylvania Electric Company.

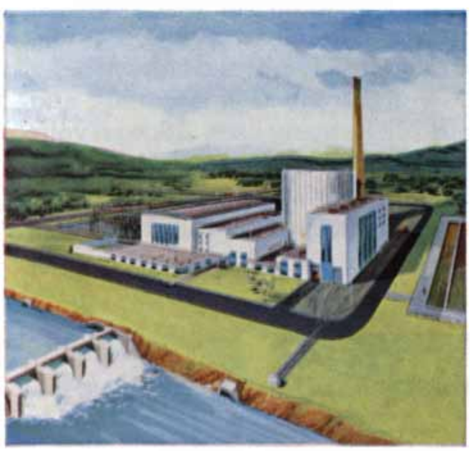
BR-3, MOL, BELGIUM. 11,500-kw plant for Centre d'Etude de L'Energie Nucleaire.

CAROLINAS-VIRGINIA. A 19,000-kw heavy water cooled and moderated pressure-tube prototype plant at Parr, S.C., for Carolinas-Virginia Nuclear Power Associates.



YANKEE. 150-megawatt plant for the Yankee Atomic Electric Co. at Rowe, Mass. New England's first atomic power plant is now producing electricity for the region's integrated power system.

SOUTHERN-CALIFORNIA-EDISON. 375-megawatt nuclear power plant proposed for Southern California (Artist's concept).



SELNI, ITALY. 186-megawatt advanced water reactor power plant for Societa Elettronucleare Italiana (Artist's concept).

SHIPPINGPORT, PA. Plant of Duquesne Light Co., the nation's first nuclear powered central station. Reactor designed by Westinghouse in cooperation with Naval Reactors Branch of the AEC.

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50 AND 100 YEARS AGO

Scientific American

DECEMBER, 1911: "On December 10 King Gustav of Sweden presented the Nobel prizes (with the exception of the peace prize) to the winners. Mme. Marie Sklodowska Curie personally received the prize for chemistry, Prof. Wilhelm Wien of Wuerzburg University the prize for physics and Prof. Allvar Gullstrand of Upsala University the prize for medicine. The Belgian minister received the prize for literature in behalf of Maurice Maeterlinck, who was ill. The Nobel prizes each amount to nearly $40,000."

"So far the study of the horrible disease known as pellagra has produced nothing to point to the etiology of the disturbances it sets up. The Italian expert, Dr. Sambon, believes that it is an infectious disease, and that it is transmitted by the buffalo gnat (*Simulium reptans*); Dr. Lavinder, the specialist of the United States Public Health and Marine Hospital Service, thinks that the disease is a metabolic or food disease."

"The extremely brilliant and dazzling head lights of motor cars are at times very objectionable and some municipal regulations forbid their use. Warren A. Greenlaw of Melrose, Mass., provides in a patent for dimming the lamp by sliding the burner away from the strong focal or reflecting point in front of the reflector. To do this he supports the burner so that it can slide longitudinally and utilizes fluid pressure to move the burner from its normal position. This enables the driver of the car to dim his light whenever desired by sliding it out of its focal relation to the reflector."

"Dr. Percival Lowell, of the Lowell Observatory at Flagstaff, Ariz., has been finally successful in obtaining photographs of Mars that establish beyond a doubt the reality of the canals of Mars. Heretofore, the value of the photos obtained by him in 1907 was questioned on account of their minuteness, being compared in size to the head of an ordinary pin. While the canals are plainly visible on the photographic plate, they will not bear printing processes. On examining the enlarged image through a screen by a stereopticon, an immense amount of elaborate detail appeared, several of the canals being plainly in evidence. As these photographs were taken a month or so before Mars had reached its nearest to our planet, we may look forward with interest to those which will be obtained on the date of nearest approach."

"The work of uncovering the *Maine* is completed, and the report of the engineers and the Board who made the investigation has been made to the Secretary. In the opinion of the Board the examination of the bottom of the ship in the region of the explosion presents evidence of a primary explosion external to the ship; and in all the main features, the recent investigations have fully corroborated the report of the Naval Board of Inquiry, made at the time of the disaster."

Scientific American.

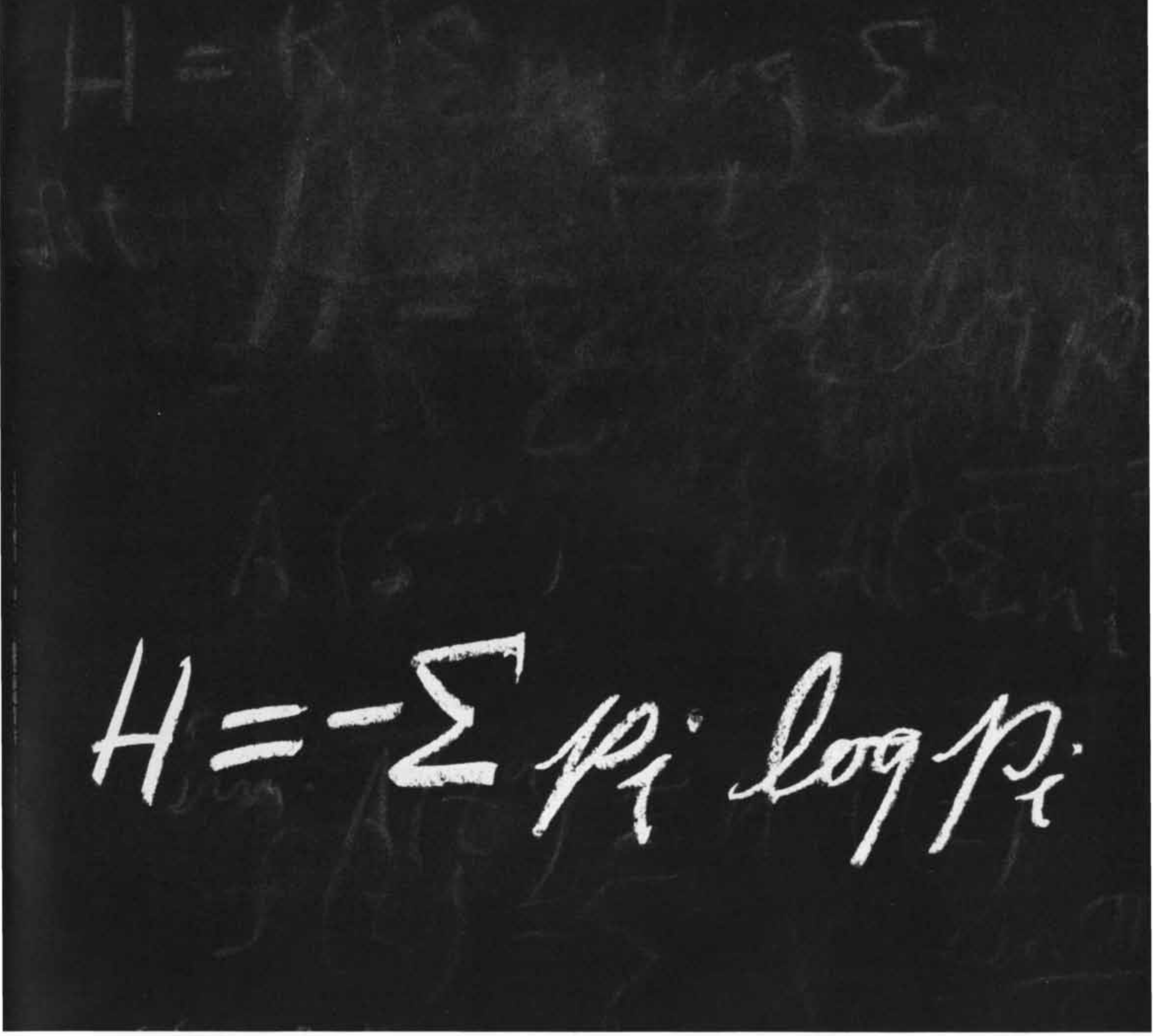
DECEMBER, 1861: "Photographers and astronomers are on the *qui vive*, making their preparations to observe the eclipse of the sun on the 31st December next, to which the recent discoveries of MM. Bunsen and Kirchhoff in celestial chemistry impart a new and additional interest. One point to which observation will be specially directed is the examination of the spectrum of the corona, with which the moon will be surrounded for a moment, in that portion nearest the sun, to see if this aureola exhibits an inversion of the ordinary solar spectrum, or not—that is to say, whether Fraunhofer's rays will be replaced by brilliant lines. Since the publication of the labors of MM. Bunsen and Kirchhoff, the question of a solar atmosphere has acquired a basis and is susceptible of proof by direct experiment. If, for example, the spectrum of the aureola, which will be produced on the 31st December next, exhibits to us an inversion of the solar spectrum, the much vexed question will be solved, and the existence of a solar atmosphere will become a definite scientific fact."

"The English papers state that the cotton speculation is going on in England at a tremendous rate; it is at present carried on by ladies, clergymen, lawyers and others not regularly engaged in business, who have fallen into the mania as others did into the railway mania of 1845. The professional cotton speculators have retired from action. They know that the bubble must burst."

"The Earl of Rosse has communicated to the Royal Society some observations on the nebulae, with practical details on the construction of large telescopes. The principal result of the observations seems to be a large addition to the list of nebulae with curved or spiral branches and many new and multiple nebulae. A variety of objects have also been pointed out, upon which, says the noble observer, the labor of a careful scrutiny with a similar instrument, even in this climate, will be amply repaid."

"The *Great Eastern* is now lying safely moored at Milford Haven, where she has satisfactorily ridden out the recent terrific gales. She is discharging her coals into vessels alongside, to hasten the completion of which relays of men are at work day and night so that she may be placed on her gridiron at Nayland (prepared for her purposely when she was last there) with all possible dispatch. Every necessary preparation is being made for speedily effecting her repairs, to expedite which even the resources of the Royal Dockyard are afforded."

"The commercial shipping of the world amounts to about fifteen millions of tuns, of which England has about five millions, the United States about five and all the rest of the nations combined about five. The nation ranking next to England and the United States is France, the commercial marine of which country amounts to about one million of tuns. A war between England and America would be a war upon the ocean and would result in the utter destruction of the shipping of both nations. England has just refused to accept our assent to the abolition of privateering, and all seas would soon be swarming with our clipper ships and steamers amply armed and crowded with men in search of the rich prizes to be found in English vessels. Like swarms of rovers, ships would issue from English harbors to prey upon our commerce, and the rich carrying trade of the world would fall mainly into the hands of the French and Dutch. When peace shall finally be restored, and the little doubtful point of international law settled, England and the United States will be degraded from their proud preeminence, and France will be the leading commercial nation of the world. It is to be hoped that the common sense of the two communities will save us from the immeasurable evils of a war between us."



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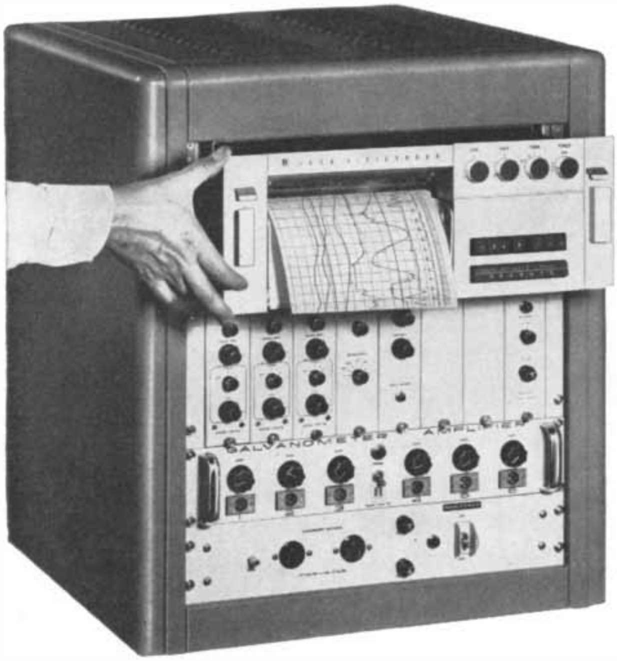

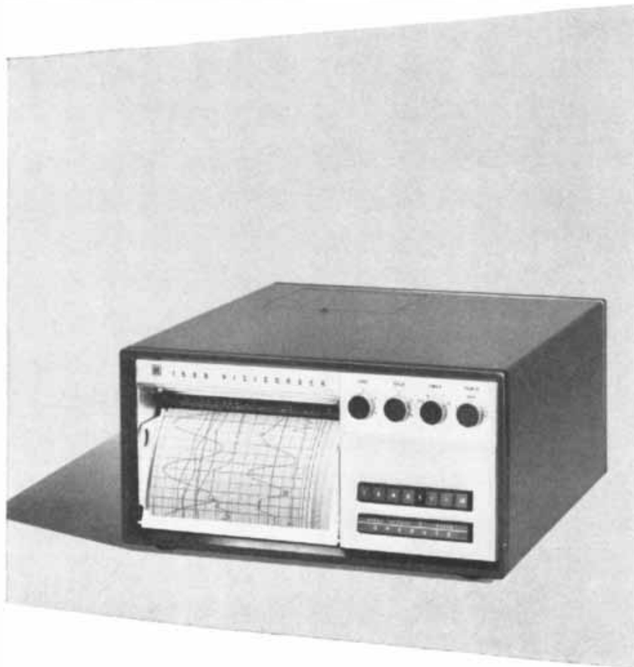

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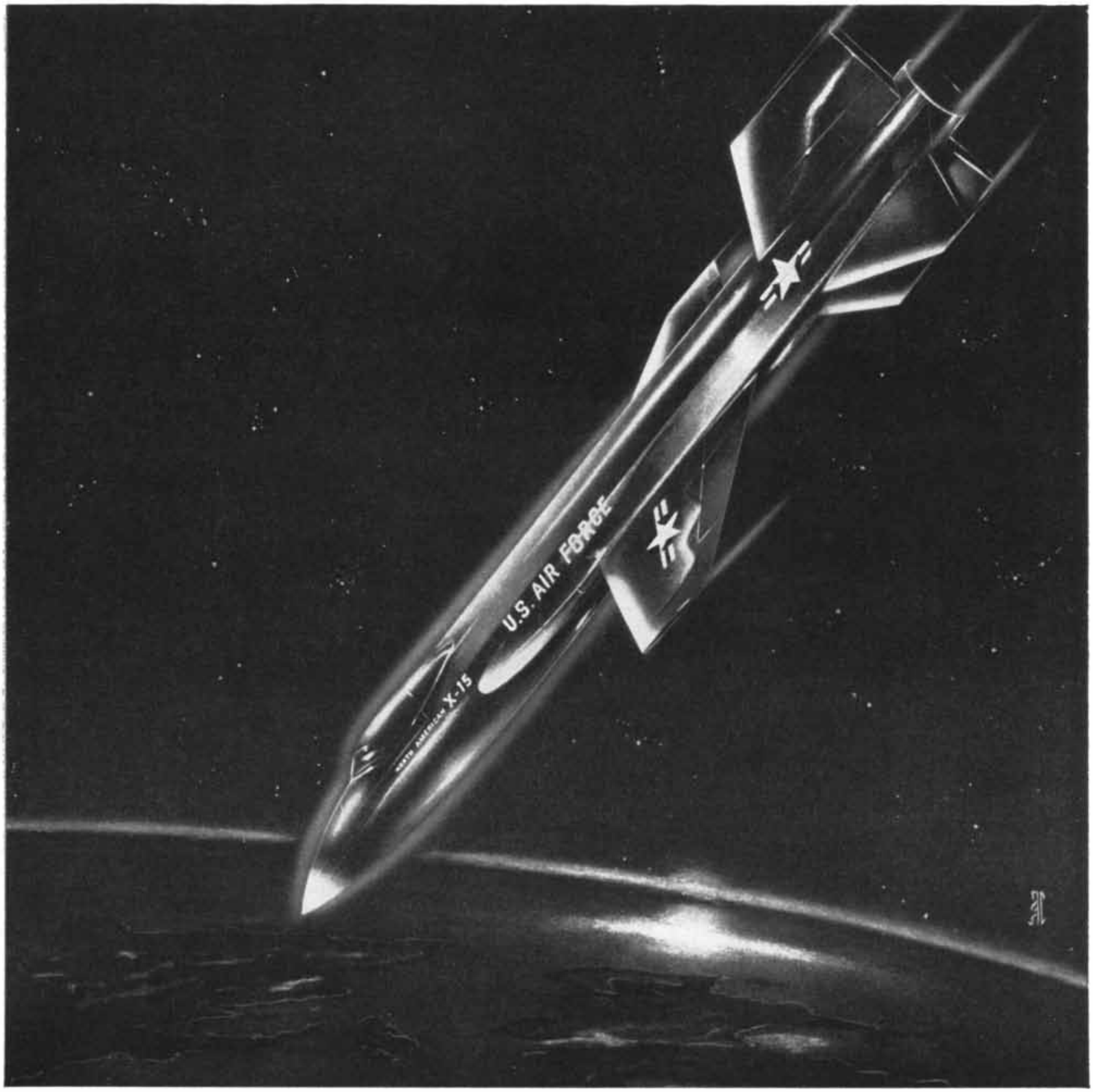

In test flight, the X-15, America's first manned space probe ship, has reached speeds as high as 3920 mph and altitudes as high as 169,000 ft. Ship was built by North American Aviation, Inc.

THE HOT RIDE HOME FROM SPACE

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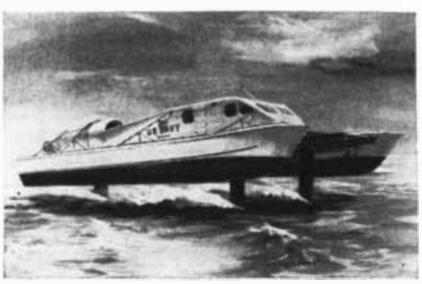
INCO RESEARCH

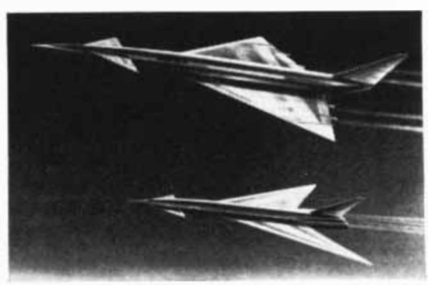
AERIAL MISSILE LAUNCHER. Photo shows Boeing B-52 missile bomber making in-flight launch of Hound Dog missile, which flies at supersonic speed toward target far ahead. In addition to missiles, versatile B-52s can carry regular bomb-bay load of gravity bombs. New B-52H, with turbofan engines and sophisticated electronics, is tailored for wide variety of Strategic Air Command mission requirements. Later, B-52H will carry hypersonic Skybolt ballistic missiles, a 1000-mile weapon under development.

Capability has many faces at Boeing



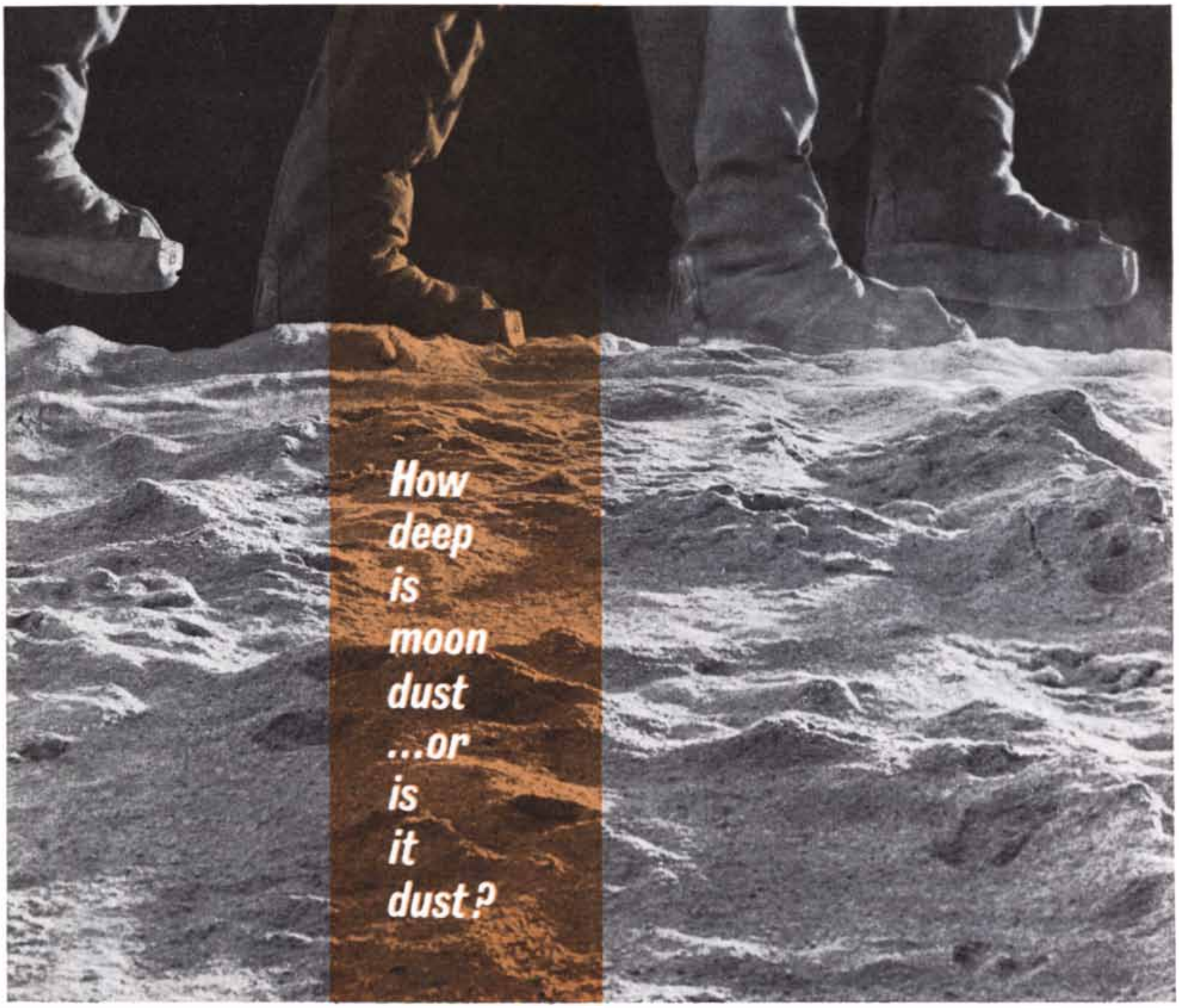
JET HYDROFOIL. Drawing shows jet-powered twin-hull test hydrofoil Boeing is designing and building for U.S. Navy. Hydrofoil will "fly" on under-water wings at 115 mph.

TWIN-TURBINE helicopter, Boeing-Vertol 107, seats 25 and will enter service soon with New York Airways. 107s have been ordered for service in Japan, Canada and Sweden. Military version is being built for U.S. Marine Corps.



SUPERSONIC JETLINERS. Boeing continues to invest substantial sums in supersonic jet transport research. Drawing shows two Boeing designs being studied. Supersonic jets would fly two to three times speed of sound, make flight from New York to London in under three hours.

BOEING



GM's DSD seeks an answer!

Scientific studies are now under way in GM's Defense Systems Division to determine the most efficient configurations for lunar-roving vehicles. Major factors under investigation include composition of the lunar surface together with the effects of large temperature ranges, lunar gravity . . . no atmosphere or humidity. Research in our Soils Laboratory on probable lunar conditions has led to a number of promising designs. Unusual studies like these, unusual facilities and unusually capable men present a great challenge and opportunity to scientists and engineers who are qualified to make a solid contribution at any level. DSD is now, as always, searching for new talent in these areas.

Scientific areas now under study: ▪ Aero-Space Operations ▪ Sea Operations ▪ Land Operations ▪ Biological Systems ▪ Technical Specialties

Moon-Roving Concept—This early model moon rover utilizes the principle of the Archimedes screw . . . and is just one of a number of vehicle types under study for known lunar conditions.

GENERAL MOTORS

DEFENSE SYSTEMS DIVISION

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THE AUTHORS

STANLEY MILGRAM ("Nationality and Conformity") is assistant professor of social psychology at Yale University. He first became interested in the subject of his article while studying French at the Sorbonne. "Along with most other foreigners," he writes, "I noticed that certain aspects of behavior were different in kind and/or degree for Frenchmen and the people back home, and I wondered whether these differences could be reduced to quantifiable measures." After receiving his A.B. from Queens College in New York in 1954 and entering the Department of Social Relations at Harvard University, Milgram began to satisfy his curiosity in 1957. Two fellowships from the Social Science Research Council enabled him to undertake experimental research in Norway and France. Of this work he says: "It was no holiday. In France it took three months before I could find a room in which to conduct the experiments, and I could retain the services of my *soliciteur* (the French assistant who set up appointments with experimental subjects) only by agreeing to surrender my personal tape recorder to him at the end of the experiment. Such is the price of cross-national research, but the rewards too are varied and rich." Milgram joined the faculty of Yale after obtaining his Ph.D. from Harvard last year.

HENRY W. MENARD ("The East Pacific Rise") is associate professor of geology at the Scripps Institution of Oceanography. Having received a B.S. degree from the California Institute of Technology in 1942, Menard spent the rest of World War II on sea duty in the western Pacific. He returned to Cal Tech to take an M.S. in 1947 and then went to Harvard University, where he received a Ph.D. in geology in 1949. From 1949 to 1955 he was an oceanographer at the U.S. Navy Electronics Laboratory in San Diego, Calif. Menard, who had been lecturing at the University of California since 1951, joined the Scripps Institution in 1955. The present article is his second for SCIENTIFIC AMERICAN. The first, "Fractures in the Pacific Floor," appeared in July, 1955.

HOLGER HYDÉN ("Satellite Cells in the Nervous System") has since 1949 been head of the Institute of Histology at the University of Göteborg in Sweden and is currently acting president of the university. Hydén studied medicine at the Royal Caroline Institute in Stockholm, which awarded him an M.D. degree in 1943. For the next six years he was affiliated with the Nobel Institute for Cell Research, first as assistant professor and then as research fellow. Hydén served as vice-president of the University of Göteborg from 1954 to 1957, at which time he became acting president. At present he is doing research on the composition and metabolism of the components of the central nervous system, and he is particularly interested in the functional relationships between nerve cells and the glial, or "satellite," cells associated with them.

R. H. DICKE ("The Eötvös Experiment") is professor of physics at Princeton University. Dicke acquired his A.B. at Princeton in 1939 and a Ph.D. in physics at the University of Rochester in 1941. From 1941 to 1946, the year he went to Princeton, Dicke was a staff member of the Radiation Laboratory at the Massachusetts Institute of Technology. In addition to the experimental work on gravitation discussed in his article, Dicke has done research on microwave thermal radiation from the sun and the moon, on optically induced polarization and on positronium (evanescent "atoms" consisting of one electron and one positron).

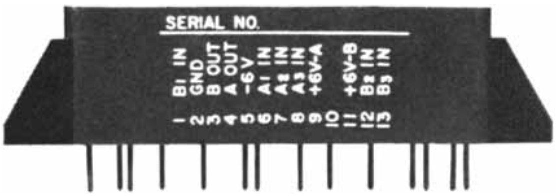
JOHN C. KENDREW ("The Three-dimensional Structure of a Protein Molecule") is deputy director of the Medical Research Council Unit for Molecular Biology in the Cavendish Laboratory at the University of Cambridge. Kendrew took his B.A., M.A. and Ph.D. degrees at Cambridge, receiving the last in 1949. A Fellow of the Royal Society and editor-in-chief of the *Journal of Molecular Biology*, Kendrew has been engaged in research on the structure of proteins since 1946.

IRENÄUS EIBL-EIBESFELDT ("The Fighting Behavior of Animals") is research associate in ethology at the Max Planck Institute for the Physiology of Behavior in Germany. He was born in Vienna in 1928 and studied zoology at the University of Vienna, acquiring his doctorate there in 1949. Later that year he joined the Institute for Comparative Behavior, where he worked with the noted student of animal behavior Konrad Z. Lorenz. When the institute was moved to West Germany in 1951 (becoming the Max Planck Institute in the process), Eibl-Eibesfeldt moved with it. Since then his study of symbiotic relationships among fishes has taken him all over the world. In 1953 he accompanied the Xarifa Expedition of the International Institute for Submarine Research to the Caribbean and the Galápagos Islands. His memorandum on the rapid destruction of flora and fauna in the Galápagos led to his being sent by UNESCO in 1957 to make a survey of the conditions there. The results of his recommendations were the creation of the Darwin Foundation in Brussels and the establishment of a biological station in the Galápagos. The following year Eibl-Eibesfeldt accompanied another Xarifa Expedition, this time to the Indian Ocean. During the first half of this year he was a visiting lecturer in ethology at the University of Chicago. He is also the author of the book *Galápagos,* which appeared earlier this year.

STANLEY W. ANGRIST ("Galvanomagnetic and Thermomagnetic Effects") is instructor in mechanical engineering at Ohio State University. A native of Texas, Angrist acquired a B.S. degree at Texas Agricultural and Mechanical College in 1955. While working in technical intelligence at the Wright-Patterson Air Force Base in Ohio, he began graduate work at the Ohio State University graduate center located at the base and received an M.S. in 1958. Angrist did his doctoral dissertation on one of the thermomagnetic effects discussed in the present article and expects to obtain his Ph.D. this month.

HANSJÜRGEN MÜLLER-BECK ("Prehistoric Swiss Lake Dwellers") is research assistant at the Bern Historical Museum in Switzerland. Müller-Beck, whose special field of interest is Pleistocene archaeology, received his Ph.D. from the University of Tübingen in 1955. He joined the Bern Historical Museum in 1956. The following year he carried out the excavation of the Neolithic village at Burgäschi described in his article. He has also done archaeological field work in Turkey, Bolivia and Uruguay.

A. RUPERT HALL, who in this issue reviews *The Mechanization of the World Picture* by E. J. Dijksterhuis, is professor of the history and logic of science at Indiana University. Formerly a member of the faculty at the University of Cambridge, Hall was an editor of the five-volume *History of Technology* published by the Oxford University Press and is the author of several books, including *The Scientific Revolution: 1500 to 1800.*



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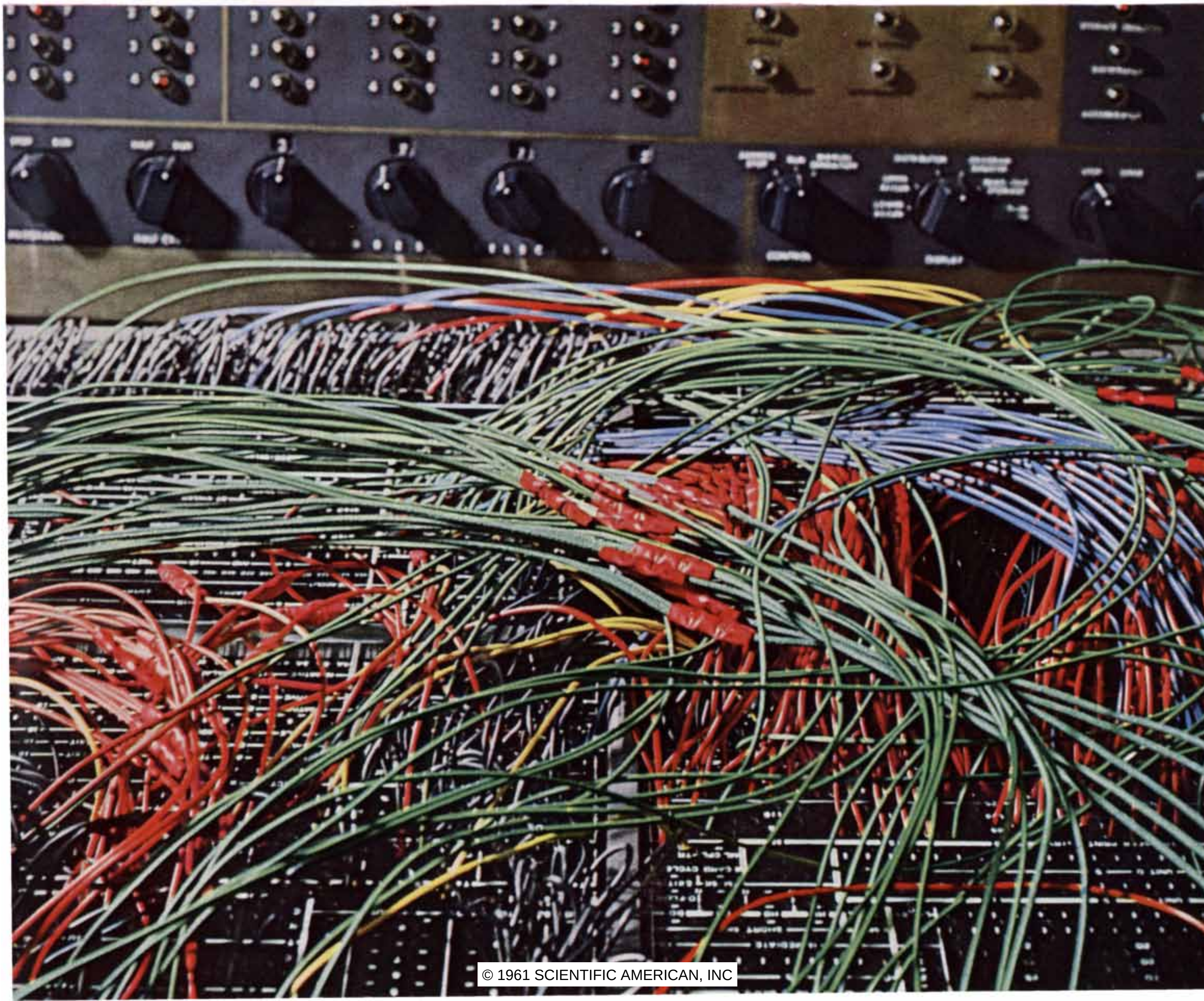

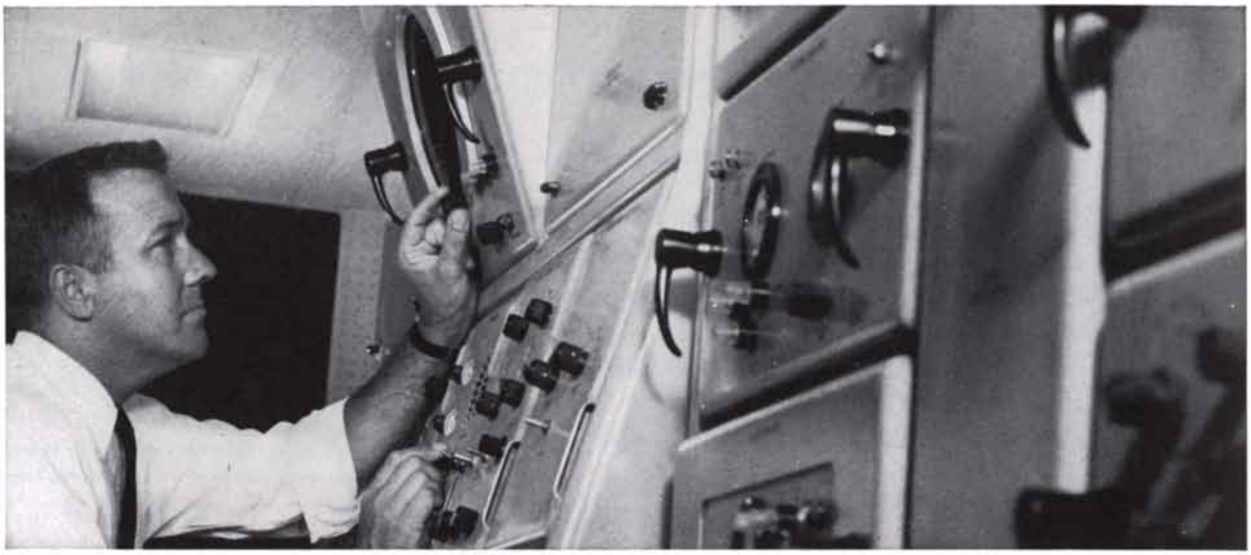

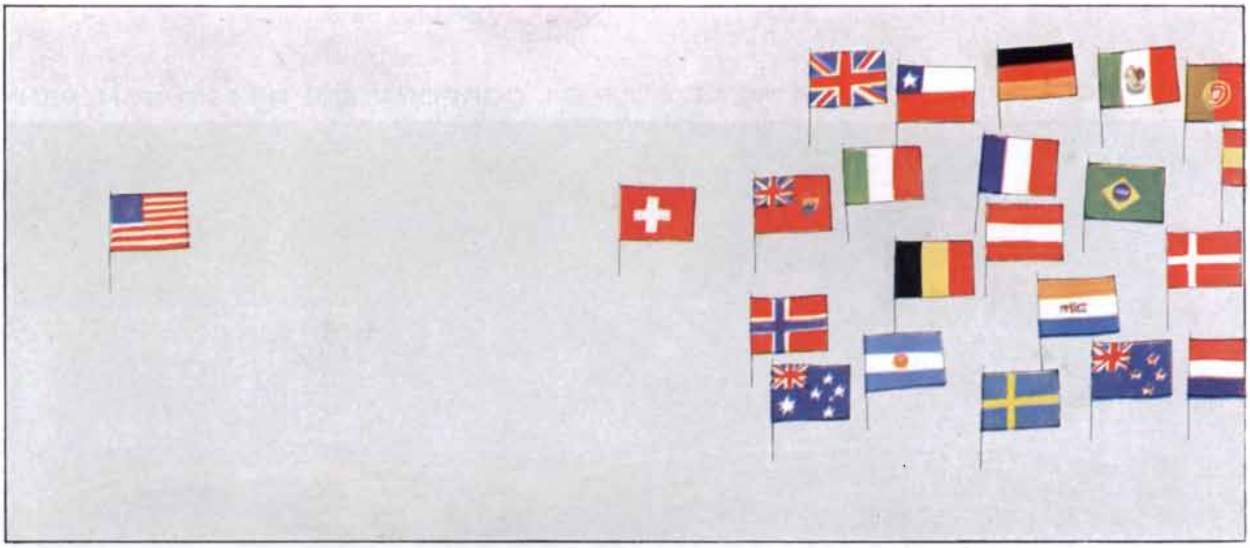

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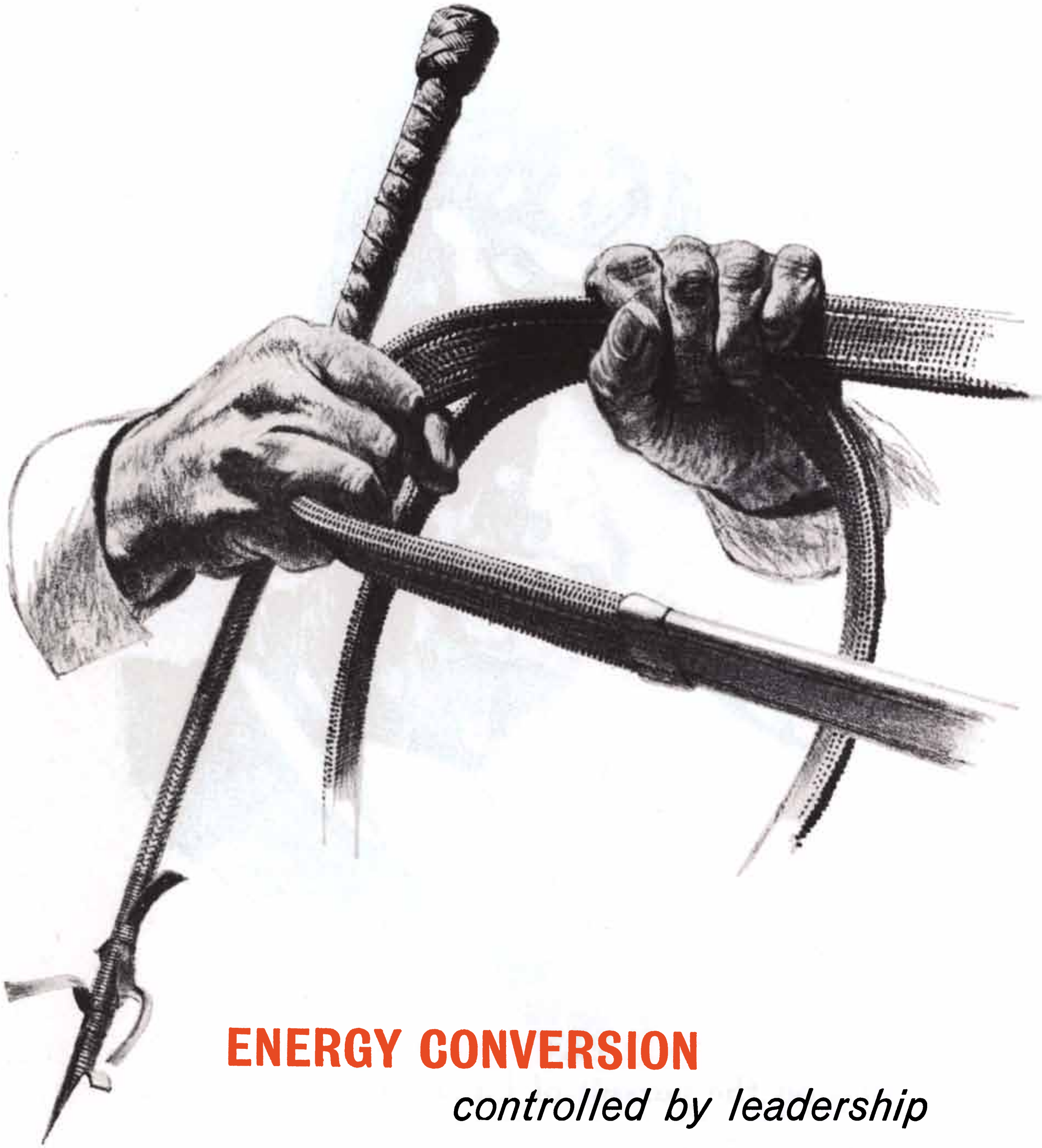


Established 1845 SCIENTIFIC AMERICAN December 1961 Volume 205 Number 6

Nationality and Conformity

Do the people of one culture conform to majority opinions more than do the people of another? An account of a study in which Norwegians and Frenchmen were separately subjected to synthetic group pressure

by Stanley Milgram

People who travel abroad seem to enjoy sending back reports on what people are like in various countries they visit. A variety of national stereotypes is part and parcel of popular knowledge. Italians are said to be "volatile," Germans "hard-working," the Dutch "clean," the Swiss "neat," the English "reserved," and so on. The habit of making generalizations about national groups is not a modern invention. Byzantine war manuals contain careful notes on the deportment of foreign populations, and Americans still recognize themselves in the brilliant national portrait drawn by Alexis de Tocqueville more than 100 years ago.

And yet the skeptical student must always come back to the question: "How do I know that what is said about a foreign group is true?" Prejudice and personal bias may color such accounts, and in the absence of objective evidence it is not easy to distinguish between fact and fiction. Thus the problem faced by the modern investigator who wishes to go beyond literary description is how to make an objective analysis of behavioral differences among national groups. By this he means simply an analysis that is not based on subjective judgments and that can be verified by any competent investigator who follows the same methods.

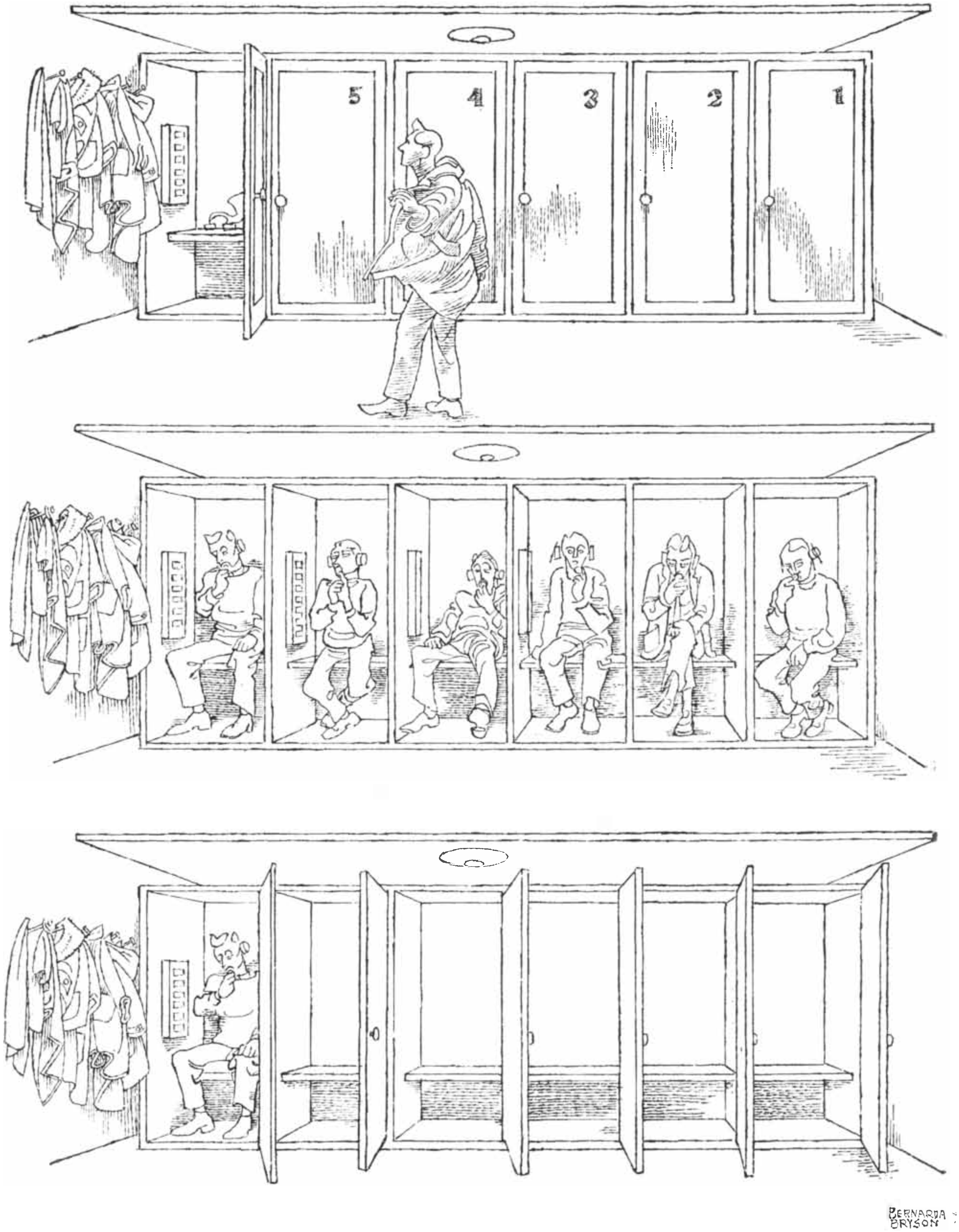
It is easy to show objectively that people in different countries often speak different languages, eat different foods and observe different social customs. But can one go further and show national differences in "character" or "personality"? When we turn to the more subtle dimensions of behavior, there is very little evidence to make a case for national differences. It is not that such differences are to be denied out of hand; it is just that we lack sufficient reliable information to make a clear judgment.

Before reporting the results of my own study let me refer briefly to some earlier efforts to achieve objectivity in studying this elusive problem. One approach has been to examine the literature and other cultural products of a nation in the hope of identifying underlying psychological characteristics. For example, Donald V. McGranahan of Harvard University studied successful stage plays performed in Germany and the U.S. and concluded that German stage characters were more devoted to principles and ideological notions, whereas the Americans were more concerned with the attainment of purely personal satisfactions. The obvious limitation of such a study is that the behavior and attitudes under examination are the synthetic ones of the stage and may bear little or no resemblance to those of real life.

Another indirect approach has relied on the tools of clinical psychology. This method was pioneered by anthropologists in the study of small, primitive societies and has only recently been applied to modern urban nations. These studies rely heavily on such tests as the Rorschach ink-blot test and the thematic apperception test (T.A.T.). In the latter the subject is shown a drawing of a situation that can be variously interpreted and is asked to make up a story about it. The major difficulty here is that the tests themselves have not been adequately validated and are basically impressionistic.

Finally, sample surveys of the type developed by Elmo Roper and George Gallup in this country have been applied to the problem. Geoffrey Gorer, an English social scientist, based his study *Exploring English Character* on a questionnaire distributed to 11,000 of his compatriots. The questions dealt with varied aspects of English life, such as courtship patterns, experiences in school and practices in the home. Unfortunately there are many reasons why an individual's answer may not correspond to the facts. He may deliberately distort his answers to produce a good impression, or he may have genuine misconceptions of his own behavior, attributable either to faulty memory or to the blindness people often exhibit toward their own actions and motivations.

These methods should not be dismissed as unimportant in the study of national characteristics. Yet in principle if one wants to know whether the people of one nation behave differently from those of another, it would seem only reasonable to examine the relevant behavior directly, and to do so under conditions of controlled observations in or-



CONFORMITY EXPERIMENT required that the subject discriminate between the lengths of two tones heard through headphones, and measured the extent to which he went along with wrong answers given—it seemed to him—by five other subjects listening to the same tones. Actually no other subjects were present; the illusion was created by tape recordings. The top drawing by Bernarda Bryson shows what the subject saw as he entered the experimental room. The middle drawing shows what the subject, seated in the far left-hand booth, imagined the situation to be while he was taking the test. The drawing at the bottom shows the actual situation.

der to reduce the effects of personal bias and to make measurement more precise.

An important step in this direction was reported in 1954 by an international team of psychologists who worked together as the Organization for Comparative Social Research. This team studied reactions to threat and rejection among school children in seven European nations, using hypotheses advanced by Stanley Schachter of Columbia University. The inquiry was not specifically designed to study national characteristics but chiefly to see if certain concepts regarding threat and rejection would hold up when tested in different countries. In the course of the study certain differences between countries did turn up, but the investigators felt they were not necessarily genuine. Conceivably they were due to defects in the experiment or to inadequacies in the theory behind it. Although its focus was on theory validation, this study is a landmark in cross-national research. Unfortunately the Organization for Comparative Social Research halted its research program when the study was completed.

My own investigation was begun in 1957. My objective was to see if experimental techniques could be applied to the study of national characteristics, and in particular to see if one could measure conformity in two European countries: Norway and France. Conformity was chosen for several reasons. First, a national culture can be said to exist only if men adhere, or conform, to common standards of behavior; this is the psychological mechanism underlying all cultural behavior. Second, conformity has become a burning issue in much of current social criticism; critics have argued that people have become too sensitive to the opinions of others, and that this represents an unhealthy development in modern society. Finally, good experimental methods have been developed for measuring conformity.

The chief tool of investigation was a modified form of the group-pressure experiment used by Solomon E. Asch and other social psychologists [see "Opinions and Social Pressure," by Solomon E. Asch, SCIENTIFIC AMERICAN, November, 1955]. In Asch's original experiment a group of half a dozen subjects was shown a line of a certain length and asked to say which of three other lines matched it. All but one of the subjects had been secretly instructed beforehand to select one of the "wrong" lines on each trial or in a certain percentage of the trials. The naïve subject was so placed that he heard the answers of most of the group before he had to announce his own decision. Asch found that under this form of social pressure a large fraction of subjects went along with the group rather than accept the unmistakable evidence of their own eyes.

Our experiment is conducted with acoustic tones rather than with lines drawn on cards. Five of the subjects are confederates of the experimenter and conspire to put social pressure on the sixth subject. The subjects listen to two tones and are asked to say which is the longer. The five confederates answer first and their decisions are heard by the subject, who answers last. The confederates have been instructed to announce wrong answers on 16 of the 30 trials that constitute one experiment.

We elected to use tones rather than lines because they are better suited to an experimental method using "synthetic groups." Two psychologists working at Yale University, Robert Blake and Jack W. Brehm, had discovered that group-pressure experiments can be conducted without requiring the actual presence of confederates. It is sufficient if the subject thinks they are present and hears their voices through headphones. With tape recordings it is easy to create synthetic groups. Tapes do not have to be paid by the hour and they are always available.

When the test subject entered our laboratory, he saw several coats on hangers and immediately got the impression that others were present. He was taken to one of six closed booths, where he was provided with headphones and a microphone. As he listened to the instructions through the headphones he overheard the voices of the other "subjects" and assumed that all the booths were occupied. During the actual experiment he would hear five taped answers before he was asked to give his own.

Except when we made a technical slip the subject never caught on to the trick. Most subjects became deeply involved in the situation, and strong tensions were generated when they realized they must stand alone against five unanimous opponents. This situation created a genuine and deeply felt conflict that had to be resolved either through independence or conformity.

Once we had refined our techniques at Harvard University we were ready to experiment abroad with Norwegian and French subjects. In which of the two national environments would people go along with the group more and in which would there be greater independence?

Most of the subjects used in the Norwegian study were students attending the University of Oslo. Because this is the only full-fledged university in Norway, a good geographic representation was obtained. Our test sample included students from beyond the Arctic Circle, from the fiord country of western Norway and from Trondheim, the former Viking capital.

When the study moved to Paris, French students were selected who matched the Norwegians in age, level of education, fields of study, sex, marital status and—so far as possible—social class. Once again a good geographic distribution was obtained, because students from all parts of France came to study in Paris. A few of the French subjects came from French North African cities. Those used in the experiment were culturally as French as people living on the mainland; they were of French parentage and had been educated in French lycées.

In Norway the entire experiment was conducted by a native Norwegian and all the recorded voices were those of natives. In France the experiments were conducted by native Frenchmen. Much effort was made to match the tone and quality of the Norwegian and French groups. We made many recordings until people who were sensitive to the nuances of both languages were satisfied that equivalent group atmospheres had been achieved.

Twenty Norwegian subjects and the same number of French subjects were studied in the first set of experiments. The Norwegian subjects conformed to the group on 62 per cent of the critical trials (that is, trials in which the group deliberately voted wrong); the French subjects conformed to the group on 50 per cent of the critical trials.

After each subject had taken part in the experiment he was told its true character and was asked to give his reactions. Almost all participants in both countries had accepted the experiment at face value and admitted feeling the strong pressure of the group. A Norwegian student from a farm in Nordland, above the Arctic Circle, said: "I think the experiment had a very ingenious arrangement. I had no idea about the setup until it was explained to me. Of course, it was a little embarrassing to be exposed in such a way." A self-critical student from Oslo remarked: "It was a real trick and I was stupid to have fallen into the trap. . . . It must be fun to study psychology." Similar reactions were obtained in France, where students were impressed with the idea of psychological experimentation. (In neither country is psychological research as widespread or as intensive as it is in the U.S., so that subjects are relatively unsophisticated about psychological deceptions.)

It would have been superficial, of course, to conduct just one experiment in Norway, another in France and then draw conclusions. In a second experiment we undertook to change the subject's attitude toward the importance of the experiment itself to see if this might alter the original findings. In this new series of trials (and in all subsequent ones) the subjects were told that the results of the experiments would be applied to the design of aircraft safety signals. In this way their performance was linked to a life-and-death issue. As one might have predicted, the subjects this time showed somewhat greater independence of the group, but once again the level of conformity was higher in Norway (56 per cent) than it was in France (48 per cent).

One possibility that had to be considered at the outset was that Norwegians and Frenchmen differ in their capacity for discriminating tonal lengths and that this led to the greater number of errors made by Norwegians in the group situation. We were able to show, however, by giving each subject a tone-discrimination test, that there was no difference in the level of discrimination of students in the two countries.

NORWEGIAN SUBJECTS were from the University of Oslo, which has students from the entire country. The dots on the map show the home town or county of the 100 students involved.

In both of the first two conformity experiments the subjects were required to do more than decide an issue in the face of unanimous opposition: they were also required to announce that decision openly for all to hear (or so the subject thought). Thus the act had the character of a public statement. We all recognize that the most obvious forms of conformity are the public ones. For example, when prevailing standards of dress or conduct are breached, the reaction is usually immediate and critical. So we decided we had better see if the Norwegians conformed more only under public conditions, when they had to declare their answers aloud. Accordingly, we undertook an experiment in both countries in which the subject was allowed to record his answers on paper rather than announce them to the group. The experiments were performed with a new group of 20 Norwegian and 20 French students.

When the requirement of a public response was eliminated, the amount of conformity dropped considerably in both countries. But for the third time the French subjects were more independent than the Norwegians. In Paris students went along with the group on 34 per cent of the critical trials. In Oslo the figure was close to 50 per cent. Therefore elimination of the requirement of a public response reduced conformity 14 percentage points in France but only 6 percentage points in Norway.

It is very puzzling that the Norwegians so often voted with the group, even when given a secret ballot. One possible interpretation is that the average Norwegian, for whatever reason, believes that his private action will ultimately become known to others. Interviews conducted among the Norwegians offer some indirect evidence for this conjecture. In spite of the assurances that the responses would be privately analyzed, one subject said he feared that because he had disagreed too often the experimenter would assemble the group and discuss the disagreements with them.

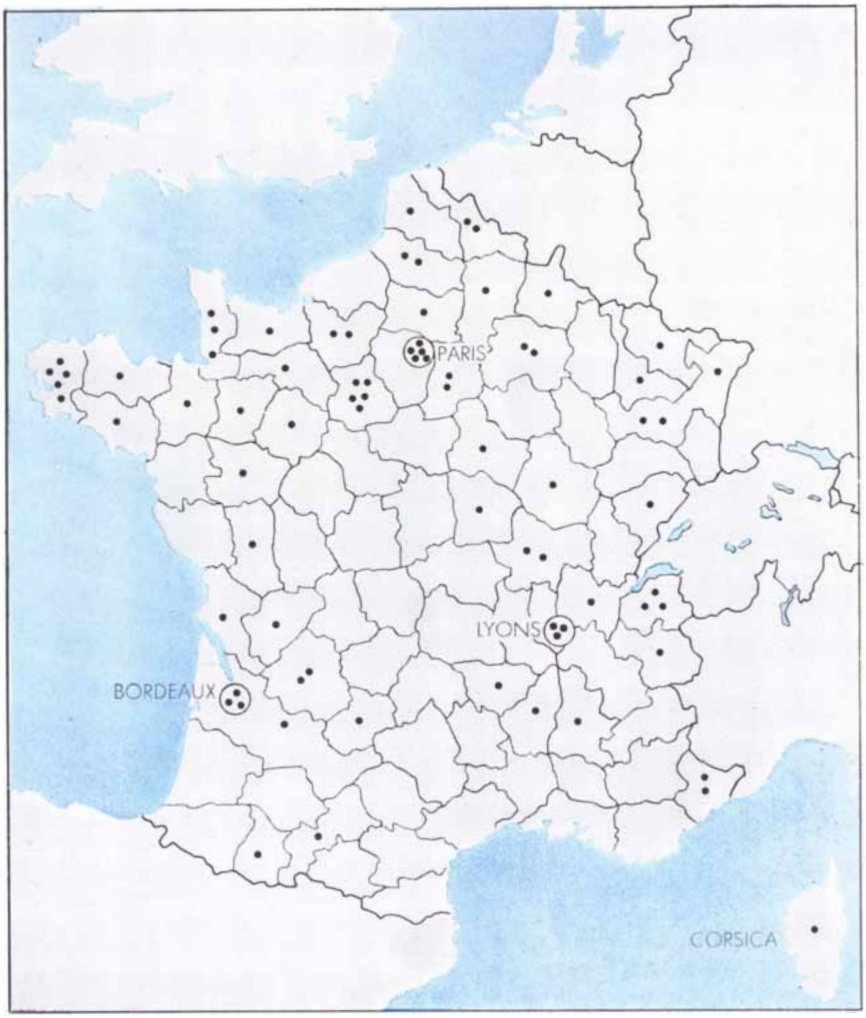
Another Norwegian subject, who had agreed with the group 12 out of 16 times, offered this explanation: "In the world now, you have to be not too much in opposition. In high school I was more independent than now. It's the modern way of life that you have to agree a little more. If you go around opposing, you might be looked upon as bad. Maybe this had an influence." He was then asked, "Even though you were answering in private?" and he replied, "Yes. I tried to put myself in a public situation, even though I was sitting in the booth in private."

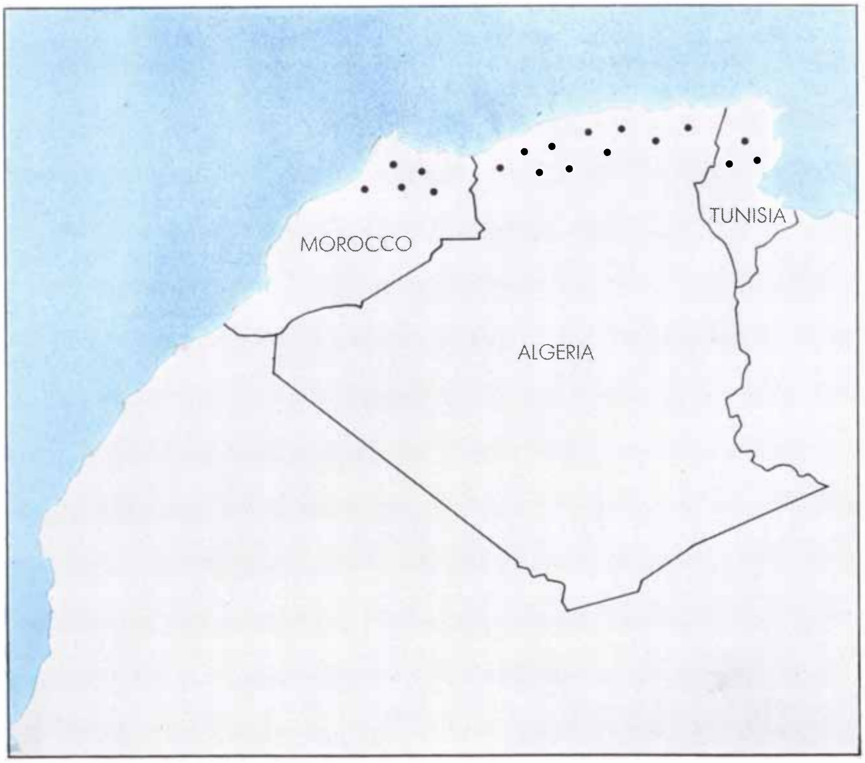
A fourth experiment was designed to test the sensitivity of Norwegian and French subjects to a further aspect of group opinion. What would happen if subjects were exposed to overt and audible criticism from the conspiratorial group? It seemed reasonable to expect a higher degree of conformity under these conditions. On the other hand, active criticism might conceivably lead to a greater show of independence. Moreover, the Norwegians might react one way and the French another. Some of my associates speculated that audible criticism would merely serve to annoy the French subjects and make them stubborn and more resistant to the influence of the group.

To test these notions we recorded a number of appropriate reactions that we could switch on whenever the subject gave a response that contradicted the majority. The first sanction, in both Norway and France, was merely a slight snicker by a member of the majority. The other sanctions were more severe. In Norway they were based on the sentence "Skal du stikke deg ut?" which may be translated: "Are you trying to show off?" Roughly equivalent sentences were used with the French group. In Paris, when the subject opposed the group, he might hear through his headphones: "Voulez-vous vous faire remarquer?" ("Trying to be conspicuous?")

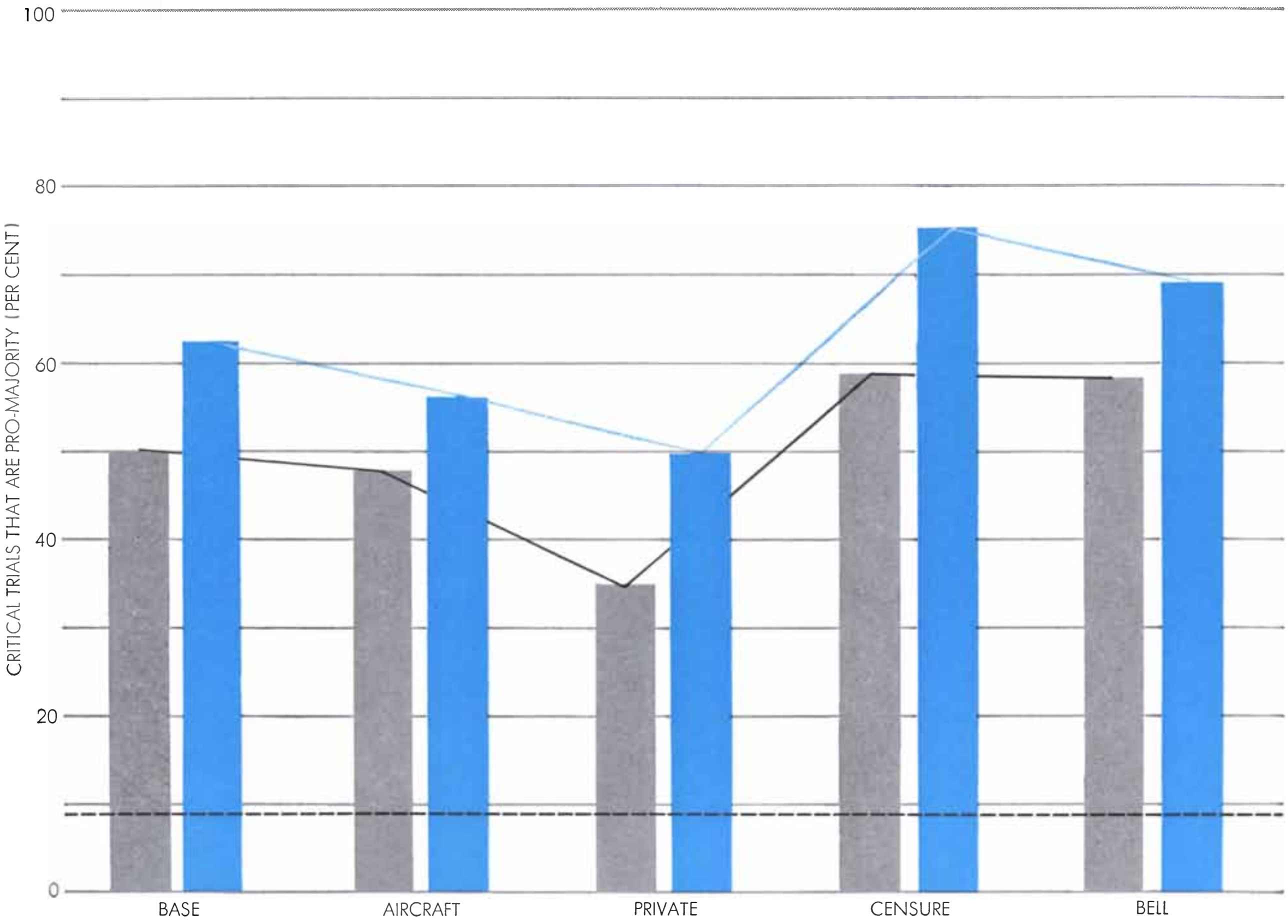
In both Norway and France this overt social criticism significantly increased conformity. In France subjects now went along with the majority on 59 per cent of the critical trials. In Norway the percentage rose to 75 per cent. But the reactions of subjects in the two countries was even more striking. In Norway subjects accepted the criticism impassively. In France, however, more than half the subjects made some retaliatory response of their own when the group criticized them. Two French students, one from the Vosges mountain district and the other from the Department of Eure-et-Loire, became so enraged they directed a stream of abusive language at their taunters.

Even after we explained in the interview session that the entire experimental procedure had been recorded on tape, many of the subjects did not believe us.





FRENCH SUBJECTS were students in Paris chosen to match the Norwegians as closely as possible. The dots show the home department (or area of North Africa) of 95 students.



LEVEL OF CONFORMITY was higher for Norwegians (*colored bars*) than French subjects (*gray bars*) in all five test situations, but fluctuated similarly for both. The broken black line indicates the error level of control groups of both nationalities in the absence of pressure. The first set of bars gives results for the basic experiment. In the next situation significance was increased by an announcement that the test results would affect aircraft safety. This "aircraft" factor was maintained in subsequent tests, in one of which the subjects recorded their answers privately instead of announcing them. In the "censure" situation critical comments (on tape) stepped up pressure on the subjects. In a final experiment censure continued and the subjects were allowed to request repetition of the test tones by sounding a bell; fewer Norwegians than Frenchmen proved "bold" enough to do so.

They could not understand how we could interject comments with such verisimilitude, particularly since we could not predict how they would respond at any given moment. This was achieved by making use of two tape recorders. One played the standard tape containing tones and the group judgments, with "dead" time for the subject; the other contained only the set of "criticisms" from members of the group. The two instruments could be controlled independently, allowing us to inject a remark whenever the subject's responses made it appropriate. The remarks followed the subject's independent responses immediately, creating a highly spontaneous effect.

Another series of experiments was designed to aid in the interpretation of the earlier findings. For example, many Norwegian subjects rationalized their behavior by stating in the interview that they went along with the others because they doubted their own judgment, and that if they had been given a chance to dispel this doubt they would have been more independent. An experiment was therefore carried out to test this notion. The subject was given a chance to reexamine the stimulus materials before giving his final judgment. He did this by sounding a bell in his booth whenever he wished to hear a pair of tones again. As before, the subject was openly censured by the group if he failed to conform, but he was not censured merely for asking to hear the tones repeated. It turned out that even the relatively simple act of requesting a repetition must be construed as an act of considerable independence. Only five of the Norwegians asked for a repetition of a tone on any trial, whereas 14 of the French subjects were "bold" enough to do so. And again the French showed more independence over-all, voting with the group on 58 per cent of the critical trials, compared with 69 per cent for the Norwegians.

The study next moved out of the university and into the factory. When we tested 40 Norwegian industrial workers, we found that their level of conformity was about the same as that of the Norwegian students. There was, however, one important difference. Students were often tense and agitated during the experiment. The industrial workers took it all with good humor and frequently were amused when the true nature of the experiment was explained. We have not yet managed to study a comparable group of industrial workers in France.

No matter how the data are examined they point to greater independence among the French than among the Norwegians. Twelve per cent of the Norwegian students conformed to the group on every one of the 16 critical trials, while only 1 per cent of the French conformed on every occasion. Forty-one per cent of the French students but only 25 per cent of the Norwegians displayed strong independence. And in every one of the five experiments performed in both countries the French showed themselves to be the more resistant to group pressure.

These findings are by no means conclusive. Rather they must be regarded as the beginning of an inquiry that one would like to see extended. But incomplete as the findings are, they are likely to be far more reliable than armchair speculation on national character.

It is useful, nevertheless, to see if the experimental results are compatible with a nation's culture as one can observe it in daily life. If there were a conflict between the experimental findings and one's general impressions, further experiments and analysis would be called for until the conflict had been resolved. Conceivably the discrepancy might be due to viewing the culture through a screen of stereotypes and prejudices rather than seeing it with a clear eye. In any case, in our study experiment and observation seem to be in reasonable agreement. For whatever the evidence may be worth, I will offer my own impressions of the two countries under examination.

I found Norwegian society highly cohesive. Norwegians have a deep feeling of group identification, and they are strongly attuned to the needs and interests of those around them. Their sense of social responsibility finds expression in formidable institutions for the care and protection of Norwegian citizens. The heavy taxation required to support broad programs of social welfare is borne willingly. It would not be surprising to find that social cohesiveness of this sort goes hand in hand with a high degree of conformity.

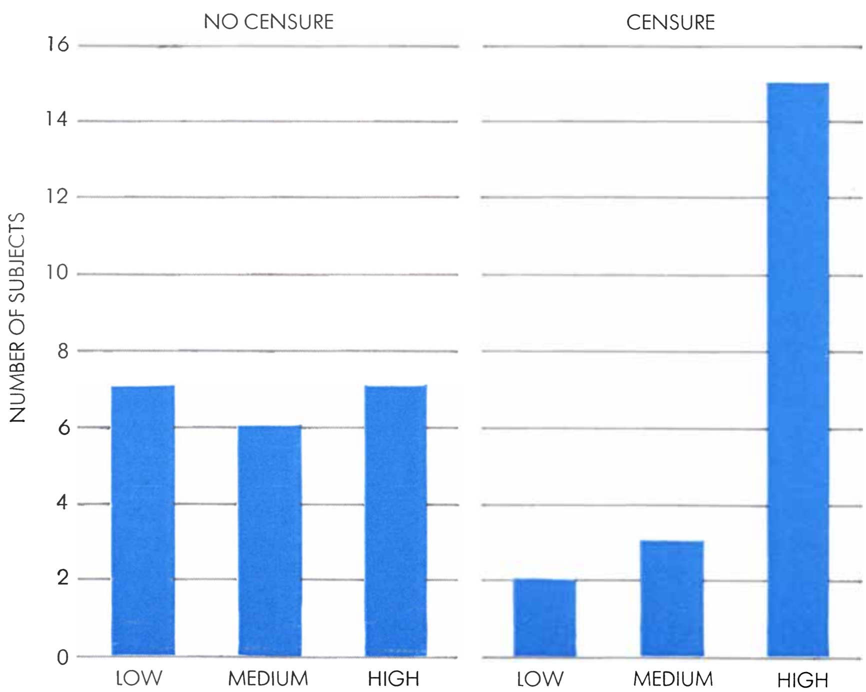
Compared with the Norwegians, the French show far less consensus in both social and political life. The Norwegians have made do with a single constitution, drafted in 1814, while the French have not been able to achieve political stability within the framework of four republics. Though I hardly propose this as a general rule of social psychology, it seems true that the extreme diversity of opinion found in French national life asserts itself also on a more intimate scale. There is a tradition of dissent and critical argument that seeps down to the local *bistro*. The high value placed on critical judgment often seems to go beyond reasonable bounds; this in itself could account for the comparatively low degree of conformity we found in the French experiments. Furthermore, as Stanley Schachter has shown, the chronic existence of a wide range of opinion helps to free the individual from social pressure. Much the same point is made in recent studies of U.S. voting behavior. They reveal that the more a person is exposed to diverse viewpoints, the more likely he is to break away from the voting pattern of his native group. All these factors would help to explain the relatively independent judgments shown by French students.

The experiments demonstrate, in any case, that social conformity is not exclusively a U.S. phenomenon, as some critics would have us believe. Some amount of conformity would seem necessary to the functioning of any social system. The problem is to strike the right balance between individual initiative and social authority.

One may ask whether or not national borders really provide legitimate boundaries for the study of behavioral differences. My feeling is that boundaries are useful only to the extent to which they coincide with cultural, environmental or biological divisions. In many cases boundaries are themselves a historical recognition of common cultural practice. Furthermore, once boundaries are established they tend to set limits of their own on social communication.

For all this, a comparison of national cultures should not obscure the enormous variations in behavior within a single nation. Both the Norwegians and the French displayed a full range of behavior from complete independence to complete conformity. Probably there is no significant national comparison in which the extent of overlap does not approach or match the extent of differences. This should not prevent us, however, from trying to establish norms and statistically valid generalizations on behavior in different nations.

We are now planning further research in national characteristics. In a recent seminar at Yale University students were given the task of trying to identify behavioral characteristics that might help to illuminate the Nazi epoch in German history. The principal suggestions were that Germans might be found to be more aggressive than Americans, to submit more readily to authority and to display greater discipline. Whether these assumptions will hold up under experimental inquiry is an open question. A team of German and American investigators is planning a series of experiments designed to provide a comparative measure of behavior in the two countries.



EFFECT OF CENSURE was to increase conformity. The charts show the degree of conformity among 20 Norwegians in the absence of censure (*left*) and when censure was introduced in the form of criticism (*right*). The "low"-conformity category includes those who gave 6 or fewer promajority responses out of 16; "medium" is 7 to 11 and "high" 12 or more.

THE EAST PACIFIC RISE

This broad, 8,000-mile-long bulge in the crust of the earth differs in many ways from the rest of the ocean bottom. It may be the result of huge convection currents in the interior

by Henry W. Menard

The waters of the Pacific Ocean off North and South America conceal a low bulge in the crust of the earth that is as extensive as both of the continents. This vast feature is known as the East Pacific Rise. It runs roughly north and south for 8,000 miles; its width varies from 1,200 miles to 2,500 miles, and it is up to three miles high. In several respects the rise differs from the rest of the ocean floor. Along its crest, marked in some places by a broken, blocky topography with ridges and troughs running parallel to the axis, the earth's crust is significantly thinner than elsewhere. The crest is a region of high earthquake activity and also of an abnormally high rate of heat flow from the interior. On the flanks of the rise the heat flow is below average.

At regular intervals straight cracks thousands of miles long cross the flanks of the rise in an east-west direction. There is evidence that across these fracture zones huge slabs of the earth's crust have shifted horizontally with respect to each other by hundreds of miles. Yet the slabs themselves are virtually undistorted; they are simply tilted a bit.

Enormous though it is, the East Pacific Rise constitutes only one segment of a 40,000-mile-long chain of undersea ridges and rises that runs almost twice around the earth. This global system, as large as all the continents put together, has been known for only a few years. It is perhaps the single most active topic in geological research, and new data on it are accumulating at an accelerating rate. At this time theories of its origin can only be highly speculative. As one might expect, there is no dearth of ideas on the subject.

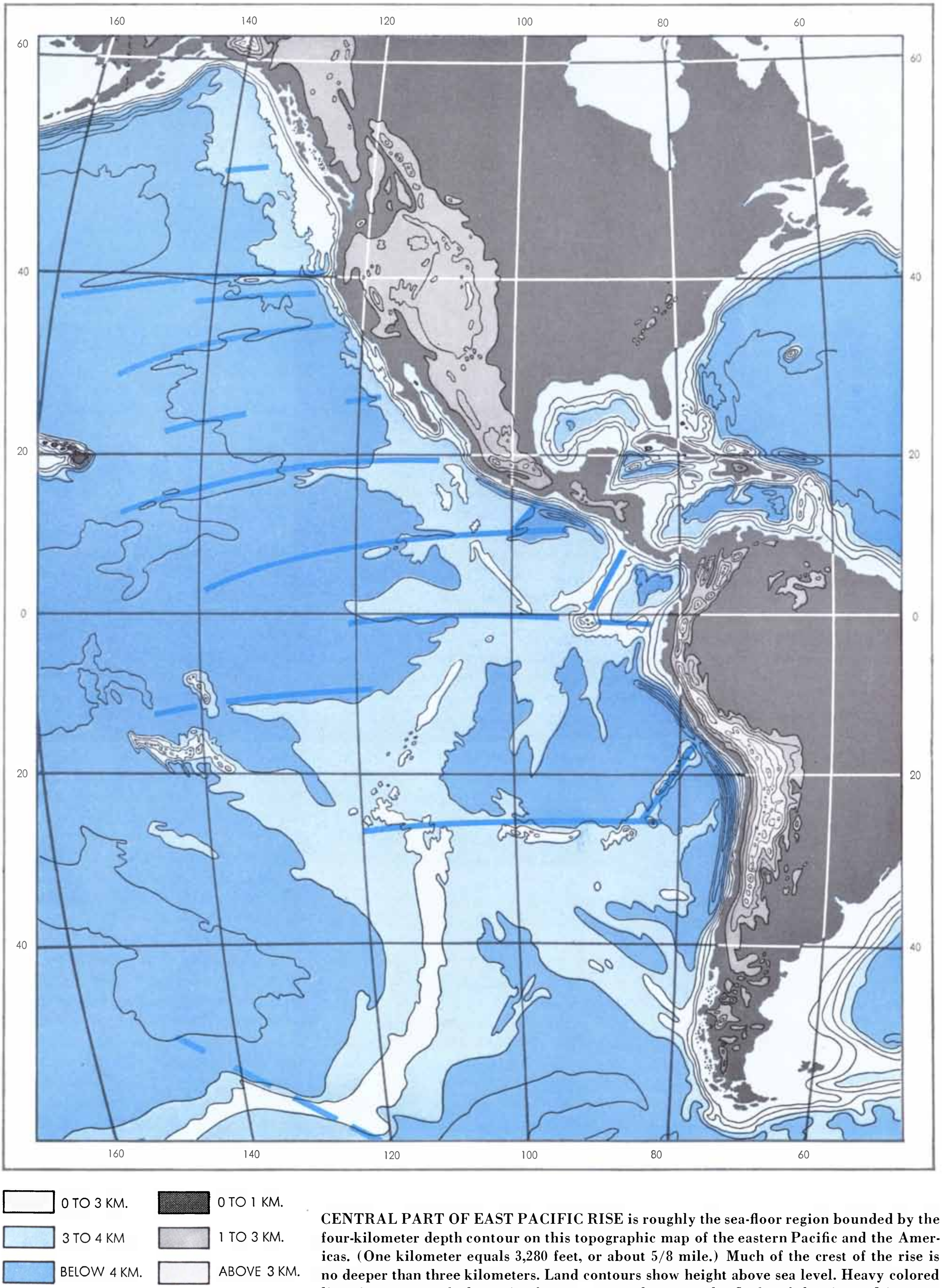
In an article in this magazine Bruce C. Heezen of the Lamont Geological Observatory of Columbia University described a number of studies of the great undersea chain and presented a hypothesis to explain it [see "The Rift in the Ocean Floor," by Bruce C. Heezen; SCIENTIFIC AMERICAN, October, 1960]. Lamont surveys show that in several places the chain is split along its crest by a deep rift valley that coincides with a narrow belt of earthquake epicenters. The epicenters extend along the crest of the mountain chain through all the oceans. By analogy, the rift was assumed to be continuous along the crest. To account for this world-wide rift Heezen advanced the hypothesis that the earth is expanding.

Recent soundings by English, German, Soviet and U.S. oceanographers make it clear that a single continuous central rift does not exist. In many places the crest displays not a single great rift but a number of parallel rifts and ridges. This makes little difference in considering the origin of the mid-ocean mountain chain, since both topographic forms indicate tension on the crest.

Our studies at the Scripps Institution of Oceanography have demonstrated a correlation along the East Pacific Rise of topography, heat flow and crustal thickness. Moreover, we have found that different sections of the world-wide submarine mountain chain have quite different characteristics, which suggests that although the chain superficially appears to be one continuous and contemporaneous system, it may be a series of distinct, though very large, topographic units that overlap in space and time. Scripps studies of the central Pacific show that a large region of the sea floor has moved up to form a rise and then subsided. Any theory of the origin of oceanic rises should explain all these observations. Many oceanographers support the hypothesis that convection currents within the earth account for the oceanic rises, past and present.

The first hint of a bulge under the southeastern Pacific came almost 90 years ago when the British expedition on the ship *Challenger* discovered a relatively shallow region between Tahiti and Chile. Sir John Murray, a member of the expedition, named it the Albatross Plateau. Around 1900 the U.S. naturalist Alexander Agassiz made an extensive reconnaissance of the southeastern Pacific, extending the earlier measurements. For the next 40 years there was little further exploration, but the old soundings were incorporated in a number of charts, which gave different names to the same places. By 1946 the name Albatross Plateau had been shifted to a region off Central America and the charts showed three distinct plateaus in the southeastern Pacific. Then the U.S. Navy, economically making use of ships traveling back and forth across the region on Antarctic expeditions, systematically developed the broad contours of the ocean bottom. The Navy soundings made it plain that in reality only one great bulge lies beneath these waters.

Beginning during the International Geophysical Year in 1956 and 1957, the Scripps Institution undertook a series of extensive studies of the East Pacific Rise, and it has now been delineated in some detail. The entire width of the low, broad feature can be traced only in the basin of the southeastern Pacific [*see illustrations on opposite page and page 55*]. But what appears to be the western flank of the rise is found all the way to the Gulf of Alaska. The crest runs into the coast of North America and disappears at the Gulf of California, then reappears off northern California and continues to British Columbia. The eastern flank dis-



CENTRAL PART OF EAST PACIFIC RISE is roughly the sea-floor region bounded by the four-kilometer depth contour on this topographic map of the eastern Pacific and the Americas. (One kilometer equals 3,280 feet, or about 5/8 mile.) Much of the crest of the rise is no deeper than three kilometers. Land contours show height above sea level. Heavy colored lines in ocean mark the major fracture zones that cross the flanks of the rise and in some cases the crest. The outermost limits of the flanks extend to a depth of five kilometers.

appears from the Pacific at Central America and Mexico. It is difficult to escape the conclusion that a bit of the crest lies under California and that the eastern flank extends under western North America. Indeed, the plateau of Mexico, the Colorado Plateau and the mountain ranges of the Great Basin of Nevada and Utah constitute an elevated region comparable in extent to the hypothetical rise underneath. Plateau highlands of similar scale exist only in central Asia and eastern Africa, and the latter lie along a continuation of the Indian Ocean Ridge.

Four of the fracture zones that cross the East Pacific Rise had been discovered by 1955 [see "Fractures in the Pacific Floor," by Henry W. Menard; SCIENTIFIC AMERICAN, July, 1955]. Now at least five more are known. The zones typically show a relief (that is, a vertical distance from highest to lowest points) of up to 10,000 feet, a width of about 100 miles and a length of more than 1,000 miles. Within them faulting has created elongated ridges and troughs running east and west, punctuated by large submarine volcanoes. Often the depths of the ocean floor on opposite sides of a fracture are different, suggesting that large blocks of the earth's crust have risen up or subsided.

A remarkable aspect of the great cracks is that they are quite straight. Only wrench faults, in which blocks of the earth's crust move horizontally, display this characteristic. Direct evidence for such movement, however, is often impossible to find in purely topographic observations, which chiefly reflect vertical displacements. In the past few years a means of measuring the horizontal slippage has been developed. Ronald G. Mason, Victor Vacquier and their colleagues at Scripps have been making detailed maps of magnetic irregularities of the sea floor off the western U.S. and, except at the fracture zones, have found a continuous, distinctive pattern of north-south striations [see "The Magnetism of the Ocean Floor," by Arthur D. Raff; SCIENTIFIC AMERICAN, October]. Across the fracture zones the patterns are interrupted. When the measurements are extended far enough, it is found that the interruptions are actually offsets, in which two parts of the pattern have been shifted horizontally with respect to each other. In this way it is possible for the first time to measure both the relative direction and the amount of movement along the shear of undersea faults. The fracture zones across the rise are among the largest faults known anywhere on the earth. The Murray fault has a right-lateral displacement of 95 miles (looking across it in either direction the opposite side appears to have moved to the right), the Pioneer fault has a left-lateral displacement of 160 miles and the great Mendocino fault has a left-lateral shift of 750 miles [*see map on page 59*]. Clearly slabs of crust almost as large as continents have here moved distances on the order of those called for by the theory of continental drift. This does not necessarily indicate that continents drift as units: displacements of the type and scale found in the Pacific would tear a continent to bits.

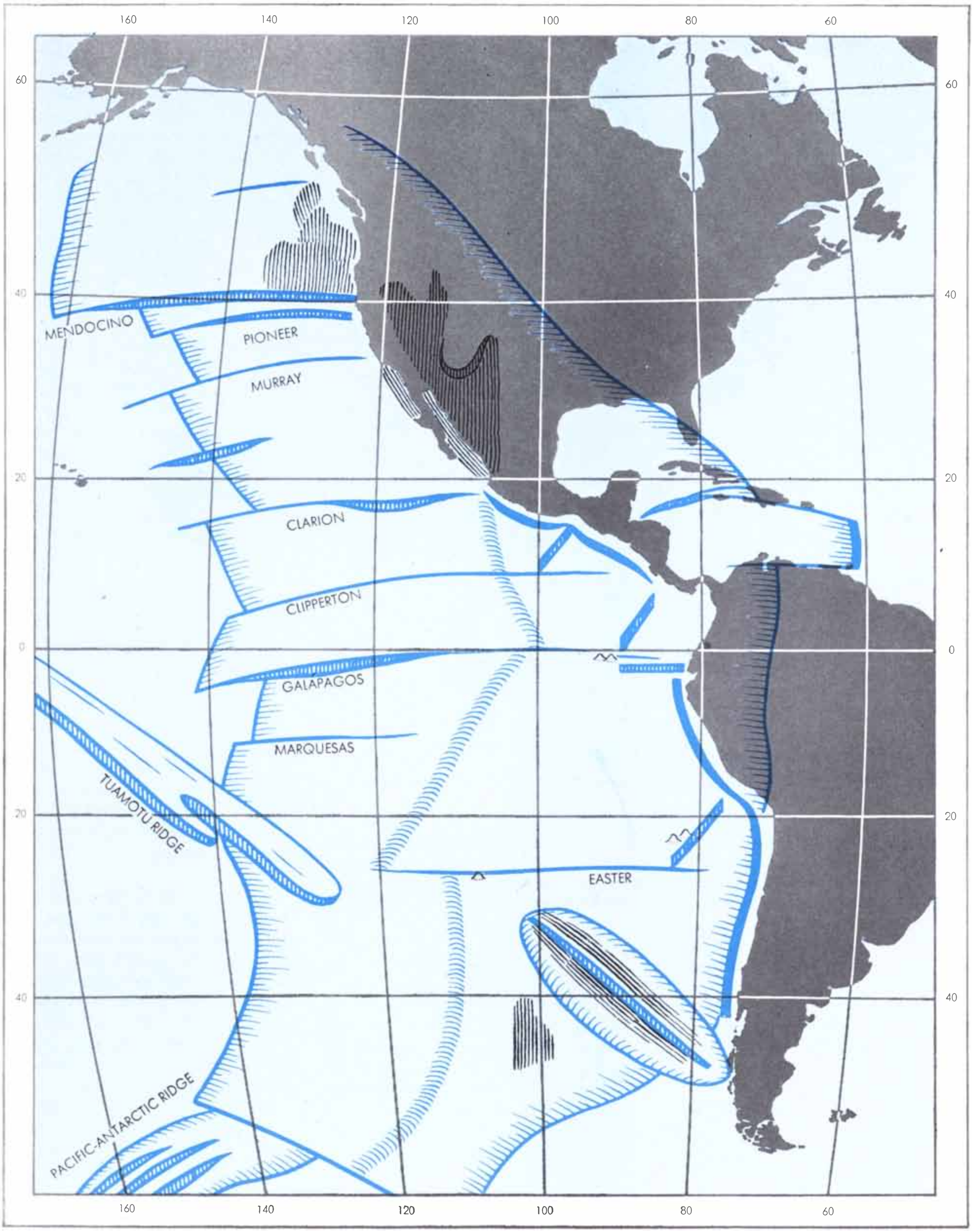
As has been indicated, our soundings show no long, central rift in the crest of the East Pacific Rise. Indeed, it seems doubtful that such a rift extends for really long distances in the crest of any rise. British oceanographers have found a central rift running for 75 miles in the North Atlantic, but closely spaced soundings by German oceanographers show that another region of the Mid-Atlantic Ridge lacks a central rift. A survey by Lamont found a rift along a line of earthquake epicenters in the Indian Ocean, but Scripps soundings have not located a rift in the Pacific, where earthquakes are equally common. Most surveys seem to show not one great rift but parallel ridges and troughs running lengthwise on the crest of oceanic rises.

Such a ridge-and-trough topography is prominently developed on the crest of the East Pacific Rise off the northwestern U.S. There it has been delineated in more detail than anywhere else in the world in an extremely precise survey by the U.S. Coast and Geodetic Survey. The ocean bottom off northern California displays a major rift between tilted and faulted ridges, but it is cut off to the south by the Mendocino fault and to the north by another fault. Two other regions with prominent ridge-and-trough topography but without a central rift lie between Chile and the crest of the East Pacific Rise.

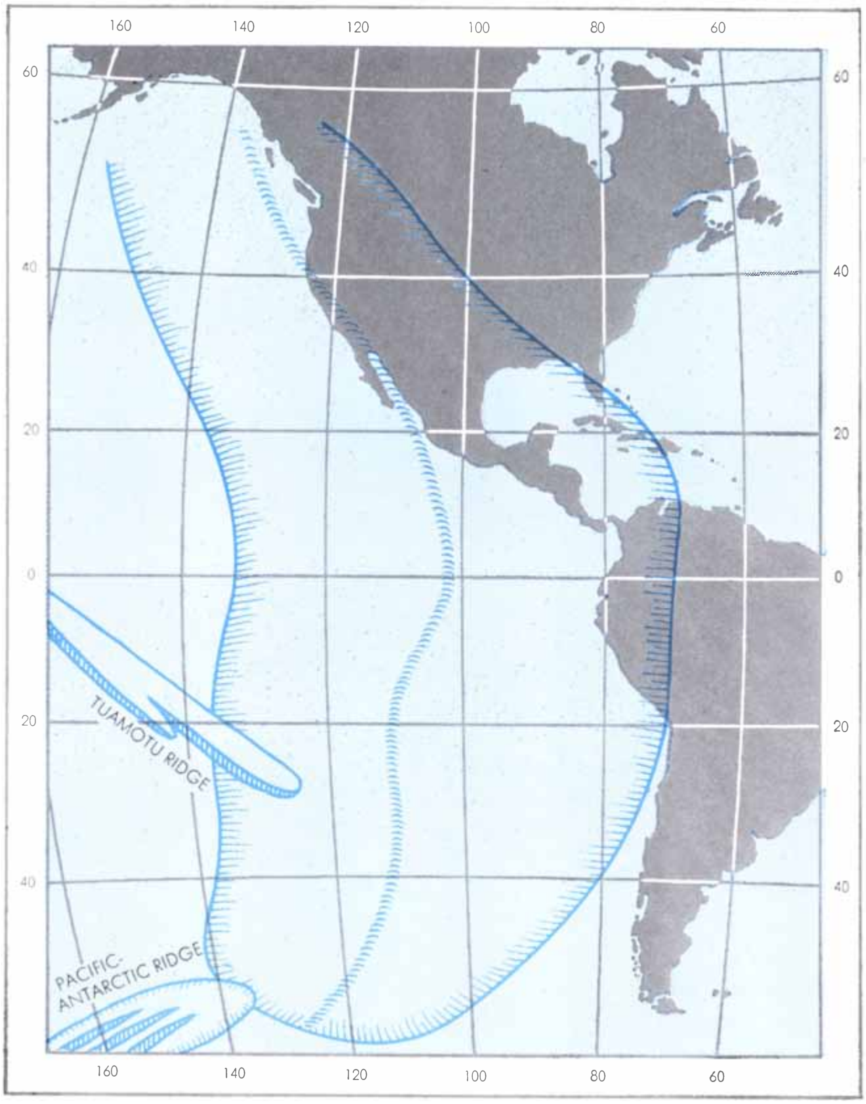
The band of earthquake epicenters along the crest of the East Pacific Rise resembles those of the Mid-Atlantic and Indian Ocean ridges. In the southeastern Pacific there are not enough seismographic stations to locate epicenters accurately, and the width of the band is not known. The earthquake belt continues from the open sea through the Gulf of California and California itself and back onto the crest of the rise off northern California. In the Northern Hemisphere closely spaced seismographic stations can pinpoint earthquake epicenters that lie in a narrow line off northern California but not in, or even parallel to, the prominent rift in the same area. Although the band is continuous, all the earthquakes may not be related to the rise. In California and probably in the Gulf of California the earthquakes are associated with the San Andreas fault, a great wrench fault parallel to the crest of the rise. Elsewhere the epicenters seem to be most common where fracture zones intersect the rise, but the quakes do not necessarily result from the transverse wrench faulting associated with the fractures. Probably stress along the crest of the rise simply tends to be relieved where the fractures have weakened the crust.

By setting off underwater explosions and measuring the velocity of the resulting sound waves through the water and through various layers of the solid bottom underneath it is possible to calculate the thickness of the earth's crust. Russell W. Raitt and G. G. Shor, Jr., of Scripps have carried out a large number of such tests and have found that the crust under the East Pacific Rise is thinner than in other parts of the ocean. In most places in the ocean basins the cross section of the crust has a remarkably constant structure consisting of several hundred feet of unconsolidated sediment as a top layer, then about 3,000 feet of "second layer," presumably volcanic rock and consolidated sediment. Below this is the "third layer," or oceanic crust proper, separated from the mantle by the Mohorovicic discontinuity. The third layer at 21 places in the Pacific not on the rise averages 16,000 feet in thickness. In contrast, the average thickness at 12 places within 900 miles of the crest of the rise is 12,500 feet, or only three-fourths of normal. This means that the rise must originate in the mantle underneath. In fact, the bulge in the mantle must have more relief than that of the ocean floor.

At the center of the rise in some places the third layer lies over some apparently abnormal material through which sound travels at about 24,600 feet per second compared to 26,200 feet per second, the usual minimum speed in the mantle. Similar low-velocity material under the Mid-Atlantic Ridge has been interpreted by Maurice Ewing of the Lamont Observatory as a physical mixture of crust and mantle rocks. In the case of the East Pacific Rise, however, Raitt and Richard



SCHEMATIC DIAGRAM OF THE RISE as it is today shows eastern flank under the Caribbean Sea and much of North America, with crest under western North America. Movement of great slabs of the earth's crust along major fractures is also represented. Some of the fracture zones do not have names. Black hatching shows regions and directions of closely spaced ridges and troughs. The crest of the rise also displays lengthwise ridges and troughs. The thick colored lines off the coasts of South and Central America mark trenches.



POSSIBLE FIRST STAGE OF THE RISE is shown in this highly schematic diagram. A broad bulge has formed in the earth's crust, but great slabs of crust have not yet moved east and west. Closely spaced ridges and troughs along the crest will appear later. The author believes that the Tuamotu and Pacific-Antarctic ridges are older than the East Pacific Rise.

P. Von Herzen believe that the low velocities are related to high heat flow on the crest; they calculate that higher temperature would reduce the velocity of sound in normal mantle rock by the amount observed.

A decade ago, when Sir Edward Bullard of the University of Cambridge and Roger Revelle of Scripps first measured the rate at which heat flows from the interior of the earth through the ocean floor, they were surprised to find the rate was the same as it is on the continents—a little more than one-millionth of a calorie per square centimeter per second. (The heat flow is not actually measured directly but is calculated from measurements of the temperature at the solid surface and at a level a few feet below the surface and from measurements of the thermal-conductivity of cores taken from the bottom.) Since the granitic crust of the continents contains more radioactive material than the basaltic crust of the ocean, everyone had thought that less heat would come from the oceanic crust. To account for the unexpectedly high value it was suggested that it might reflect convection currents in the mantle, which were carrying hot material from lower levels to the underside of the crust. But in that case, as several geologists pointed out, there should also be regions of abnormally low heat flow where the currents turned downward again.

Further probing at sea showed two such areas, one in the Middle America Trench and the other on the western flank of the East Pacific Rise. The idea of convection currents in the mantle is not a new one, and the Dutch geophysicist F. A. Vening Meinesz had earlier proposed that trenches are formed when sinking convection currents drag down the crust with them. The low heat flow in the Middle America Trench seemed to support this hypothesis.

About two dozen observations of heat flow had been carried out in the Pacific before the 1956 Scripps expedition in the ship *Downwind.* On that cruise Von Herzen made 32 more measurements. These showed that heat flow and topography are broadly correlated. A strip about 100 miles wide along the crest of the rise has a heat flow ranging from two to eight times normal, whereas a band as much as 2,000 miles wide on the western flank has a low heat flow, ranging down to 10 per cent of normal [*see illustration on page 58*]. The few observations made on the eastern flank of the rise indicate a similarly low heat flow there.

After Downwind, Von Herzen redesigned the temperature probe for use on lighter wire with high-speed winches. In a two-month tour de force he collected data from 60 places in the Gulf of California, off California and around the Mendocino fracture zone. They demonstrated that the belt of high heat flow extends along the crest of the rise for at least 6,500 miles, continuing right up to the point at which the crest disappears under the coast of California and picking up and resuming where it emerges off northern California.

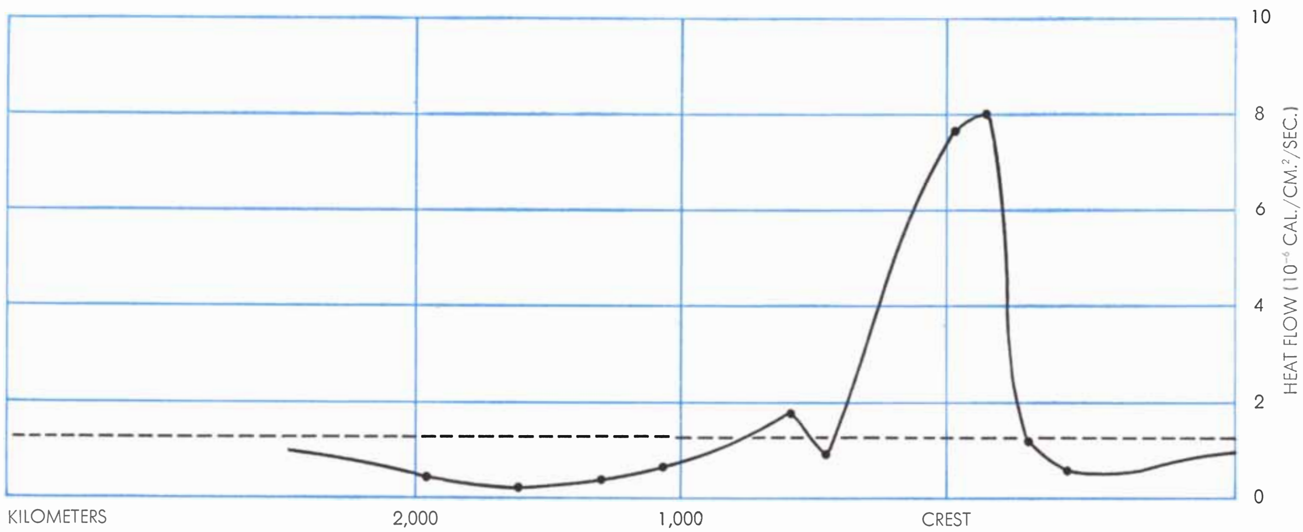
In summary, the Scripps studies indicate that the East Pacific Rise results from a bulge in the mantle; that the crust of the earth is thinned along the crest and in many places broken into small blocks that run parallel to the rise; that large, undistorted slabs of crust on the flanks have been moved long distances; and that the flow of heat is high along the crest and low on the flanks.

All these facts can be accounted for by the hypothesis that two parallel, oppositely rotating convection cells in the mantle well up under the crest of the rise [*see top illustration on page 59*]. Assuming that the cells have a roughly circular cross section with a diameter equal to the width of one flank of the rise, they extend roughly 1,000 miles down into the mantle. The thin scum of continental and oceanic crust would have little or no effect on such large currents.

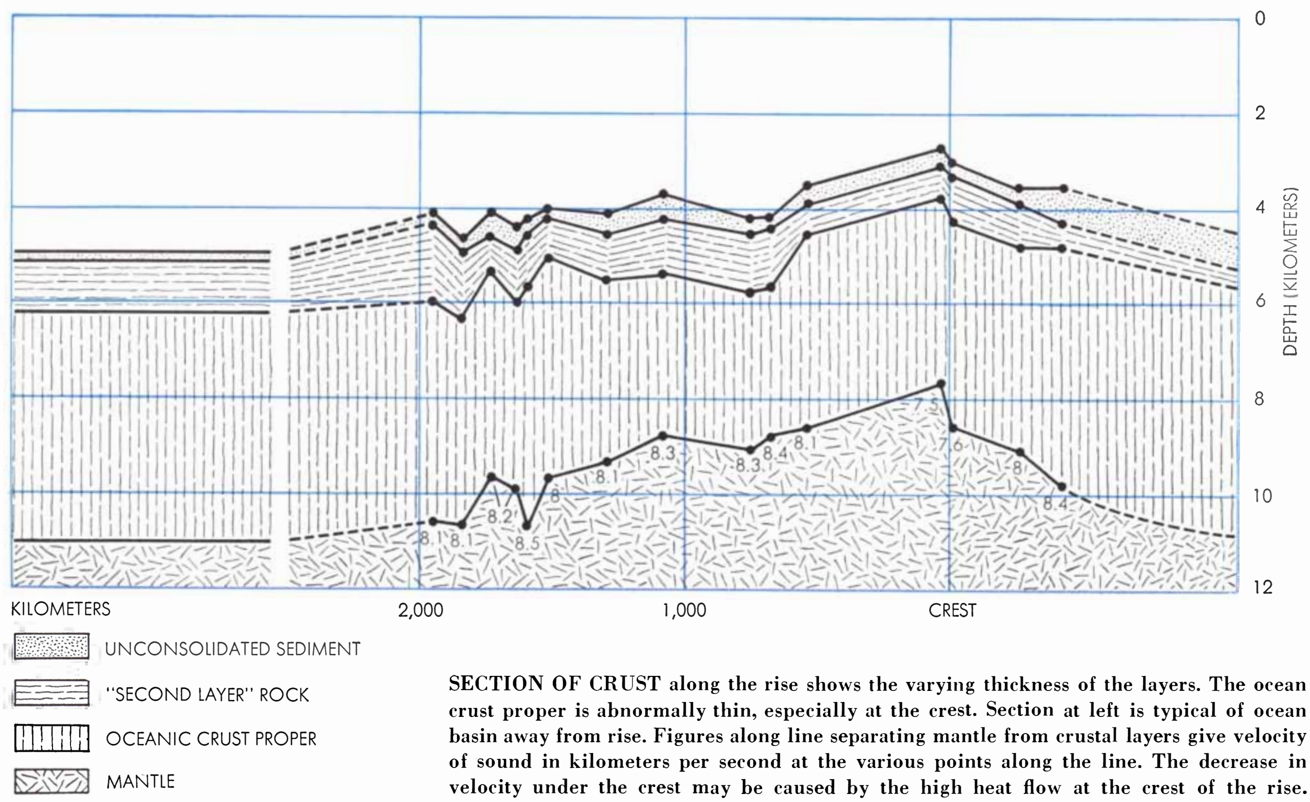
Where the cells rise, the crust arches up because of thermal expansion and physicochemical changes. As the flow diverges under the crest of the arch, cracks open, producing the topography of parallel ridges and faults along the crest. Under the flanks of the rise the horizontal current moves large slabs of crust, bounded by fracture zones, outward from the crest. The outward displacement stretches the crust, leaving it thinner on the crest. Finally, along the line where material wells up from deep in the mantle the flow of heat through the surface is increased, whereas over the regions of horizontal and downward motion it is decreased.

The convection hypothesis seems to meet the only semiquantitative test proposed so far: a comparison of the horizontal displacements along the fracture zones with the amount of thinning of the crust on the crest. The thin region now averages 1,750 miles wide. When it was as thick as the other parts of the Pacific basin, it would have been only 1,400 miles wide. Assuming that the thinning is due to stretching, the crust has moved 350 miles. This agrees, at least as to order of magnitude, with the horizontal offsets of 95, 160 and 750 miles observed at the great wrench faults of the fracture zones.

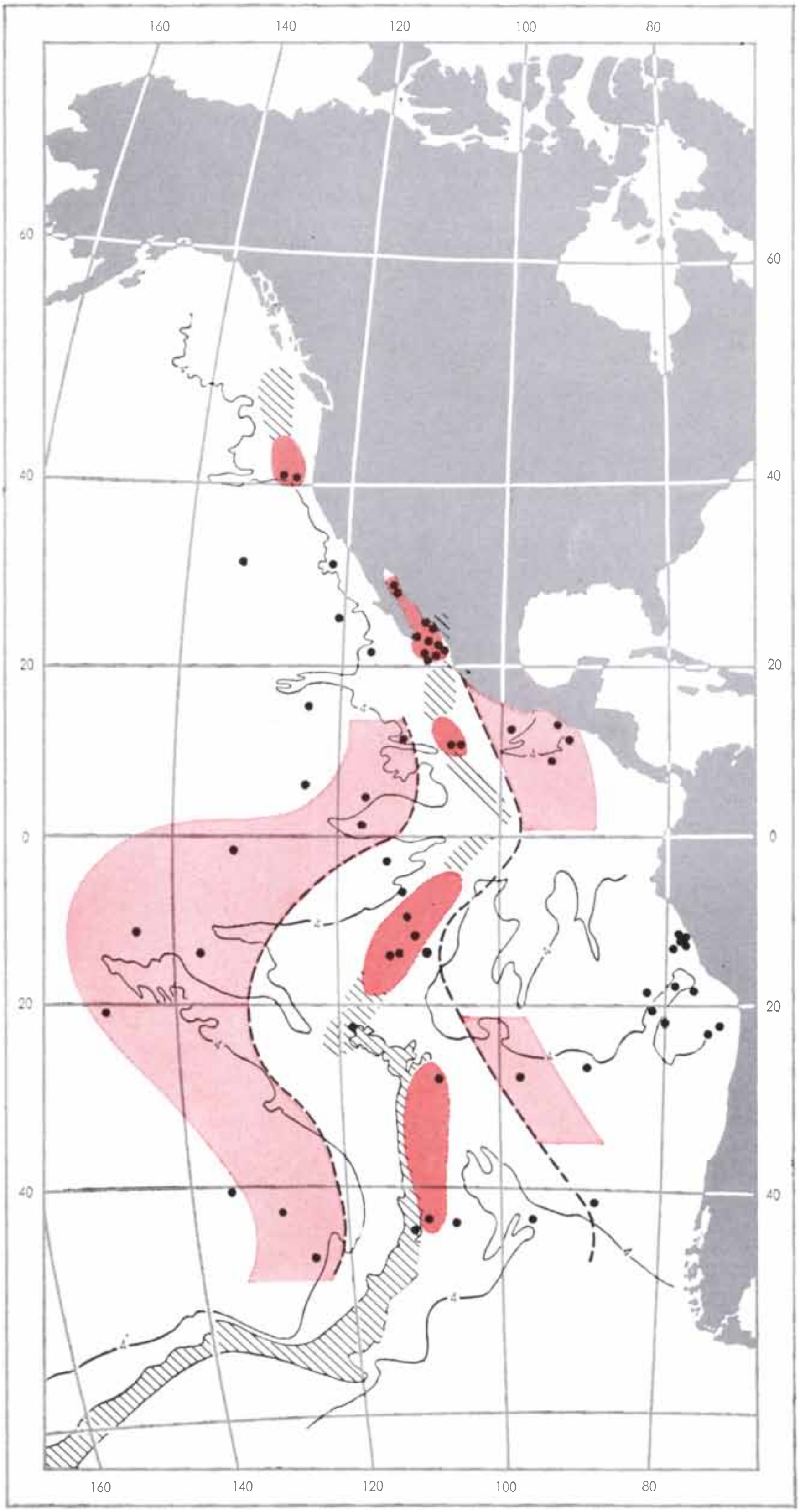
Because some parts have moved farther than others, the average crustal thinning on the crest is not so significant



HEAT FLOW FROM RISE is extremely high along crest, whereas along flanks it is below average for ocean (*average is shown by broken line*). Horizontal scale shows distance from crest. Vertical scale is in millionths of a calorie per square centimeter per second.



SECTION OF CRUST along the rise shows the varying thickness of the layers. The ocean crust proper is abnormally thin, especially at the crest. Section at left is typical of ocean basin away from rise. Figures along line separating mantle from crustal layers give velocity of sound in kilometers per second at the various points along the line. The decrease in velocity under the crest may be caused by the high heat flow at the crest of the rise.



HIGH HEAT FLOW ALONG CREST (*dark color*) and low heat flow along flanks (*light color*) characterize the rise. Dots mark sites of measurements. Broken lines are approximate borders of regions of abnormally low heat flow. White regions have average or unknown heat flow. The pattern of heat flow is believed to be the result of convection currents in the earth's mantle.

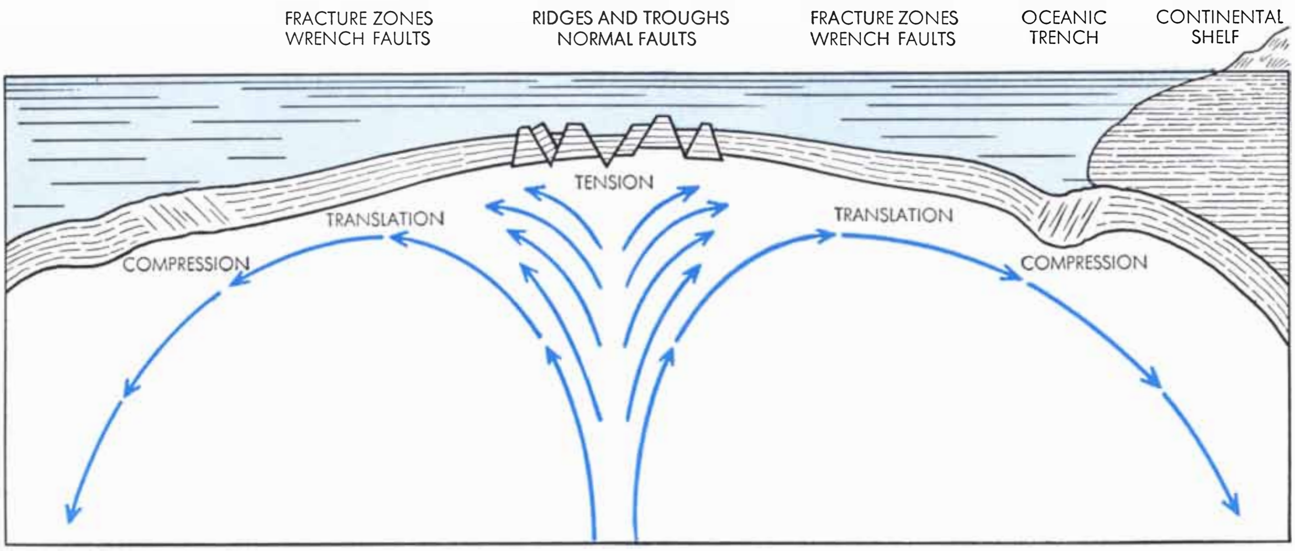
as the thinning in the region of any particular displaced block. At present there are too few thickness measurements to disclose a definite pattern. A preliminary shipboard calculation made recently by Raitt seems to show that the thinnest crust in the Pacific is on the crest of the rise north of the Mendocino fault, where the largest horizontal displacement has occurred. The width of the broken ridge-and-trough region on the crest of the rise also seems to be correlated with the displacement on the flanks. In the region north of the Mendocino fault it is very wide; off central California there is no broken area, and the one in the Gulf of California is relatively narrow [*see bottom illustration on opposite page*]. It would appear that the block of crust off central California remained almost stationary, whereas the blocks north and south of it moved away from the crest.

As to the eastern flank, the data are much spottier, and the encroachment of the North American continent complicates matters. Along the Mendocino fault the great left-lateral displacement at sea changes to a 60-mile right-lateral displacement on land. Although this may indicate that the eastern flank has moved eastward north of the fault, other evidence makes this simple interpretation dubious.

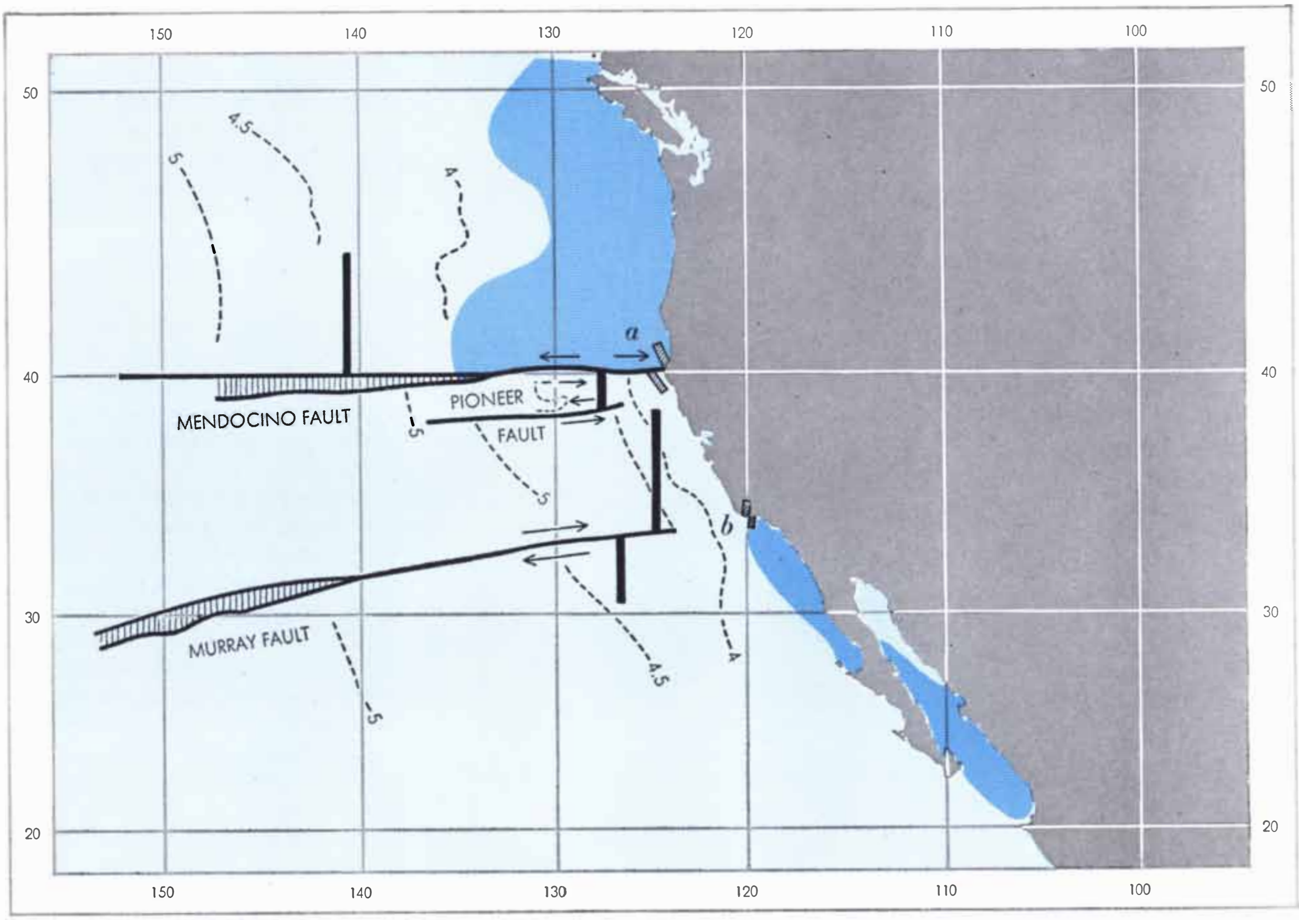
Oddly enough, the only other measurements bearing on movement of the crust on the eastern flank come from the Caribbean Sea. Although it is not even in the Pacific, it is no farther from the crest of the East Pacific Rise than the outer parts of the western flank. Harry Hess and his colleagues at Princeton University have shown that the Caribbean basin is bounded on the north and south by east-west fault zones and that the floor of the basin has moved about 475 miles to the east with respect to South America and Cuba. Hess attributes the displacement to a convection current that ends by plunging down in the vicinity of the Lesser Antilles.

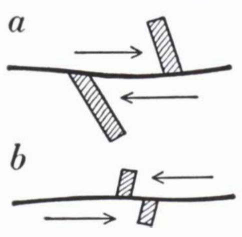
If such a current exists, it could well be a continuation of the cell originating on the crest of the East Pacific Rise. This would mean that the current passes under Central America. If the width of the cell is approximately constant, the edge of the eastern flank farther south must reach at least as far as the coast of South America.

The general similarities among the different undersea ridges and rises strongly suggest that the same type of mechanism created them all. Because



CONVECTION-CURRENT HYPOTHESIS is illustrated in diagram of a cross section of the crust of the rise. Two convection cells in mantle (*arrows*) rise under crest, creating tension as they diverge. The tension breaks the crust into the ridges and troughs that lie on and parallel to the crest. As the currents move horizontally they drag slabs of crust along, creating the great wrench faults of the fracture zones. Then the oceanic crust is compressed (*right*) against the continent, making a trench. Finally the currents sink.

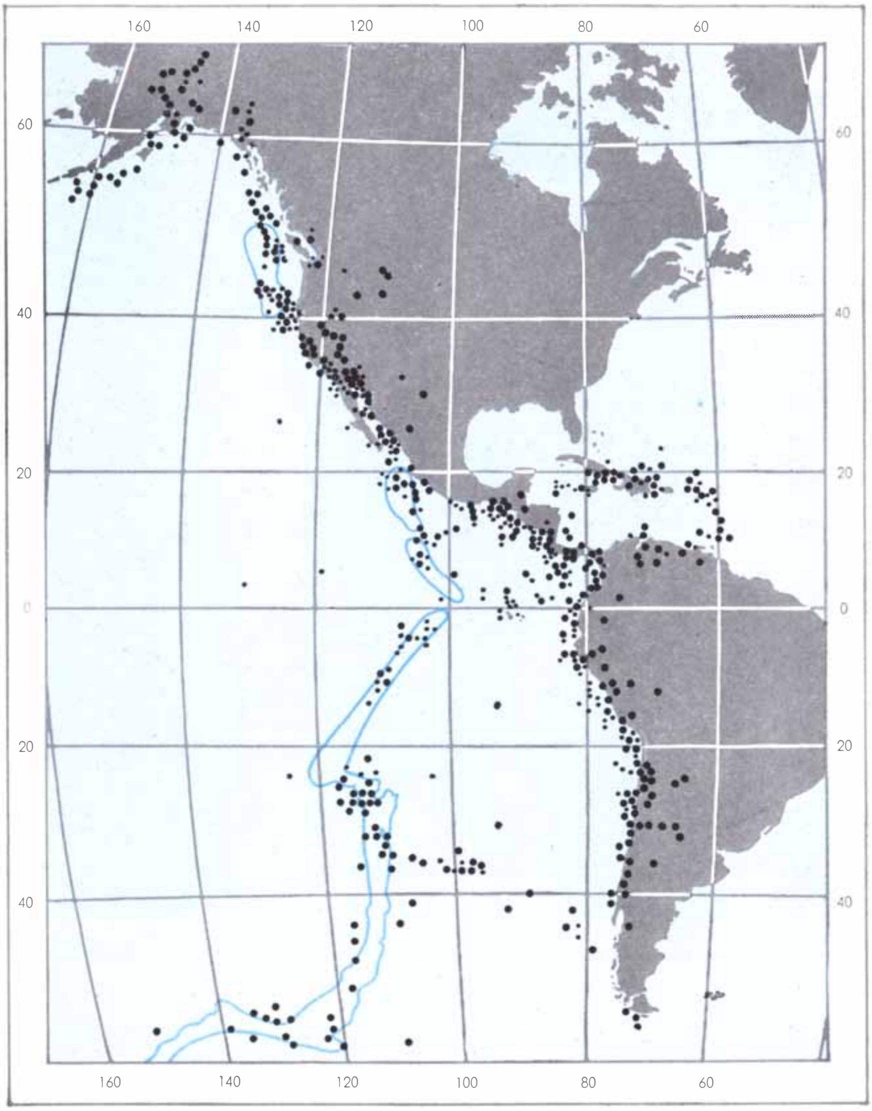




OFFSETS OF GREAT WRENCH FAULTS off California are shown by heavy vertical lines and arrows. The smaller offsets on land (*"a" and "b"*) are enlarged at left. The regions of smaller ridges and troughs along the crest of the rise (*dark color*) are roughly proportional in width to amount of movement along the shear of the nearest great fault in the ocean. Westward movement of blocks of crust and the minor faults on the crest suggest that the crest is stretched and thinned. Broken lines are depth contours in kilometers.

they are connected, many oceanographers have assumed that they were formed at the same time. As has already been pointed out, this is not necessarily true; their sheer size makes it inevitable that they should overlap anyway. As a matter of fact, there are positive reasons for believing that some parts of the range are older than others. A most striking example is the sharp change found at the junction of the East Pacific Rise and the Pacific-Antarctic Ridge in the central South Pacific. The ridge has just been explored in the region south of New Zealand by the Scripps *Monsoon* expedition. A comparatively narrow elevation lying between New Zealand and the Antarctic, the Pacific-Antarctic Ridge contains high and steep-sided ridges and troughs parallel to the crest. Topographically it resembles the Indian Ocean and Mid-Atlantic ridges, with which it is also connected. Several measurements show that heat flow on the crest is about the same as the average for the continents and ocean basins. In this respect it is like parts of the connecting Indian Ocean Ridge, which *Monsoon* also explored. The Mid-Atlantic Ridge, on the other hand, has a high heat flow, at least in the one location on the crest where it has been measured.

The Pacific-Antarctic Ridge extends north to almost 50 degrees south latitude, where the crest is offset more than 600 miles to the southeast. Here it grades into the East Pacific Rise, which, unlike the Pacific-Antarctic Ridge, is not centered in an ocean basin, is extremely broad and relatively unfaulted on the crest and exhibits a high heat flow along the crest.



SHALLOW EARTHQUAKES in the eastern Pacific tend to occur along the crest of the rise (*color outline*). Large dots mark the stronger quakes, small dots the weaker. In California most of the earthquakes are probably associated with the San Andreas fault system.

These two great ridges, although connected, are significantly different and may represent stages of an evolutionary process in which a broad, smooth arch with high heat flow gradually subsides along the flanks, leaving a central ruin of ridges, troughs and volcanoes along a line of normal heat flow. Presumably the change occurs when the convection cells in the mantle die out or shift location. According to this hypothesis the East Pacific Rise would be younger than the Mid-Atlantic Ridge, which in turn would be younger than the Pacific-Antarctic Ridge.

Oldest of all would be the great narrow ridges that occupy the center of the Pacific. The fact that they are no longer seismically active indicates that they have completed their development. The central Pacific ridges are of special interest because they give some indication of the lifetime of an oceanic rise. The atolls of the Tuamotu and the Line islands, as well as the guyots (drowned ancient islands) of the Mid-Pacific Mountains west of Hawaii lie along the midline of the Pacific basin. Unlike most other oceanic islands, which are volcanoes rising from the deep-sea floor, these island groups rise above long, steep-sided ridges. Various Scripps expeditions have dredged fossils from the guyots of the Mid-Pacific Mountains and from guyots scattered among the atolls of the Tuamotu Islands. Although the fossils come from depths of 3,000 to 6,000 feet, they are typical of shallow water and show that the ridges were much higher 60 million to 100 million years ago.

Apparently the whole central region of the Pacific has subsided 3,000 to 6,000 feet in less than 100 million years. The region is not depressed, however, and it seems probable that it first rose and then sank to its original level. In short, it followed the proposed sequence of development of an oceanic rise and in a time that is a small fraction of the age of the earth.

The displacement of crustal blocks bounded by great fracture zones is an integral part of the convection hypothesis as it is discussed here. Consequently fracture zones should exist in parts of the submarine mountain chain other than the East Pacific Rise. When the hypothesis was first proposed, the evidence for such fractures was very scanty. Ivan Tolstoy of the Lamont Geological Observatory and Ewing had described a transverse trough in the Mid-Atlantic Ridge, and Hess had discovered another Atlantic trough that appeared to be a fracture zone. The soundings, however,

TEMPERATURE PROBE measures the heat flowing out of the earth's interior through the crust. The probe is the long slender tube. The watertight cylinder above it contains recording instruments. Here oceanographers are preparing to lower it into the water.

were too few for accurate contouring in any of these places.

A recent paper by Heezen and Marie Tharp, also of Lamont, contains the first definite confirmation of fracture zones not on the East Pacific Rise. They have mapped east-west fracture zones, exactly like those in the Pacific, at several places in the equatorial Atlantic. Each zone is several hundred miles long and offsets the crest of the Mid-Atlantic Ridge, suggesting left-lateral faulting.

The discovery of the offsets is of crucial importance because it confirms the idea that displacements have occurred after the mountain chain was formed. This suggests that the mountain-forming process also produced the fractures, a concept that is supported by the fact that 17 fracture zones have been found cutting oceanic rises, and none have been traced beyond the rises.

The convection hypothesis can account for all the information available to date on the various oceanic ridges and rises and can even place them in an evolutionary sequence. It may also support the hypothesis of continental drift. Large convection currents under the continents may have broken the overlying land apart and sent pieces drifting, just as they may have caused large pieces of the sea floor to drift. The direction of such movement may be essentially random, changing as new convection cells begin and old ones stop.

Satellite Cells in the Nervous System

Precise analytical methods reveal the composition of single nerve cells and their satellites, the glial cells, showing how the two collaborate. The work suggests that giant molecules provide the basis of memory

by Holger Hydén

The British physiologist Sir Charles Sherrington once described the brain as "an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one...." To Sherrington, writing more than two decades ago, and to most physiologists today the brain is essentially a prodigious switchboard ceaselessly traversed by electrical impulses. For nearly a century the tools of electrophysiology have become steadily keener at resolving and measuring this activity, but they are unable in principle to reveal anything more than its transient "dissolving" patterns. If the "flashing shuttles" leave abiding patterns anywhere—as one assumes they must—they elude the electrodes of the physiologist. Moreover, electrophysiology has told us virtually nothing of the curious satellite cells—the neuroglial cells—that surround the nerve cells, outnumbering them about 10 to 1 and making up about half of the total volume of the brain.

It is only recently that enough has been learned of the chemistry of the nerve cells and glial cells to support a working hypothesis about the way these two very dissimilar types of cell may collaborate. From the point of view of the neurochemist the high rate at which the nerve cells synthesize proteins is every bit as remarkable as the electrical activity found by the physiologist. Indeed, certain nerve cells exceed even pancreatic cells—long regarded as the most highly specialized protein-producing cells—in their ability to manufacture proteins. Although much of the nerve protein, in the form of enzymes, is probably required to support the electrical activity of the nerve, it seems plausible that some of the protein enters into the abiding patterns we describe as memory.

Over the past 12 years my associates and I at the University of Göteborg in Sweden have devised techniques for determining the chemical composition and activity of individual brain cells and of the glial cells that immediately surround them. In our work the common units of volume measurement are the cubic micron (a million-millionth of a milliliter) and, for larger samples, the micromilliliter (a millionth of a milliliter). The bodies of mammalian nerve cells range in volume from about 10 micromilliliters to less than a thousandth of a micromilliliter. In analyzing individual cells we must be able to measure cell constituents that weigh as little as a million-millionth of a gram, or a micromicrogram. This has called for methods that are a million times more sensitive than ordinary microchemical methods.

Our experimental materials are nerve cells and glial cells removed from the central nervous system of small mammals, usually rats and rabbits. Although nerve cells are of many sizes and shapes, they all have certain features in common. Attached to each nerve cell, or neuron, is a long fiber, the axon, which conducts nerve impulses away from the cell body. Fanning out from the cell body are shorter and finer processes called dendrites. The cell body and dendrites provide a receiving area for scores of nerve fibers carrying impulses that originate in other neurons. Where these incoming fibers join a cell body and its dendrites they form "synaptic knobs."

The space between neurons is filled largely by glial cells, the name of which derives from the Greek word *glios*, meaning glue. There are at least five distinct types of glial cell; the bodies and nuclei of all are small compared with those of neurons. Radiating outward from the surface of the glial cell body are thin, delicate processes. The entire surface of each neuron, except for the synaptic contact points between neurons, is covered by the processes of neighboring glia. Some glial cells are in contact with others by means of intertwining processes, and other glial cells sheathe the capillaries that supply blood to the brain. Most investigators now believe that substances cannot pass from the blood into the neurons without first passing through the glia. Thus the glia seem to constitute the "blood-brain barrier" that makes the nerve cells extraordinarily resistant to toxic agents circulating in the blood. When glial cells and nerve cells are grown in tissue culture, the glia exhibit peculiar, pulsating movements and can be seen climbing up and down the neurons like spiders on a flower.

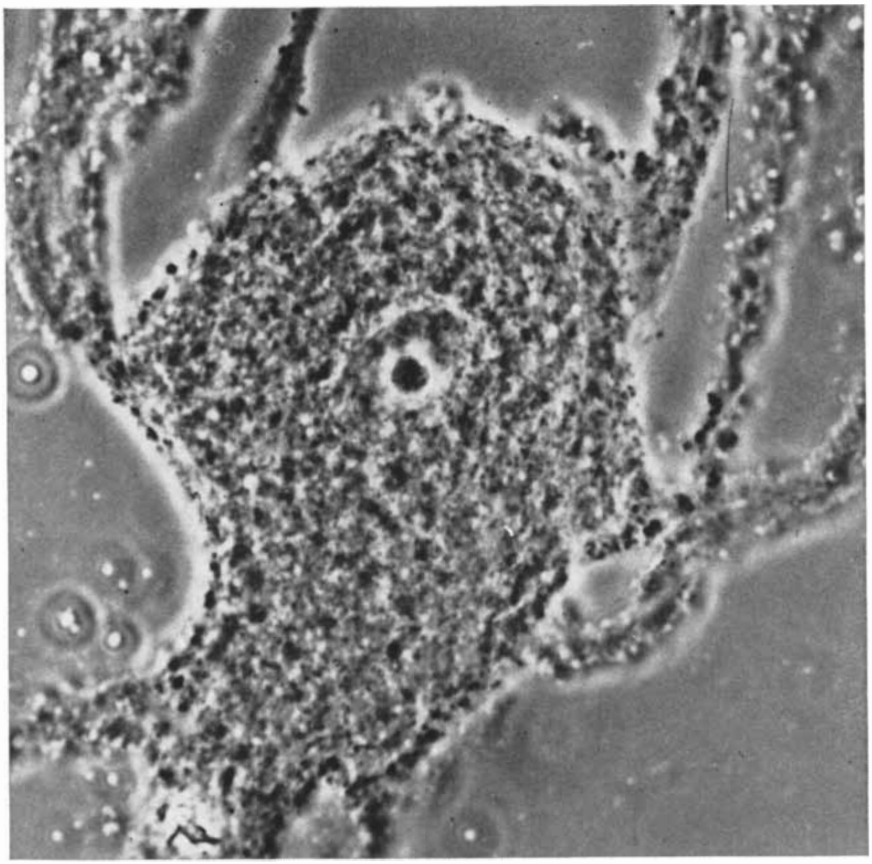
It is clear that a chemical analysis of, say, one milligram of brain tissue cannot indicate the composition of neurons and glia separately. The analysis will give only an average value for nervous tissue, without anatomical correlation. Beginning about 1950 we set out to analyze nerve cells and glia separately. For this purpose we wanted not just any kind of glia but only those glial cells that closely surrounded the nerve cells. An ordinary micromanipulator proved unsatisfactory for all chemical studies in which speed is desirable. I therefore learned to sample single fresh nerve cells freehand, using a small steel instrument and a stereomicroscope at a magnification of 80 to 100 diameters. It is important that the bases of the dendrites projecting from the cell body be included in the sample, because they are the site of high enzyme activity. They are lost if one tries to remove the cell from embedded nerve tissue.

With practice I found that I could completely free a nerve cell from the surrounding glial cells by gently manipulating the cells with the instrument from below. Once the nerve cell is lifted free, the glial cells have a tendency to stick together. They are then removed in a clump and are trimmed down to match the volume of the nerve cell body [*see bottom illustration on this page*]. For analytical purposes we prefer the nerve cell and the matching sample of glia to be of the same weight.

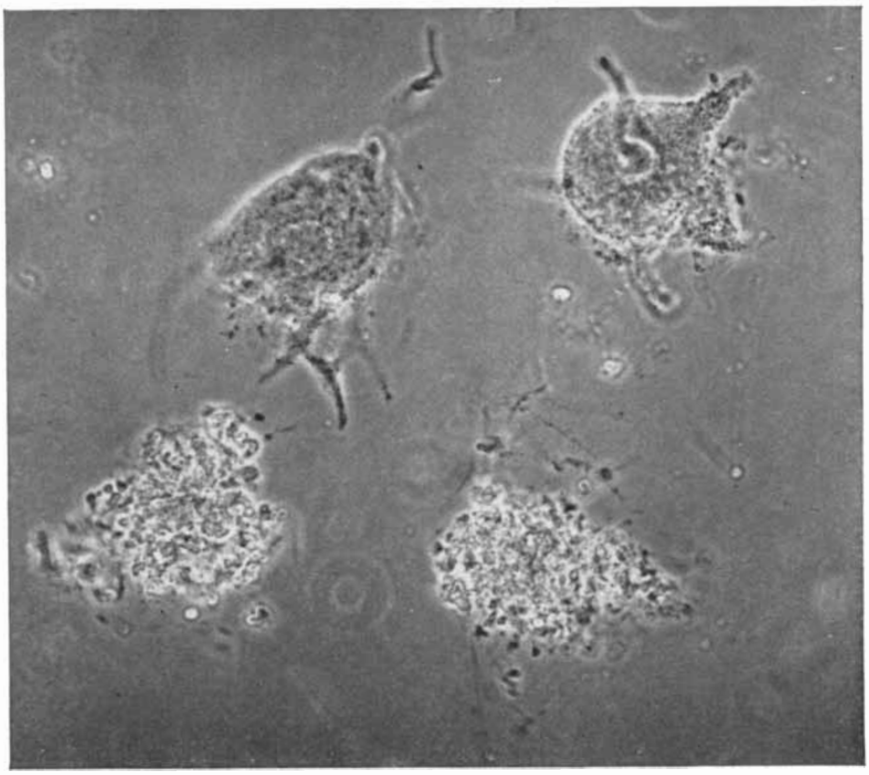
Our methods enable us to determine four things: the content of ribonucleic acid (RNA); the proportions of the four subunits, called bases, that distinguish different samples of RNA; the content of proteins and lipids (fatty substances) in the sample; and the enzymatic activity of the sample. Each of these analytical procedures will be described in order.

RNA is a giant molecule whose central chain consists of alternating links of ribose sugar and phosphate; to each sugar is attached one of four nitrogenous bases: adenine, guanine, cytosine and uracil. RNA molecules can differ from one another in the relative amount and sequence of these four bases, which may number in the thousands. Current concepts assign to RNA the main role in guiding the synthesis of various types of protein needed by each type of cell. Each type of protein is evidently formed on a template consisting of a specific RNA molecule. RNA itself appears to be synthesized in the nucleus of the cell, particularly in the nucleolus. From the nucleus the RNA moves into the surrounding cytoplasm and makes up about half of the substance of the particles called ribosomes, which are the principal site of protein synthesis.

In micrographs made with ultraviolet radiation, areas rich in RNA show up as dark patches. This provides the basis for the microanalytic method devised by my colleague Jan-Erik Edström. Working with individual nerve cells—or equal volumes of glial cells—we add a microdrop of a solution containing the enzyme ribonuclease [*see illustration on page 65*]. This enzyme partly breaks down RNA and carries it into solution. The cell is exposed to ribonuclease for a total of 60 minutes in three separate extractions. The extracts are transferred by a micropipette to a quartz glass slide, where the solvents evaporate, leaving behind the partly decomposed RNA. In the next step the RNA is redissolved in a glycerol solution, which forms a microdrop with a diameter of about .2 millimeter. The drop, illuminated by ultraviolet light with a wavelength of 2,600 angstrom units, is photographed in a microscope. The density of the micro-



FRESHLY ISOLATED NERVE CELL from the vestibular nucleus of a rabbit brain is a giant among nerve cells. This cell, magnified 1,800 diameters, was photographed in the phase-contrast microscope. Processes extending from the cell body are dendrites. The dark particles are synaptic knobs, the sites where other nerve cells make functional contact.



SATELLITES OF THE NERVE CELL, the glial cells, are the two clumps in the lower portion of the micrograph. Each clump, containing about 20 glia, has been made to match in volume and weight the nerve cell (*top*) around which the glia were originally clustered.

graphic image is scanned photometrically to provide a measure of the RNA present in the microdrop and hence in the original cell. By this method the amount of RNA in the range of 20 to 1,000 micromicrograms can be measured with a standard error of ± 5 per cent.

The RNA content of different types of nerve cell varies over a wide range, from 45 micromicrograms in small cells to more than 1,500 micromicrograms in the very large nerve cells, called Deiters' cells, located in the region of the brain stem known as the vestibular nucleus. We find that about 10 per cent of the total RNA in the nerve cell is located in the dendrites. In the impulse-propagating axon of mammalian nerve cells there is no measurable amount of RNA. Recently, however, Edström has found small amounts of RNA in the axons of the giant nerve cells of fishes. When we compare the RNA in the nerve cell with that in an equal weight of surrounding glial cells, we find that the glia contain about 10 per cent as much RNA as the nerve cell.

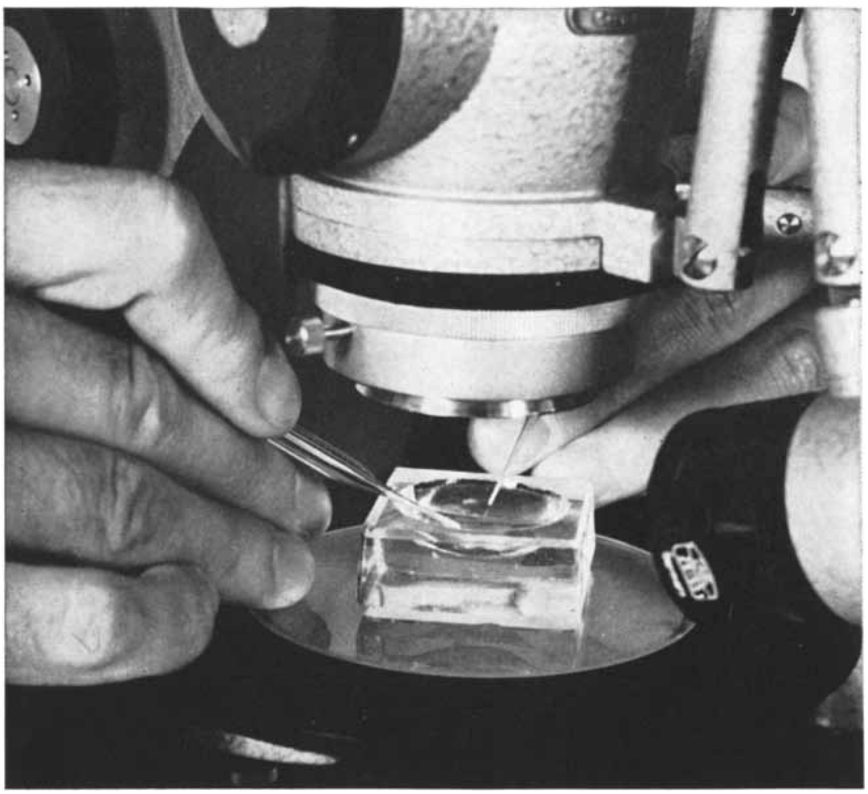
We next sought to answer the question: Does brain RNA differ from RNA found in other organs of the body? In 1954 Edström and I were able to show that its composition is fundamentally the same. The analytical method, also developed by Edström, starts with the RNA extracted from a cell by ribonuclease. The extract is hydrolyzed, or broken down, with hydrochloric acid, releasing the four bases adenine, guanine, cytosine and uracil. The hydrolyzed material is applied to one end of a specially treated microscopic cellulose thread, stretched on a quartz glass slide. When a potential gradient of 2,000 to 3,000 volts is applied to the thread for about 10 minutes, the bases migrate at different speeds and come to rest in four distinct concentrations along the thread. Migration of this sort, induced by an electric potential, is called electrophoresis. The thread is photographed under a microscope by ultraviolet light, revealing where the bases have concentrated. Photometric scanning of the density patterns on the thread provides a quantitative measure of each of the four bases. The base composition of 300 micromicrograms of RNA can be established by this method with a standard error of ± 7 per cent for each constituent.

Our third analytical method is designed to measure the proteins and lipids that constitute the principal bulk of the cell. Again it was important that we determine these two substances quantitatively for single cells. The method Sven-Olof Brattgård and I developed was an extension of one devised in 1950 by Arne Engström and B. Lindström of the Royal Caroline Institute in Stockholm. In their method a dry, thin tissue sample is placed against fine-grained film emulsion and is exposed to X rays in the wavelength range between 8 and 12 angstrom units. Exposed at the same time is a so-called step-wedge, which serves as a reference system for subsequent calculations. In the tissue sample the absorption of X rays is proportional to the amount of carbon, nitrogen and oxygen present. The sample is X-rayed twice, once in its original state and again after it has been washed with solvents that remove lipids but not proteins. The two radiographs are then scanned by microphotometry to measure the X-ray absorption region by region. In our version of the method, freshly isolated nerve cells (or glial cells) are placed on ultrathin aluminum foil and rapidly dried. The X-ray microradiographs resolve details down to .2 micron.

To carry out the X-ray analysis automatically, we have built an electronic scanning and computing device. The scanning unit divides the sample into 12,000 parts and measures the density of each. A computer converts the densities into a two-digit number, from 00 to 99, giving the amount of material present in each tiny area, calculated either as proteins or lipids. The instrument provides information in two forms. The writing unit can print a picture covered with a mosaic of figures showing the distribution of proteins or lipids within the cell [*see illustration on page 69*]. If desired, the calculating unit will add together all the values from the 12,000 areas and present an integrated sum in four minutes.

The fourth of the analytical methods I shall describe has to do with the metabolic activity of the two types of brain cell. It was believed for a long time that the brain could only metabolize, or "burn," glucose as a source of energy. Within the past 15 years, however, a number of workers have shown that the brain can readily utilize other substances, including amino acids (derived from proteins) and lipids.

Cell metabolism involves a large number of different enzyme systems that cooperate in disassembling glucose or other energy-containing substances and make the energy available to the cell for its manifold functions. In this process hydrogen and electrons are removed from the fuel substance and passed on in a series of steps, mediated by enzymes, until finally both hydrogen and electrons are accepted by oxygen and water



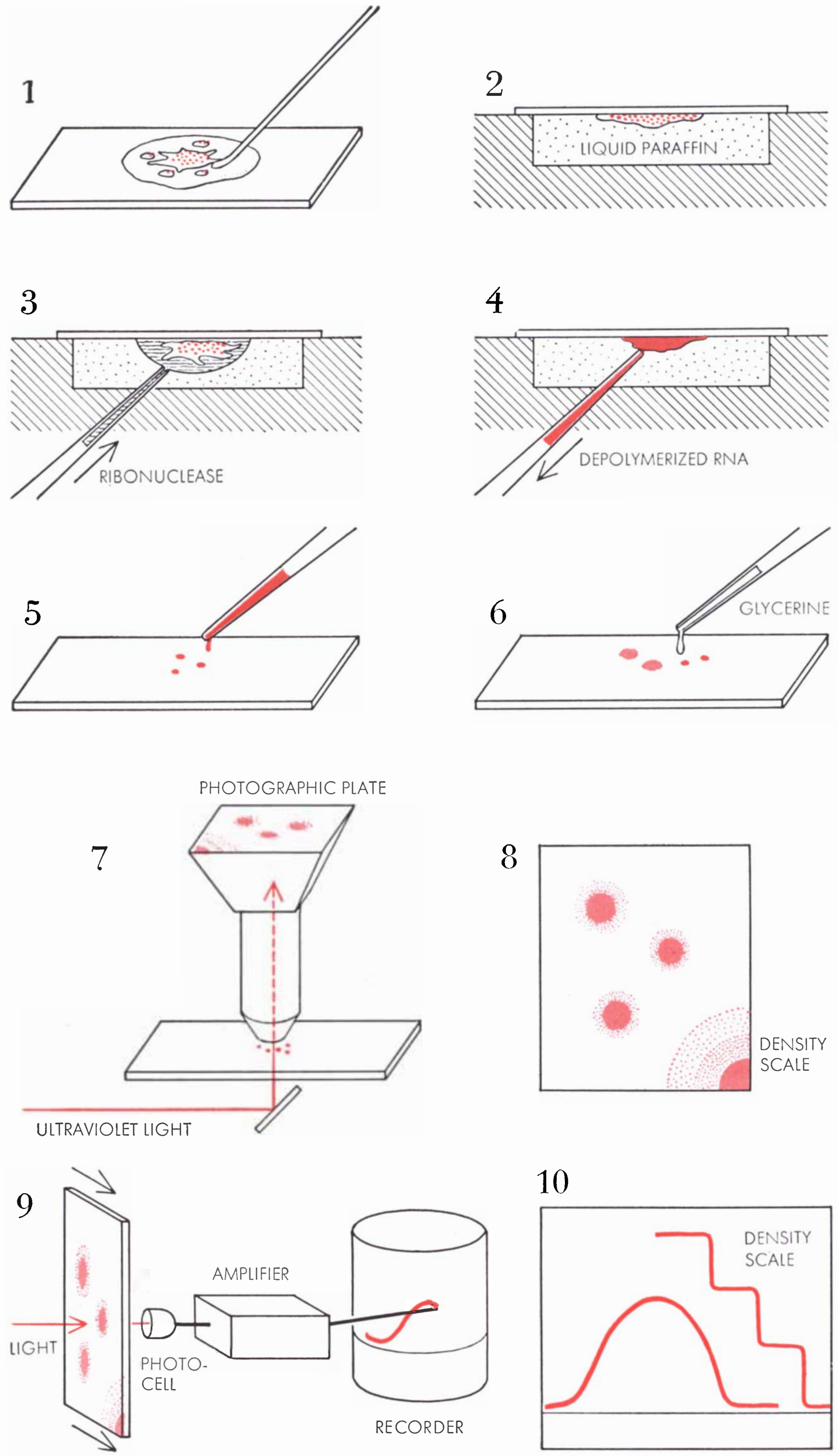
ISOLATION OF NERVE CELLS is accomplished freehand by the author, using a binocular microscope of about 100 power. The instrument used for cell removal is a thin steel thread having a diameter of 15 microns, or less than a tenth of the diameter of a human hair.

is formed. Simultaneously the carbon atoms in the fuel are oxidized to form carbon dioxide. The energy released by this metabolic chain is temporarily stored in the energy-rich substance adenosine triphosphate (ATP) until it is needed by the cell.

Some of the finest work on the glucose metabolism of single nerve cells has been carried out by Oliver H. Lowry and his collaborators at the Washington University School of Medicine. Lowry has shown that among all brain structures the greatest capacity for glucose metabolism is found in the nerve cell body and its dendritic processes. He also finds that these processes are the site of the highest enzyme activity.

For our purposes we needed a method that would show the enzyme activity of nerve cells and glial cells separately. Since we were working with living cells, we decided to measure the rate of oxygen consumption using microtechniques developed by Erik Zeuthen at the Carlsberg Laboratory in Copenhagen. In this method a single nerve cell is sucked into a small Cartesian diver, a tiny vessel open at one end and so delicately balanced that when it is placed in water, it will remain suspended below the surface, neither rising nor sinking. If the density of the diver changes ever so slightly, the diver will move up or down a short distance until a new equilibrium is reached. In our tiny divers (which have a volume of about a tenth of a microliter) the cell is provided with a chemical medium that enables it to manufacture a particular enzyme. When the cell uses respiratory enzymes to consume the oxygen contained in a tiny air bubble, the bubble gets smaller and liquid is drawn in to replace the volume of gas consumed. This increases the density of the diver and makes it sink slightly. The rate of sinking is translated into oxygen consumption per hour per cell. The hourly rate is measured in tenths of a micromilliliter. The two principal enzymes involved in our studies are succinoxidase and cytochrome oxidase. The latter, being active at the final step of the respiratory chain, reflects in a general way the rate at which the cell uses energy.

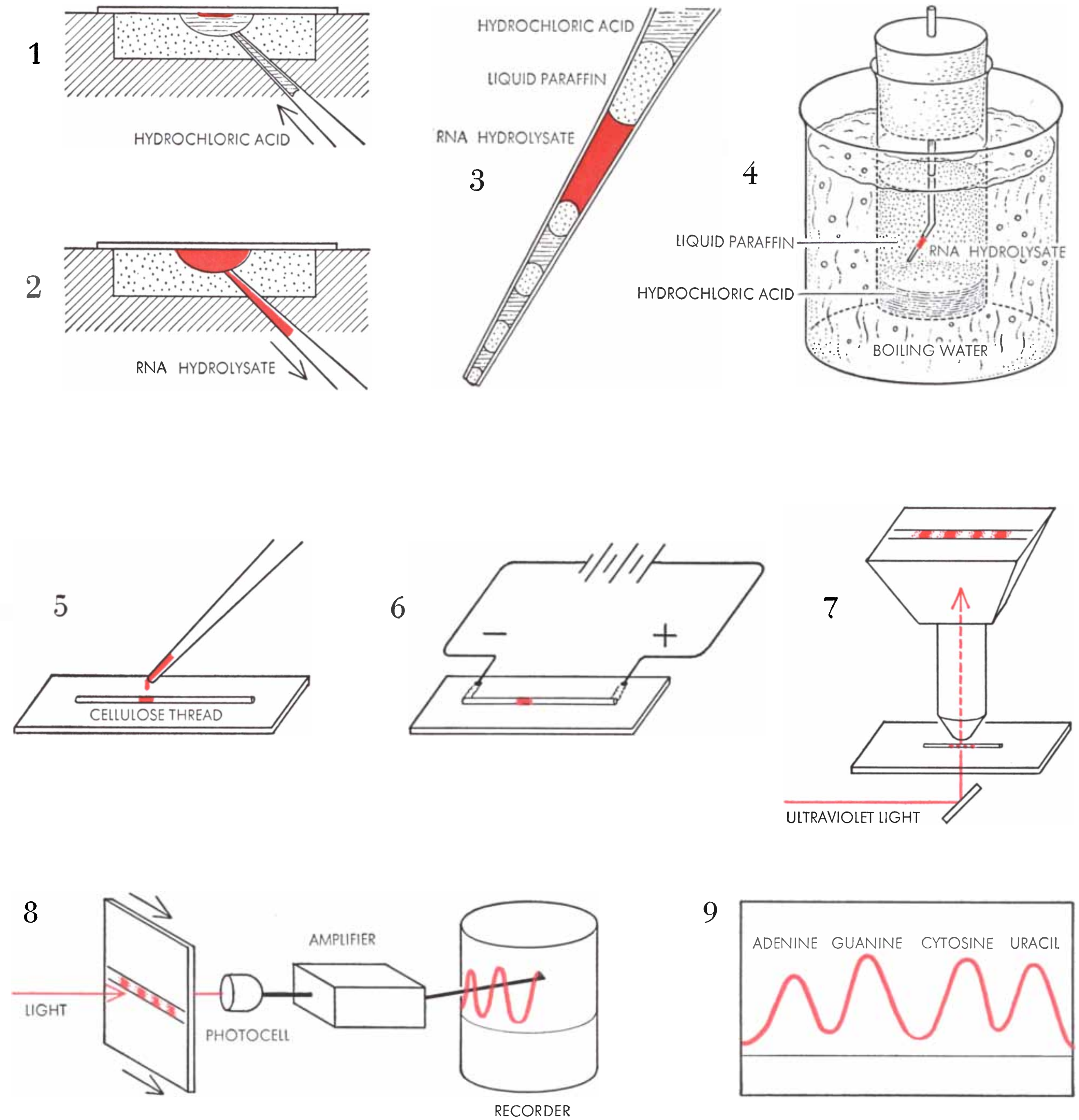
Let me now summarize some of the findings we have made with our micromicro techniques. Perhaps the most striking is the finding that the RNA content of the nerve cell ranks with the highest among all cells in the body. Nerve cells of all sizes contain about 10 per cent as much RNA as protein. In absolute amounts the 1,550 micromicrograms of



MEASUREMENT OF RIBONUCLEIC ACID (RNA) in brain cells, either nerve cells or their satellites, is based on ultraviolet absorption. The amount of RNA in single nerve cells ranges from about 45 to 1,550 micromicrograms. (A micromicrogram is one million-millionth of a gram.) The first step is to remove a single nerve cell (or equal mass of glia) from brain tissue. The cell is placed under a glass slide, where it is protected by paraffin (*2*). The enzyme ribonuclease (*3*) breaks down the giant molecules of RNA (*colored spots*) and carries depolymerized RNA into solution (*4*). Dried specks of RNA (*5*) are redissolved in a glycerine solution, forming microdrops (*6*). Micrography by ultraviolet light (*7*) yields an image of the drops and a density scale for measuring purposes (*8*). A scanner (*9*) produces a curve showing the RNA content of each microdrop (*10*).

RNA in the largest vestibular nerve cells (Deiters' cells) represents a maximum value for a single mammalian cell of any type. It is no accident, of course, that the RNA content is almost a constant fraction of the protein content, since the primary role of RNA is to preside at the synthesis of protein. Thus the largest neurons can be regarded as the body's most highly specialized cells for producing RNA and protein. Among mammalian cells their only competitors seem to be pancreatic cells from small animals with a high metabolism, such as the desert rat.

In man we have found that the RNA content of the motor nerve cells in the spinal cord increases significantly from the third year of life to age 40. From 40 to 55 or 60 the RNA content remains fairly constant, then declines rapidly. I should perhaps mention that nerve cells do not divide and are never replaced. With time the number of functioning



DETERMINATION OF RNA COMPOSITION is the second of the microanalytic methods used to measure differences between the nerve cell and its satellites. In the first step a solution of hydrochloric acid is added to depolymerized RNA extracted from a nerve cell or from several glia. The acid makes RNA break up into its subunits to form a hydrolysate (*2*). These subunits, or bases, are adenine, guanine, cytosine and uracil. The hydrolysate, carefully sealed in a micropipette (*3*), is transferred to a hot bath to complete the hydrolysis (*4*). The hydrolysate is placed on a thread (*5*), where application of an electric potential (*6*) makes the bases move at different speeds and so become separated. The separation is revealed by micrographing the thread with ultraviolet radiation (*7*). A photometric scanner converts the density patterns into a curve showing the relative amounts of the bases present (*8 and 9*).

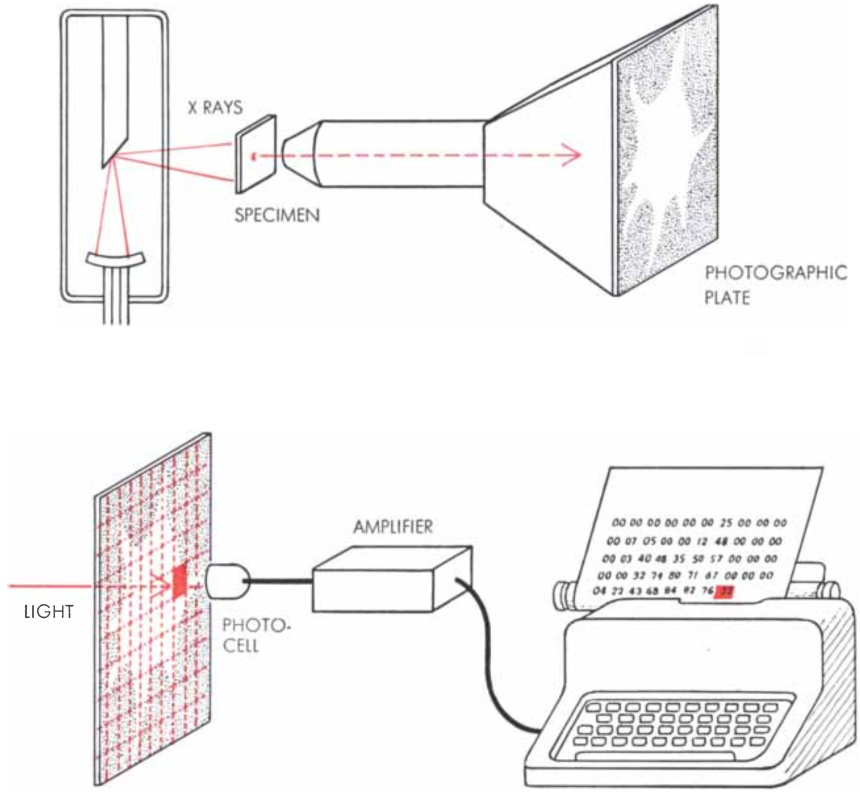
nerve cells decreases and between the ages of 30 and 90 the mass of the brain declines about 10 per cent.

Presumably the increase in RNA content of nerve cells during the first half of life is directly associated with the sensory stimulation of the cell. We have found that if an animal is deprived of stimulation in one of its sensory systems, say sight or hearing, the neurons constituting that particular system do not develop biochemically, although their structure appears entirely normal. The deprived nerve cells are more or less empty bags, impoverished in both RNA and proteins.

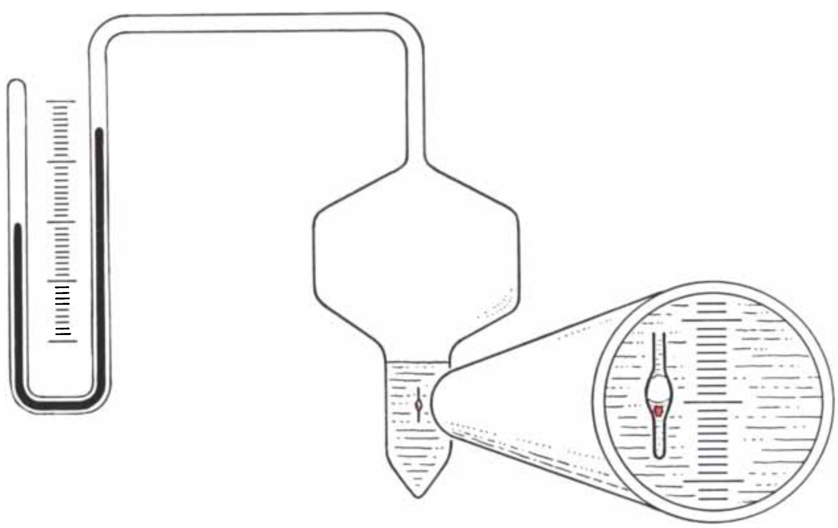
Conversely we find that when a sensory or motor nerve center is stimulated within physiological limits, its individual nerve cells show an increased content of RNA, proteins and lipids. This increased production begins immediately when the level of stimulation is increased and reverses within hours when it is decreased. To study such changes in content of the large vestibular cells, which help an organism to maintain its equilibrium, we trained rats to balance on a metal thread strung at an angle of 45 degrees. After an hour of this exercise, spread over four days, the RNA content of vestibular nerve cells increased from an average of 650 micromicrograms per cell to 730 micromicrograms. If the animal became exhausted, the RNA content fell below normal, but the level could be restored by rest. If the cell is damaged, however—by a strong sound, radiation, virus attack or poison—the RNA content becomes exceedingly low and the cell may not recover.

What happens to the glial cells when a nerve system is stimulated? To answer this question we stimulated the vestibular system in more than 100 rabbits by mild rotation at 30 revolutions per minute, 25 minutes a day for a week. We then analyzed the large Deiters' nerve cells and the surrounding glial cells in these experimental animals and in a comparable number of controls. In general we found that the biochemical changes in the glial cells are the opposite of those in the nerve cells [*see illustrations on page 70*].Whereas the RNA content of the nerve cells increased by about 5 per cent, that of the glial cells fell by about 30 per cent. At the same time the cytochrome oxidase activity of the nerve cells rose by about 50 per cent and that of the glial cells fell by about 70 per cent.

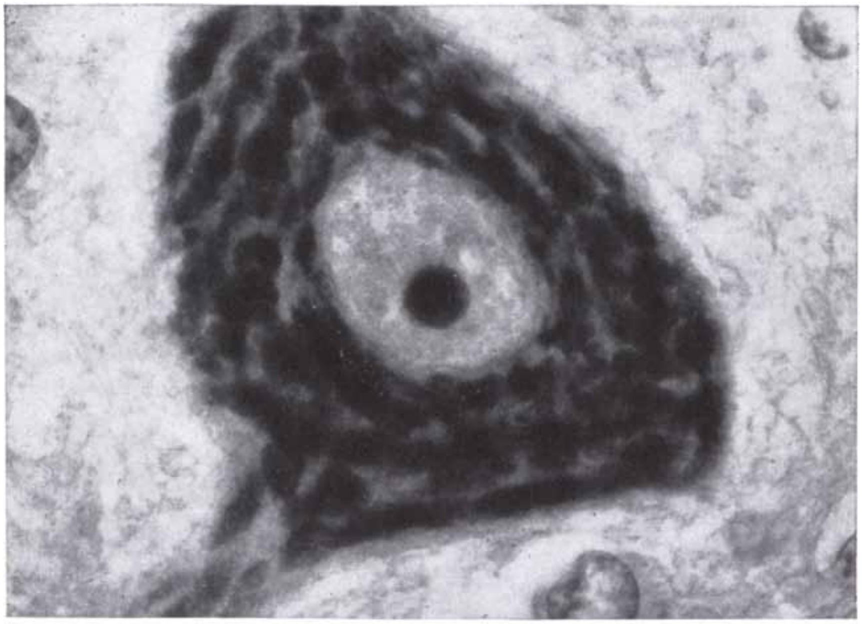
In spite of the opposite response observed in the two types of cell, it can be shown that the changes are not in one-to-one correspondence. In other



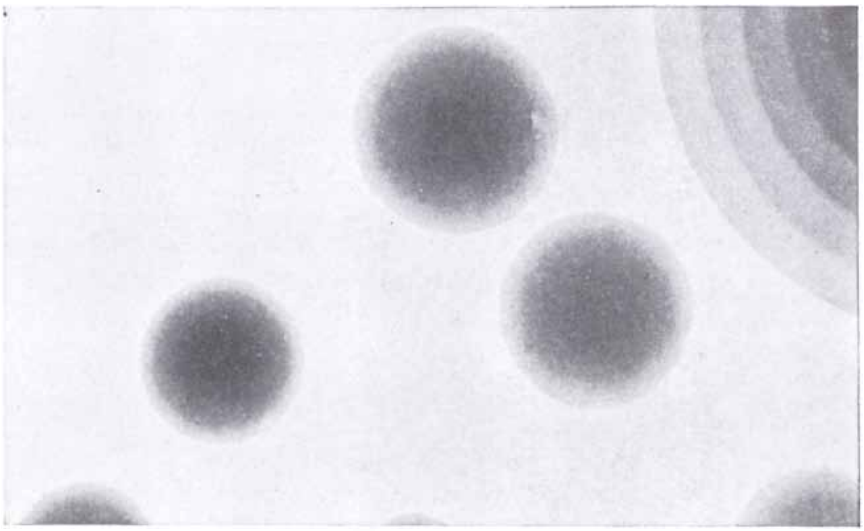
MEASUREMENT OF PROTEINS AND LIPIDS in single nerve cells is based on the capacity of individual atoms of carbon, oxygen and nitrogen to absorb X rays. The analysis begins with a microradiograph of the dried cell (*top*). A scanner (*bottom*) measures the density of each of 12,000 areas in the photograph. A computer converts density into values for "total organic mass," which are typed out for each area. By repeating the analysis after the lipids have been extracted from the specimen, proteins and lipids can be calculated separately.



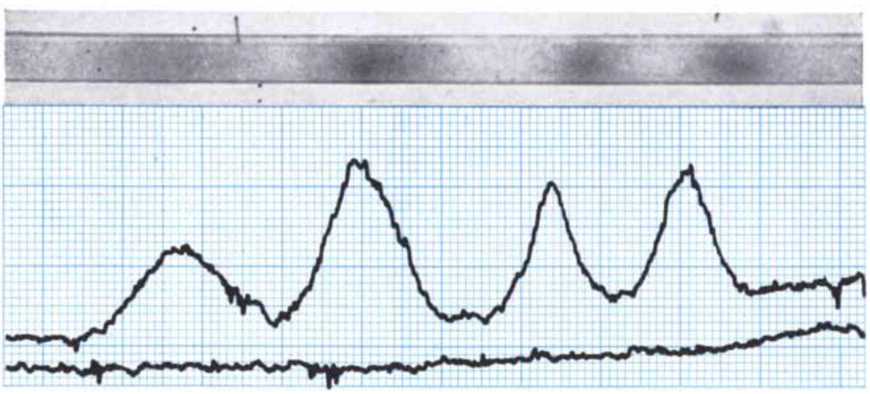
ENZYME ACTIVITY OF BRAIN CELLS is measured with a tiny Cartesian diver, a device that floats underwater. A single living nerve cell (or glial mass) is placed in the diver, together with chemicals that the cell can oxidize by metabolic processes. As the cell absorbs oxygen from an air bubble in the diver, the diver's density increases and it slowly sinks. The rate of sinking is observed and provides an extremely precise measure of enzyme activity.



LOCATION OF RNA IN NERVE CELL is revealed by dark areas in this micrograph made by ultraviolet light. The capacity of RNA to absorb ultraviolet radiation of certain wavelengths provides the basis for extremely sensitive microanalytic methods (*see below*).



MICRODROPS CONTAINING RNA, extracted by the method illustrated on page 65, produced this ultraviolet micrograph. The circular pattern at upper right is a density scale.



RNA COMPOSITION is indicated by the four dark regions in the ultraviolet micrograph (*top*) made by the method illustrated on page 66. The curve (*bottom*) is a photometric plot of these regions; the peaks stand for adenine, guanine, cytosine and uracil respectively.

words, there is probably no direct transfer of enzymes from glia to nerve cell. Yet it is obvious that glial cell and neuron are energetically linked together.

This past summer, at the International Congress of Biochemistry in Moscow, my colleague Joseph T. Cummins and I reported on experiments that begin to throw light on the nature of this link. We find, in brief, that the nerve cell is rich in the energy-carrying substance ATP and that the glia are poor in ATP. When we look for the enzyme adenosine triphosphatase (ATP-ase), which releases the energy in ATP, we find it present in the glia but not on the *surface* of the nerve cell membrane. Inside the membrane, however, there is a good deal of ATP-ase, and it seems to be of a distinctly different type from that in the glia.

How can these findings be interpreted? We suggest the following picture. In the glia there exists an active ATP-ase that is able to release energy for the transport of nutritional materials from the blood capillaries to the surface of the neuron. These materials are then transported through the membrane and into the nerve cell by the activity of the ATP-ase residing directly inside the nerve membrane. This ATP-ase seems capable of transporting a wide variety of substances across the membrane.

Let us now see how one could frame a hypothesis relating the transient and dissolving patterns of the nerve's electrical activity with the neurochemical studies revealing a high rate of RNA production and protein synthesis within the nerve. The electric currents that propagate nerve impulses are produced by the movement of sodium and potassium ions across the membrane of the axon, the long fiber extending from the cell body. As the nerve impulse passes a given point, sodium ions flow into the axon; an instant later, in the wake of the impulse, potassium ions briefly flow out. In the resting state of the axon an energy-requiring mechanism continuously pumps sodium out of the axon and potassium into it, creating the conditions necessary for the propagation of a nerve impulse. One may postulate, therefore, that RNA is required, in the first place, to provide the enzymes (proteins) needed to operate the sodium-potassium pump.

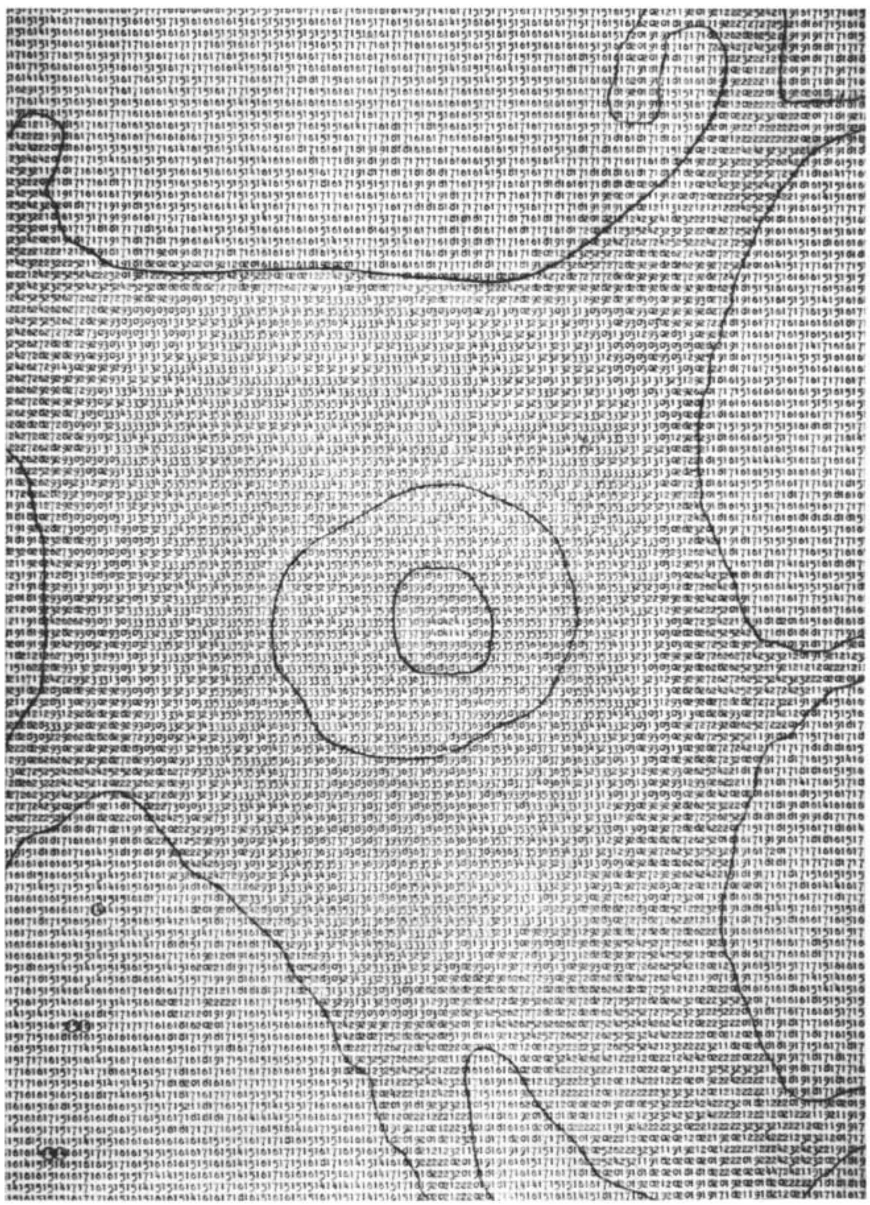
The second role of RNA is much more speculative and I offer it only to stimulate further discussion. Most neurophysiologists would admit that a satisfactory explanation of memory is lacking. The memory capacity of the human brain is prodigious. Although it is impossible to make an accurate estimate, it is not unreasonable to expect that in a lifetime the brain stores 10^{15} bits of information. (Here "bit" means the smallest possible quantity of information.) Even this figure represents only a tiny fraction of the total number of nerve impulses that travel through the nervous system in a lifetime. When one is awake, something on the order of three billion impulses per second—two billion provided by the visual system alone—are generated in the nervous system.

In the complex structure of RNA, and in the many permutations permitted by the rearrangement of its four bases, one has a molecular substance that in principle could encode 10^{15} or more bits of information. The steps by which a pattern of nerve impulses is translated into an RNA molecular code providing a basis for memory could be as follows.

As a first step we can imagine that the internal electrochemical environment of the nerve cell can be sensitively altered by the pattern of nerve impulses entering the cell. Slight changes in this environment could determine the stability of one or more of the four bases at a given site on a pre-existing RNA molecule. A given impulse pattern could therefore make a base from the surrounding pool replace a base whose link to the molecule had been weakened. The changed sequence would then remain. This new RNA molecule, although differing from the original at only one point, would direct the synthesis of a protein molecule differing slightly but significantly from that previously produced by the cell. This is step two of the hypothetical process.

We conjecture further that the protein has the property of responding to the same electrical pattern that created the RNA. The protein's response is to dissociate rapidly and so provide a molecular fragment that will react with a complementary molecule already present in the cell. The result of this reaction is to cause the explosive release of the so-called transmitter substance at the synapse where the nerve cell makes contact with the next cell in the neuronal chain. The explosion of the transmitter substance (possibly an explosion patterned in time) allows the electrical pattern to bridge the synapse and be passed along by the second cell, then by a third and so on.

According to this hypothesis a nerve cell responds differently depending on whether an incoming pattern of impulses is a new one or a familiar one. If the pattern is a new one, none of the protein molecules present in the cell will have the proper configuration to dissociate in response to the pattern. The electrical pattern must first shape a new RNA molecule, which will then shape a protein molecule capable of dissociating and thereby triggering off transmission across a synapse. If the incoming impulses have a familiar pattern, how-

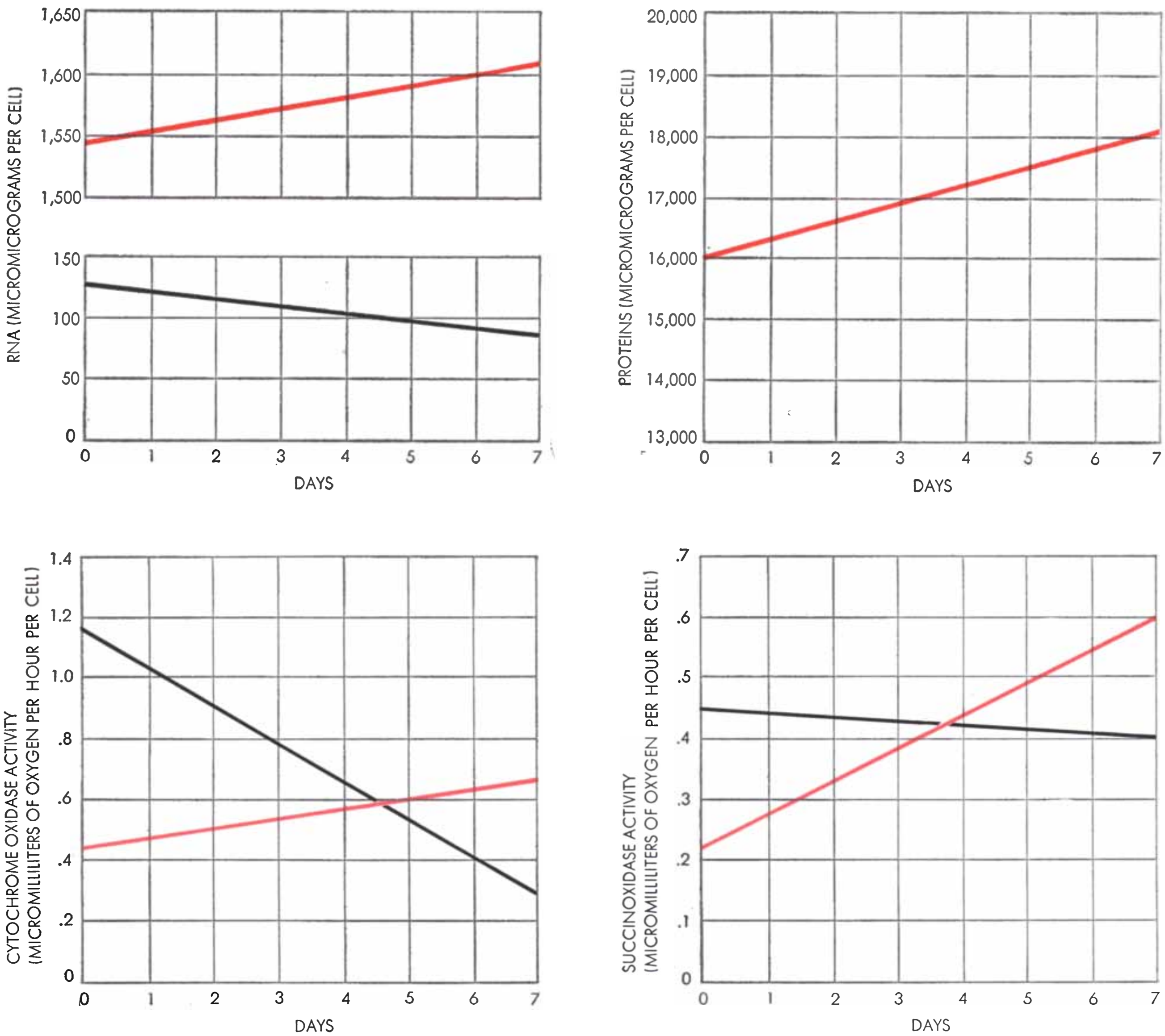


TOTAL ORGANIC MASS OF NERVE CELL is calculated from its opacity to X rays of certain wavelengths, using the method illustrated at top right on page 67. The microradiograph (*left*) shows a large nerve cell magnified 800 diameters. A photometric device divides the X-ray picture into 12,000 equal areas and measures the density of each. A computer converts these density values into values from 00 to 99 representing "total organic mass," which are then typed out automatically in a large table (*right*), over which the outline of the original cell can be drawn to show mass distribution. The method can also indicate proteins and lipids.

ever, protein molecules will already be present that can dissociate very rapidly. These "sensitive" protein molecules are perpetuated within the cell, presumably throughout most of a lifetime, by uniquely patterned RNA molecules, which, in their turn, are "descended" from RNA shaped by some early pattern of impulses. Each cell may perpetuate within itself an enormous number of unique patterns of RNA and protein. Conceivably a giant molecule of RNA or protein could accommodate along its great length many different patterns shaped by different impulse patterns. One can also surmise that the same patterns must be laid down and preserved in all the nerve cells—by the thousands and millions—that have to co-operate in producing the complex behavior we observe in ourselves and in other organisms. This diffuse and multiple storage of memory "records" would account for the well-established observation that memory is not destroyed by the removal of large sections of the brain.

How the organism gains access to these stored records is a separate and baffling problem. The difficulty probably lies in our inability to imagine how many neurons are involved in recognizing and recording the simplest item of information. The shape of a triangle, for example, could hardly be recorded in a single configuration of RNA and protein, but would have to be represented, if storage is molecular, by a multiplicity of coded molecules at every step in the visual system extending from the retina to multiple projection areas in the cerebral cortex.

I should emphasize again that all this is highly speculative and may be quite mistaken. The important lesson of neurochemical research is that the rich electrical activity of the nervous system is paralleled by an equally rich chemical activity. We will not make much progress in understanding how our brains work until we know how the two forms of activity are related.

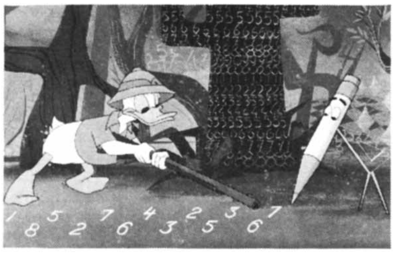


EFFECT OF SENSORY STIMULATION on the nerve and glial cells in the vestibular region of the brains of rabbits is depicted in this set of charts. The stimulation consisted of placing the rabbits on a rocking turntable 25 minutes a day for a week. Vestibular cells from these rabbits were then compared with similar cells from control animals. Values obtained from the controls provide the initial levels at the left of each chart; values from the stimulated animals provide the seven-day values at right. Nerve cells are indicated by colored lines, glial cells by black. The collaboration signified by these results is discussed in the text.

Kodak reports on:

hopes stirred by an artificial duck . . . new personal monitoring film, very sensitive . . . faraway warm spots

8mm audio-visuals



© Walt Disney Productions

On Sunday evening, September 24th, a new associate of ours named Walt Disney broadcasted from 168 television stations a film called "Mathmagicland." It featured an artificial duck he owns named Donald. The film illustrated the mathematical unity of nature and man, while the duck quacked in order to reassure 20,000,000 viewers that there is no harm in such a discussion. Some pre-teens among the 20,000,000 may have gone off to math class the next morning with an attitude that may eventually show up as a slight upsurge in doctorates conferred by American universities in June, 1974.

Lots of kids who were too young for "Donald in Mathmagicland" this fall will be ready for it next year in the classroom. With the skill and resources of a Disney, movies can teach conic sections as easily as pie-throwing. Movie-makers with lesser resources and less abstract subjects can also teach laudably. This is hardly news any more. What bothers the classroom teacher a little about 16mm movies is how to get the one she wants when she wants it instead of seven weeks later. Nobody is to blame. Very few school systems are rich enough to buy as many prints of a film on photosynthesis as there are classes in the system studying photosynthesis at the same point in the school year.

A remedy is just rising over the horizon. Its first rays spell out *Kodak Sound 8 Projector*. This projects 8mm movies with commentary from a magnetic sound stripe on the film.

The greatly reduced cost and bulk of 8mm film and equipment are what got home movies off the ground. The vast improvement in sharpness and color fidelity in the 8mm Kodachrome II Film introduced this year is making movies really soar as entertainment in the home. In the schoolroom it looks as though 8mm sound movies are about to have an effect comparable to the impact of the paperback on the book business. The teacher will be able to handle a teaching film more like a weekly magazine and less like a shipment of gold bullion. Remember when librarians were more intent on collecting 2¢ fines than on luring patrons into the library?

Keep your eye and ear on 8mm audio-visuals. If thinking of producing some yourself, you are welcome to talk it over with Advisor on Non-Theatrical Films, Eastman Kodak Company, Rochester 4, N. Y.

Down with the administrative dose

Two little packets of film are extracted from a factory-fresh carton. One is locked away in a clean safe. The other is worn by a worker in the vicinity of ionizing radiation. After a month the two are processed together. Both turn out equally blank. A good densitometer discloses no difference in their optical densities. What can be inferred about the quantity of ionizing radiation the worker has absorbed?

Anybody who draws the obvious conclusion has failed fully to engage his brain cells in thought. The answer to the question depends on the sensitivity of the film. Once that is known, one can say how much of a dose the worker has probably had less than.

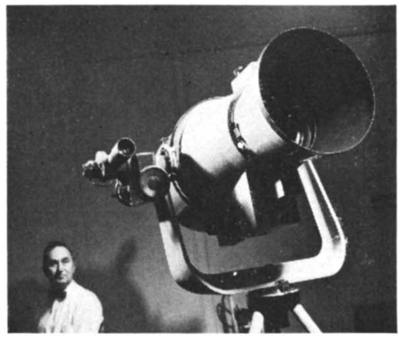
Social ethics in advanced countries require the assumption that the worker has actually *had* that much radiation. This is known as the "administrative" dose. Records are kept as in a bank. When administrative and physical doses add up to a critical figure, the worker is shifted to a different job. He may habitually spend every Saturday night cruising the center line of a busy highway at 80 m.p.h. Nevertheless, the critical figure assumes that he wants to live forever and become the progenitor of an infinite line of biologically perfect descendants. Pressure to squeeze it down will never let up, we hope.

Without relaxation of solicitude, we have taken steps to cut down the waste of his job experience. By reducing the administrative dose (which is the only kind of radiation dose he really ought ever to get on the job), we can keep him in his slot longer. It is within our power. All we have to do is make more sensitive film. This we have now done. It is called *Kodak Personal Monitoring Film, Type 3*.

The packet it comes in also includes a piece of low-sensitivity film. Its sensitivity is so low that it can measure 1800 roentgens, a horrible thought. The lower limit of dose measurement for the high-sensitivity film in the packet runs somewhere below 10 milliroentgens. Its precise determination depends on such a complexity of factors that we won't try to explain it here.

If interested, prepare yourself by studying pp. 10-53 to 10-75 of Radiation Hygiene Handbook *(McGraw-Hill Book Company, Inc., 1959). Then bring your knowledge up to date by requesting a data sheet on* Kodak Personal Monitoring Film, Type 3 *from Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. Be impressed with the fact that the boys who built this film have just finished measuring the dose to which a recent Discoverer satellite exposed itself in its travels. It's no administrative dose.*

50 winking lights



This infrared scanning head contains a line of 50 gas-discharge lamps that wink in correspondence to infrared radiation imaged by a 10-inch-aperture $f/0.76$ Schmidt system on a 50-element linear array of Kodak Ektron Detectors. While the image is oscillated across the line of detectors, the line of lamps is effectively swept in synchronism across the visual field of the beholder. He sees a picture of a 20° chunk of the infrared environment for search and track of objects differing in temperature from the background by a number of degrees that is determined by which of several types of interchangeable detector arrays happens to be in place. The instrument is also useful in another mode of operation with multi-channel oscillographs for radiometry of faraway warm spots.

For further information write Eastman Kodak Company, Advanced Planning Group, Apparatus and Optical Division, Rochester 4, N. Y.

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

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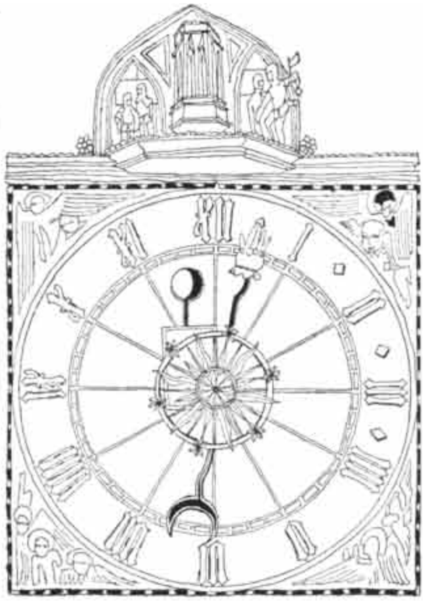


A Hundred Million More

With an explosion at the end of October estimated at 57 megatons the U.S.S.R. brought to about 100 megatons the energy released in its latest series of nuclear-weapons tests (the energy equals the output of 100 million tons of TNT). The total of air explosions by all countries prior to the present Soviet series is estimated at 170 megatons, approximately two-thirds of which was set off by the U.S. and Britain and one-third by the U.S.S.R. Although it is now responsible for well over half the energy released in nuclear-weapons tests, the Soviet Union still trails in the number of individual detonations: the U.S. has carried out about 170 and the U.S.S.R. about 100.

In all pre-1961 tests, an average of 50 per cent of the yield of so-called thermonuclear devices came from fission reactions. (The devices are actually fission-fusion-fission bombs, in which a small fission charge triggers a thermonuclear reaction, which in turn sets off another fission explosion in a surrounding blanket of material.) Following the first tests in the latest series, measurements of the amount and kind of contamination in the lower atmosphere were said to indicate about the same proportion. Most of the fallout, however, will come from the two largest explosions—some 30 and 50 megatons. If these too were 50 per cent fission, the U.S.S.R. will have injected 60 per cent as much radioactivity into the atmosphere in two months as had been put there during all the rest of the atomic age. If, as some observers think likely, the Russians have succeeded in increasing the fusion-to-fission ratio in their high-yield devices, the explosions will turn out to be somewhat cleaner and the fallout correspondingly lower.

The U.S. Public Health Service has said it does not expect "dangerous" levels of fallout radiation from the tests, although the levels might occasionally reach "Range Two"—a newly established classification that calls for checks in the amount of radioactive materials entering the human food chain. One official estimated that the strontium 90 in the bones of children in the Northern Hemisphere might increase 50 per cent, but that the amount will remain comfortably below the currently accepted "maximum permissible concentration."

Elsewhere, particularly in countries nearer the high latitudes where the explosion took place, reaction was sharper. Before the big explosion the Scandinavian countries had set up emergency monitoring networks. Norway had installed radioactivity warning sirens; Britain and the Netherlands were storing food, especially dried milk; the Japanese rushed to harvest fruits and vegetables. At the United Nations, Canada's Secretary of State for External Affairs, Howard C. Green, announced that after the Soviet tests in September radiation counts in Toronto were up 1,000-fold. "The time has come," he told the General Assembly, "when it is not sufficient merely to express concern and record blame. We must find a means of compelling the countries responsible to cease the testing of nuclear weapons." The French physicist Frances Perrin said that fallout from the 50-megaton weapon could kill 10,000 persons over the next 30 years.

The Nobel Prizes

The 1961 Nobel prize in physics was shared by Robert Hofstadter of Stanford University and Rudolf L. Mössbauer, now at the California Institute of Technology. Hofstadter won his award for studies of the size and internal structure of the atomic nucleus and its component parts: protons and neutrons [see "The Atomic Nucleus," by Robert Hofstadter; SCIENTIFIC AMERICAN, July, 1956]. Using the large linear accelerator at Stanford as a "microscope," Hofstadter and his group directed its electron beam at nuclei and at protons and neutrons, and observed the patterns in which the bombarding particles were scattered. From these patterns they were able to determine the structure of the target. For some years, while the maximum energy of their machine was about 600 million electron volts, they concentrated chiefly on nuclei, which were shown to have a dense core and to become fuzzy toward the outside. Later the beam energy was increased to a billion electron volts, giving it a resolving power sufficient for a detailed study of individual protons and neutrons. They have been found to consist of several concentric clouds of mesons.

Mössbauer's prize-winning work was published in 1958, when the physicist was 29, as a doctoral dissertation at the Munich Institute of Technology. He found a way to tap the almost perfectly constant frequency of the gamma radiation from excited atomic nuclei [see "The Mössbauer Effect," by Sergio De Benedetti; SCIENTIFIC AMERICAN, April, 1960]. The frequency of any radiation depends on the energy of its photons, or quantum units. In the case of gamma rays the energy is derived from transitions between nuclear energy levels, and these are precisely the same for nuclei of a given species. In an ordinary gamma emitter, however, some of the available energy goes into recoil of the nuclei that send out photons; the amount varies from one nucleus to the next, depending on thermal motion. By locking nuclei of excited iridium in a crystal lattice and cooling it to the temperature of liquid air, Mössbauer virtually eliminated recoil and produced a beam of photons of practically identical energy and frequency. The frequency was constant to about one part in 100 billion, as demonstrated by observation of the rays in a second iridium crystal. Within a year of the discovery physicists in many laboratories were applying it to a wide range of experiments of previously undreamed-of accuracy. One of these provided the first unequivocal demonstration of the "gravitational red shift" predicted by the general theory of relativity. It was shown that the frequency of gamma rays decreases when they move upward against the earth's gravitational field, and increases when they "fall."

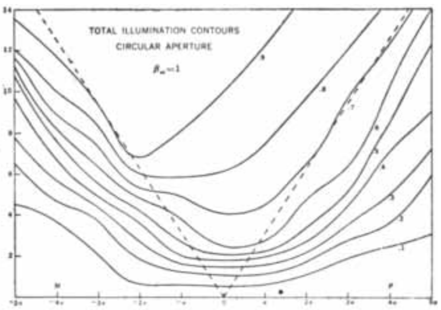
The prize in chemistry went to Melvin Calvin of the University of California for elucidating the chemical pathways by which carbon is assimilated in photosynthesis [see "Progress in Photosynthesis," by Eugene I. Rabinowitch; SCIENTIFIC AMERICAN, November, 1953]. For more than 10 years he and his colleagues have been studying the growth of the green alga *Chlorella*, analyzing its incorporation of carbon dioxide labeled with radioactive carbon. By interrupting the process at intervals the California chemists have been able to extract and identify the short-lived intermediate compounds that eventually combine to make carbohydrates and other substances. Recently Calvin's group has found that starches and sugars are by no means the only primary products of photosynthesis. A substantial fraction of incoming carbon is converted directly, and with the help of light energy, to protein and probably to a number of other materials as well.

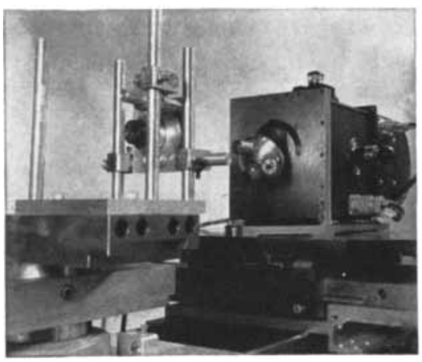
The prize in physiology and medicine was awarded to Georg von Békésy, senior research fellow in psychophysics at Harvard University. Von Békésy was cited for "his discoveries concerning the physical mechanisms of stimulation within the cochlea." The announcement added: "There is hardly any problem concerning the physical mechanics of acoustic stimulation to which von Békésy has not added clarity and understanding and this applies even to those cases in which the primary discoveries have been made by others." One of the chief fruits of von Békésy's work was an understanding of how the ear discriminates pitch. When he began his studies, it was generally supposed that the basilar membrane of the inner ear contained groups of fibers "tuned" to vibrate in sympathy with sounds of different frequency and that the groups stimulated different nerve endings. Von Békésy showed that the entire basilar membrane vibrates when sound waves strike the ear, but that each tone causes maximal vibration in a different area of the membrane; this, he found, is the source of the differing nerve signals that the brain interprets as pitch [see "The Ear," by Georg von Békésy; SCIENTIFIC AMERICAN; August, 1957]. Von Békésy was born in Hungary, where he began his career as a telephone engineer.

Project Haystack

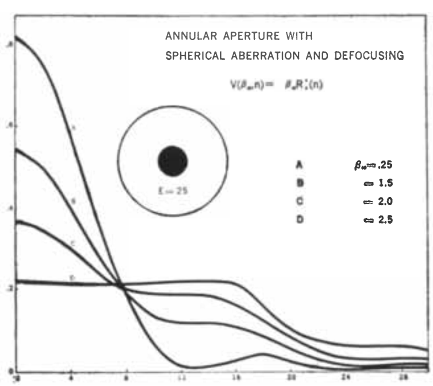
More than two weeks after they had been put into orbit the controversial needles of Project West Ford had failed to show up on radar. If the tiny

Optical Craftsman





Sine Wave Analyzing Bench



Knowledge is of two kinds

We know a subject ourselves, or we know where we can find information upon it.
— SAMUEL JOHNSON

Since the beginning of recorded history, man's ability to store and retrieve information has paced his progress. Today man's volume of information is developing at an exponential rate, in thousands of forms and languages. However, lacking the means to store, collect, catalog, and retrieve it quickly and simply — much of this information is useless.

Itek Laboratories, the research division of Itek Corporation, is dedicated to making this information available for use. At Itek Laboratories scientists, engineers, and craftsmen from over 20 scientific disciplines blend their skills to discover, develop and adapt new systems and methods which will allow other men to transform information into knowledge.

Optics

The Optical Department, as a critical part of Itek Laboratories' research and development efforts in the new industry of Information Technology, is given the support of the Laboratories' fullest resources, including some of the world's most advanced optical equipment and a modern, rewarding working environment. Applications of previously developed equipment have ranged from high-resolution camera systems for reconnaissance to desk-top size information storage and display systems.

Opportunity to join our Optical Department is extended to men with the following qualifications:

Optical Engineers with an advanced degree in Optics or Physics, experience in geometric lens design and knowledge of automatic computers and procedures.

Optical Craftsmen with experience in either optical testing, optical assembly or optical fabrication. These positions require knowledge of advanced techniques gained in work on extremely precise lenses developed to the closest optical tolerances.

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wires had escaped from their containers as planned, they should have spread out enough to produce a detectable radar reflection in a day or two. The wires had been expected eventually to form a thin belt around the earth, which would serve as a reflector for high-frequency radio communication over long distances. The experiment is being conducted for the Air Force by the Lincoln Laboratory of the Massachusetts Institute of Technology.

Although the project had the advance blessing of a special panel of the President's Science Advisory Committee, the launching occasioned protests from a number of astronomers. Sir Bernard Lovell, director of Britain's Jodrell Bank Radio Observatory, said the plan "does not represent a scientific experiment" but is "devised by U.S. military scientists and intended to provide a secure means of military communication." While accepting the U.S. committee's finding that the wires sent up in the first test would not interfere with radio or visual astronomy, Lovell declared that "the contamination of space in this manner for communications purposes cannot possibly be justified in view of the satellites and other means now available for long-distance communication, which can be made secure from enemy action."

In a policy statement last summer the U.S. Government gave assurance that "no further launching of orbiting dipoles will be planned until after the results of the West Ford experiment have been analyzed and evaluated. The findings and conclusions of foreign and domestic scientists...should be carefully considered." Nevertheless, Lovell expressed the fear that a successful outcome would lead to further launchings "and the position will deteriorate rapidly."

Among the astronomers who went on record against the experiment are Martin Ryle of the University of Cambridge, Harold F. Weaver of the University of California, Jan H. Oort of the Netherlands, who is president of the International Astronomical Union, K. A. Thernoe of Denmark, Guglielmo Righini of Italy and Fred Hoyle of England.

Memory Molecules

It has recently been suggested that memory may consist of information coded in giant molecules of ribonucleic acid (RNA), which are preserved by replication within the cells of the nervous system [see "Satellite Cells in the Nervous System," by Holger Hydén, page 62]. A test lending support to this hypothesis has been reported by W. C.

ANACONDA COMMENTS...

new facts about copper—man's oldest metal

No. 3 of a series

SPECIAL REPORT:

New facility will probe for more new facts about copper

Anaconda American Brass metallurgical research and laboratory divisions have moved to a new Research and Technical Center in Waterbury, Connecticut. Working together, scientists and engineers will apply concentrated effort to two basic goals: (1) The discovery of new copper alloys having combinations of properties not inherent in existing alloys, (2) The development of more information about copper and its alloys and new ways to use them.

A Thumbnail Tour

The Anaconda Research and Technical Center contains 50,000 square feet of floor space. Auditorium, technical library, and administrative offices occupy two floors; while laboratories and test facilities are housed on three adjoining floors.

Physical metallurgical equipment, on the first floor, includes: machine shop facilities for preparation of specimens; apparatus for tests involving welding, casting, pickling, X-ray diffraction, electron metallography, electronics, elevated temperatures, and cryogenics. Chemical metallurgical research equipment, on the second floor, includes: apparatus for tests involving coating, finishing, corrosion resistance, and performance in adverse environments. Central chemical laboratory equipment, on the third floor, includes: apparatus for metallography and spectroscopy testing, product control tests and chemical analysis, specimen preparation, and special tests for customers in areas of fuels, lubricants, and other nonmetallic materials.

One Important Project

Anaconda scientists, making immediate use of these facilities, are now developing an advanced high-speed metallurgical-

control analysis method, which combines techniques of X-ray and Direct-Reading Emission Spectroscopy.

The Anaconda research staff, which pioneered industrial direct-reading spectroscopy, has retained this method's precise determination of trace impurities and minor alloying elements . . . and added the rapid analysis of major alloy constituents inherent in X-ray spectroscopy techniques.

This combined analytical technique—which makes a complete determination of major and trace elements in only three minutes, whereas hours are required for wet chemical analysis—has been useful in developing improved properties of existing alloys. For example, Anaconda Free Cutting Brass-271—with a permissible copper range of 60 to 63% and a lead range of 2.5 to 3.7% (ASTM B 16-60)—was rapidly tailored to meet specific machinability, ductility and other mechanical-property requirements by controlling these elements to small increments within the permissible limits and by controlled mill processing for desired variations in alpha or alpha-beta grain structure.

The new instrumentation technique is now projected for production-line use after several years of thorough investigation and experimentation. Anaconda predicts this process will provide an ideal method for rapid-fire quality control.

Well Rounded

The new building, and the diversified research activities occurring within, round out Anaconda's ability to provide copper metals and production techniques for current and future applications. A question about how Anaconda copper can go to work for your company? Contact: Anaconda American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

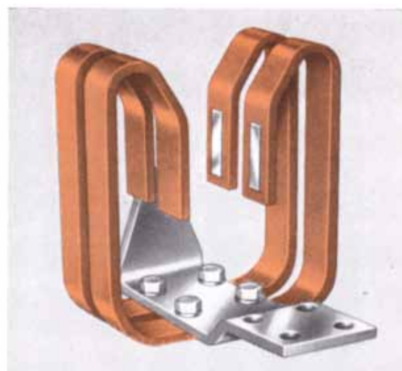
Value analysis and Anaconda Copper build a better air-break switch jaw

The trouble with beryllium copper, specified for the break jaw in the original Westinghouse V-2 air-break switch design, was in production. The jaw was hard to fabricate, demanding an assembly of beryllium copper components; the material was costly. Westinghouse probed the problem, and teamed up with Anaconda value analysts to find a solution.

The Anaconda specialists, thoroughly familiar with the range of available electrical coppers and copper alloys, learned that spring and strength characteristics of beryllium copper far exceeded operational requirements placed on the break jaw. They suggested a switch to AMZIRC®* (Zirconium Copper)-134, a less expensive alloy with superior electrical properties and sufficient spring to assure proper contact with low operating effort.

Using zirconium copper, Westinghouse engineers developed a one-piece, reverse-loop jaw (see photo), which operates more effectively, fabricates more easily, and greatly improves the performance of the new V-2 air-break switch. In this application, Westinghouse discovered that: *zirconium copper* provides high electrical conductivity—90 to 95% IACS; *zirconium copper*, before heat treatment, is easy to machine and cold form; *zirconium copper* after heat treatment, exhibits excellent mechanical properties—50,000 psi tensile strength, 45,000 psi yield strength at 0.2% offset, and 25% elongation in 2 inches.

Value analysis is one more way in which Anaconda is helping designers improve product quality and reduce product cost—through the use of today's coppers. For technical assistance with your metal selection problem, write: Anaconda American Brass Company, Waterbury 20, Connecticut. 61-992



Break jaws of new Westinghouse V-2 air-break switch, formed with Anaconda zirconium copper rod. Fabrication process includes machining, brazing silver inserts, bending and age hardening pieces at 400-425°C for two hours to impart high mechanical properties.

*Registered trademark of American Metal Climax, Inc.

ANACONDA®

AMERICAN BRASS COMPANY

Corning and Erwin R. John of the Center for Brain Research at the University of Rochester.

The two investigators based their experiment on the fact that planarians, or flatworms, can be conditioned to make a simple response to a stimulus, and that when a flatworm is cut in two, the head end grows a new tail and the tail end a new head. Moreover, when a conditioned planarian is cut in two, the conditioned response is "remembered" by both of the regenerated organisms. Evidently some memory of the response is transmitted to the tail of the planarian before it is cut in two, and this memory is then transmitted back to the new head as it regenerates.

To see if the transmitting substance could be RNA, Corning and John conditioned planarians to avoid a light and divided them into two groups. Planarians in one group were cut in half and allowed to regenerate normally in pond water. Those in the second group were cut in half and placed in pond water containing a small amount of the enzyme ribonuclease. Since this enzyme breaks down RNA, it should presumably interfere with the passage of intact RNA to the regenerating portion of the severed organism.

In a careful series of tests Corning and John found that the conditioned response was indeed "forgotten" by the tails that regenerated new heads in the presence of ribonuclease. However, heads that regenerated new tails in the presence of ribonuclease retained their conditioning. In other words, the memory trace preserved in the head section was unaffected by ribonuclease, but that in the tail section could no longer be transmitted back to a new head, where it is evidently needed if the planarian is to recall its conditioning. Although the tests do not prove that the conditioning is stored in RNA, they are consistent with that hypothesis.

Light Pipes for Color Vision?

The long history of research in color vision has been marked by a signal failure: the inability to locate in the human (or other mammalian) eye physiological or biochemical elements that react in such a way as to distinguish different colors. Now Jay M. Enoch, a physiologist at the Washington University School of Medicine, has found that colors are differentiated in a simple, physical way during the passage of light through the cones, the color-vision elements of the retina.

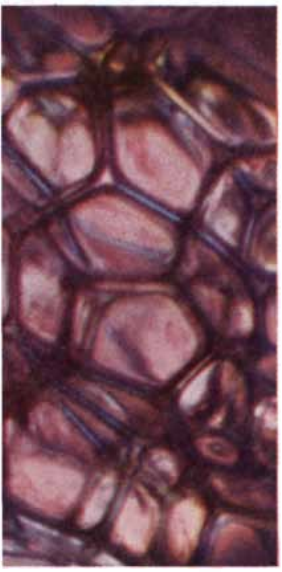
Enoch mounted sections of retina with

FROZEN FOODS STAY SMACKING-GOOD IN TRAILERS WITH BUBBLE-FILLED WALLS

A liquid plastic that expands and solidifies into a rigid foam full of tiny bubble cells is helping manufacturers build "reefers" that haul frozen foods at 0°F, even across Death Valley at high noon.

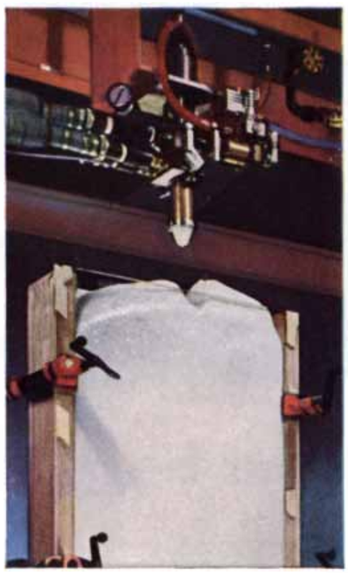
By developing a practical way of combining urethane polymer with a fluorinated hydrocarbon blowing agent, Glidden chemists have made high-efficiency insulating foam readily available to the transportation and food handling industries.

Glidfoam®, product of Glidden research, is poured into the walls of refrigerated trucks, trailers and railroad cars. It quickly expands to form an airtight solid barrier to heat transfer. Glidden experience with resins and chemicals makes possible Glidfoam recipes which assure desired foam generation, cell size, and aging characteristics.

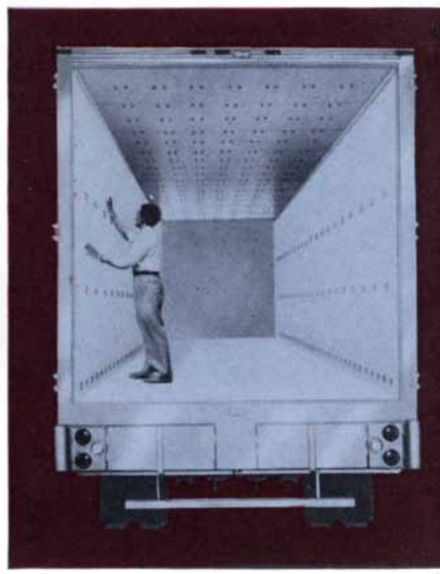


1 Under 50X magnification, rigid Glidfoam shows myriad of individual fully sealed airtight cells which give this moisture-resistant plastic its low density of only 2.0 lbs./cu. ft.

2 Glidden chemists formulate custom recipes of resin, catalysts, blowing agents, and surfactants to meet the specific flow and foaming requirements of each Glidden application . . . reefer bodies, pallatized containers and commercial freezers.



3 This transparent mold, simulating double-wall trailer construction, shows how Glidfoam, pumped as a two-component liquid, solidifies into a homogeneous bubble-filled rigid foam of uniform density with no shrinkage at successive pour "knit lines."



4 On a reefer-trailer production line, the temporary form has been removed from the trailer interior for final inspection of the poured Glidfoam after setting. Note that Glidfoam is a sturdy, self-supporting, continuous, thermal barrier that cannot vibrate down and leave uninsulated heat paths at the trailer roof-line.

If your product requires a finish, a coating or a resin, Glidden is ready to work with you. To obtain the formulation best suited to your product and application methods, write or phone:

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cones (obtained from patients undergoing eye surgery) in a chamber resembling the eye socket, arranging the apparatus so that he could examine the retina from behind with a microscope. Illuminating the cones with white light and examining the image on the retina, he found that different cones transmitted light of different colors.

Discussing the experiment in the *Journal of the Optical Society of America*, Enoch points to more than one mechanism that could account for the differences in color transmission. All depend on the fact that cones are tiny "light pipes," or fiber optics: like other transparent substances with a high index of refraction, they can "pipe" light along their length [see "Fiber Optics," by Narinder S. Kapany; SCIENTIFIC AMERICAN, November, 1960]. The diameter of the cones is very small—in the neighborhood of one micron (twice the wavelength of visible light). Fibers this thin show marked differences in the way they transmit light of different wavelengths (colors). A fiber with a given index of refraction and given length and diameter transmits light of one wavelength while letting most of the light of other wavelengths leak out through the side. Moreover, another mode of light transmission, called wave-guide transmission because it resembles the transmission of radio microwaves in wave guides, comes into play in fibers a micron in diameter. In wave-guide transmission reinforcement and interference effects occur among the different wavelengths of white light. The net effect is to deliver "modal" patterns, characteristic for light of each color, at the end of the fiber.

Whatever the mechanism or combination of mechanisms that acts in the cones, the result is a separation of light paths in the eye on the basis of color. How the rest of the organ makes use of this separation remains to be learned.

Synthetic Messenger

Two biochemists at the National Institutes of Health have produced new evidence that the hereditary instructions for the synthesis of proteins in living cells are carried by a "messenger" RNA (ribonucleic acid). Marshall W. Nirenberg and J. Heinrich Matthaei have also been able to substitute a simplified synthetic messenger for the natural product. This has provided a start toward deciphering the code in which the genetic message is written.

A wide variety of experiments has now made it clear that the master plan for protein synthesis is contained in the deoxyribonucleic acid (DNA) of the cell nucleus, and that proteins are assembled in the ribosomes, small bodies outside the nucleus. The amino acid units that make up protein molecules are brought to the ribosomes by a special soluble form of RNA. In the past year or so it has been suggested that the ribosome is a general-purpose factory and that the templates on which proteins are assembled are continually renewed by the hereditary material and transmitted to the ribosomes in the form of messenger RNA. The work of Nirenberg and Matthaei, reported in the *Proceedings of the National Academy of Sciences,* seems to confirm this suggestion.

Nirenberg and Matthaei prepared from the colon bacillus (*Escherichia coli*) a cell-free extract of ribosomes, enzymes and DNA. When they added a mixture of the 20 amino acids of which most proteins are composed, together with compounds to supply energy, they found that the extract manufactured protein from the raw materials. When the extract was treated with a DNA-destroying enzyme, its synthetic activity was unimpaired for 20 minutes but then dropped sharply. This could mean that the first 20 minutes is occupied in finishing the assembly of molecules begun in the intact cells, and that activity after that time depends on the production of new messenger RNA by DNA.

Adding RNA obtained from the ribosomes of other colon bacilli greatly stimulated the synthetic activity of the extract. When this additional template material was supplied, the destruction of DNA no longer inhibited the assimilation of amino acid into protein. To demonstrate the nonspecific action of the ribosomes themselves Nirenberg and Matthaei tried adding template RNA from yeast cells and from tobacco mosaic virus and found that their colon bacillus extract manufactured protein at an increased rate. Finally they substituted polyuridylic acid: a long-chain molecule consisting of repeating units of uridylic acid, one of the four bases that comprise natural RNA. This material proved to stimulate the production of polyphenylalanine: a short "protein" chain containing only units of the amino acid phenylalanine. Evidently the code for phenylalanine on the RNA template consists of one unit of uridylic acid or of a consecutive sequence of such units.

Nirenberg and Matthaei's preparation retains its activity after long periods of storage. This will greatly facilitate additional experiments. In the past, cell-free extracts have had to be made afresh for each experiment.


THE Bendix CORPORATION

THE EÖTVÖS EXPERIMENT

Around 1900 a Hungarian baron conducted exquisite measurements to demonstrate that all bodies fall at precisely the same rate. His result, crucial to the general theory of relativity, has now been confirmed

by R. H. Dicke

Some 350 years ago Galileo Galilei performed one of the most famous experiments in the history of science. From a "high tower" in Pisa (not necessarily the famous Leaning Tower) he dropped weights of wood and lead to determine their rate of fall. He concluded from this and other experiments, as well as from logical reasoning, that but for air resistance all bodies fall with the same acceleration. The constancy of gravitational acceleration was tested many times thereafter, culminating in the extraordinarily precise experiments made between 1889 and 1908 by Baron Roland von Eötvös of Hungary.

The date of these experiments has led some physicists to believe that Eötvös' work had a decisive influence on Albert Einstein as he was formulating his general theory of relativity between 1908 and 1915. The fact is, as Einstein wrote in 1934, he "had no serious doubts about [the constancy of gravitational acceleration] even without knowing the results of the admirable experiments of Eötvös, which—if my memory is right—I only came to know later." Nevertheless, it is entirely accurate to say that if the results of the Eötvös experiments had been anything but negative, every physicist would have heard the astonishing news within days and the whole foundation on which the general theory of relativity rests would have vanished before the theory had been conceived.

It follows that any experiment capable of testing the constancy of gravitational acceleration with higher accuracy than that achieved by Eötvös would provide a fundamental test of Einstein's theory. The apparatus used by Eötvös tested the constancy with an accuracy of five parts in 10^9 (five parts in a billion). I shall describe a new experiment, still in process in our laboratory at Princeton University, in which the accuracy of the experiment has been improved substantially, with further improvement still possible. I shall also discuss the significance of the experiment for contemporary physics.

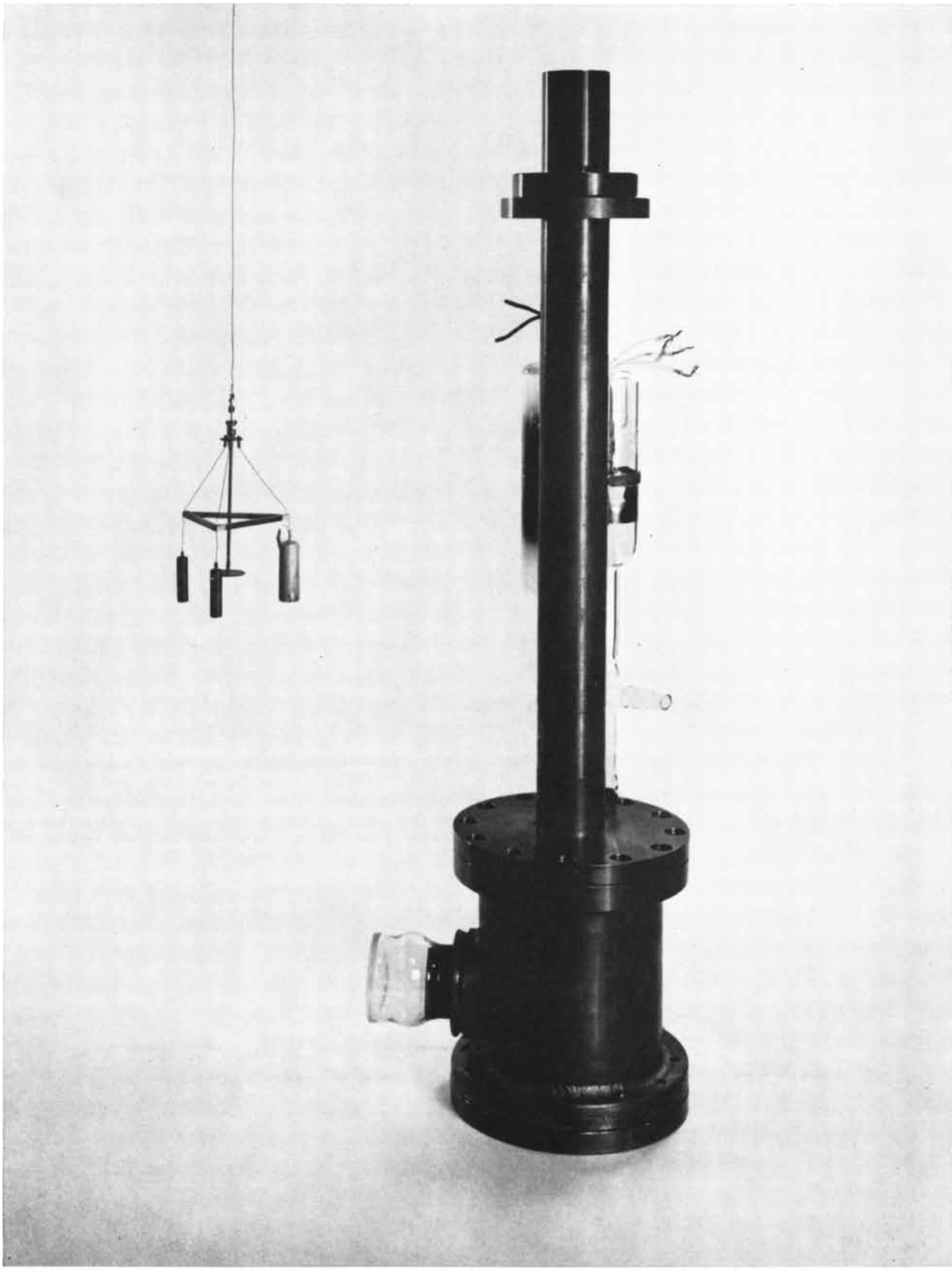
As the old Galilean experiment is commonly described, it is not always made clear that two fundamental questions are involved. First, do objects of different mass fall at the same rate? Second, do objects of different composition fall at the same rate? It is primarily the second question that concerns us here. One could make a crude Galilean test of this question by dropping a wooden ball and a hollow lead ball of the same weight and external dimensions. (The object of making the two balls the same size is to equalize air friction and thus obviate the need for a vacuum chamber for the test.) From the experiment one would learn if carbon and oxygen (the chief constituents of wood) respond to gravity in the same fashion as lead, even though the nuclei of carbon and oxygen atoms contain equal numbers of neutrons and protons and the nucleus of the lead atom contains 50 per cent more neutrons than protons.

At least four important conclusions could be drawn from an experiment showing that objects accelerate equally regardless of composition. First, that single neutrons and hydrogen atoms (or electron-proton pairs) would be expected to fall with the same acceleration. Second, that the strong nuclear forces that bind the nucleus of the atom together, although quantitatively different in light elements and in heavy elements, have no effect on acceleration. Third, that the greater electrostatic energy associated with the nuclei of heavy elements has no effect. Fourth, that the velocities of electrons occupying the inner shells of heavy elements, although higher than those in light elements, have no effect on gravitational acceleration.

Although Eötvös made his investigations long before the complex nature of the atom was known, he was evidently aware of the importance of working with different materials. Among the substances he tested were brass, glass, cork, snakewood, copper, water and platinum.

Roland von Eötvös was born in Budapest on July 27, 1848; he was the son of Baron József von Vásárosnemény Eötvös, a writer and statesman. At 21 the young Eötvös went to the University of Heidelberg, where he studied physics under Hermann von Helmholtz and Gustav Kirchhoff and chemistry under Robert Bunsen. His early experiments dealt broadly with molecular phenomena; it was not until 1889, at the age of 41, that he published the first of his famous papers on gravitation. We can only wonder what made him enter a field so different from that in which he had worked for so long.

After this initial investigation Eötvös used modifications of his original apparatus to investigate the distribution of mass in mountain ranges. For this work he is remembered by geophysicists. Then, using a sensitive instrument he had developed for his geophysical studies, Eötvös repeated his first fundamental experiment on gravitation. A paper describing this work won for Eötvös the Benecke Prize awarded by the University of Göttingen in 1909. For some reason the paper was not formally published until 1922, three years after his death. In 1935 J. Renner of Hungary repeated the Eötvös experiment using the baron's old



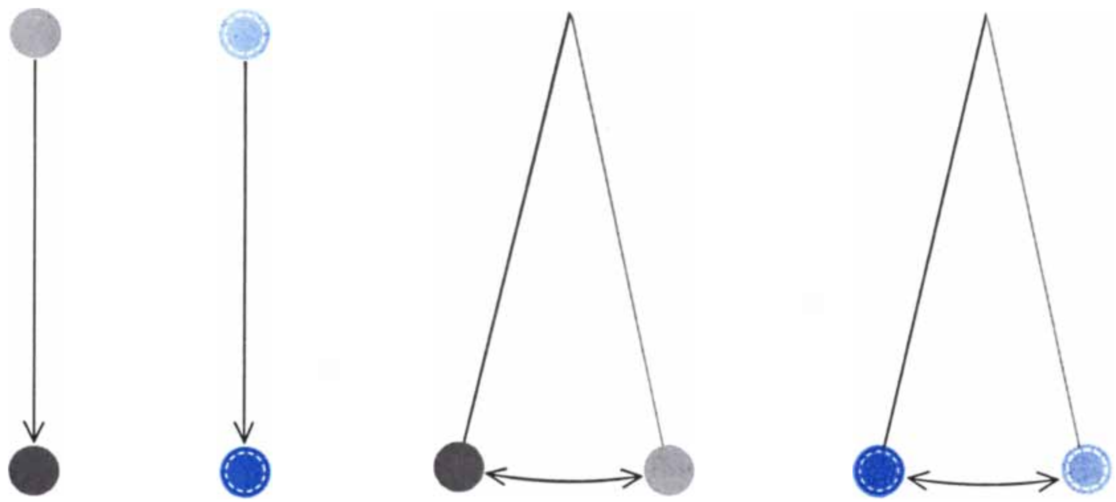
NEW "EÖTVÖS" EXPERIMENT, being conducted by the author and his colleagues, uses the arrangement of three weights shown at left and also on the cover of this issue. The two similar weights are copper; the third weight, sealed in a glass flask, is lead chloride. The triangle is quartz. During the experiment the triangle and weights are suspended inside the high-vacuum chamber at right, which is sealed belowground (*see illustration on page 94*). The principle of the experiment is diagramed on pages 88 and 89.

apparatus and claimed to have improved on the accuracy of the work.

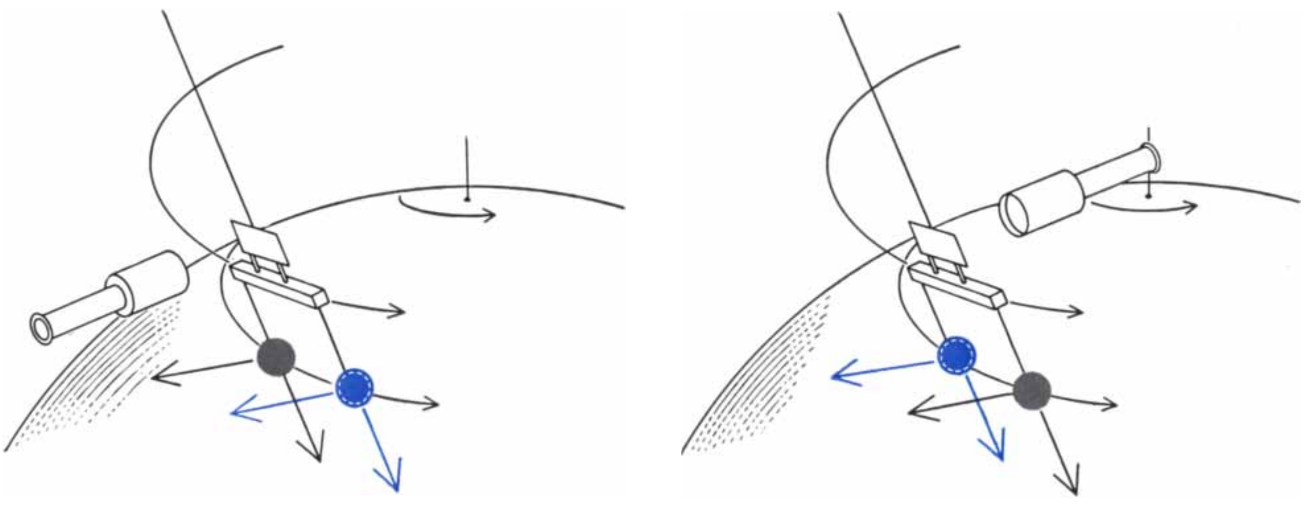
The principal instrument used by Eötvös was extremely simple [*see illustration on opposite page*]. It consisted of a light horizontal beam, 40 centimeters long, suspended by a thin platinum-iridium wire. Attached to the ends of the beam were two weights, one of them suspended 20 centimeters lower than the other. Although this configuration was useful for measuring small gravitational gradients in geophysical work, it made his fundamental experiment more difficult.

The principle used by Eötvös in his most accurate experiments can be visualized by imagining a weight suspended from a plumb line. In a rotating coordinate system, where the earth appears to be at rest, the mass can be thought of as being acted on by two forces: the gravitational attraction causing the mass to fall toward the center of the earth and the centrifugal force—a form of inertial force—tending to throw the mass outward [*see bottom illustration on this page*]. If weights of different composition are used, will the plumb line always hang in precisely the same direction, thereby indicating a strict proportionality between these two different kinds of force?

In the actual experiment the beam supporting the two masses was lined up facing east and west. Any small difference in the proportionality between gravitational and inertial forces would produce a torque on the beam, making it rotate. Since Eötvös could detect no rotation that could be clearly attributed to a lack of proportionality, regardless of the substance he tested, he reported a null result within the limits of accuracy of his experiment. (In a few of his ex-



EARLY GRAVITY EXPERIMENTS were performed by dropping weights (Galileo's famous experiment was not the first of its kind) or by observing the period of pendulums. Two pendulums of the same length should swing in synchrony regardless of the nature of the suspended masses. Isaac Newton observed the periods of pendulums supporting many different substances to show that all reacted in the same fashion to the force of gravitation. In the diagrams the broken lines inside the colored circles indicate that a dense substance, such as lead, has been hollowed out to make it equal in mass to a lighter substance (*gray circles*).



EÖTVÖS EXPERIMENT, performed in two series, first in 1889 and again in 1908, demonstrated the constancy of gravitational acceleration with great accuracy. Eötvös observed the effect on a torsion balance when two weights affixed to a beam were acted on simultaneously by two forces: the gravitational force of the earth and the centrifugal force created by the earth's rotation. Conceivably two masses of different composition might react differently to these two forces and produce a torque resulting in a slight rotation of the balance. By observing the balance in different orientations Eötvös verified that no significant rotation took place.

periments Eötvös used a version of the experimental arrangement, to be described later, that we have adopted in our Princeton study.)

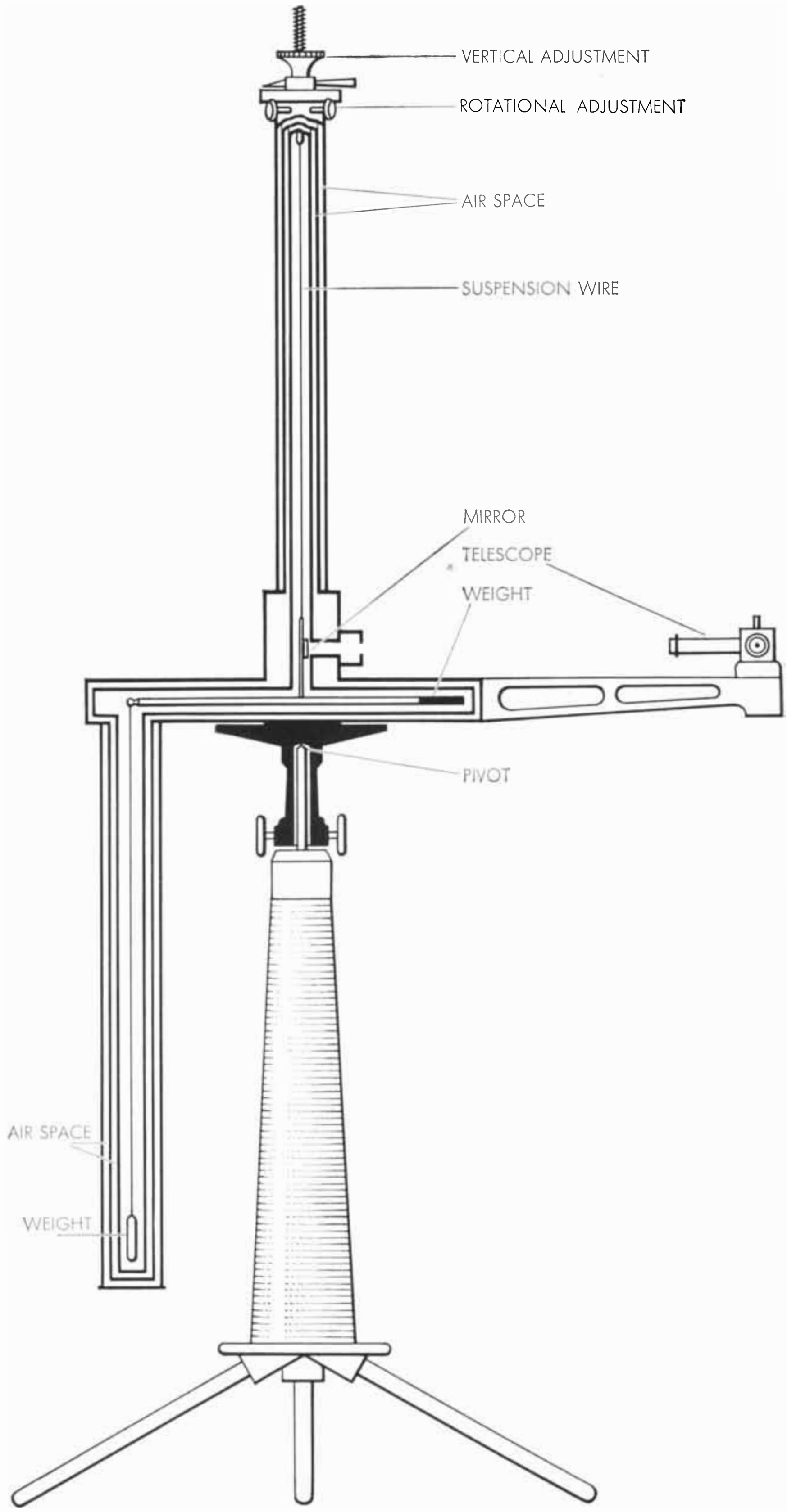
In order to duplicate Eötvös' accuracy by dropping weights in a tall vacuum chamber having a height equal to that of the Leaning Tower of Pisa, one would have to be able to time the fall of the weights with an accuracy of a hundred-millionth of a second.

It remained for Einstein to perceive a profound meaning in the constancy of gravitational acceleration. By coincidence his fresh insight dates from the very year—1908—in which Eötvös was carrying out his prize-winning experiments. Einstein reasoned that if substances of all kinds experience the same gravitational acceleration, then the acceleration could be regarded as characteristic of the physical space in which the matter is falling rather than of the matter itself.

Einstein proposed, therefore, that the gravitational acceleration be interpreted as a purely geometrical effect and that the trajectories of falling bodies be regarded as geometrical curves imposed on them by the "curvature" of space. Since a falling body moves in both space and time, its trajectory is defined by four variables, three of space and one of time. The resulting trajectory is a curve in four-dimensional space-time.

The curvature of a four-dimensional space-time can be most easily grasped by analogy with familiar two-dimensional surfaces. Whatever the shape of the surface, there is a way to connect two points with a shortest line or, more correctly, a line whose length is an "extremum." Such lines are defined as geodesics. On the earth geodesic lines yield the "great circle" courses followed by ships and aircraft—courses that usually look curved when drawn on flat maps. On a spherical surface a geodesic is formed by a plane that intersects the center of the sphere and the two points on the sphere that one wishes to connect.

In the Einstein view four-dimensional space is pictured as uncurved or Euclidean only in the absence of matter. The presence of a massive object such as the sun has the effect of warping the surrounding space in such a way that planets move around the sun on "natural" paths, which are geodesic lines for space of that particular curvature. The curved space around the sun or other star is merely a local fluctuation in the much gentler curvature produced by all the



EÖTVÖS APPARATUS consisted of a light horizontal beam suspended by a thin platinum-iridium wire. Attached to the beam were two weights, one suspended 20 centimeters below the other—an arrangement that only increased the difficulty of the experiment. Any small rotation of the beam could be observed by viewing a calibrated scale through a telescope.

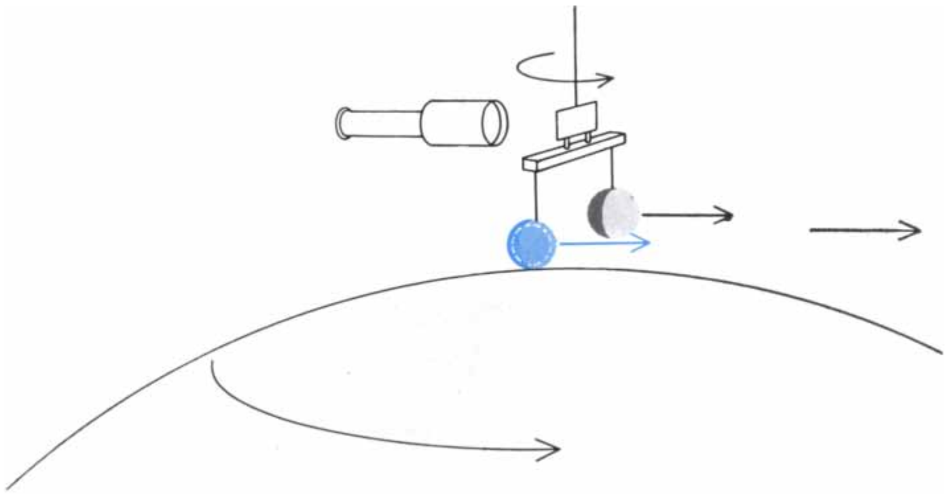
stars in a galaxy, and the curvature in the neighborhood of a galaxy is again a local fluctuation in the over-all curvature of the universe.

Einstein assumed that meter bars and clocks had such properties that they could be used to establish the same geodesic curves as those produced by the trajectories of freely falling bodies. It is implicit in this assumption that a platinum meter bar would hold the "same" length and an accurate clock would keep the "same" time no matter where they were placed in the universe. In modern examinations of distant objects the meter bar and clock are replaced by atomic measuring sticks and atomic clocks. If we follow Einstein, we assume that atoms in the remotest galaxy are of the same size and radiate light at the same frequencies as atoms on the earth or in the sun. This assumption of Einstein's is in effect a definition of the units of length and time everywhere in the universe, and so long as the definition is unambiguous there is much to be said for its adoption.

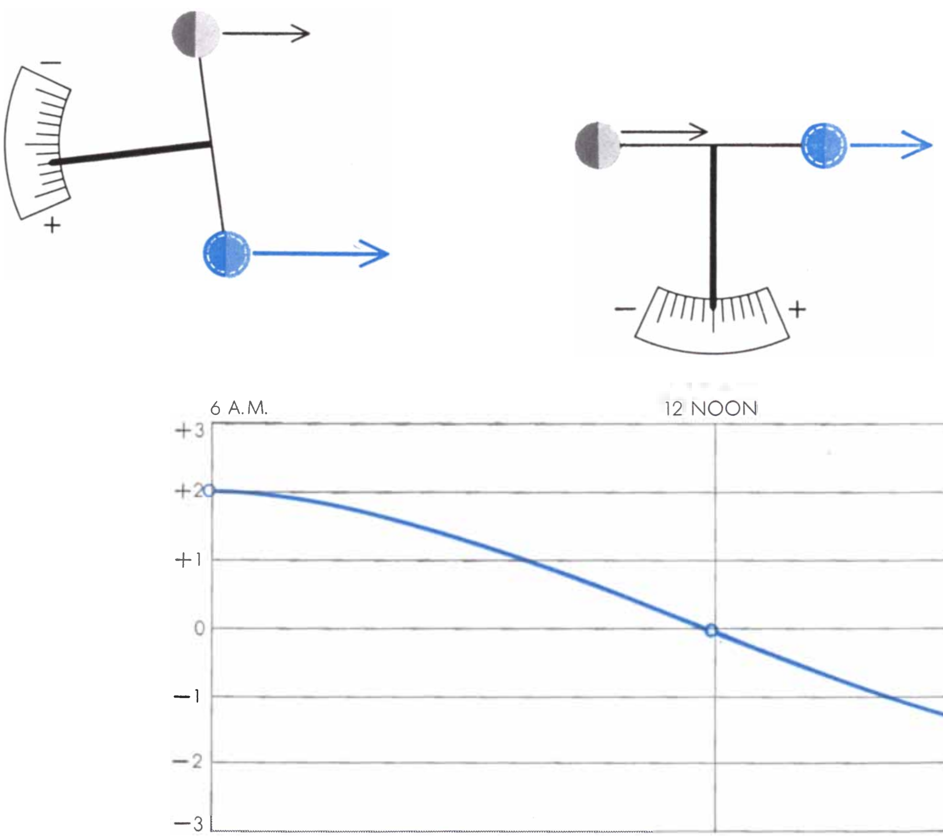
Unfortunately there is always room for ambiguity to creep in. For example, the unit of length could be taken as the diameter of the hydrogen atom, radius of the helium nucleus, wavelength of the electron or perhaps as the "gravitational radius" of an elementary particle. This last value can be defined as the radius of an electrically charged elementary particle considered to be gravitationally held together against the electrical forces tending to disrupt it. It is a very small number, about 10^{-33} centimeter. If the ratios of these various lengths to one another should vary at different space-time points in the universe, we would be perplexed as to which should be a standard measure. Each of the possible choices would lead to a different geometrical picture of space.

The consequences of ambiguity in selection of standards of length and time can be illustrated by a simple example. Let us imagine a surface inhabited by two races of men, the Flatlanders and the Roundlanders. The Roundlanders note that they and the Flatlanders are the same size only when they are at one particular point on the surface. As the Flatlanders move away from that point in any direction they are affected (so the Roundlanders think) by some mysterious field of force that makes them grow smaller and smaller. To the Flatlanders, who of course sense no change in their own size, the Roundlanders seem to grow steadily taller as they move away from the same point. The matter is made the more puzzling because each race can show that its own size remains constant as measured by its own yardsticks.

What happens, then, when each surveys the surface and plots geodesic lines? When the Roundlanders connect three points by geodesic lines, they find that the angles of the resultant triangle add up to more than 180 degrees; they conclude from this that they are living on a spherical surface [*see top illustration on page 92*]. The departure from 180 degrees enables them to compute the diameter of the spherical surface on which they live.



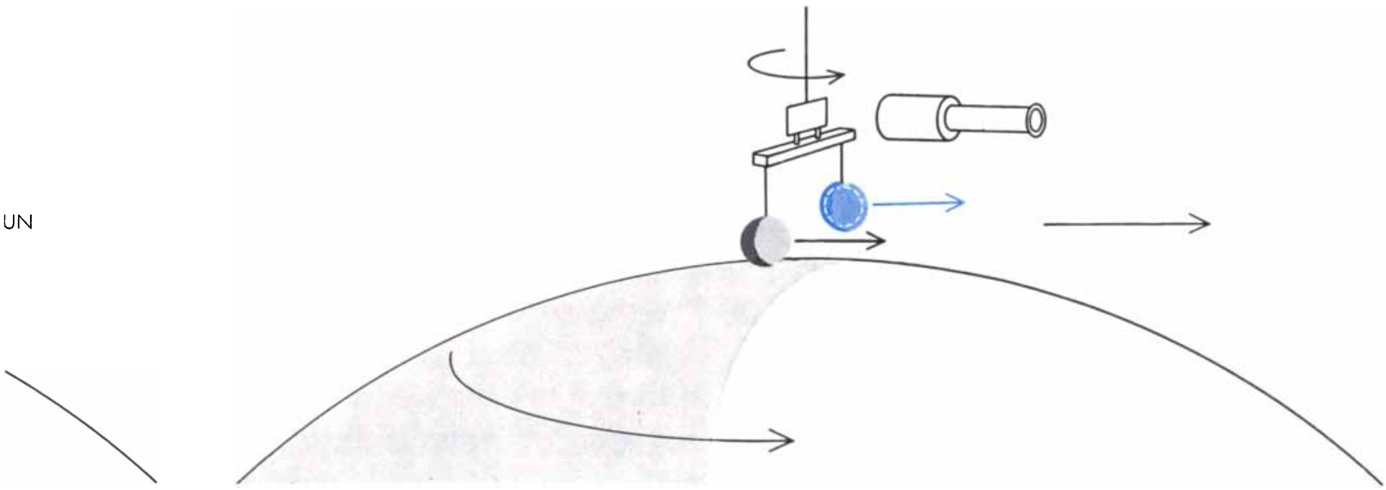
NEW TEST OF GRAVITATION, being conducted at Princeton University, attempts to learn whether or not there is any discrepancy in the rate at which masses of different composition fall toward the sun. In the idealized form of the experiment diagramed, two weights are suspended at the North Pole and revolve with the earth as it turns on its axis. At



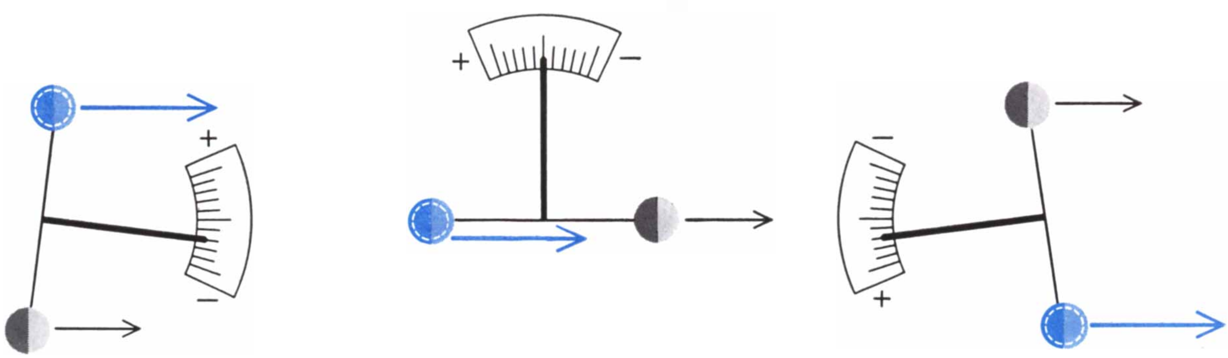
HYPOTHETICAL POSITIVE RESULT of the author's experiment would lead to the asymmetry diagramed. The suspended weights, as viewed from above, are carried around in a full circle every 24 hours by the earth's rotation. If both weights experience the same

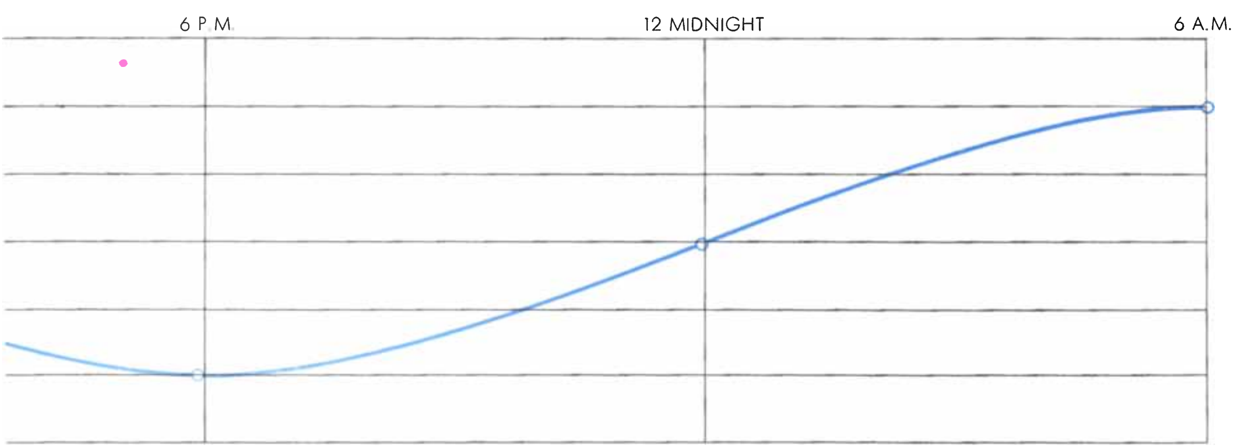
When the Flatlanders connect the same three points with geodesic lines, using their own yardsticks, they obtain a very different sort of triangle [*see bottom illustration on page 92*]. Observing that the angles of this triangle do add up to 180 degrees, the Flatlanders conclude they are living on a flat surface. The lesson to be learned from this story is that there is no absolute way to determine which of several possible measuring sticks is fixed and unchanging, that any of the sets may be regarded as the standards of length and that the geometry of the measured surface depends on the selection that has been made.

The Eötvös experiment can tell us nothing directly about the suitability of our measuring sticks or clocks for confirming the geodesics traced out by fall-



"6 a.m." (*left*), when the beam is perpendicular to a line drawn to the sun, the colored weight is being carried toward the sun by the earth's rotation. Twelve hours later (*right*) the same weight is being carried away from the sun. As a consequence, if the colored weight should tend to fall toward the sun faster than the other, it will alternately make the beam rotate slightly faster than the earth for 12 hours and then slightly slower for the next 12 hours. This hypothetical positive result is illustrated below.





gravitational acceleration toward the sun, their rate of rotation will be absolutely uniform. If, however, one weight (*color*) should tend to fall slightly faster, it would speed up the rotation rate while it was being carried toward the sun (*e.g., at "6 a.m."*) and slow it down while being carried away from the sun (*e.g., at "6 p.m."*). In actual fact, no asymmetry has been observed in the rotation.

ing bodies in their movement through space. Indirect arguments based on the experiment, however, can be used to show that at least some of the units of length and time derived from the atom are suitable for this purpose. The arguments used are general and powerful, but, like all powerful medicines, there is some small danger that although they are strong they are also wrong.

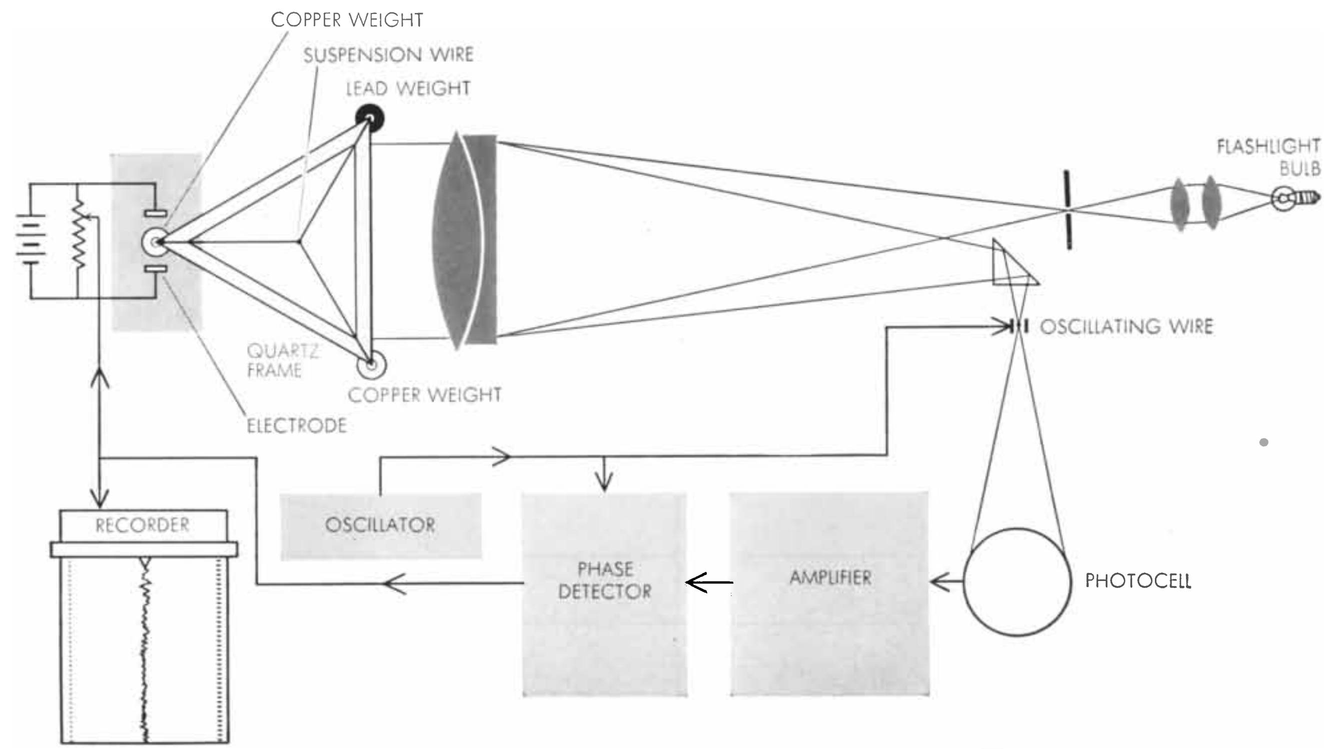
One argument is based on the following hypothetical situation. Suppose we carefully fabricate two objects from different materials to serve as standards of mass. In order to ascertain that they have the same mass we do not weigh them (since we want to avoid, for the present, a measurement dependent on gravitation) but we determine their inertial mass by accelerating them with a force of standard strength. We add or remove material until both masses reach the same velocity when accelerated by the same force. We can then say that both have the same inertial mass. Let us then raise the two bodies to a new position—say to the top of a building—and again compare their masses by acceleration. Now, to continue the hypothesis, let us imagine that the inertial masses are no longer equal; one has increased.

Inasmuch as mass and energy are equivalent, we conclude that for one body to have gained mass it must have gained internal energy. Indeed, we know that even a small change in mass represents an enormous amount of energy. This implies in turn that a certain amount of work had to be done on the body, either by the person who carried it to a higher position or by some external field of force (other than gravitational), which put energy into the body while it was being raised. If the work were provided by the person, he would sense that the body felt anomalously heavy. As a direct result of this extra gravitational pull the body would fall anomalously fast if allowed to drop. If, on the other hand, the work were provided by some mysterious new field of force capable of putting energy into the body as it was being raised, the person carrying it might not be able to sense a gain in weight. Moreover, in this case there need not be an anomalous increase in gravitational acceleration when the body is allowed to fall freely. The force field that had put energy into the body when it was being raised would remove it just as surreptitiously when it was falling.

The best evidence that the first of these strange events cannot take place is just the sort of experiment performed by Eötvös. At least within the regions of space occupied by the earth in circling the sun, the null result of the Eötvös experiment assures us that gravitational accelerations are very nearly constant, regardless of the composition of the object, and that only extremely tiny changes in inertial mass with height are possible. As for the possibility of a mysterious new force field, that has its own troubles. For such a field to act without being detected by an Eötvös experiment it would have to have precisely the right strength for particles bound in all sorts of configurations.

Thus from the Eötvös experiment it seems reasonable to infer that any ordinary measuring stick or clock, including atomic ones, is a suitable unit for determining the geometry of space. This is what was meant by saying that the arguments based on the Eötvös experiment are powerful.

On the other hand, one can suggest perfectly good clocks that are not necessarily suitable for checking the geometry of space. One example of such a clock would be the orbital period of a satellite moving about an astronomical body. If



THE PRINCETON APPARATUS uses an electrooptical system to monitor and record any slight rotation in the suspended triangle, whether due to gravitation or some other disturbing force. One leg of the triangle is silvered so that it serves as a mirror in the optical system. A slit placed in the beam of a flashlight bulb is reflected by the mirror and is brought to a focus on a wire oscillating at 3,000 cycles per second. Because of this oscillation the intensity of the light striking the photocell varies with time. If the mirror turns slightly, the signal from the photocell changes and gives rise to a direct-current voltage, which, applied to the electrodes, exerts a restoring force on one of the copper weights. The magnitude of this force is logged continuously on a strip recorder.

for any reason over a stretch of time the strength of the gravitational interaction (the gravitational coupling constant) were to weaken, the period of the satellite would lengthen accordingly. Such a change in the gravitational constant would have no measurable effect on an atomic clock.

As it happens, it is precisely the constancy of the gravitational interaction that might most be questioned on theoretical grounds. It seems strange that the gravitational interaction is so excessively weak when compared with the electrical and nuclear forces. The gravitational interaction between the electron and the proton in a hydrogen atom is only about 10^{-40} (the fraction $1/10^{40}$) of the strength of the electrical interaction between the two particles. Is such a curious number as 10^{-40} to be regarded as totally unrelated to other dimensionless numbers obtained from nature?

During the 1920's the English astronomer Sir Arthur Eddington tried, with debatable success, to show that 10^{-40} could be derived from a complex theory. In 1938 the English physicist P. A. M. Dirac pointed out that the age of the universe deduced from the recession rate of the galaxies can be expressed as a number whose magnitude is roughly 10^{40}—a number obtained by expressing 10 billion years in units based on the length of time required for light to travel the diameter of an atomic nucleus. Noting also that the universe out to its visible limits seems to contain about 10^{80} atoms, Dirac perceived that 10^{40} divided by 10^{80} yields 10^{-40}. He suggests that as the universe grows older all three numbers would change in such a way as to make the gravitational value grow weaker, being inversely proportional to the age of the universe.

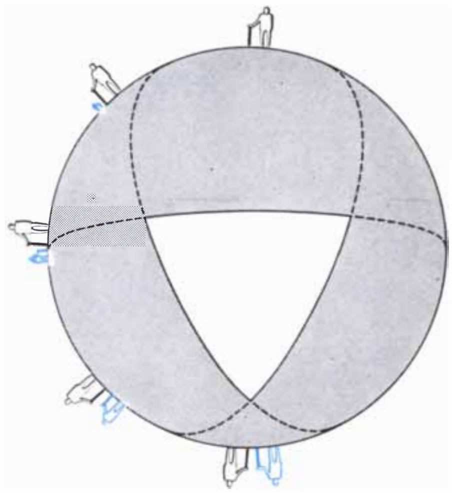
More recently certain apparent difficulties with the general theory of relativity having their origin in the concept of inertia have been traced to the assumption of a constant gravitational interaction. Carl Brans and I have proposed a modification of the general theory, similar to one proposed by the German physicist Pascual Jordan some years ago, that is capable of treating inertial forces in a way consistent with what is called Mach's principle. (According to one interpretation, this principle states that the inertial forces that act on objects in an accelerated laboratory—such as a laboratory on the earth—may be considered as gravitational forces generated by distant matter in the universe [see "Inertia," by Dennis Sciama; SCIENTIFIC AMERICAN, February, 1957]. In our modification the gravitational interaction is a variable quantity. An Eötvös type of experiment can shed no light on such a deep-seated issue. The reason is that the gravitational force tending to hold the small masses of an Eötvös apparatus together are so extremely weak that the strength of the gravitational interaction could change appreciably from one location to another without producing anomalous accelerations that could be detected.

But even granting this limitation, it seemed important to us that the Eötvös experiment should be repeated. For the past two years Robert V. Krotkov, Peter Roll, Barry Block, David Curott and I have been attempting to improve on the old result using a new apparatus at Princeton. We have been impressed by how difficult it is to achieve accuracies on the order of a few parts in a billion.

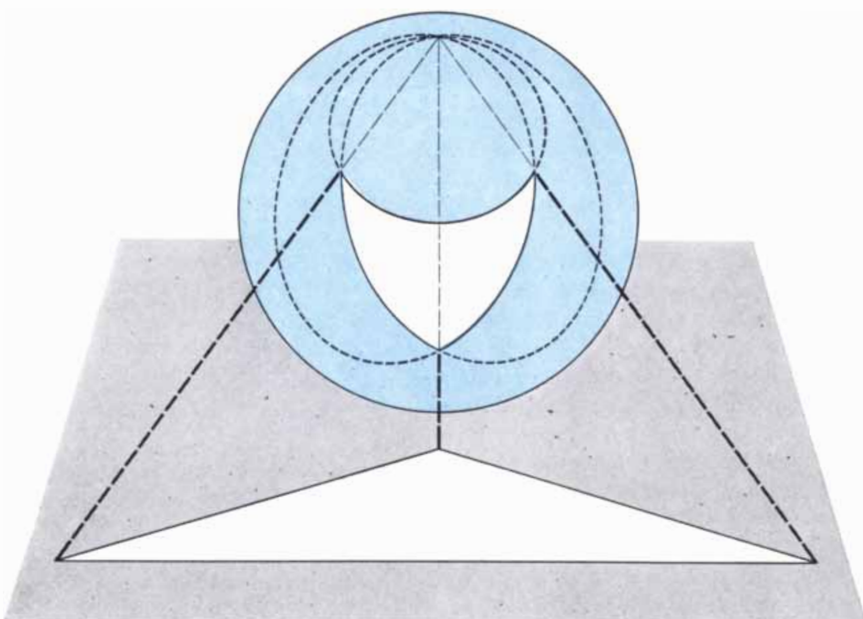
To begin with, we have redesigned the experiment so that it contains its own built-in control measurement. In most of his work Eötvös compared the centrifugal acceleration created by the earth's rotation with the earth's gravitational acceleration. Because neither acceleration can be turned off, such an experiment is not a controlled one. In contrast, our experiment depends on the acceleration of the earth—and earthbound objects—toward the sun. What we do, in principle, is to suspend two weights on a beam so they fall freely toward the sun. Since the rotation of the earth on its axis causes the beam to turn through 360 degrees every 24 hours, any hypothetical difference in gravitational acceleration experienced by the two weights would show up as an oscillation of the beam with a 24-hour period [*see illustrations on pages 88 and 89*].

In addition we have designed a wholly new type of apparatus. In the Eötvös instrument one weight hangs lower than the other. This serves no useful purpose and only makes the device sensitive to gravitational gradients. We were also rather startled to discover that if one pictures a hypothetical Baron von Eötvös seated at his apparatus, the calculated gravitational disturbance of the torsion balance created by the Baron's mass is at least 200 times his quoted probable error. Since he did not even mention this effect, we have no way of knowing how it was overcome. We assume that he must have stayed away from his instrument until it had come to rest and then moved in quickly to read the scale position before the instrument had time to respond to the disturbing force.

In the Princeton apparatus the sensitivity to gravitational gradients is reduced in three ways. First, the weights are all at the same height. Second, instead of two weights, there are three suspended from the corners of an equilateral triangle; all the weights are about the same mass and two of the three are the same material. (Two are copper, the third is lead chloride.) This configuration of weights is highly insensitive to gravitational gradients. The third improvement, which further minimizes gradients, is to make the triangle small—about five centimeters on a side.



GEODESICS DRAWN BY ROUNDLANDERS lead them to believe they dwell on a spherical surface. Among other things they note that when they connect three points with shortest lines (geodesics), the angles of the resulting triangle add up to more than 180 degrees. The Roundlanders (*black figures*) and their yardsticks are shown here to be of uniform size. Flatlanders (*colored figures*), who dwell on the same surface, are believed by the Roundlanders to grow smaller as they move away from what Roundlanders regard as their South Pole. The triangle that results when Flatlanders draw geodesics is shown below.



GEODESICS DRAWN BY FLATLANDERS lead them to believe they dwell on a flat surface. They believe that as Roundlanders move away from a particular point on this surface they grow mysteriously larger. When Flatlanders draw a triangle with their geodesics, its angles add up to exactly 180 degrees. They could obtain this result even on a spherical surface if they and their yardsticks were to grow smaller and smaller as they approached one of the poles. Geodesic curves drawn with such elastic yardsticks would be defined by planes passing through that "vanishing" pole and the two points to be connected. However, if a triangle formed by these geodesics were projected onto a flat surface, it would have a normal appearance—and Flatlanders similarly projected would be everywhere the same size.

Our next concern was to reduce the instrument's sensitivity to temperature. In order to reduce temperature gradients Eötvös placed a triple shell of metal around the chamber containing the torsion balance. The chamber itself, however, was filled with air at standard pressure, and one would expect this to produce slow convection currents even if the temperature difference in different parts of the apparatus were virtually unmeasurable.

Convection difficulties can be eliminated by reducing the pressure of the air in the chamber. But then a new thermal problem arises: in a partial vacuum air molecules can travel relatively long distances without striking other molecules. As a consequence, moving molecules can create a "wind" pressure when those leaving a warm surface are traveling faster than those leaving a cooler one. For example, one can calculate that even if the air pressure had been reduced to 10^{-2} millimeter of mercury (or 10^{-5} atmosphere), a temperature difference of a millionth of a degree between walls on opposite sides of the weights would create air movements sufficient to spoil the accuracy claimed by Eötvös for his experiment.

In our own experiment we have not only employed multiple-wall thermal radiation shields but have also sealed the freely suspended parts of the apparatus in a high vacuum. The first experiments were run at a pressure of about 10^{-6} millimeter of mercury. In the latest version of the vacuum chamber we hope to maintain a pressure of less than 10^{-8} millimeter for months at a time. In addition to minimizing disturbances due to gas streaming, high-vacuum operation minimizes the random disturbances of the weights resulting from bombardment by individual gas molecules.

Still another source of difficulty, familiar to Eötvös, is magnetic contamination of the moving parts of the apparatus. Even small magnetic impurities will result in sizable torques produced by the earth's magnetic field. If one of the suspended weights in Eötvös' apparatus contained a single strongly magnetized iron fragment weighing only a few millionths of a gram, it would produce a deflection in the balance 1,000 times greater than the probable error given by Eötvös. He says that he overcame such troubles by canceling the earth's magnetic field, but he does not explain in detail how he did it or what criteria he used to determine when the field was canceled.

In our experiment it is only the diurnal variations in the magnetic field that are troublesome, not the total field, so magnetic contamination is less of a problem for us than for Eötvös. It was largely because of the magnetic problem, nevertheless, that we made two of our weights of copper, believing that in electrolytically refined metal the magnetic contamination would be negligible. Unfortunately this proved not to be so. We found, however, that by proper heat-treating, the contaminants could be put into solid solution and made harmless.

An atom of copper contains 29 protons and 34 neutrons, which is about as low a ratio of neutrons to protons as in any element except hydrogen. Since we wanted the third weight to have a high ratio of neutrons to protons we selected lead, in which the ratio is 125 to 82. We are using not the metal itself but lead chloride, because this compound can be highly refined by repeated crystallization. As a final precaution we have installed two sensitive magnetometers next to our apparatus to monitor continuously the two horizontal components of the earth's magnetic field. From these records we can, if necessary, determine the magnitude of torques produced by magnetic disturbances.

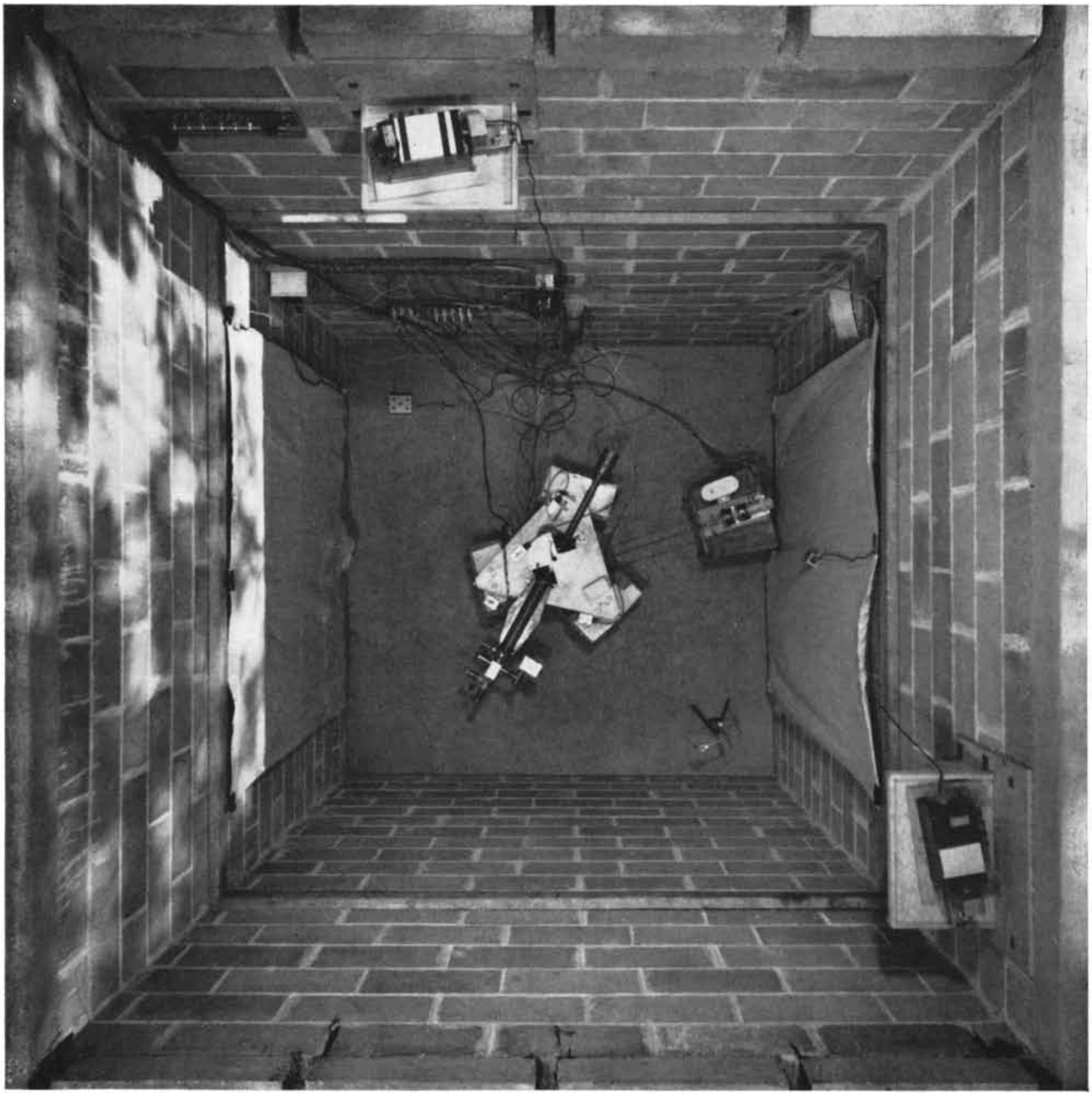
The ultimate limitation on the experiment as performed by Eötvös was optical diffraction in the telescope he used to read the scale on his instrument. The probable error given by Eötvös and his colleagues corresponds to a 200th of the smallest scale division, and this represents, in turn, a 40th of the full width of the diffraction pattern of his telescope. This represents an accuracy for a single reading of a 20th of a scale division.

In our apparatus the human observer is eliminated and with him the possibility, which is not to be ignored, of personal bias. A combined electrooptical system continuously monitors the rotation angle of the suspended triangle and is able to determine (over an observation period of 10 seconds) any rotation amounting to about 10^{-7} degree of arc. One of the three weights is suspended between two electrodes, by means of which a very small torque can be applied electrically to cancel any rotation that is detected. In other words, a feedback control system prevents the apparatus from rotating, and the torque required for this purpose is registered on a continuous recorder. The artificial damping provided by this system would be essential in any case, because there is no air around the balance to provide natural damping.

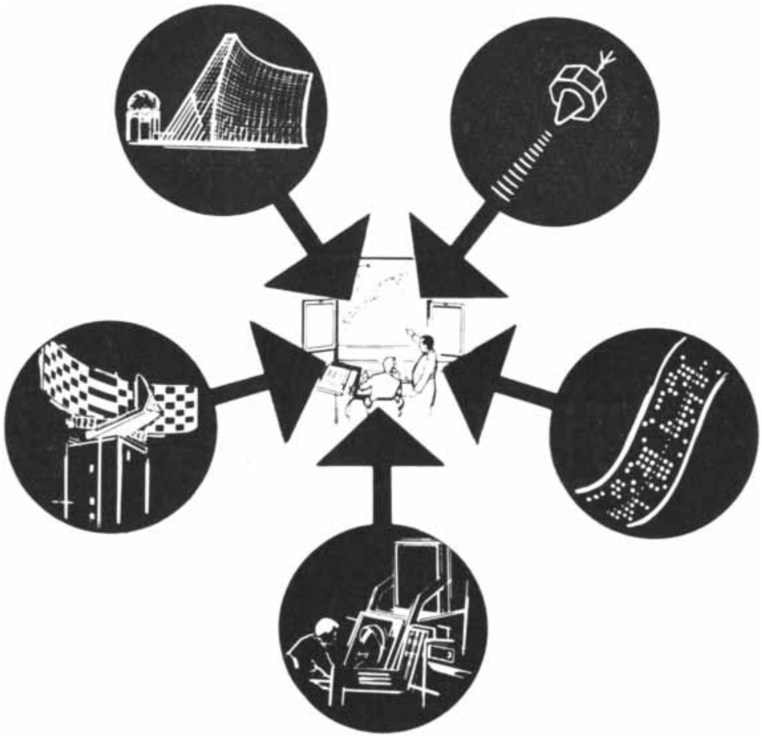
The whole apparatus is mounted at the bottom of a pit 12 feet deep not far from the Princeton football stadium. When an experiment is in progress, the top of the pit is sealed by a four-foot plug of thermal insulation.

In an experiment lasting several months, whose results were analyzed this past summer, we found no significant rotation of the suspended weights. Surprisingly, with all our modern techniques we have been able to improve on the accuracy of the Eötvös results only by a factor of 50. With an accuracy of about one part in 10^{10} we can say that the gravitational acceleration of lead and copper are equal. We hope that in a new run, soon to be started, we can extend this accuracy by another factor of 10.

Contemplating all the potential sources of error besetting such an experiment—gravitational gradients, thermal and magnetic disturbances and optical limitations—it seems almost incredible that Eötvös could have achieved the accuracy he claimed. Still, it would be a mistake, and uncharitable as well, to underestimate the technical skill that a dedicated investigator can develop through years of experience with familiar pieces of apparatus. The new experiment might have shown Eötvös to be in error, and it has not.



EXPERIMENTAL CHAMBER for the author's gravity investigation is a solidly constructed pit 12 feet deep, not far from the Princeton football stadium. The torsion balance, within its vacuum housing (all within a second chamber), rests on the center of triangular base at the bottom of the pit. The long tube projecting toward the lower left of the photograph is a telescope; the tube directly opposite is a counterweight. The whole apparatus can be rotated. The electric blankets on the walls were used to test the temperature sensitivity of the equipment. When the experiment itself is in progress, the top of the pit is sealed by four feet of thermal insulation.



The Three-dimensional Structure of a Protein Molecule

The way in which the chain of amino acid units in a protein molecule is coiled and folded in space has been worked out for the first time. The protein is myoglobin, the molecule of which contains 2,600 atoms

by John C. Kendrew

When the early explorers of America made their first landfall, they had the unforgettable experience of glimpsing a New World that no European had seen before them. Moments such as this—first visions of new worlds—are one of the main attractions of exploration. From time to time scientists are privileged to share excitements of the same kind. Such a moment arrived for my colleagues and me one Sunday morning in 1957, when we looked at something no one before us had seen: a three-dimensional picture of a protein molecule in all its complexity. This first picture was a crude one, and two years later we had an almost equally exciting experience, extending over many days that were spent feeding data to a fast computing machine, of building up by degrees a far sharper picture of this same molecule. The protein was myoglobin, and our new picture was sharp enough to enable us to deduce the actual arrangement in space of nearly all of its 2,600 atoms.

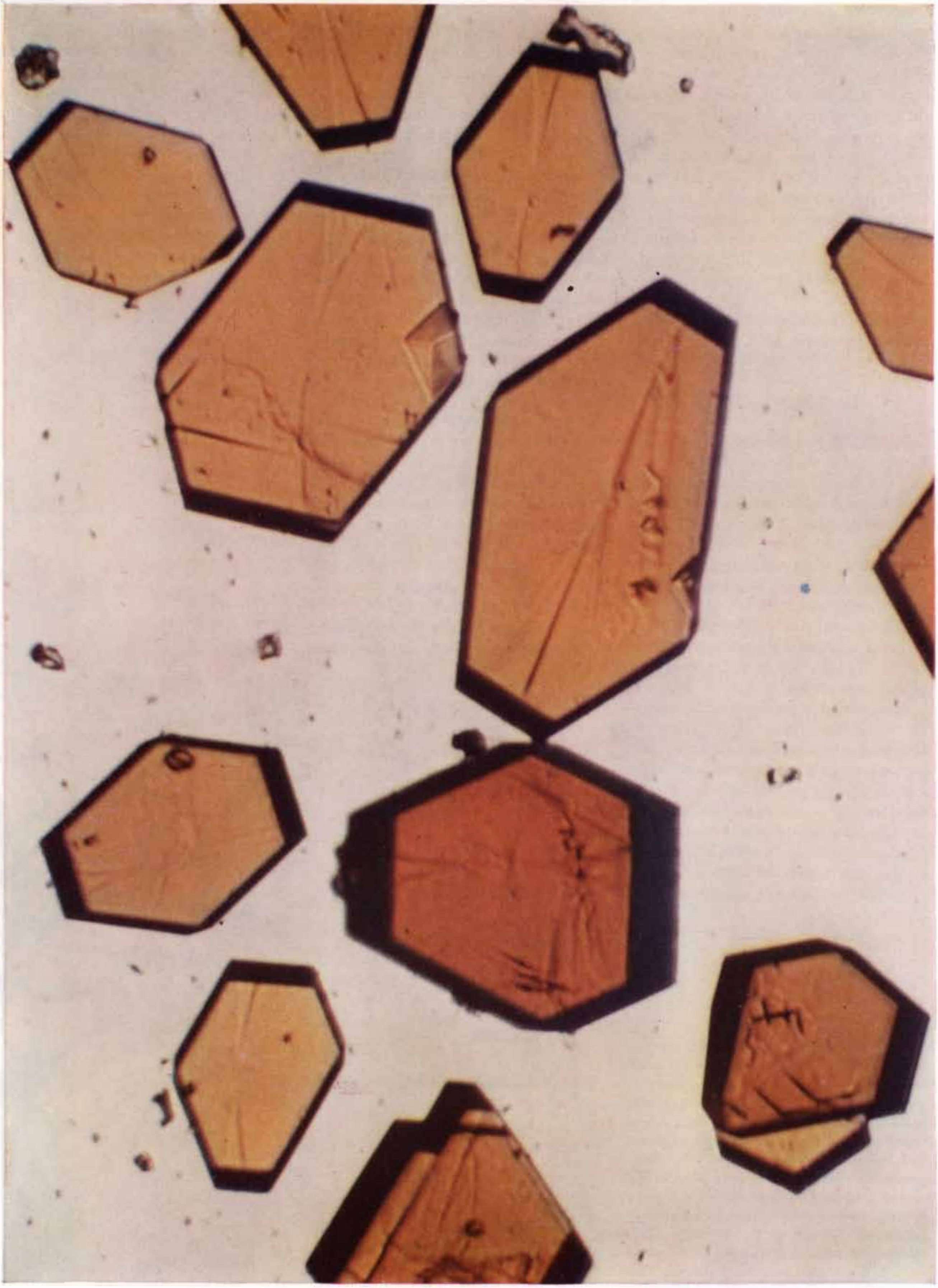
We had chosen myoglobin for our first attempt because, complex though it is, it is one of the smallest and presumably the simplest of protein molecules, some of which are 10 or even 100 times larger. The purpose of this article is to indicate some of the reasons why we thought it important to elucidate the three-dimensional architecture of a protein, to explain something of the methods we used and to describe our results.

In a real sense proteins are the "works" of living cells. Almost all chemical reactions that take place in cells are catalyzed by enzymes, and all known enzymes are proteins; an individual cell contains perhaps 1,000 different kinds of enzyme, each catalyzing a different and specific reaction. Proteins have many other important functions, being constituents of bone, muscle and tendon, of blood, of hair and skin and membranes. In addition to all this it is now evident that the hereditary information, transmitted from generation to generation in the nucleic acid of the chromosomes, finds its expression in the characteristic types of protein molecule synthesized by each cell. Clearly to understand the behavior of a living cell it is necessary first to find out how so wide a variety of functions can be assumed by molecules all made up for the most part of the same few basic units.

These units are amino acids, about 20 in number, joined together to form the long molecular chains known as polypeptides. Each link in a chain consists of the group –CO–CHR–NH–, where C, O, N and H represent atoms of carbon, oxygen, nitrogen and hydrogen respectively, and R represents any of the various groups of atoms in a side chain that differs for each of the 20 amino acids. All protein molecules contain polypeptide chains, and some of them contain no other constituents; in others there is an additional group of a different kind. For example, the hemoglobin in red blood corpuscles contains four polypeptide chains and four so-called heme groups: flat assemblages of atoms with an iron atom at the center. The function of the heme group is to combine reversibly with a molecule of oxygen, which is then carried by the blood from the lungs to the tissues. Myoglobin is, as it were, a junior relative of hemoglobin, being a quarter its size and consisting of a single polypeptide chain of about 150 amino acid units together with a single heme group. Myoglobin is contained within the cells of the tissues, and it acts as a temporary storehouse for the oxygen brought by the hemoglobin in the blood.

Following the classic researches on the insulin molecule by Frederick Sanger at the University of Cambridge, several groups of investigators have been able to discover the order in which the amino acids are arranged in the polypeptide chains of a number of proteins [see "The Chemical Structure of Proteins," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, February]. This laborious task does not, however, provide the whole story. A polypeptide chain of perhaps hundreds of links could be arranged in space in an almost infinite number of ways. Chemical methods give only the order of the links; equally important is their arrangement in space, the way in which particular side chains form crosslinks to bind the whole structure together into a nearly spherical object (as most proteins are known to be). Also of equal importance is the way in which certain key amino acid units, perhaps lying far apart in the sequence, are brought together by the three-dimensional folding to form a particular constellation of precise configuration—the so-called active site of the molecule—that enables the protein to perform its special functions. How is it possible to discover the three-dimensional arrangement of a molecule as complicated as a protein?

The key to the problem is that many proteins can be persuaded to crystallize, and often their crystals are as regular and as nearly perfect in shape as the crystals of simpler compounds. The fact that pro-



CRYSTALS OF MYOGLOBIN prepared from sperm-whale muscle are enlarged some 50 diameters. In them the molecules of myoglobin are stacked in regular array. By directing a beam of X rays at a single crystal and analyzing the pattern of the reflected rays, the author and his colleagues were able to plot the density of electrons in the molecule and thereby to locate the atoms in it.

teins crystallize is interesting in itself, for crystallization implies a regular three-dimensional array of identical molecules. If all the molecules did not have the same detailed shape, they could not form the repeating arrays that are necessary if the aggregate is to possess the regular external shape of a crystal. Therefore it appears that all protein molecules of a given type are identical—that is, they are not simply "colloidal" aggregates of indefinite shape. The existence of protein crystals means, in fact, that proteins do have a definite three-dimensional structure to solve. And the most powerful techniques for studying the structures of crystals are those of X-ray crystallography.

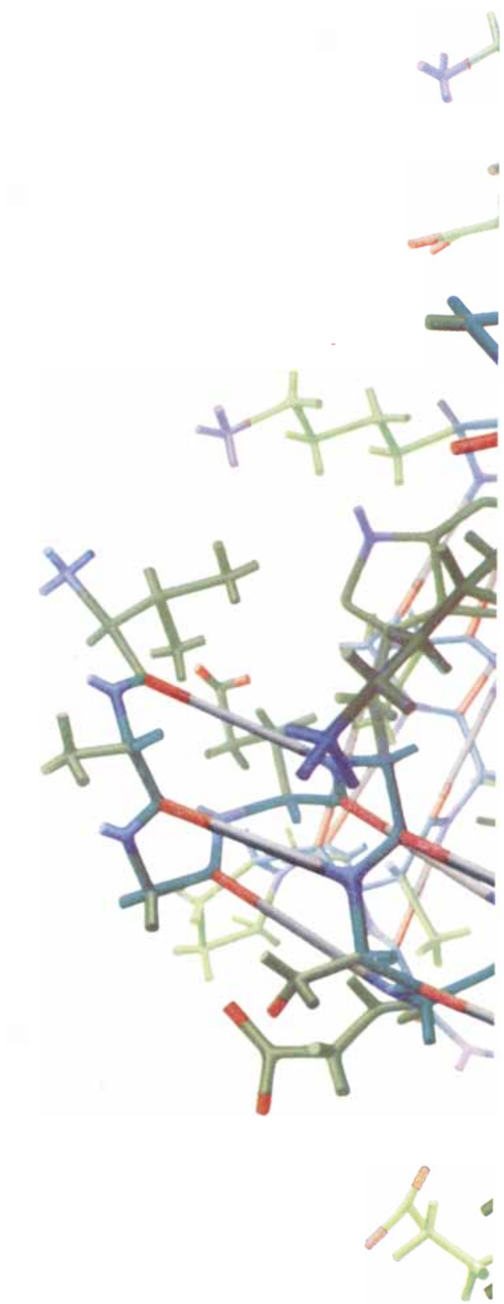
The X-Ray Approach

In 1912 Walter Friedrich, C. M. Paul Knipping and Max von Laue discovered that if a crystal is turned in various directions while a beam of X rays is sent through it, some of the X rays do not travel in a straight line. When the transmitted rays fall on a photographic plate, they produce not only a dark central spot but also a pattern of fainter spots around it. The reason for this diffraction pattern is that X rays are scattered, or reflected, by the electrons that form the outer part of each atom in the crystal.

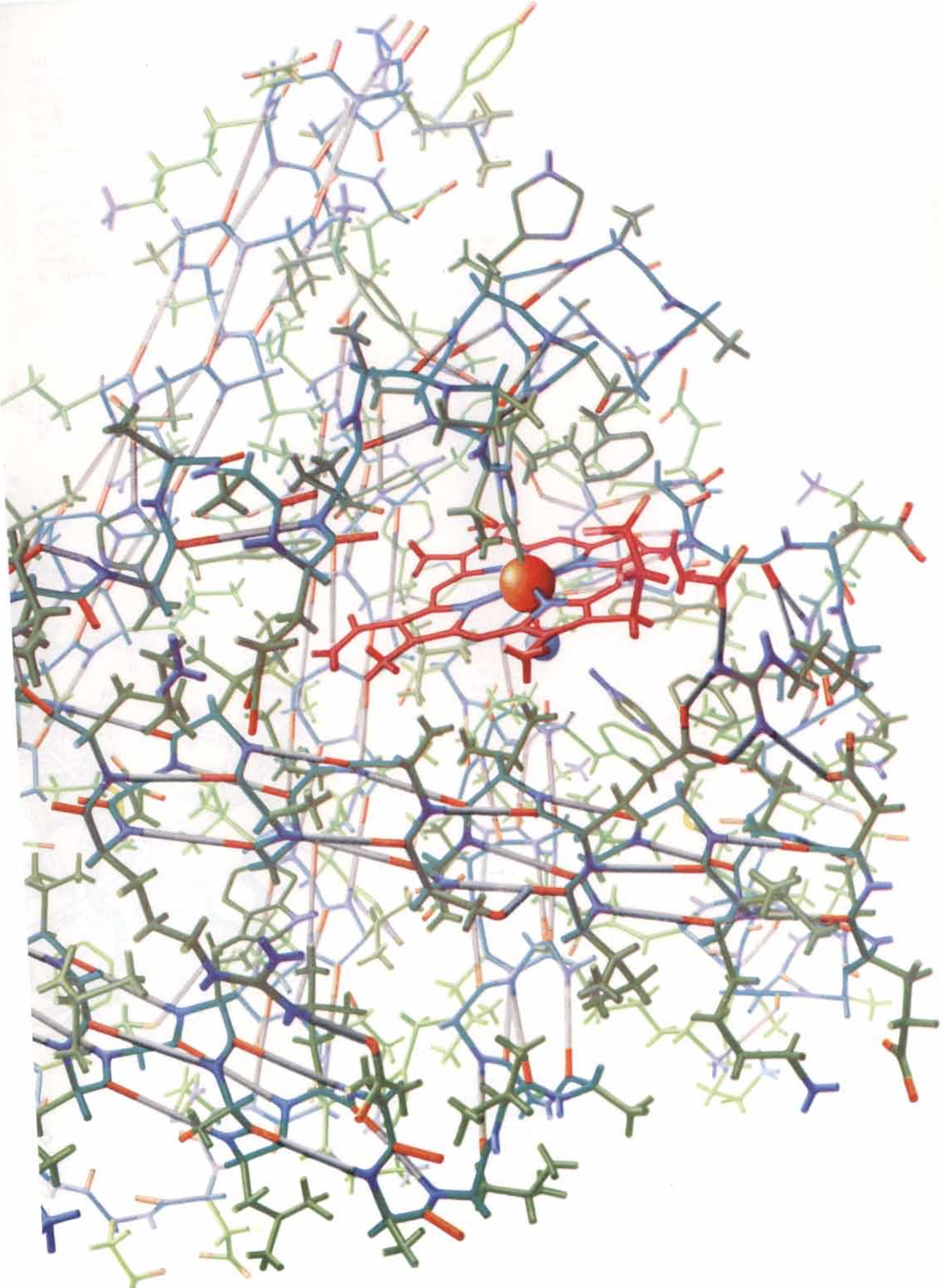
The atoms are arranged in an orderly array, something like the trees in a regularly planted orchard. As one drives past an orchard in an automobile and looks into it along different directions, one sees one set after another of lines of trees coming into view end on. Similarly, if one could look at the atoms of a crystal, one would see different planes of atoms in different directions. The X-ray beam is reflected by these sets of planes much as light is reflected from the surface of a mirror; that is to say, the angle of reflection is equal to the angle of incidence. But it can be shown that because the reflection is a set of parallel planes rather than a single surface, as in a mirror, the reflected beam will "flash up" only at a particular angle of incidence between incident beam and planes, this angle becoming greater the closer together the planes of the set are. Thus each spot in the X-ray diffraction pattern corresponds to a particular set of planes; and the spots farthest out in the pattern (those made by X rays diffracted through the biggest angles) correspond to the most closely spaced sets of planes. In an X-ray camera the crystal is rotated in a predetermined manner so that one after another of the sets of planes comes into the correct reflecting position. As each set does so, the corresponding reflected beam flashes up and makes its imprint on the photographic plate.

Each type of crystal has its own characteristic arrangement of atoms and so will produce its own specific X-ray pattern, the features of which can be unambiguously, if tediously, predicted by calculation if the structure of the crystal is known. X-ray analysis involves the reverse calculation: Given the X-ray pattern, what is the crystal structure that must have produced it?

In analyzing complex crystals the calculation is carried out by applying a method known as Fourier synthesis to the repeating, three-dimensional configuration. To understand what this involves, consider first a one-dimensional analogy: a musical note. Physically, a steady musical note is a repeating sequence of rarefactions and condensations in the air between the listener and the instrument producing the note. If the den-



THREE-DIMENSIONAL MODEL of the myoglobin molecule is depicted in this painting by Irving Geis. The key to the model is at the left side of the painting. The molecule consists of some 150 amino acid units strung together in a single chain with a heme group attached to it. At the center of the heme group is a single atom of iron. Most of the amino acid units are arranged in helical sections such as the one running diagonally across the bottom of the painting. Each amino acid unit in the model is identified in the illustration on the following two pages. The model is the result of work by the author, R. E. Dickerson, B. E. Strandberg, R. G. Hart, D. R. Davies, D. C. Phillips, V. C. Shore and H. C. Watson.



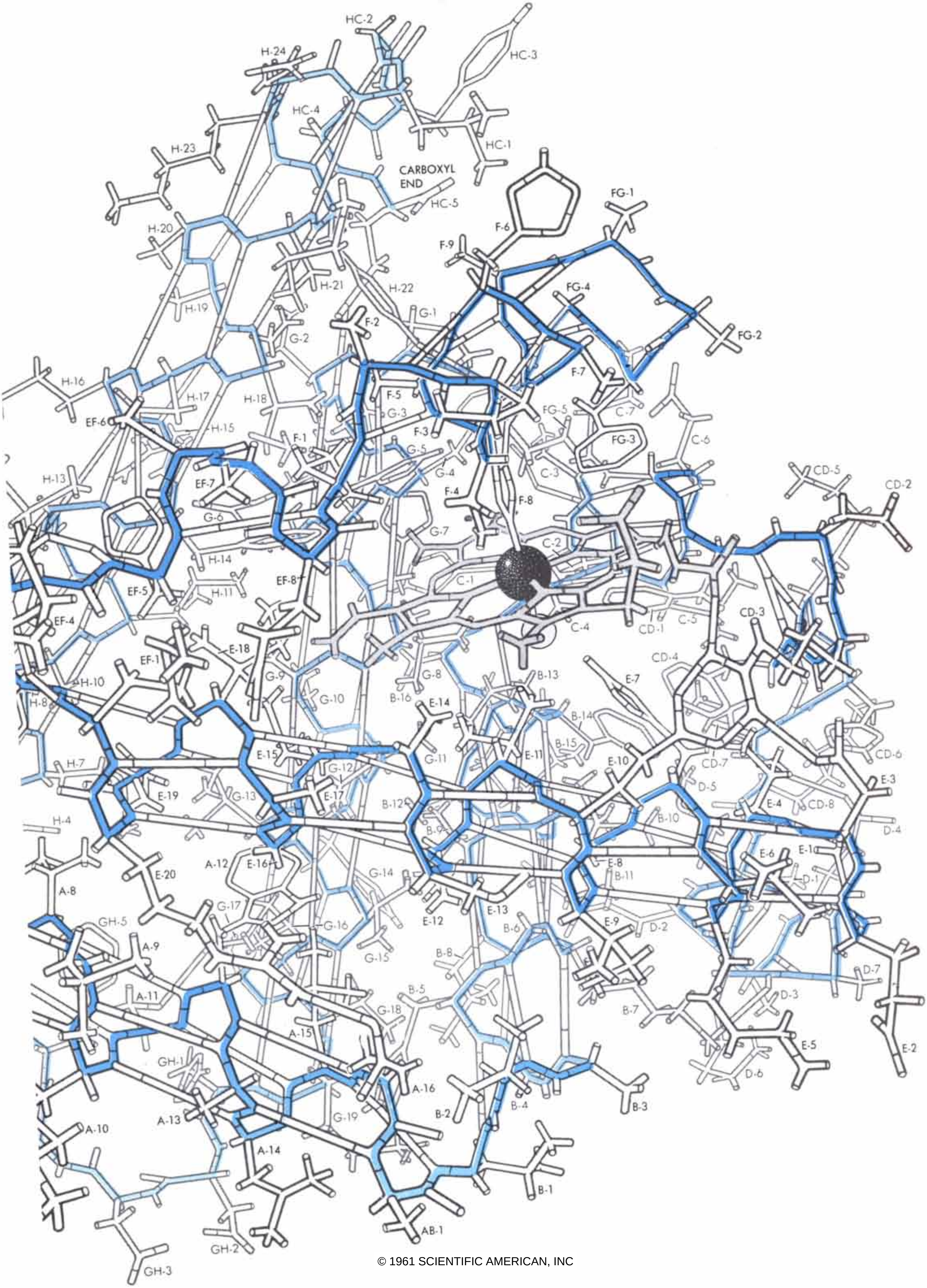
sity of the air is plotted along the path, the graph is a complex but perfectly repetitive wave form. More than 150 years ago the French physicist Jean Baptiste Fourier discovered that any such wave form can be decomposed, or analyzed, into a set of harmonics that are pure sine waves of shorter and shorter wavelength and thus of higher and higher frequency [see "The Reproduction of Sound," by Edward E. David, SCIENTIFIC AMERICAN, August]. The reverse process—Fourier synthesis—consists in combining a series of pure sine waves of the proper relative amplitude in the proper relative phases (that is, in or out of step with one another to the correct extent) so as to reproduce the original wave form, or note. In practice it is not necessary to use all the components to obtain a reasonably faithful reproduction. The greater the number of higher harmonics that are included, however, the more nearly perfect is the rendering of the note.

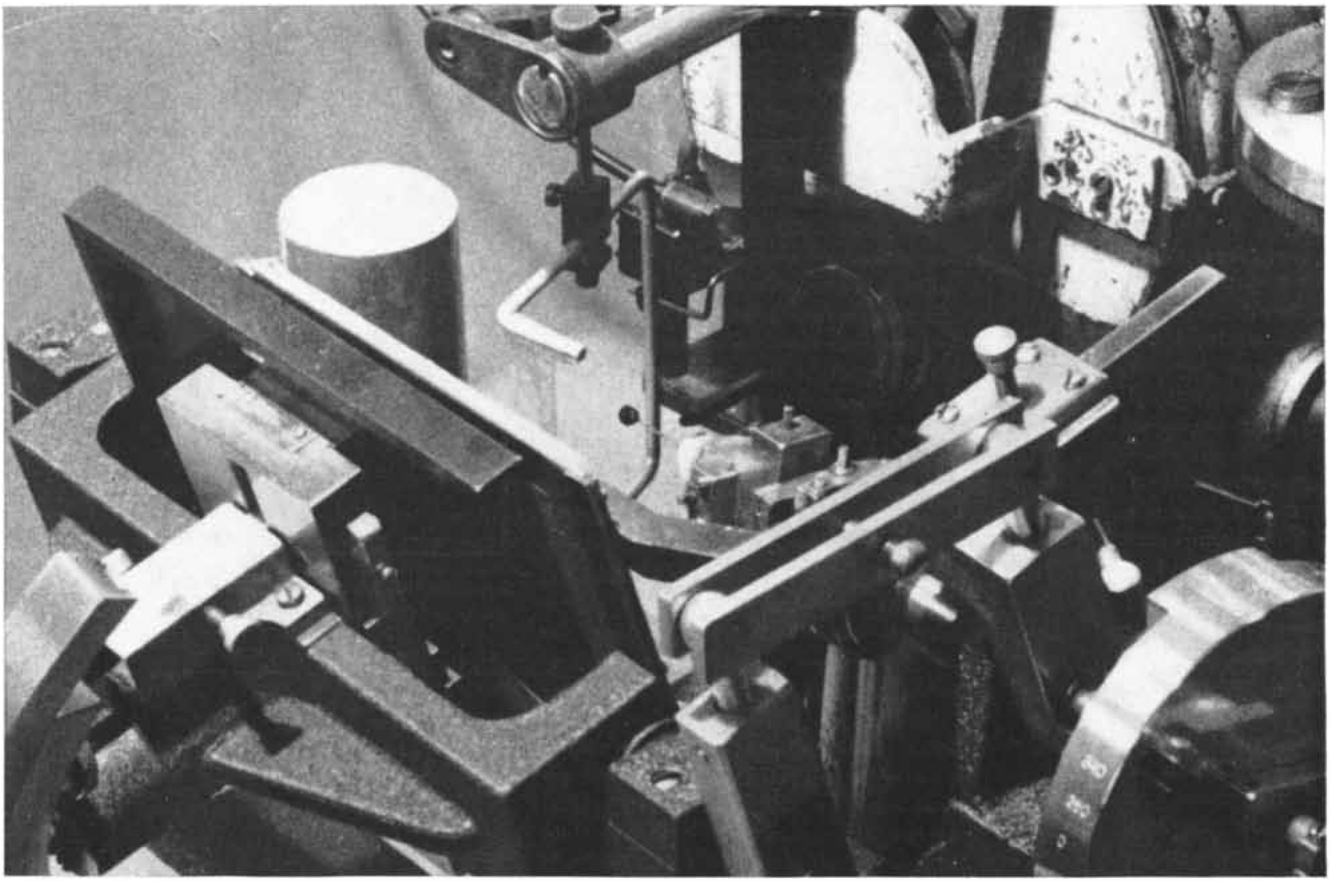
To an X-ray beam a crystal is an extended electron cloud, the density of

ALANINE	ALA
ARGININE	ARG
ASPARTIC ACID OR ASPARAGINE	ASP
GLUTAMIC ACID OR GLUTAMINE	GLU
GLUTAMIC ACID	GLU. C
GLYCINE	GLY
HISTIDINE	HIS
ISOLEUCINE	ILEU
LEUCINE	LEU
LYSINE	LYS
METHIONINE	MET
PHENYLALANINE	PHE
PROLINE	PRO
SERINE	SER
THREONINE	THR
TYROSINE	TYR
VALINE	VAL

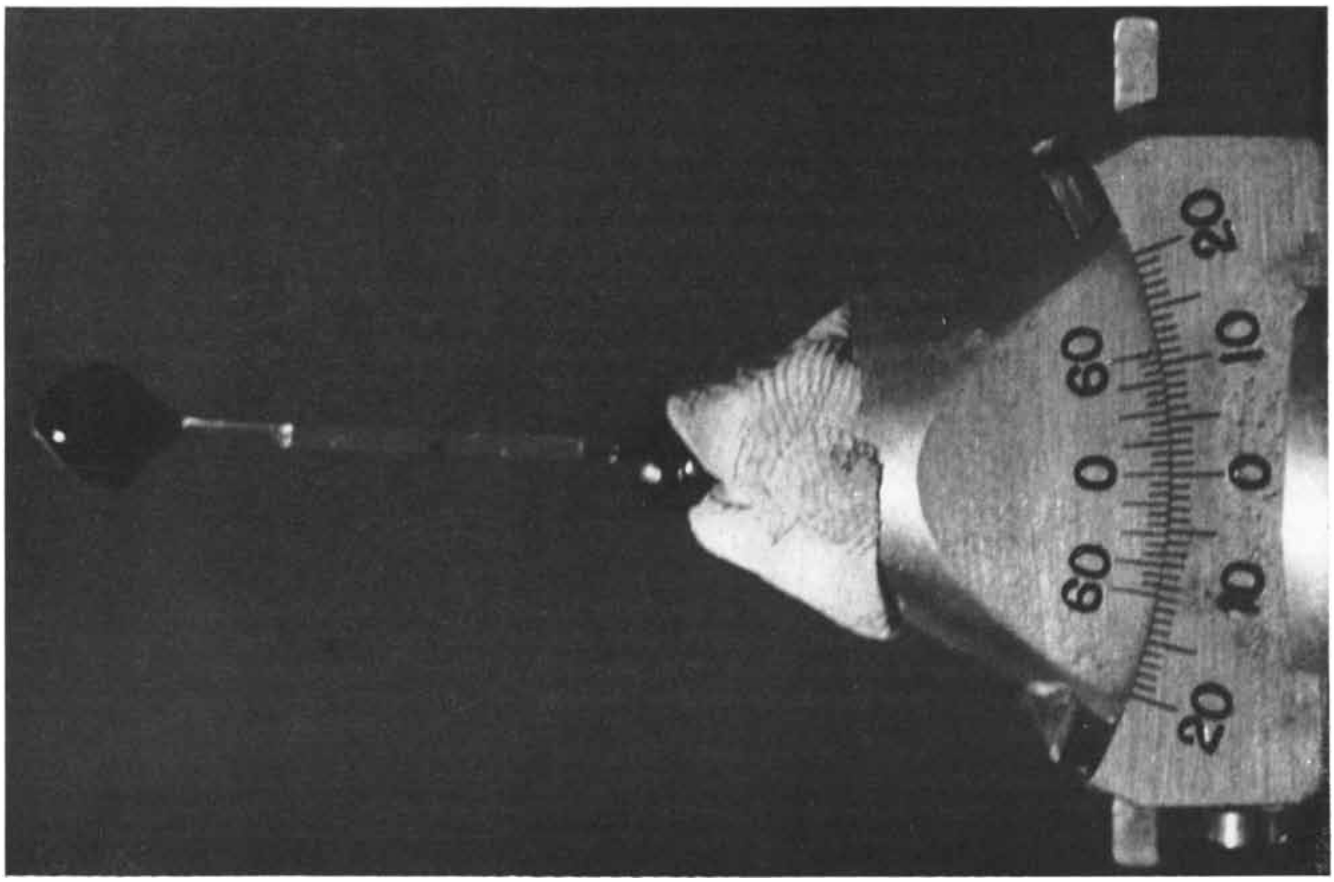
A- 1 VAL (AMINO END)
2 ALA
3 GLY
4 GLU
5 TRY
6 SER
7 GLU
8 ILEU
9 LEU
10 LYS
11 (NOT GLY)
12 TRY
13 (NOT GLY)
14 LEU
15 LEU
16 GLU
AB- 1 (NOT GLY)
B- 1 LEU
2 VAL OR THR
3 ALA
4 GLY
5 HIS
6 GLY
7 LYS
8 LEU
9 THR
10 LEU
11 ILEU
12 SER
13 LEU
14 PHE
15 LYS
16 SER
C- 1 HIS
2 PRO
3 GLU.C
4 THR
5 LEU
6 GLU
7 LYS
CD- 1 PHE
2 ASP
3 ARG
4 PHE
5 LYS
6 HIS
7 LEU
8 LYS
D- 1 THR
2 GLU.C
3 ALA
4 GLU.C
5 MET
6 LYS
7 ALA
E- 1 SER
2 GLU.C
3 ASP
4 LEU
5 LYS
6 VAL
7 HIS
8 GLY
9 ILEU
10 GLU
11 VAL
12 ASP
13 (NOT ALA, GLY)
14 ALA
15 LEU
16 GLY
17 ALA
18 ILEU
19 ASP
20 ARG
EF- 1 LYS
2 LYS
3 GLY
4 LEU
5 HIS
6 (NOT GLY)
7 (NOT GLY)
8 GLU
F- 1 GLU
2 ALA
3 PRO
4 THR
5 ALA
6 HIS
7 SER
8 HIS
9 ALA
FG- 1 (NOT GLY)
2 (NOT GLY)
3 PHE
4 (NOT ALA)
5 ILEU
G- 1 PRO
2 ILEU
3 LYS
4 TYR
5 (NOT ALA, GLY)
6 GLU
7 HIS
8 LEU
9 SER
10 (NOT GLY, ALA)
11 ALA
12 VAL OR THR
13 ILEU
14 HIS
15 VAL
16 ARG
17 ALA
18 THR
19 LYS
GH- 1 HIS
2 ASP
3 ASP
4 GLU
5 PHE
6 GLY
H- 1 ALA
2 PRO
3 ALA
4 ASP
5 GLY
6 ALA
7 MET
8 GLY
9 LYS
10 ALA
11 LEU
12 GLU.C
13 LEU
14 PHE
15 ARG
16 LYS
17 ASP.C
18 ILEU
19 ALA
20 ALA
21 LYS
22 TYR
23 LYS
24 GLU.C
HC- 1 LEU
2 GLY
3 TYR
4 GLY
5 GLU.C (CARBOXYL END)

SEQUENCE OF AMINO ACID UNITS in the model of myoglobin is indicated by the letters and numbers in the illustration on these two pages. The amino acid unit represented by each symbol is given in the table above; the key to the abbreviations is at top left in the table. The brackets in the table indicate those amino acid units which form a helical section. The direction of the main chain is traced in color in the illustration; the chain begins at far left (*amino end*) and ends near the top (*carboxyl end*). Here the heme group is indicated in gray. Not all the amino acid units in the model have been positively identified. In some cases it has only been determined that they cannot be certain units. The over-all configuration of the molecule, however, is known with a considerable degree of confidence.


HC-2
H-24
HC-3
HC-4
HC-1
H-23
CARBOXYL END
HC-5
FG-1
H-20
F-6
F-9
FG-4
H-21
H-22
H-19
G-1
F-2
G-2
FG-2
H-16
F-7
H-17
H-18
F-5
G-3
FG-5
C-7
EF-6
H-15
F-3
F-1
G-5
FG-3
C-6
H-13
EF-7
G-4
C-3
CD-5
F-4
CD-2
F-8
G-6
G-7
C-2
H-14
EF-8
C-1
EF-5
H-11
CD-3
CD-1
C-5
EF-4
C-4
E-18
EF-1
CD-4
B-13
E-7
G-9
G-8
H-10
H-8
G-10
B-16
E-14
B-14
B-15
E-15
G-11
E-11
CD-6
E-10
H-7
G-12
CD-7
E-3
E-17
D-5
E-19
G-13
B-12
E-4
CD-8
B-10
H-4
D-4
B-9
E-16
A-12
E-8
E-6
E-1
G-14
B-11
D-1
E-20
A-8
E-13
G-17
E-12
E-9
D-2
GH-5
G-16
B-6
A-9
B-8
G-15
D-7
A-11
B-5
D-3
G-18
B-7
A-15
E-5
E-2
GH-1
D-6
A-16
B-3
B-2
B-4
A-13
G-19
A-10
A-14
B-1
AB-1
GH-2
GH-3



SPECIAL X-RAY CAMERA is used to make X-ray diffraction photographs of the myoglobin crystal. The crystal is contained in the thin glass tube exactly at the center of the photograph. The beam of X rays comes out of metal tube just to the right of glass one.



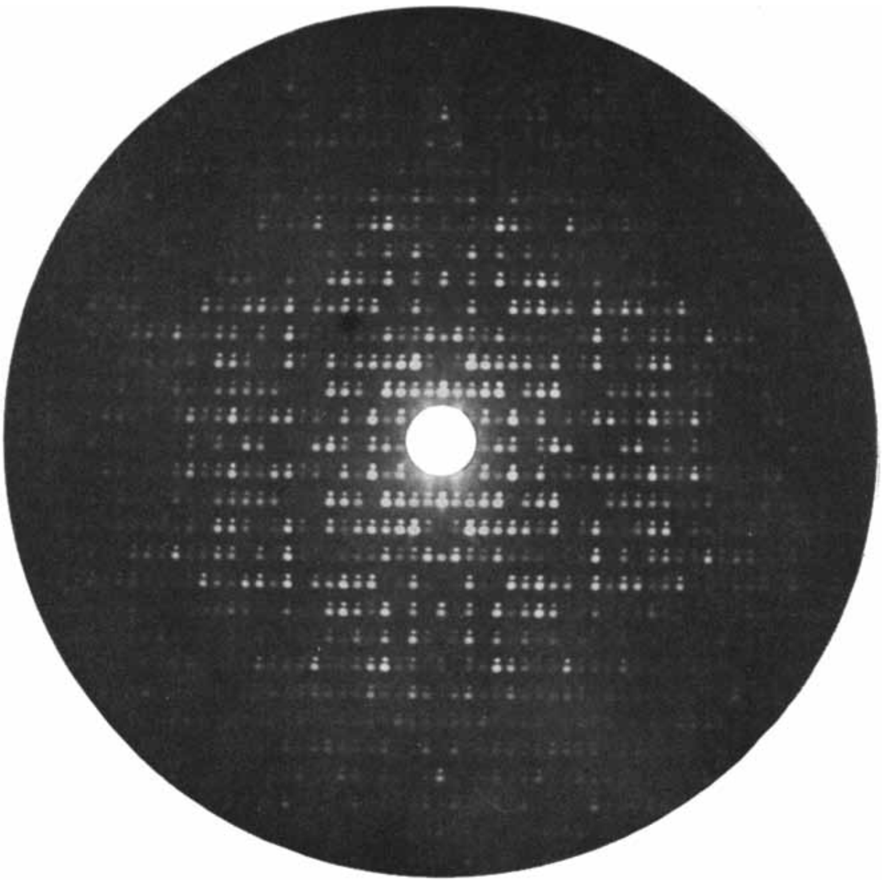
CRYSTAL OF MYOGLOBIN is the dark speck in the middle of the glass tube in this close-up. As the X-ray exposure is made the crystal is rotated so that the X rays reflected from planes of atoms in the crystal "flash up" to make spots on a photographic plate.

which varies from place to place in three dimensions but in a regular, repeating way. (The density at any point depends on the types of atom in the neighborhood and their spatial arrangement.) The crystal can therefore be thought of as a kind of three-dimensional sound wave consisting of rarefactions and condensations of electrons rather than of air particles. This wave too can be decomposed into harmonics—that is, simple, repetitive patterns of density variation; along any single direction the density of each harmonic varies sinusoidally.

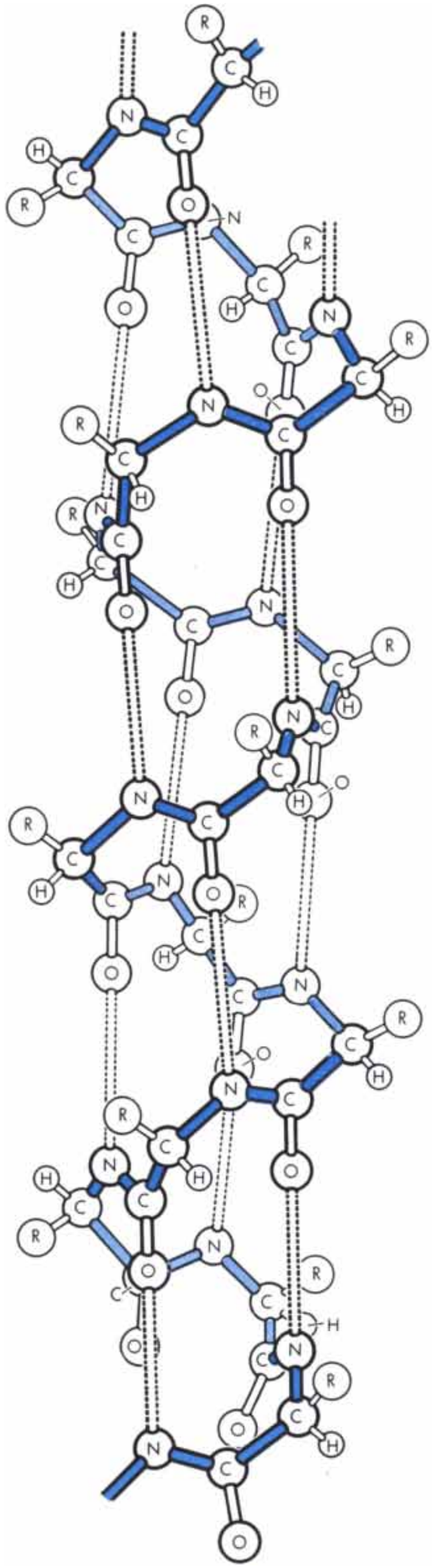
It turns out that each harmonic corresponds to one particular spot in the X-ray diffraction pattern. The reason is that each set of possible atomic planes in the crystal constitutes one element, so to speak, of the over-all periodic structure. That is just what a harmonic is: a component of the over-all periodic structure. From the position and darkness of a spot, the "wavelength" (the spacing between high-density peaks) and "amplitude" (the value of the density at the peaks) of the corresponding harmonic can be computed. So the problem is reduced to calculating the harmonics from the spot pattern and then adding them together to arrive at the total structure.

There is, however, a serious catch: the diffraction pattern provides information on the wavelength and amplitude of the harmonics but not on their relative phases. In the case of sound, phase is not particularly important in synthesizing a wave; the ear is rather insensitive to phase difference and hears very nearly the same note so long as the relative amplitudes of the harmonics are correct. On the other hand, the shape of the wave as seen by the eye varies greatly when the relative phases of the components are shifted.

In deriving crystal structure the correct shape of the three-dimensional "wave" is precisely what one is looking for. But the X-ray picture contains only half of the information required; it contains the amplitudes but not the phases. In simpler structures crystallographers get around the difficulty by a method of trial and error; from a plausible model structure they calculate the phases and use these in conjunction with the measured amplitudes to calculate a Fourier synthesis, that is to say, an enlarged picture of the distribution of the electrons (and hence of the atoms) in the structure. The result should be a good deal closer to the real structure than the original model, and from it crystallographers can calculate a new and improved set of phases. If the original model was good enough to put them on



X-RAY PHOTOGRAPHS of myoglobin are patterns of spots. At top is a photograph of a normal crystal. At bottom is a photograph of a different type in which patterns of normal crystal and one labeled with heavy atoms are superimposed slightly out of register. Differences in density between two sets made it possible to determine phase of X-ray reflections.



ALPHA HELIX of a protein molecule is a coiled chain of amino acid units. The backbones of the units form a repeating sequence of atoms of carbon (*C*), oxygen (*O*), hydrogen (*H*) and nitrogen (*N*). The *R* stands for the side chain that distinguishes one amino acid from another. The configuration of the helix is maintained by hydrogen bonds (*broken lines*). The hydrogen atom that participates in each of these bonds is not shown.

the right track, they gradually approach the true structure by a series of successive approximations, or refinements.

As in the case of the musical note, the greater the number of higher harmonics that are included, the sharper and more precise is the resulting picture. The higher harmonics of a musical note are, of course, the components of shortest wavelength (highest frequency); in a crystal structure the harmonics are correspondingly the reflections from the most closely spaced sets of planes. As has been mentioned, these reflections occur at the largest angles and show up as spots farthest out in the pattern. The resolution of the final picture—that is, the smallest scale of detail it can show—depends on the outer limit of the spots included in the analysis; the number of spots that have to be included goes up in proportion to the cube of the resolving power required.

The first X-ray photographs of protein crystals were made nearly 25 years ago, but for many years it was not possible even in principle to imagine how the structures of crystals so complex could be discovered. Their X-ray patterns contained many thousands of reflections, paralleling the complexity of the molecules themselves. There was no hope of proceeding by trial and error; the first model could never be good enough to provide a useful starting point. So although protein crystallographers discovered many interesting facts about protein crystals, they did not succeed in extracting much information bearing directly on the molecular structure.

In 1953 the whole prospect was transformed by a discovery of my University of Cambridge colleague Max F. Perutz, who had been studying hemoglobin crystals for many years. The hemoglobin molecule contains two free sulfhydryl groups (SH) of the amino acid cystine; by well-known reactions it is possible to attach atoms of mercury to these groups. Perutz found that if he made crystals of hemoglobin labeled with mercury, their X-ray pattern differed significantly from that of unlabeled crystals, even though the mass of a mercury atom is very small compared with that of a complete hemoglobin molecule. This made it possible to apply the so-called method of isomorphous replacement in the Fourier synthesis.

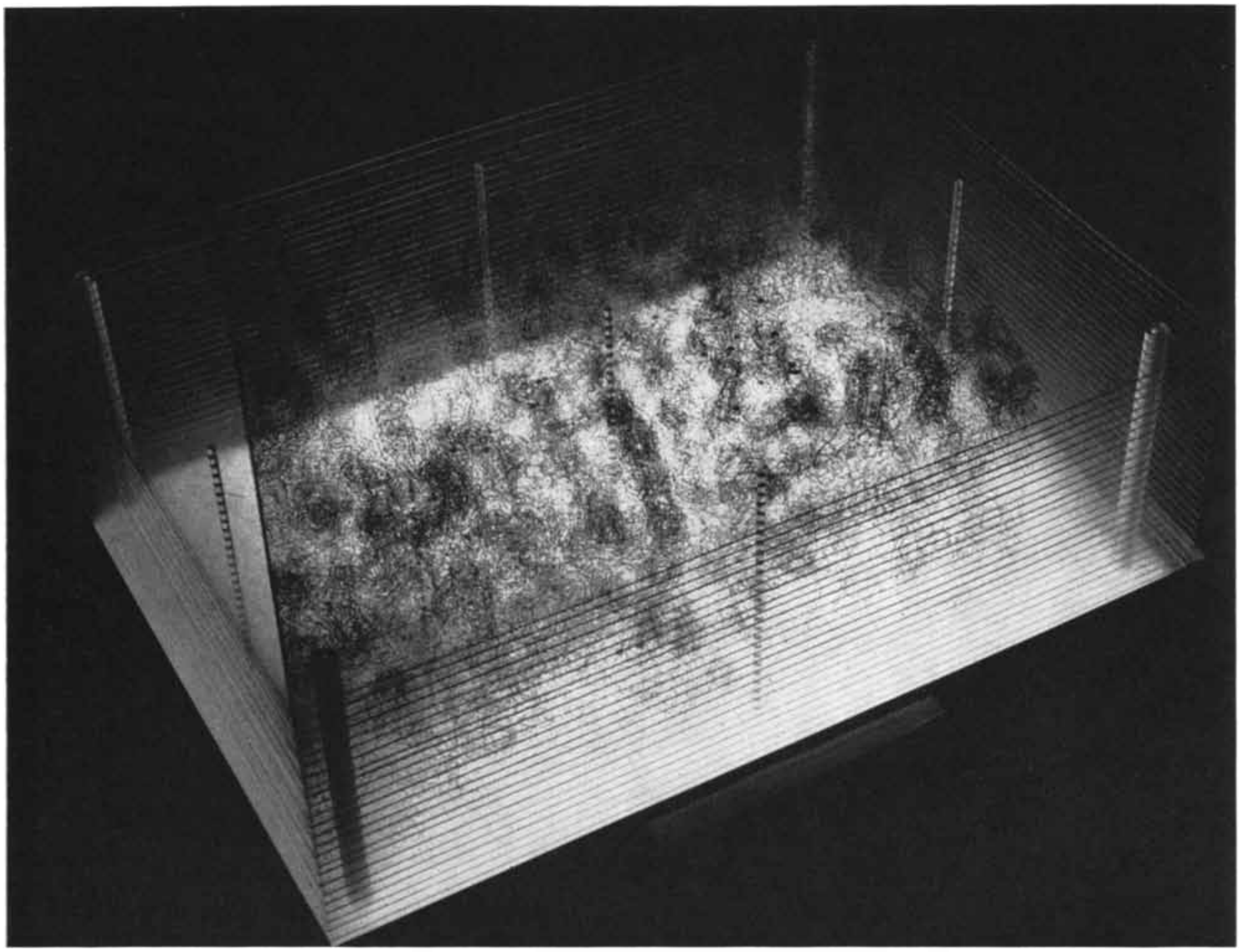
A full explanation of the method is beyond the scope of the present article. Suffice it to say that by comparing in detail the X-ray patterns of crystals with and without heavy atoms it is possible to deduce the phases of all the reflections, and this without any of the guesswork of the trial-and-error method. Thus Perutz' observation for the first time made it possible, in principle at least, to solve the complex X-ray pattern of a protein crystal and to produce a model of the structure of the molecule.

In our studies of myoglobin we could not follow Perutz' method for attaching mercury atoms, because myoglobin lacks free sulfhydryl groups. We were, however, successful in finding other ways to attach four or five kinds of heavy atom at different sites in the molecule, and we were then able to proceed to a study of the three-dimensional structure of the crystal. A complete solution would involve including all the reflections in the X-ray pattern in our calculation—some 25,000 in all. At the time this work began no computers in existence were fast enough or large enough to handle so great an amount of data; besides, we thought it better in the first instance to test the new method on a smaller scale.

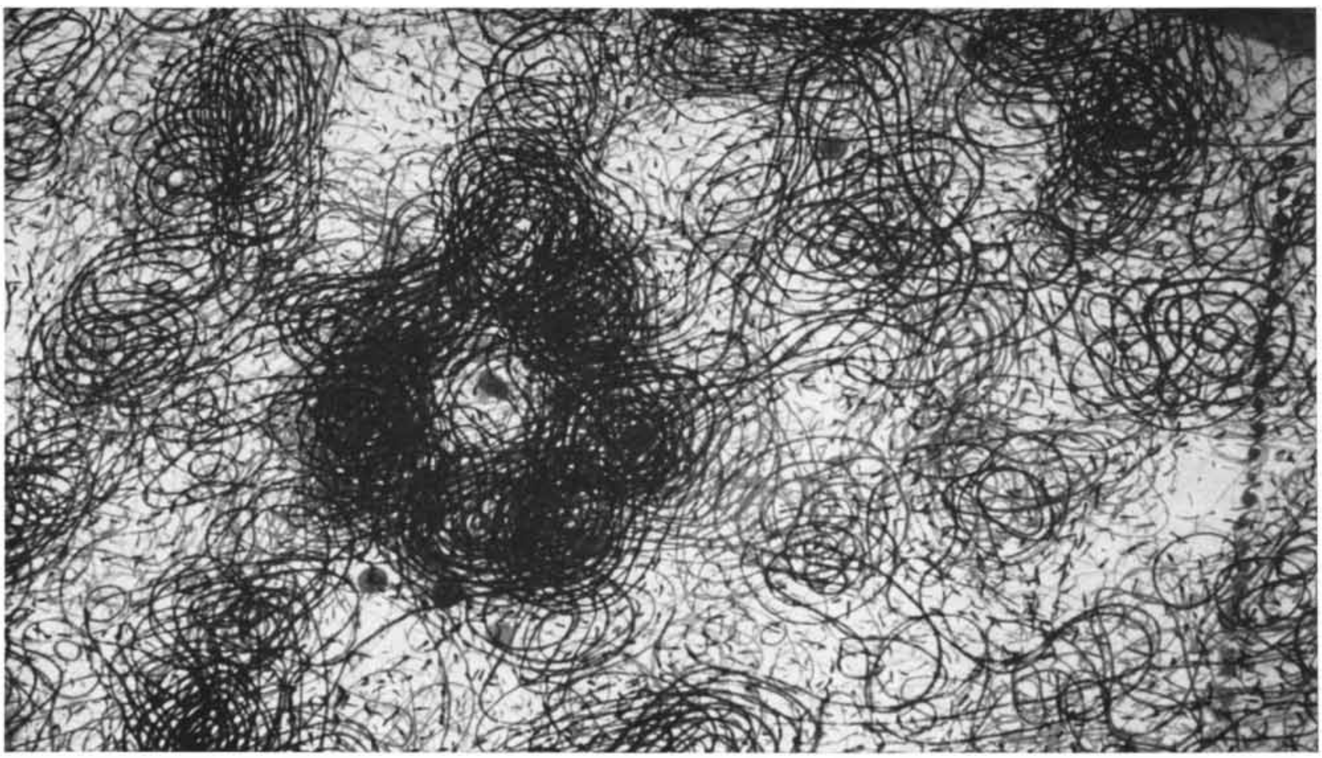
The Six-Angstrom-Unit Picture

As has already been indicated, if we include only the central reflections of the pattern, we obtain a low-resolution, or crude, representation of the structure. The higher the resolution that is desired, the farther out in the pattern must the reflections be measured. We decided that in the first stage of the project we would aim for a resolution of six angstrom units (an angstrom unit is one hundred-millionth of a centimeter). This would be sufficient to reveal the general arrangement of the polypeptide chains in the molecule, but not the configuration of the atoms within the chains or that of the side chains surrounding them. To achieve a six-angstrom resolution we had to measure 400 reflections from the unlabeled protein and from each of five types of crystal containing heavy atoms. Our calculations, which were completed in the summer of 1957, gave us the density of electrons at a large number of points in the crystal, a high electron density being found where many atoms are concentrated. Crystallographers usually represent a three-dimensional density distribution, or Fourier synthesis, by cutting an imaginary series of parallel sections through the structure. The density distribution in each section is represented by a series of density contours drawn on a lucite sheet. When all the sheets are stacked together, they give a representation in space of the density throughout the molecule.

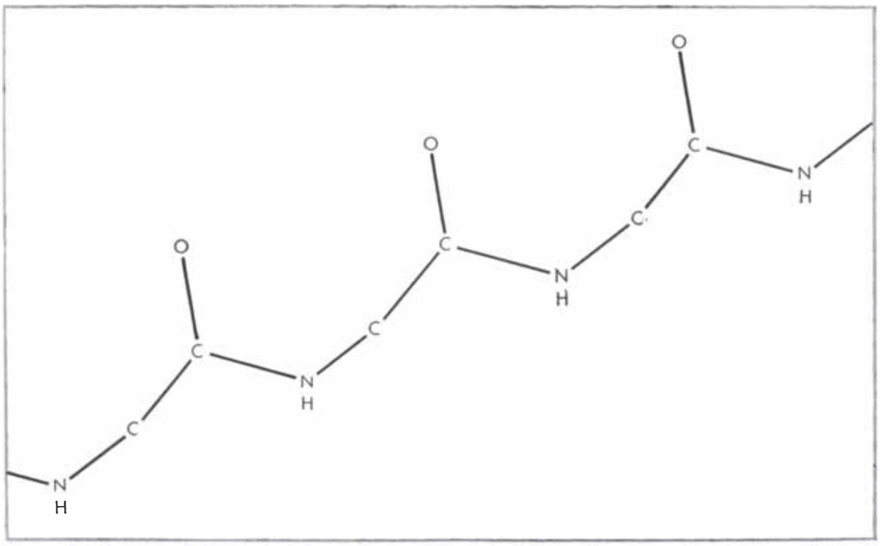
As soon as we had constructed our



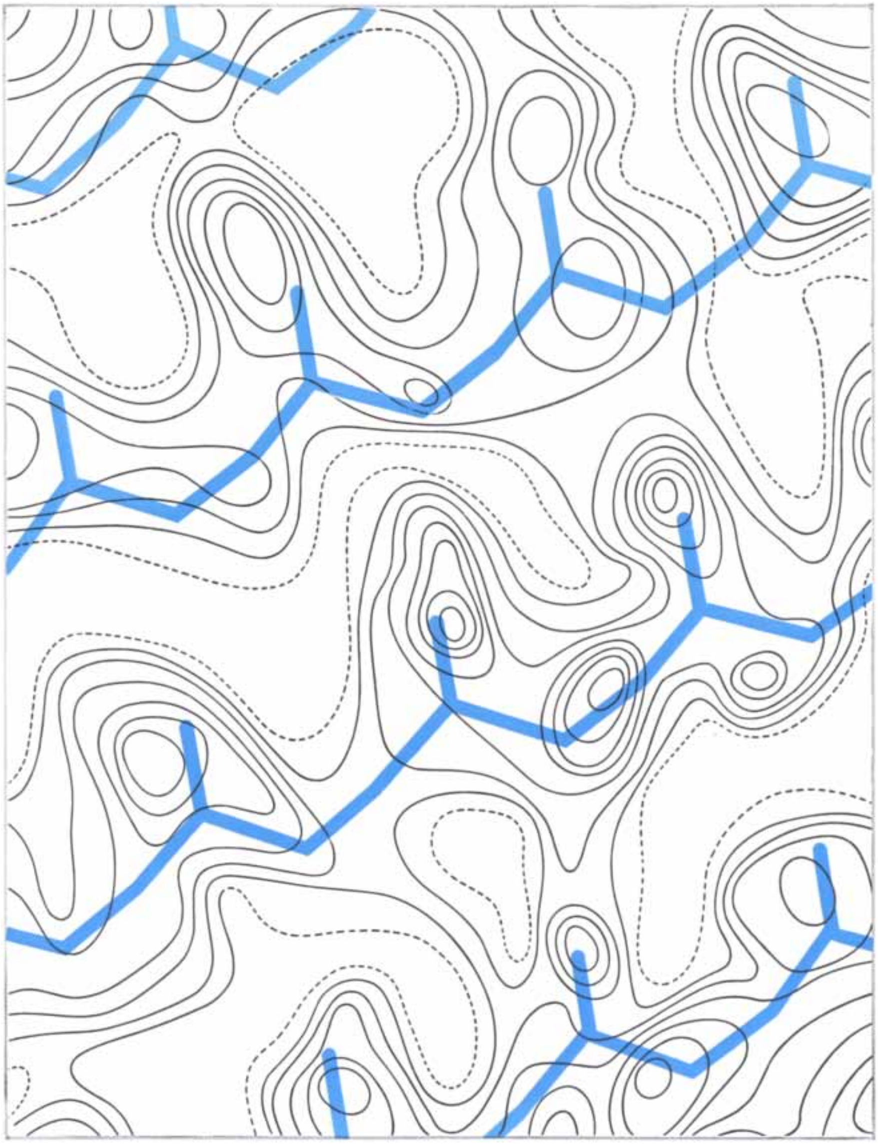
ELECTRON-DENSITY MAP of the myoglobin crystal is made up of lucite sheets, on each of which are traced the contours of electron density at that depth. The dark band in the middle is the heme group. This map was made at a resolution of two angstrom units.



MAP SHOWS ALPHA HELIX when it is seen from the appropriate angle. Here the camera looks through the contours on a series of lucite sheets. Alpha helix is the dark ring at left center. Thus it is seen along its axis, as though it were a cylinder seen from the end.



BACKBONE OF THE ALPHA HELIX is shown schematically in this diagram. The sequence of atoms in the helix is —CO—CHR—NH—. Here the HR attached to isolated C is omitted.



BACKBONE IS SUPERIMPOSED on contours made by plotting on a cylinder density along helix in crystal. Cylinder was then unrolled. Backbone thus appears to repeat.

first lucite density map of the myoglobin crystal, we could see at a glance that it contained the features we were looking for, namely a set of high-density rods of just the dimensions one would expect for a polypeptide chain. Closer examination showed that in fact it consisted of almost nothing but a complicated and intertwining set of these rods, sometimes going straight for a distance, then turning a corner and going off in a new direction. In addition to the rods we were able to see very dense peaks, which we took to be the heme groups themselves. The iron atom at the center of the heme group, being by far the heaviest atom in the molecule and therefore having the largest number of planetary electrons, would be expected to stand out as a prominent feature. It was not at all easy, however, to gain any impression of what the molecule was actually like, largely because the molecules are packed together in the crystal and it is hard to see where one begins and the next one ends.

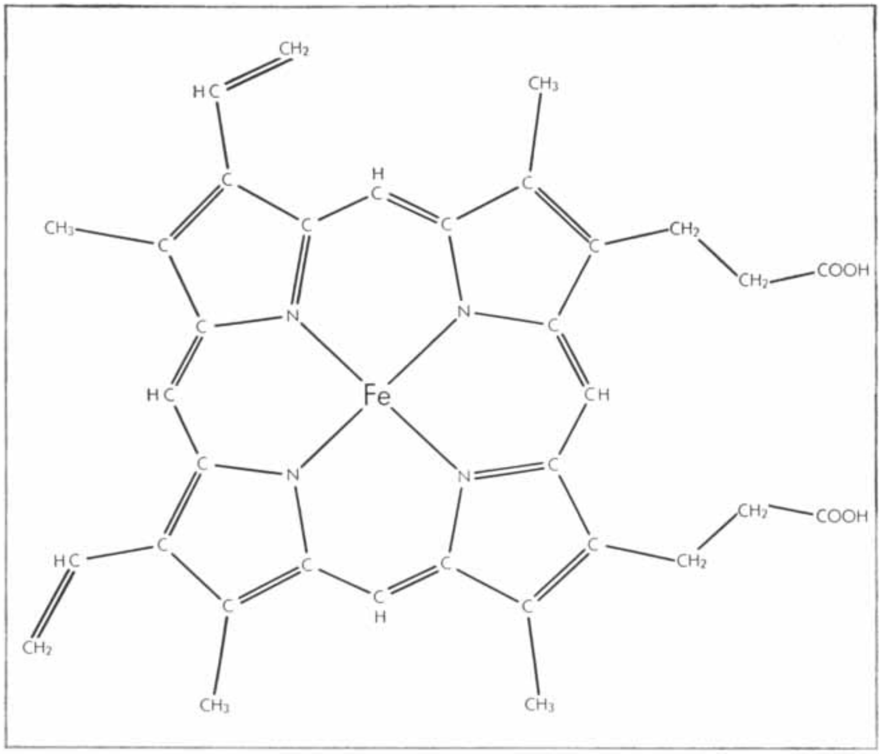
Our next task was to dissect out a single molecule from the enlarged density map of the crystal so that we could look at it separately. Fortunately all protein crystals, including myoglobin, contain a good deal of liquid which fills up the interstices between neighboring molecules, and which at low resolution looks like a uniform sea of density, so that it can easily be distinguished from the irregular variations of density within the molecule itself. By looking for the liquid regions we were able to draw an outline surface around the molecule and so isolate it from its neighbors. Extracted in this way, the molecule stood forth as the complicated and asymmetrical object shown in the top illustration on page 109. The polypeptide chain winds irregularly around the structure, supporting the heme group in a kind of basket. For the most part the course of the polypeptide chain could be followed, but we could not be sure of its route everywhere, since its density became lower at the corners and it tended to fade into the background at those points. Our model did, however, give us a good general picture of the layout of the molecule, and it showed us that it was indeed much more complicated and irregular than most of the earlier theories of the structure of proteins had suggested.

The Two-Angstrom-Unit Picture

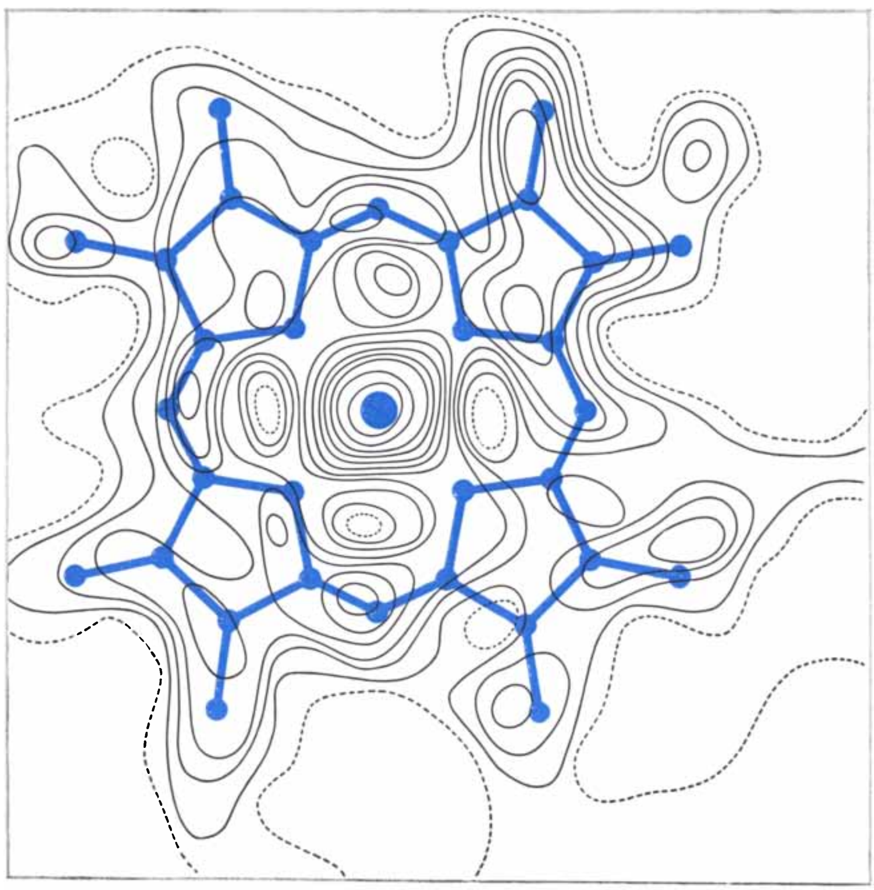
At a resolution of six angstroms we could not expect to see any details of the polypeptide chain or of the side chains attached to it. To see all the atoms of a structure as separate blobs of density it would be necessary to work at a resolution higher than 1.5 angstroms, for neighboring atoms attached to one another by chemical bonds lie only from one to 1.5 angstroms apart. A Fourier synthesis of myoglobin at 1.5 angstroms resolution would involve 25,000 reflections; we decided in the second stage of the work to limit our ambitions to a resolution of two angstroms. Even this required that we include in our calculations nearly 10,000 reflections for the unsubstituted crystal and the same number for each of the heavy-atom derivatives. It was necessary to measure a formidable number of X-ray photographs, a task that took a team of six people many months to complete. At the end of this time the mass of data that we had accumulated was so great that it could be handled only by a truly fast computer. We were fortunate that a machine of this class—EDSAC Mark II—had recently come into service at the University of Cambridge, and we were able to use it for deducing the phases of all the 10,000 reflections and for the ensuing calculations of the Fourier synthesis itself. Fast though it is, we taxed the powers of EDSAC II to the utmost, and it was clear that any further improvement in resolution would demand the use of still more powerful machines.

Once more our results were plotted in the form of a three-dimensional contour map [*see top illustration on page 105*]. Since we were looking for finer details, it was necessary to cut sections through the structure at closer intervals than before; in fact, this time we had about 50 sections compared to 16 in the six-angstrom map. To construct the new map it was necessary to calculate the electron density at 100,000 points in the molecule. Indeed, the amount of information contained in the final synthesis was so great that drawing and building the density map was in itself a lengthy task, amounting to some six man-months of work. The result was a complicated set of dense and less dense regions that at first sight seemed completely irregular. Our first step was to see what we could learn from it about the configuration of the polypeptide chains, which in our earlier synthesis had appeared merely as solid rods.

Here I shall digress briefly to consider some earlier work on the fibrous protein of hair. In fibrous proteins the polypeptide chains probably run parallel to the axis of the fiber for considerable distances. Such protein fibers were among the earliest biological macromole-



SKELETON OF THE HEME GROUP is outlined in this diagram. At the center of the group is the iron atom (*Fe*). There are four such groups in hemoglobin and one in myoglobin.



SKELETON IS SUPERIMPOSED on another section of the electron-density map of the myoglobin crystal. Here bonds to the iron atom are omitted to show contours around atom.

cules to be examined by X-ray methods. W. T. Astbury, in his classical work carried out at the University of Leeds in the early 1930's, showed that a human hair gave a characteristic X-ray pattern, which on stretching changed reversibly into quite a different pattern. He was able to show that the pattern of stretched hair—the so-called beta form—corresponded to the polypeptide chains being almost fully extended; it followed that in the unstretched, or alpha, form the chains must assume some kind of folded configuration. For many years different workers proposed a succession of more or less unsatisfactory models of the folded chain in unstretched hair, but finally in 1951 Linus Pauling and Robert B. Corey of the California Institute of Technology found the definitive solution, showing that the chain actually took up a helical or spiral shape, the now famous alpha helix [*see illustration on page 104*]. In this configuration the successive turns of the helix are held together by weak hydrogen bonds between NH groups on one turn and CO groups opposite them on the next turn. The alpha helix turned out to be present in several other fibrous proteins besides hair; and although there was no definite proof of the fact, indirect evidence indicated that the alpha helix, or something like it, could exist in the molecule of globular proteins too.

The first thing we wanted to do when we finished our Fourier synthesis at two angstroms resolution was to see whether or not there was anything to the idea of helical structures in a globular protein. Accordingly we looked through the stack of lucite sheets in a direction corresponding to the axis of one of the rods we had seen at low resolution. We were delighted to find that the dense rod now revealed itself as a hollow cylinder running dead straight through the structure [*see bottom illustration on page 105*]. Closer examination showed that the density followed a spiral course along the surface of the cylinder, indicating that the polypeptide chain indeed assumed a helical shape. Detailed measurement of the spiral density showed that it followed precisely the dimensions of the alpha helix deduced by Pauling and Corey 10 years earlier. In fact, it turned out that about three-quarters of the polypeptide chain in the molecule took the form of straight lengths of alpha helix, the helical segments being joined by irregular regions at the corners. In all there were eight such segments, varying in length from seven to 24 amino acid units. In each segment it was possible to fit the alpha helix exactly to the observed density in such a way that we could be reasonably sure of the placing of each atom, even though at this resolution we had not secured full separation between one atom and its neighbors.

The next object of interest was the heme group. Looking at the map from the appropriate angles, we now saw this group as a flat object with a region of high density at the iron atom in the center. A section through the map through the plane of the flat object shows a variation in density that closely follows the known chemical structure of the system of rings in the heme group [*see illustrations on preceding page*].

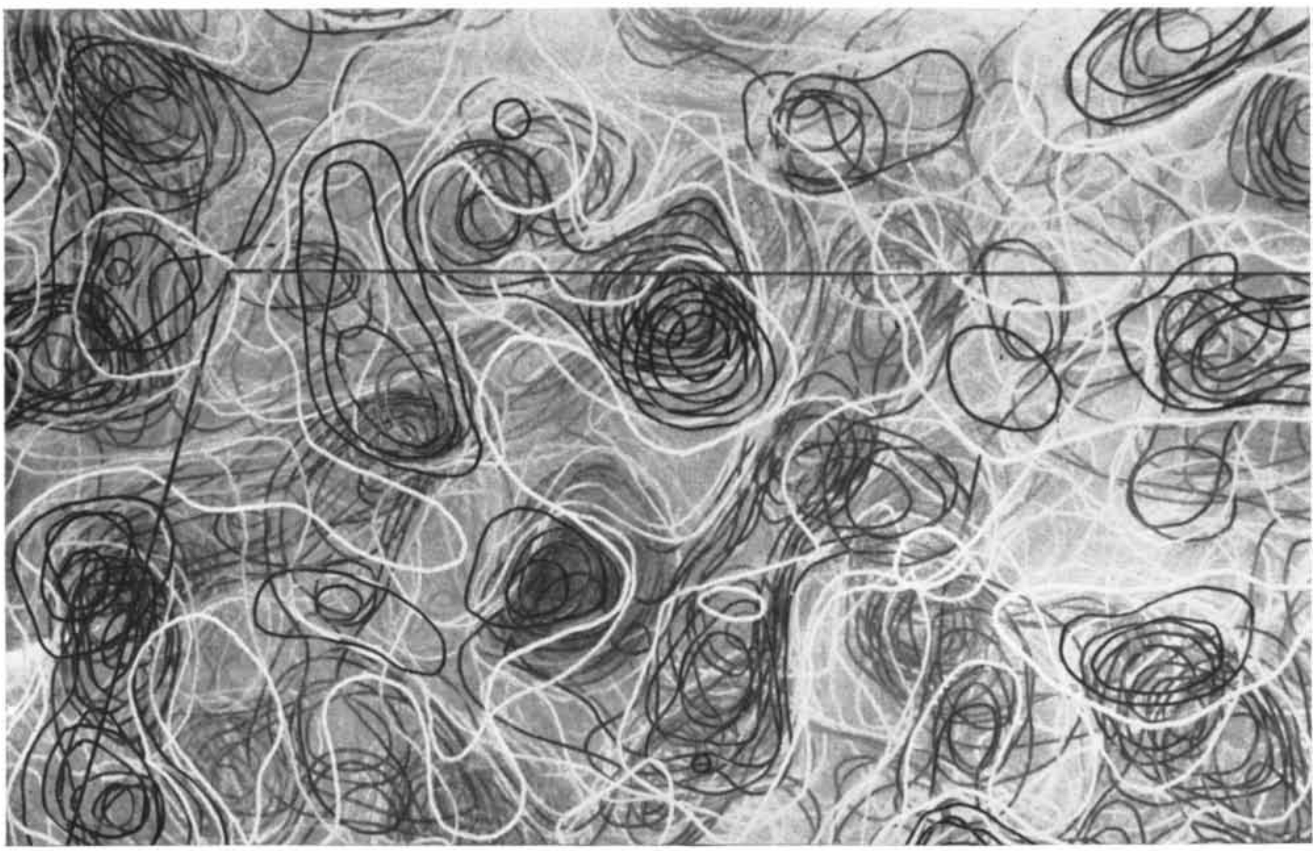
The Three-dimensional Model

When we came to study our structure in detail, we soon felt the need of a better way to represent the three-dimensional density distribution. We wanted some method that would enable us to fit actual atomic models to the features we could see. Our solution was to erect a forest of steel rods on which we placed colored clips to represent the distribution in space of points of high density, different colors representing different values of the density [*see illustration on page 110*]. The scale of this model was five centimeters per angstrom, so that the whole model would fit in a cube about six feet on a side. Each helical segment of polypeptide chain could be seen as a spiral of colored clips passing through the model, and we were then able to insert actual alpha helices made of skeleton-type models (similar to the familiar ball-and-spoke models but with the balls omitted) and to show that they precisely followed the dense trail of clips. In this way we were able to trace the polypeptide chain from beginning to end, right through the molecule, and to establish its configuration in each of the irregular corners joining neighboring helices. Once the course of the main chain had been delineated with atomic models, we were able to see the side chains emerging from it at appropriate intervals as dense branches of various sizes. At first we thought it unlikely that we would be able to identify many of the side chains, but after some practice we found that in fact we were able to do so surprisingly often. As mentioned earlier, side chains in proteins are of only 20 kinds (in myoglobin only 17), and they are of very different shapes and sizes, ranging from the one in glycine, which is only a single hydrogen atom (invisible to the crystallographer), to the chain in tryptophan, with a double-ring system of 10 carbon and nitrogen atoms. Our problem was reduced to deciding among 17 possible side chains in each case.

Some of our identifications were definite, others were tentative. Fortunately an independent check on our conclusions lay at hand. For several years A. B. Edmundson and C. H. W. Hirs, working in Stein and Moore's laboratory at the Rockefeller Institute, had been trying to establish the amino acid sequence of myoglobin by chemical methods. Their work is still incomplete, but they have broken down the molecule into a set of short pieces, or peptides, the compositions—and in some cases the internal sequences—of which they have determined. The order in which the peptides are arranged in the intact molecule has yet to be established chemically. We have been able, however, to place almost every one of the peptides with certainty in its correct position along the chain by comparing its composition with our X-ray identifications of the side chains. There are virtually no gaps left, nor are there peptides unplaced. Once assigned to their correct positions, the peptides often help to confirm doubtful X-ray identifications, and by putting the two types of evidence together we arrive at a nearly complete amino acid sequence for the whole molecule.

Simply to determine the amino acid sequence was not our main aim in undertaking the X-ray analysis of myoglobin. We were much more concerned with the three-dimensional arrangement of the side chains in the molecule and with the interactions between them that produce and maintain the molecule's characteristic configuration. To study these interactions we undertook to make a model of the whole molecule, with every side chain in place [*see illustration on pages 98 and 99*]. The result was an object still more complex than the low-resolution model, although of course all the features of the latter are still apparent in the former. We can now discern many of the types of interaction that protein chemists have postulated on the basis of physicochemical studies. For example, positively charged basic groups such as those of lysine and arginine are held by electrostatic attraction close to negatively charged acid groups such as aspartic or glutamic acid; several types of hydrogen-bond interaction can be seen, among them NH groups in the main chain bonded to the oxygen atom of serine or threonine; and everywhere we find a close interlocking of hydrocarbon groups such as CH_2 or CH_3, giving rise to the so-called van der Waals' attraction. The structure is not yet sufficiently complete in all details to allow a

EARLY MODEL of the myoglobin molecule was made at a resolution of six angstrom units. This model has the same general configuration as that of the model depicted on pages 98 and 99, but it lacks detail. The heme group is the flat section at upper right.



CLOSE-UP OF CONTOURS of map on which the six-angstrom model was based shows that contours are coarser than those in two-angstrom map. Early model was based on work of author, G. Bodo, H. M. Dintzis, R. G. Parrish, H. W. Wyckoff and D. C. Phillips.

full analysis of the interactions, but at least we can now see the general pattern of forces that maintains the integrity of the molecule.

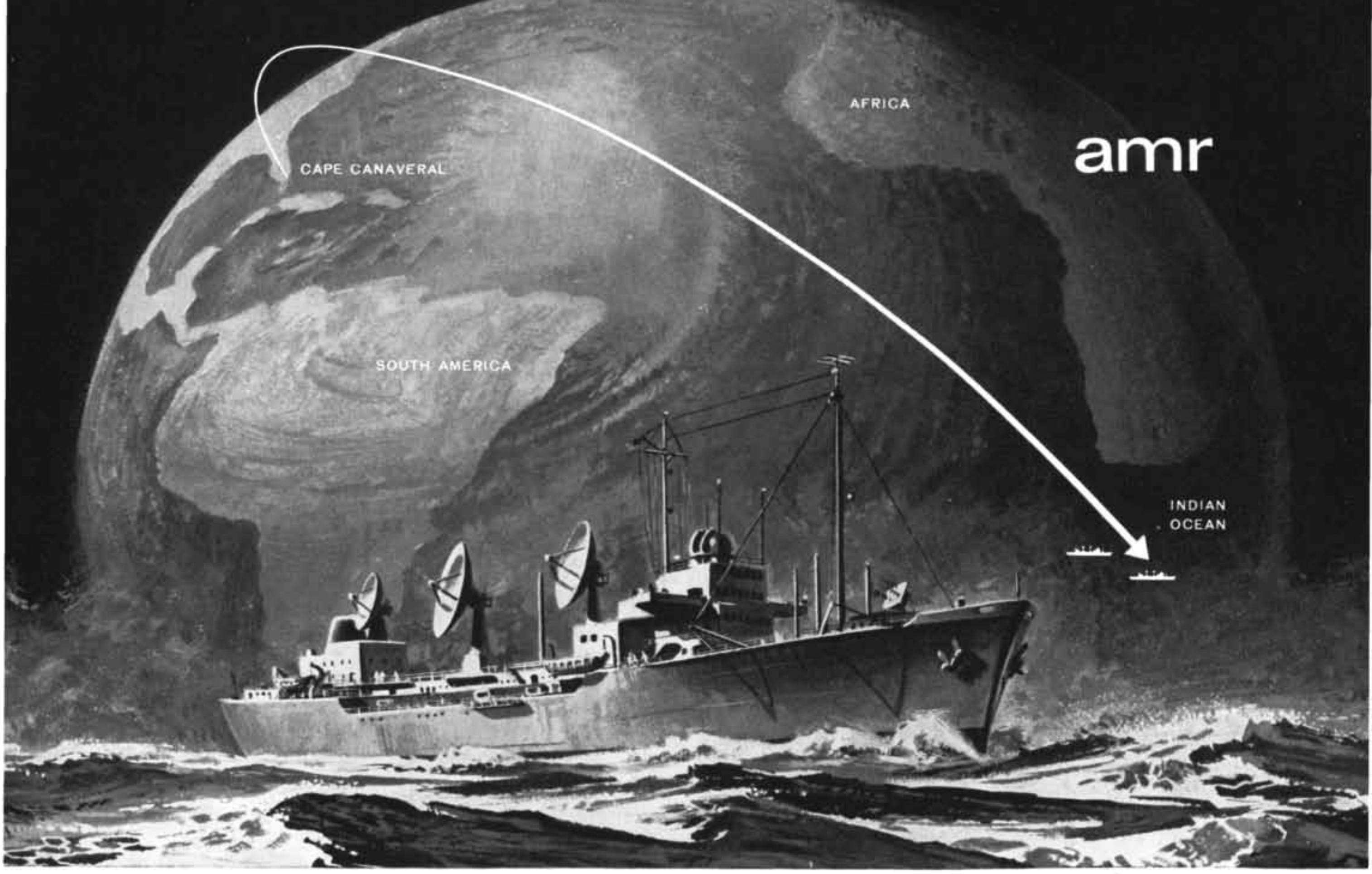
We can also often see why helical segments end at a particular place; in many instances proline side chains are found at the ends of helices and, as was pointed out several years ago, proline is bound to interfere with helix formation because of its peculiar shape, unlike that of any other naturally occurring amino acid. Finally, we can examine the way in which the heme group itself is attached to the rest of the molecule; the iron atom is attached to a nitrogen in a histidine side chain (as had been suggested years ago on the basis of chemical evidence), and the flat ring system is stabilized by hydrocarbon side chains, especially ring side chains, lying parallel to it.

In similar studies of the larger hemoglobin molecule Perutz and his collaborators have shown that, at least to the resolution of 5.5 angstroms that they have so far achieved, there is an astonishing similarity between the three-dimensional structure of myoglobin and the structure of each of the four subunits formed by the individual polypeptide chains of hemoglobin. This is a most remarkable result considering that we are dealing with two distinct proteins, one found in muscle and the other in red blood cells, one derived from sperm whale and the other from horse. Furthermore, the amino acid compositions of the two proteins are known to differ substantially.

The amino acid sequences of the hemoglobin chains have been completely determined. We have found that when we lay the hemoglobin sequences alongside those of myoglobin, making appropriate allowances for slight differences in their length, there are many correspondences, often just at those points where a study of the myoglobin molecule indicates that a crucial stabilizing reaction takes place. We can even begin to find chemical explanations for some of the peculiarities of the congenitally abnormal hemoglobins present in individuals suffering from certain rare blood diseases.

Even in the present incomplete state of our studies on myoglobin we are beginning to think of a protein molecule in terms of its three-dimensional chemical structure and hence to find rational explanations for its chemical behavior and physiological function, to understand its affinities with related proteins and to glimpse the problems involved in explaining the synthesis of proteins in living organisms and the nature of the malfunctions resulting from errors in this process. It is evident that today students of the living organism do indeed stand on the threshold of a new world. Analyses of many other proteins, and at still higher resolutions (such as we hope soon to achieve with myoglobin), will be needed before this new world can be fully invaded, and the manifold interactions between the giant molecules of living cells must be comprehended in terms of well-understood concepts of chemistry. Nevertheless, the prospect of establishing a firm basis for an understanding of the enormous complexities of structure, of biogenesis and of function of living organisms in health and disease is now distinctly in view.

FOREST OF RODS was used to build up the two-angstrom model of the myoglobin molecule from electron-density map. Densities were indicated by clips on rods, and model was based on position of clips. Outline of heme group is visible at upper left center.



Objective: increase capability of the Atlantic Missile Range—sponsored by the Missile Test Center of the Air Force Systems Command—to study missiles and space vehicles during the critical terminal phase of flight with a refinement never before possible. Prime requisite: *mobility* . . . ability to move to the most advantageous position in thousands of miles of ocean.

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SPERRY

The Fighting Behavior of Animals

Combat between members of a species serves useful functions. Death or serious injury to a contender is avoided by formal tournaments, the behavior patterns for which appear to be innate in the species

by Irenäus Eibl-Eibesfeldt

Fighting between members of the same species is almost universal among vertebrates, from fish to man. Casual observation suggests the reason: Animals of the same kind, occupying the same niche in nature, must compete for the same food, the same nesting sites and the same building materials. Fighting among animals of the same species therefore serves the important function of "spacing out" the individuals or groups in the area they occupy. It thereby secures for each the minimum territory required to support its existence, prevents overcrowding and promotes the distribution of the species. Fighting also arises from competition for mates, and thus serves to select the stronger and fitter individuals for propagation of the species. It is no wonder, then, that herbivores seem to fight each other as readily as do carnivores, and that nearly all groups of vertebrates, except perhaps some amphibians, display aggressive behavior.

A complete investigation of fighting behavior must take account, however, of another general observation: Fights between individuals of the same species almost never end in death and rarely result in serious injury to either combatant. Such fights, in fact, are often highly ritualized and more nearly resemble a tournament than a mortal struggle. If this were not the case—if the loser were killed or seriously injured—fighting would have grave disadvantages for the species. The animal that loses a fight is not necessarily less healthy or less viable; it may simply be an immature animal that cannot withstand the attack of a mature one.

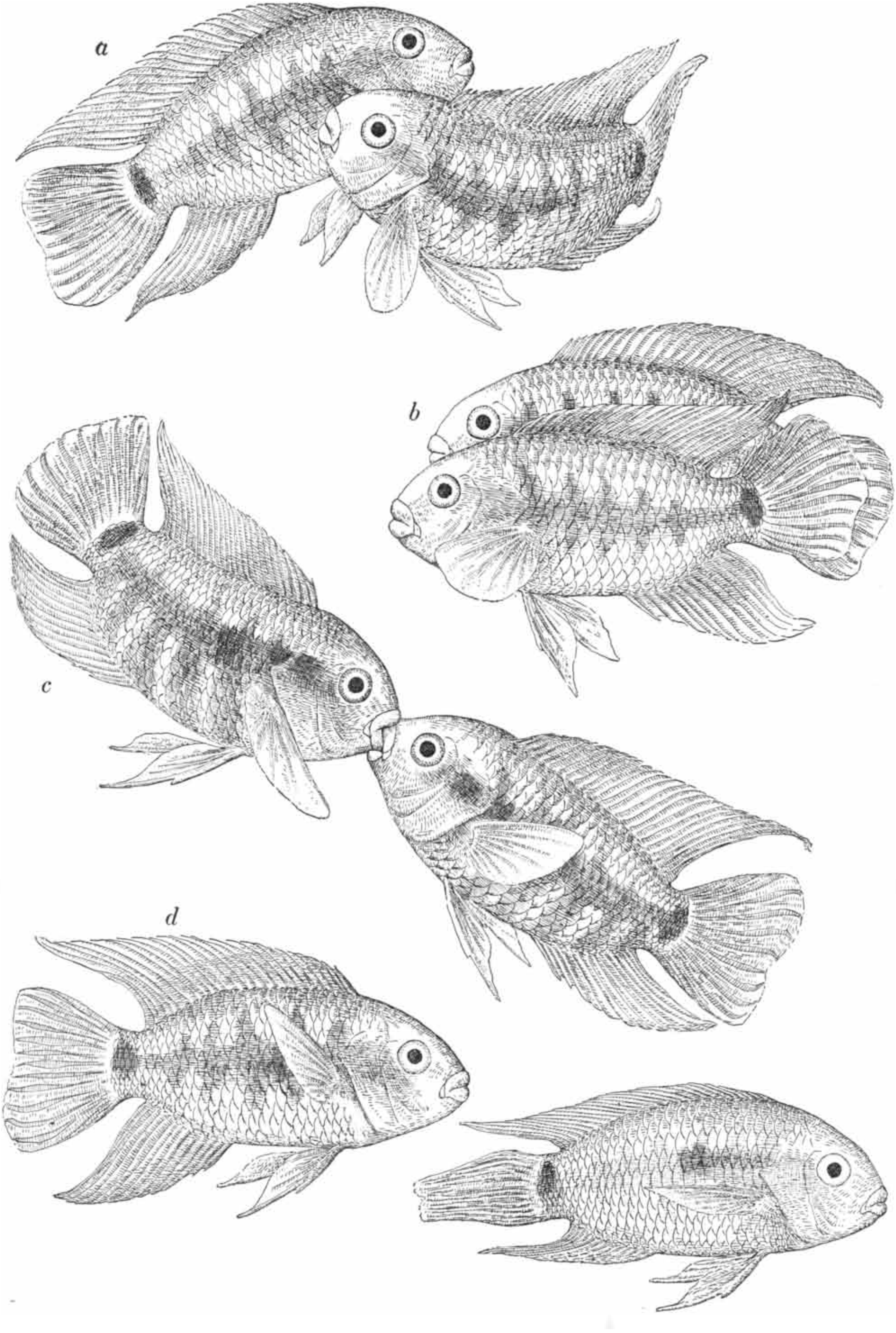
In view of the disadvantages of serious injury to a member of the species, evolution might be expected to have exerted a strong selective pressure against aggressive behavior. But spacing out through combat was apparently too important to permit a weakening of aggressive tendencies; in fact, aggressiveness seems to have been favored by natural selection. It is in order to allow spacing out—rather than death or injury—to result from fighting that the ceremonial combat routines have evolved.

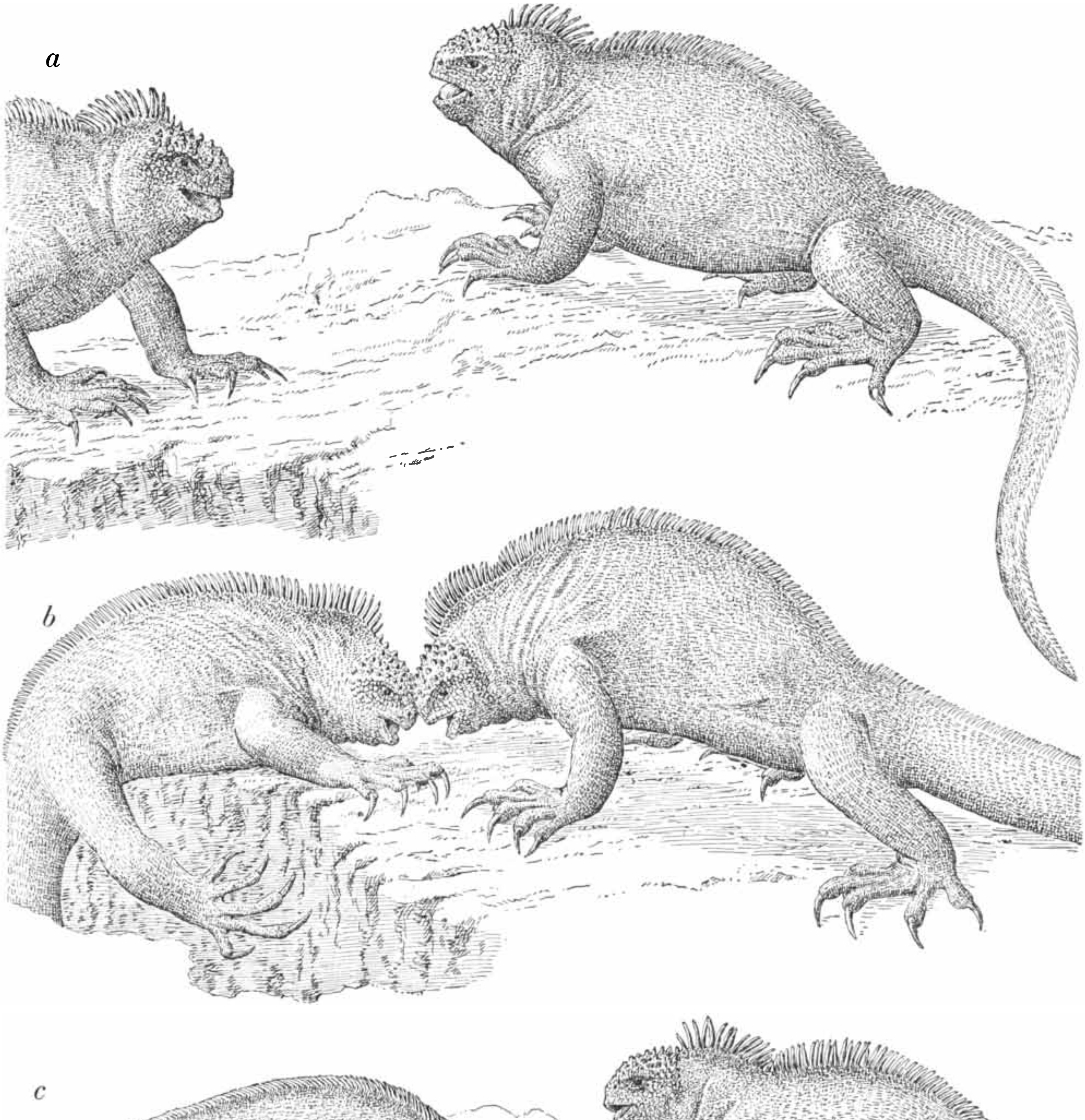
Investigators of aggressive behavior, often strongly motivated by concern about aggressive impulses in man, have usually been satisfied to find its origin in the life experience of the individual animal or of the social group. Aggressiveness is said to be learned and so to be preventable by teaching or conditioning. A growing body of evidence from observations in the field and experiments in the laboratory, however, points to the conclusion that this vital mode of behavior is not learned by the individual but is innate in the species, like the organs specially evolved for such combat in many animals. The ceremonial fighting routines that have developed in the course of evolution are highly characteristic for each species; they are faithfully followed in fights between members of the species and are almost never violated.

All-out fights between animals of the same species do occur, but usually in species having no weapons that can inflict mortal injury. Biting animals that can kill or seriously injure one another are usually also capable of quick flight. They may engage in damaging fights, but these end when the loser makes a fast getaway. They may also "surrender," by assuming a submissive posture that the winner respects. Konrad Z. Lorenz of the Max Planck Institute for the Physiology of Behavior in Germany has described such behavior in wolves and dogs. The fight begins with an exchange of bites; as soon as one contestant begins to lose, however, it exposes its vulnerable throat to its opponent by turning its head away. This act of submission immediately inhibits further attack by its rival. A young dog often submits by throwing itself on its back, exposing its belly: a pet dog may assume this posture if its master so much as raises his voice. Analogous behavior is common in birds: a young rail attacked by an adult turns the back of its head —the most sensitive part of its body— toward the aggressor, which immediately stops pecking. Lorenz has pointed out that acts of submission play a similar role in fights between men. When a victim throws himself defenseless at his enemy's feet, the normal human being is strongly inhibited from further aggression. This mechanism may now have lost its adaptive value in human affairs, because modern weapons can kill so quickly and from such long distances that the attacked individual has little opportunity to appeal to his opponent's feelings.

Most animals depend neither on flight nor on surrender to avoid damaging fights. Instead they engage in a ceremonial struggle, in the course of which the contestants measure their strength in bodily contact without harming each other seriously. Often these contests begin with a duel of threats—posturings,

CICHLID FISH (*Aequidens portalegrensis*) perform a ritual fight that begins with a threat and proceeds to bodily contact without damage to either. After a formal display (*a*) the fish fan their tails to propel currents of water at each other (*b*). Then the rivals grasp each other with their thick-lipped mouths and push and pull (*c*) until one gives up and swims away (*d*).


a
b
c
d

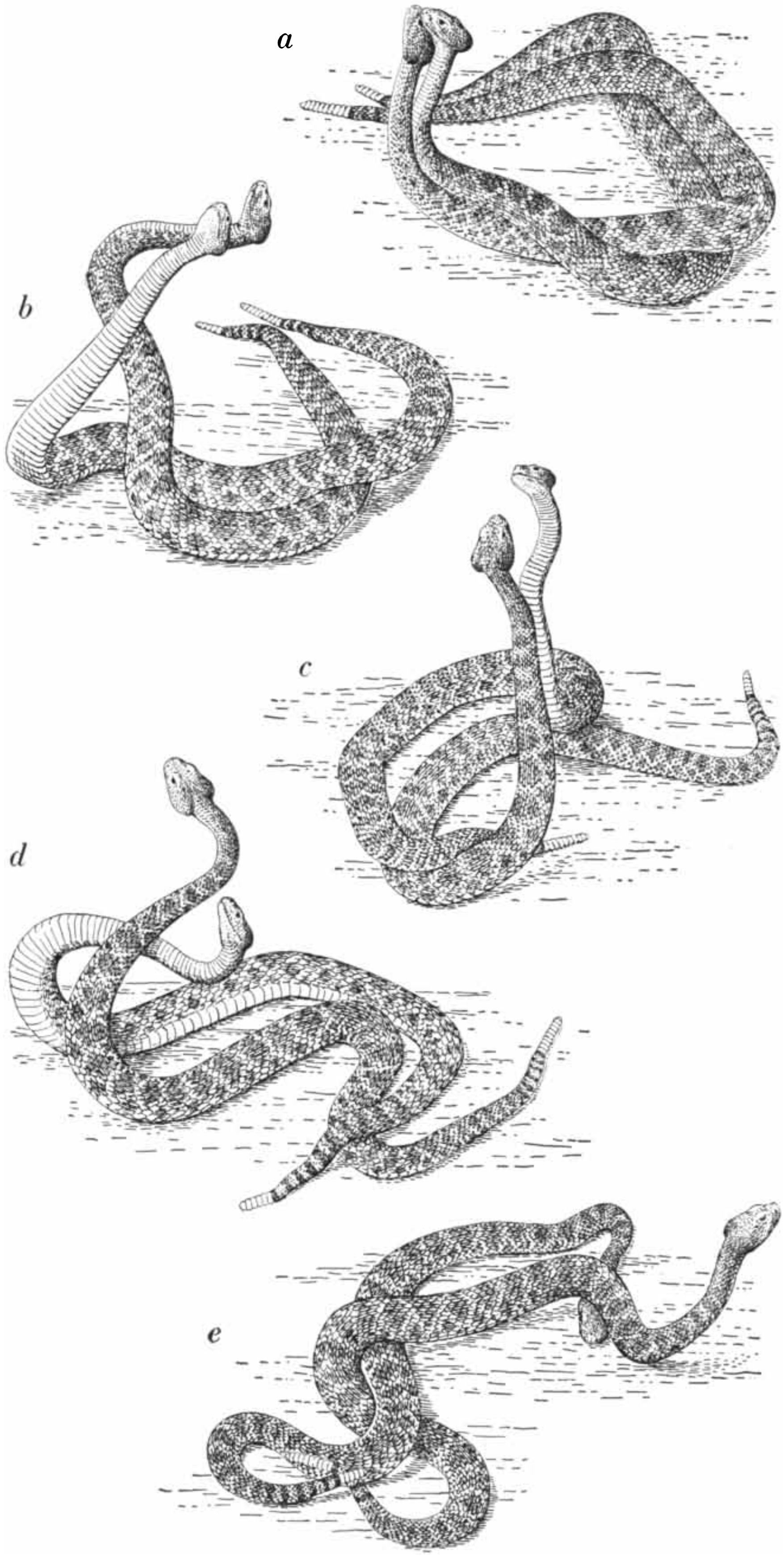


MALE MARINE IGUANA (*Amblyrhynchus cristatus*) of the Galápagos Islands defends his territory against intruding males. As the rival approaches (*a*), the territory owner struts and nods his head. Then the defender lunges at the intruder and they clash head on (*b*), each seeking to push the other back. When one iguana (*left at "c"*) realizes he cannot win, he drops to his belly in submission.

movements and noises—designed to cow the opponent without any physical contact at all. Sometimes this competition in bravado brings about a decision; usually it is preliminary to the remainder of the tournament.

On the lava cliffs of the Galápagos Islands a few years ago I observed such contests between marine iguanas (*Amblyrhynchus cristatus*), large algae-eating lizards that swarm by the hundreds over the rocks close to shore. During the breeding season each male establishes a small territory by defending a few square yards of rock on which he lives with several females. If another male approaches the territorial border, the local iguana responds with a "display." He opens his mouth and nods his head, presents his flank to his opponent and parades, stiff-legged, back and forth, his apparent size enlarged by the erection of his dorsal crest. If this performance does not drive the rival off, the resident of the territory attacks, rushing at the intruder with his head lowered. The interloper lowers his head in turn and the two clash, the tops of their heads striking together. Each tries to push the other backward. If neither gives way, they pause, back off, nod at each other and try again. (In an apparent adaptation to this mode of combat the head of the marine iguana is covered with hornlike scales.) The struggle ends when one of the iguanas assumes the posture of submission, crouching on its belly. The winner thereupon stops charging and waits in the threatening, stiff-legged stance until the loser retreats [*see illustration on opposite page*]. A damaging fight is triggered only when an invader does not perform the ceremonies that signal a tournament; when, for example, the animal is suddenly placed in occupied territory by a man, or crosses another animal's territory in precipitous flight from an earlier contest. On these occasions the territory owner attacks by biting the intruder in the nape of the neck. Female iguanas, on the other hand, regularly engage in damaging fights for the scarce egg-laying sites, biting and shaking each other vigorously.

The lava lizard (*Tropidurus albemarlensis*) of the larger Galápagos Islands engages in a similar ceremonial fight that begins with the rivals facing each other, nodding their heads. Suddenly one of them rushes forward, stands alongside his opponent and lashes him with his tail once or several times, so hard that the blows can be heard several yards away. The opponent may reply with a



RATTLESNAKES (*Crotalus ruber*) **perform the combat dance shown in these drawings based on a study by Charles E. Shaw of the San Diego Zoo. The rivals move together** (*a*) **and then "Indian wrestle" head to head** (*b*)**. Sometimes they face each other, weaving and rubbing their ventral scales** (*c*)**. Finally one lashes out and throws** (*d*) **and pins** (*e*) **the other.**

tail-beating of his own. Then the attacker turns and retreats to his original position. The entire procedure is repeated until one of the lizards gives up and flees.

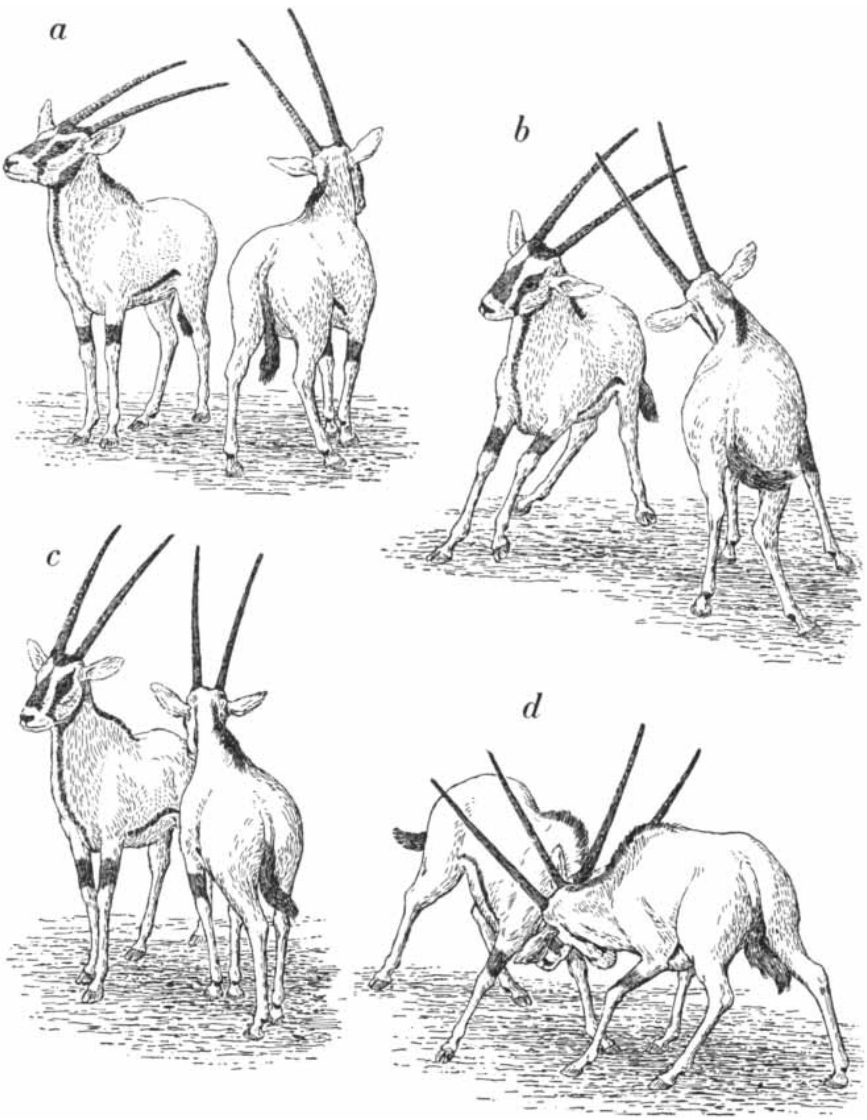
According to Gertraud Kitzler of the University of Vienna, fights between lizards of the central European species *Lacerta agilis* may terminate in a curious manner. After an introductory display one lizard grasps the other's neck in his jaws. The attacked lizard waits quietly for the grip to loosen, then takes his turn at biting. The exchange continues until one lizard runs away. Often, however, it is the biter, not the bitten, that does the fleeing. The loser apparently recognizes the superiority of the winner not only by the strength of the latter's bite but also by his unyielding resistance to being bitten.

Beatrice Oehlert-Lorenz of the Max Planck Institute for the Physiology of Behavior has described a highly ritualized contest between male cichlid fish (*Aequidens portalegrensis*). The rivals first perform a display, presenting themselves head on and side on, with dorsal fins erected. Then they beat at each other with their tails, making gusty currents of water strike the other's side. If this does not bring about a decision, the rivals grasp each other jaw to jaw and pull and push with great force until the loser folds his fins and swims away [*see illustration on page 113*]. John Burchard of the same institution raised members of another cichlid species (*Cichlasoma biocellatum*) in isolation from the egg stage and found that they fought each other in the manner peculiar to their species.

The ritualization of fighting behavior assumes critical importance in contests between animals that are endowed with deadly weapons. Rattlesnakes, for example, can kill each other with a single bite. When male rattlesnakes fight, however, they never bite. Charles E. Shaw of the San Diego Zoo has described the mode of combat in one species (*Crotalus ruber*) in detail. The two snakes glide along, side by side, each with the forward third of its length raised in the air. In this posture they push head against head, each trying to force the other sideways and to the ground, in accordance with strict rules reminiscent of those that govern "Indian wrestling." The successful snake pins the loser for a moment with the weight of his body and then lets the loser escape [*see illustration on preceding page*]. Many other poisonous snakes fight in a similar fashion.

Among mammals, the fallow deer (*Dama dama*) engages in a particularly impressive ceremonial fight. The rival stags march along side by side, heads raised, watching each other out of the corners of their eyes. Suddenly they halt, turn face to face, lower their heads and charge. Their antlers clash and they wrestle for a while. If this does not lead to a decision, they resume their march. Fighting and marching thus alternate until one wins. What is notable about this struggle is that the stags attack only when they are facing each other. A motion picture made by Horst Siewert of the Research Station for German Wildlife records an occasion on which one deer turned by chance and momentarily exposed his posterior to his opponent. The latter did not take advantage of this opportunity but waited for the other to turn around before he attacked. Because of such careful observance of the rules, accidents are comparatively rare.

Mountain sheep, wild goats and antelopes fight similar duels with their horns and foreheads, the various species using their horns in highly specific ways. From observation of clashes between rapier-horned oryx antelope (*Oryx gazella beisa*) and other African antelope, Fritz Walther of the Opel Open-Air Zoo for Animal Research concludes that the function of the horns is to lock the heads of the animals together as they engage in a pushing match. In one instance a



ORYX ANTELOPE (*Oryx gazella beisa*) has rapier-shaped horns but does not gore his rival. Two bulls begin combat with a display (*a*), then fence with the upper portion of their horns (*b*). After a pause (*c*) the rivals clash forehead to forehead (*d*) and push each other, using their horns to maintain contact. Drawings are based on observations by Fritz Walther.

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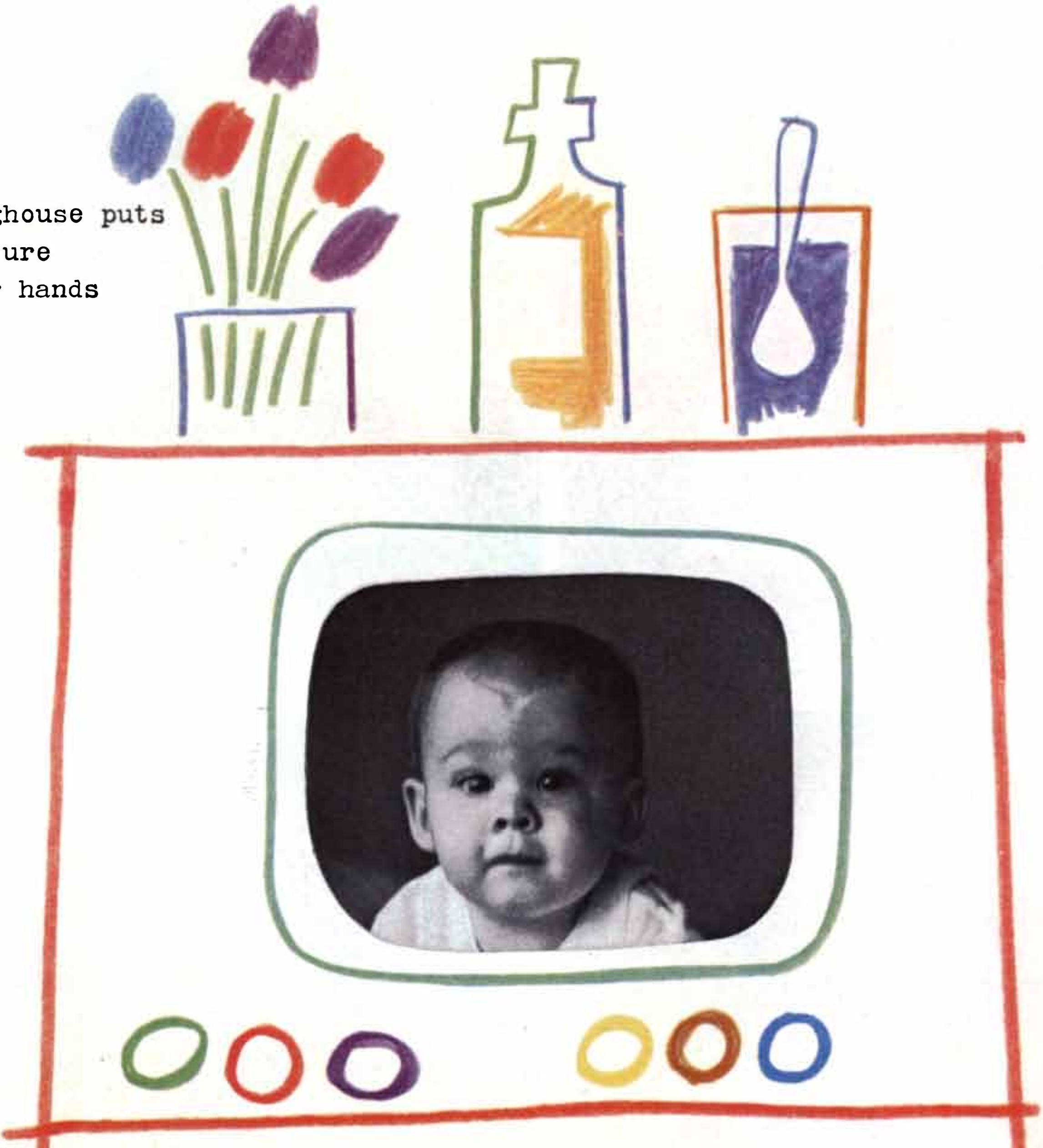

Television tape may help save your child's life

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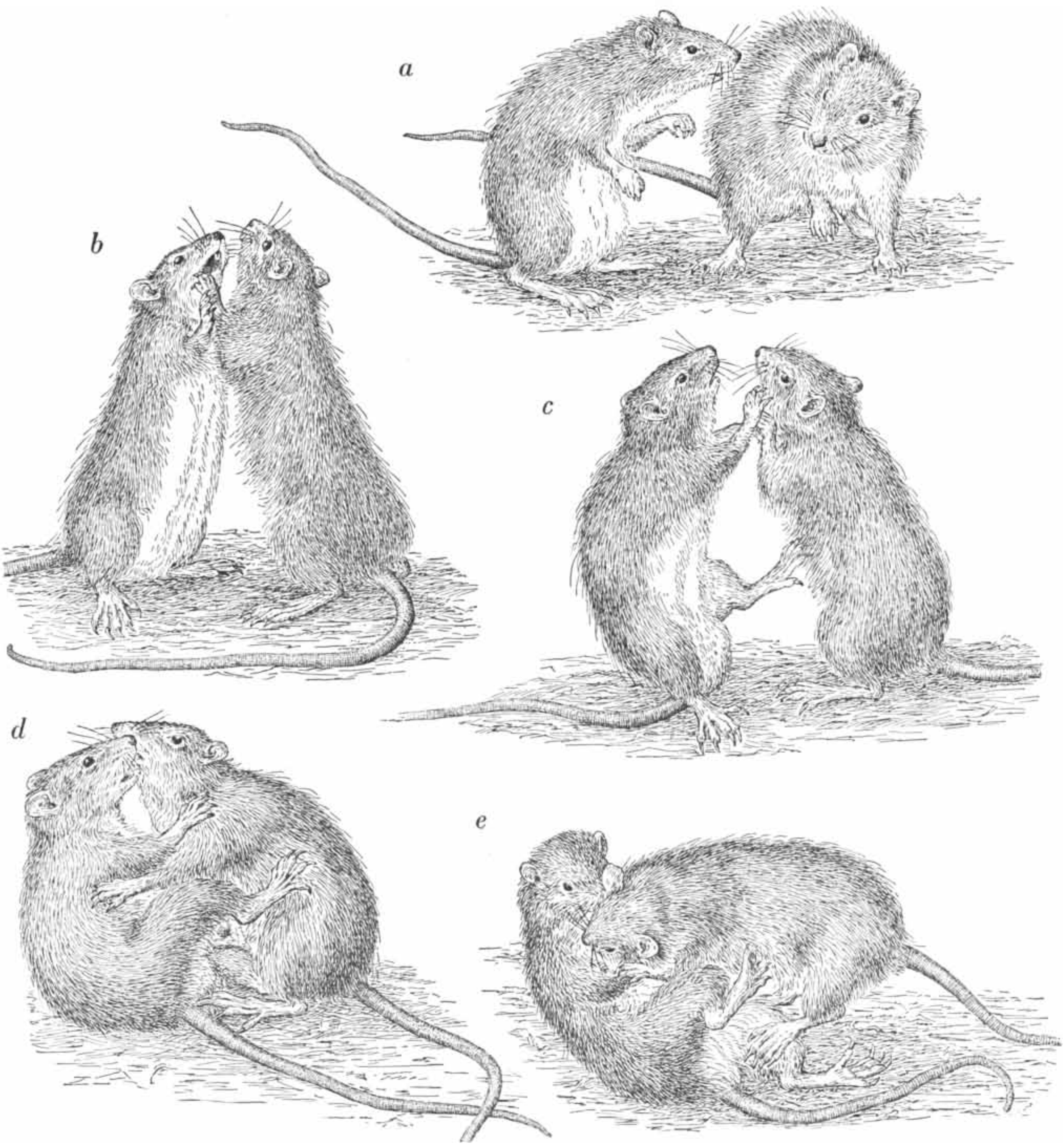
You can be sure...if it's **Westinghouse** duel between two oryx antelope in the wilderness was observed to begin with a display in which the two bulls stood flank to flank, heads held high. Then they came together in a first clash, only the upper third of their horns making contact. After a pause the animals charged again, this time forehead to forehead. They maintained contact by touching and beating their horns together [*see illustration on page 116*]. Oryx antelope never use their horns as daggers in intraspecies fights. One hornless bull observed by Walther carried out the full ritual of combat as if he still had horns. He struck at his opponents' horns and missed by the precise distance at which his nonexistent horns would have made contact. Equally remarkable, his opponents acted as though his horns were in place and responded to his imaginary blows.

Until field observations of this kind had accumulated in support of the innateness of fighting behavior, laboratory experiments had made a strong case for the notion that such behavior is learned. Experiments by J. P. Scott of the Roscoe B. Jackson Memorial Laboratory in Bar Harbor, Me., had indicated, for example, that a rat or a mouse reacts aggressively toward another rat or mouse primarily because of pain inflicted by a nestmate early in life. Scott suggests that aggressiveness should therefore be controllable by a change in environment; in other words, rats that have had no early experience of pain inflicted by another rat should be completely unaggressive.

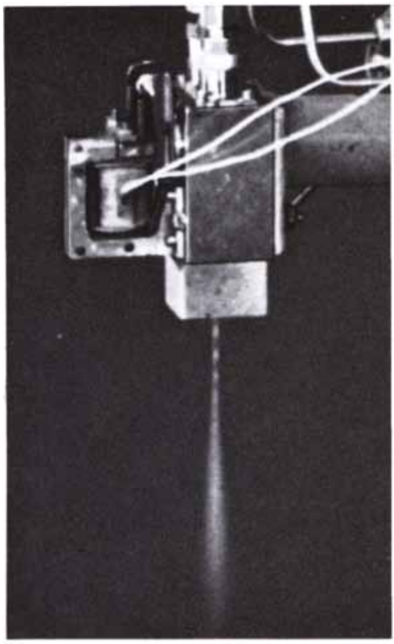
To test this conclusion I raised male Norway rats in isolation from their 17th day of life, an age at which they do not show any aggressive behavior. When each was between five and six months old, I put another male rat in the cage with him. At first the hitherto isolated rat approached the stranger, sniffed at him and sometimes made social overtures. But this never lasted long. The completely inexperienced rat soon performed the species-specific combat display—arching his back, gnashing his teeth, presenting his flank and uttering ultrasonic cries. Then the two rats pushed, kicked and wrestled, standing on their hind legs or falling together to the ground. Sometimes the fights ended at this point, the rat that landed on his back giving up and moving away. But usually the rats went on to exchange damaging bites. The patterns of display, tussling and biting were essentially the same in the case of the inexperienced rats as in the case of those who had been brought up with other rats and were faced by an outsider [*see illustration below*]. The steps in the ritual are apparently innate and fixed behavior patterns; many of the movements seem to be available to each rat like tools in a toolkit.

Raising rats in groups, where there was an opportunity for young rats to undergo early painful experiences, provided another check on the Scott theory. The members of a group displayed almost no aggressive behavior toward each other. The few fights that took place rarely included biting; for the most part the animals merely pushed each other with their paws. But when a stranger was introduced into the group, he was attacked viciously and was hurt. This agrees with observations of wild Norway rats; they live peacefully together



NORWAY RATS (*Rattus norvegicus*) fight in a species-specific manner whether they are raised in isolation or with a group of other rats. The aggressor approaches, displaying his flank and arching his back (*a*). Then, standing on their hind legs, the two rats wrestle. They push with their forelegs (*b*) and sometimes kick with their hind legs (*c*). If one rat is forced to his back as they tussle (*d*), he sometimes gives up; otherwise the tournament phase ends and the real fight begins with a serious exchange of bites (*e*).

Technicians prepare prototype pulse rocket firing during one of continuing series of tests.



Firing of integrated design, pulse modulated control rocket at Vickers Research and Development Laboratories.

Pulse modulated control rocket fired

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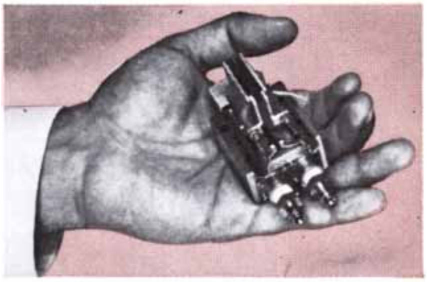

Prototype pulse rocket designed for thrust level of 1 lb. Basic design concept is applicable to any forseeable control rocket thrust level.

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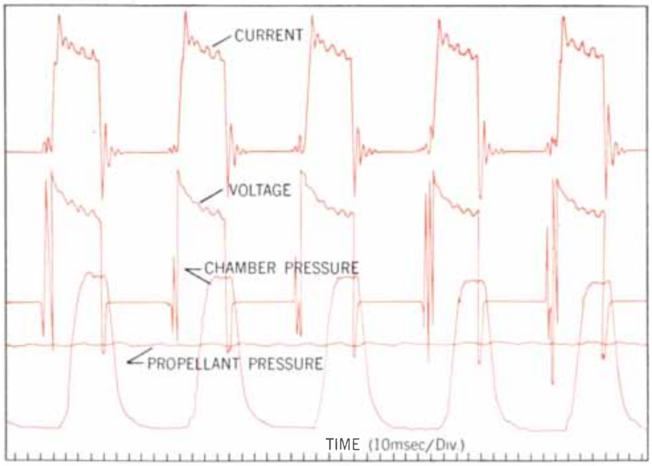
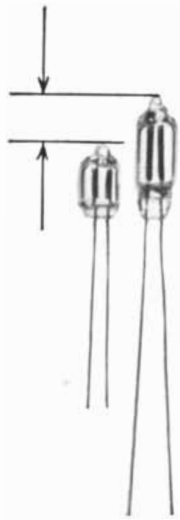


Recording of pulse rocket firing showing typical system response.



in large packs but attack any rat not a member of their group. Because the attacked animal is able to escape, the species has not developed a tournament substitute for biting. In the laboratory a strange rat introduced into a colony from which it cannot escape is likely to be killed. In sum, the experiments demonstrate that aggressiveness is aroused in adult male rats whenever a stranger enters the territory, even when the defender has had no painful experience with members of its species. Similar experiments on polecats (*Putorius putorius*) have shown the same results.

The view that aggressiveness is a basic biological phenomenon is supported by physiological studies of the underlying neural and hormonal processes. Some investigators have actually elicited fighting behavior in birds and mammals by stimulating specific areas of the brain with electrical currents. The mind of a newborn animal is not a blank slate to be written on by experience. Aggressive behavior is an adaptive mechanism by which species members are spaced out and the fittest selected for propagation. Learning is no prerequisite for such behavior, although it probably has an influence on the intensity and detailed expression of aggressiveness.

In the human species, it seems likely, aggressive behavior evolved in the service of the same functions as it did in the case of lower animals. Undoubtedly it was useful and adaptive thousands of years ago, when men lived in small groups. With the growth of supersocieties, however, such behavior has become maladaptive. It will have to be controlled—and the first step in the direction of control is the realization that aggressiveness is deeply rooted in the history of the species and in the physiology and behavioral organization of each individual.

In this connection, it should be emphasized that aggressiveness is not the only motive governing the interaction of members of the same species. In gregarious animals there are equally innate patterns of behavior leading to mutual help and support, and one may assert that altruism is no less deeply rooted than aggressiveness. Man can be as basically good as he can be bad, but he is good primarily toward his family and friends. He has had to learn in the course of history that his family has grown, coming to encompass first his clan, then his tribe and his nation. Perhaps man will eventually be wise enough to learn that his family now includes all mankind.

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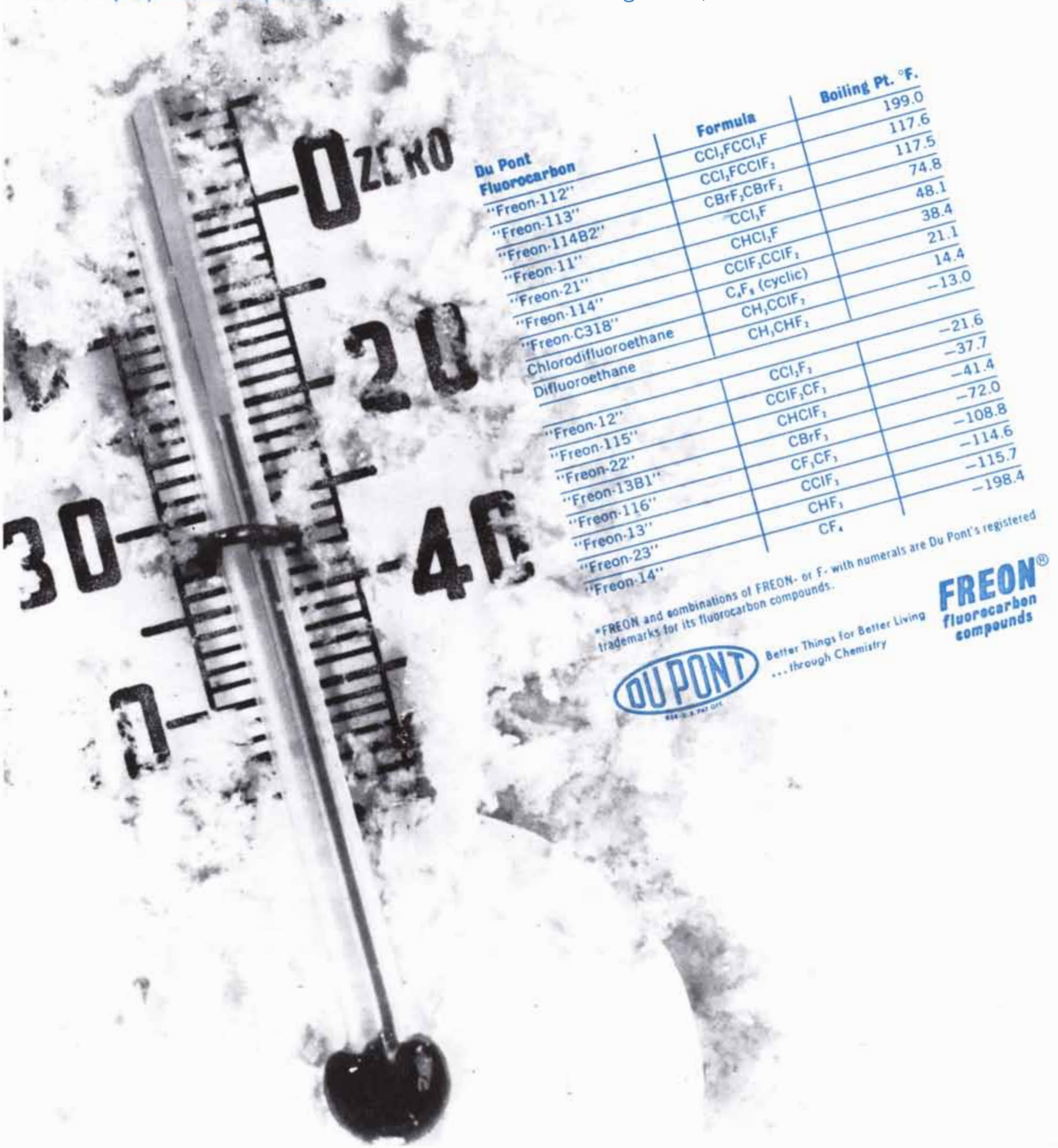

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"Freon-113"	CCl_2FCClF_2	117.6
"Freon-114B2"	$CBrF_2CBrF_2$	117.5
"Freon-11"	CCl_3F	74.8
"Freon-21"	$CHCl_2F$	48.1
"Freon-114"	$CClF_2CClF_2$	38.4
"Freon-C318"	C_4F_8 (cyclic)	21.1
Chlorodifluoroethane	CH_3CClF_2	14.4
Difluoroethane	CH_3CHF_2	−13.0
"Freon-12"	CCl_2F_2	−21.6
"Freon-115"	$CClF_2CF_3$	−37.7
"Freon-22"	$CHClF_2$	−41.4
"Freon-13B1"	$CBrF_3$	−72.0
"Freon-116"	CF_3CF_3	−108.8
"Freon-13"	$CClF_3$	−114.6
"Freon-23"	CHF_3	−115.7
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Galvanomagnetic and Thermomagnetic Effects

Discovered in the 19th century, these phenomena (which involve the interaction of a magnetic field and an electric or thermal current) have recently begun to find technological applications

by Stanley W. Angrist

In following where curiosity leads him, the scientific investigator is continually turning up odd, unexpected facts that have no apparent place in the mainstream of developing knowledge. Often their meaning is obscure, but they hardly seem worth the effort of serious study. In the long run, however, nature has no trivial secrets; science or technology takes a new turn and a half-forgotten curiosity becomes a topic of lively interest. The point is strikingly illustrated by the so-called galvanomagnetic and thermomagnetic phenomena. Their very names—the Hall effect, the Ettingshausen effect, the Nernst effect and the Righi-Leduc effect—have the musty air of the old textbooks in which they were tucked away as afterthoughts in the sections on electricity and magnetism. Today they are under active investigation in many laboratories. A number of promising applications for them have already emerged and more are on the way. Yet until a few years ago it took a well-equipped laboratory and a careful experimenter to detect the effects at all.

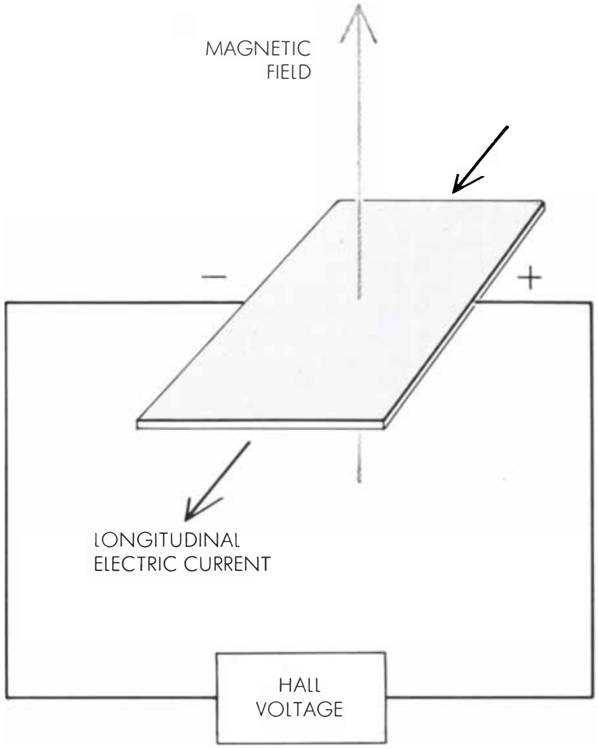
The reason for the sudden flare of attention is the advent of semiconductors. These materials are having a truly revolutionary impact on the understanding of the electrical behavior of solids and on the technology that flows from this understanding. Their importance is by no means limited to transistors. They have made possible a young industry based on thermoelectricity [see "The Revival of Thermoelectricity," by Abram F. Joffe; SCIENTIFIC AMERICAN, November, 1958], and they are in a fair way to do the same for galvanomagnetism and thermomagnetism, both of which are closely related to thermoelectricity.

This is getting ahead of the story, however. To begin with, just what are these ponderously named effects? The first to be discovered, and the best known, was reported in 1879 by E. H. Hall at Johns Hopkins University. It is most easily demonstrated in a flat, ribbon-like conductor. When the conductor is placed in a strong magnetic field perpendicular to the plane of the ribbon and an electric current is sent along its length, a voltage difference appears between points on the opposite edges of the ribbon [*see illustration at top left on opposite page*]. The amount of the voltage is directly proportional to the strength of the current and of the field and is inversely proportional to the thickness of the ribbon (that is, to the dimension parallel to the field). Reversing the current or the field reverses the direction of the voltage. The Hall effect is very small in metallic conductors. For example, a copper ribbon one-hundredth of an inch thick, carrying one ampere of current and placed in a field of 12,000 gauss develops a potential difference of .24 microvolt. (A microvolt is a millionth of a volt.)

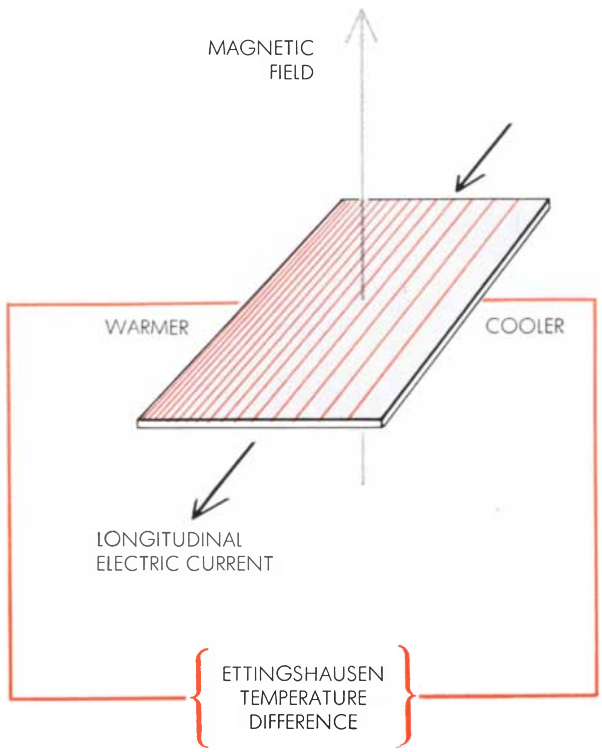
The second galvanomagnetic effect is a temperature difference produced in the same way as the Hall voltage. It was first observed in 1887 by a German physicist, Albert von Ettingshausen. As in the former case, the temperature difference appears in a direction at right angles to both the electric current and the magnetic field [*see illustration at top right on opposite page*]. The magnitude of the effect again varies directly with the current and field strength and inversely with thickness; it also reverses with a reversal of the current or the field. In a copper electrode under the same conditions given above, the temperature difference from edge to edge is .000075 degree Centigrade.

In 1886, while studying the Hall effect in bismuth, Ettingshausen and Walther Nernst noticed certain irregularities in the results that suggested a different type of experiment. They placed their bismuth ribbon in a magnetic field, but instead of sending an electric current through the conductor they warmed one end so that a current of heat would flow down the ribbon instead. Connecting a galvanometer between the opposite edges, they detected a flow of current. As they had suspected, the magnetic field and heat current combined to produce a voltage in the direction perpendicular to both [*see illustration at bottom left on opposite page*]. The size of the Nernst effect, as this thermomagnetic effect came to be called, varies directly with the magnetic-field strength, the temperature gradient along the strip and the width from side to side. Reversing the field or the heat flow reverses the voltage. A bismuth strip in a field of 9,000 gauss, with a temperature gradient of 100 degrees C. per inch, develops .0012 volt per inch of separation between the electrodes.

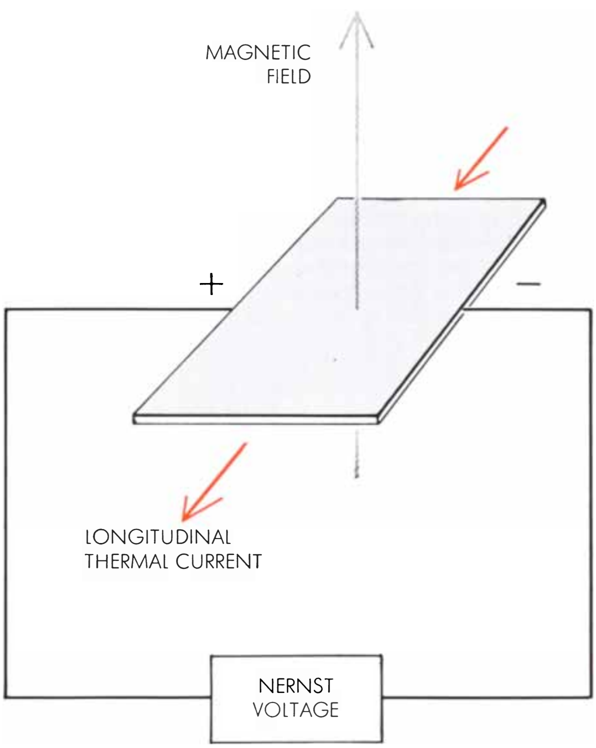
In the course of their thermomagnetic investigation Ettingshausen and Nernst also looked for a transverse temperature difference, but they failed to find one. In the next year, however, Augusto Righi in Italy and Sylvestre Anatole Leduc in France independently and almost simultaneously discovered that a magnetic field does produce a temperature difference across the width of a metal strip through which a heat current is flowing longitudinally [*see illustration at bottom right on opposite page*]. In a bismuth plate under the conditions just mentioned the difference amounts to about one degree C. between the sides (perpendicular to the field and the heat current). As the reader will probably have anticipated, the Righi-Leduc lateral temperature difference turns out to be directly proportional to the field strength, to the temperature gradient along the



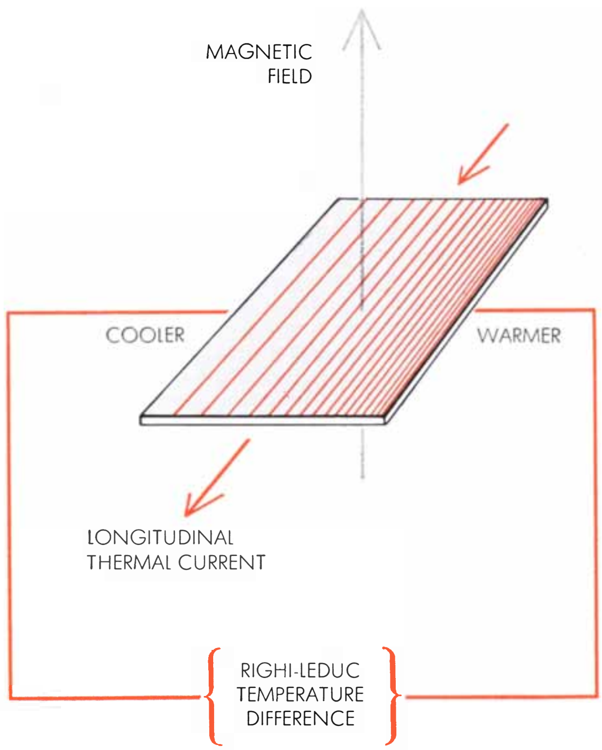
HALL EFFECT, or Hall voltage, is the transverse voltage difference that appears when a magnetic field is applied perpendicularly to a longitudinal electric current. The effect is galvanomagnetic.



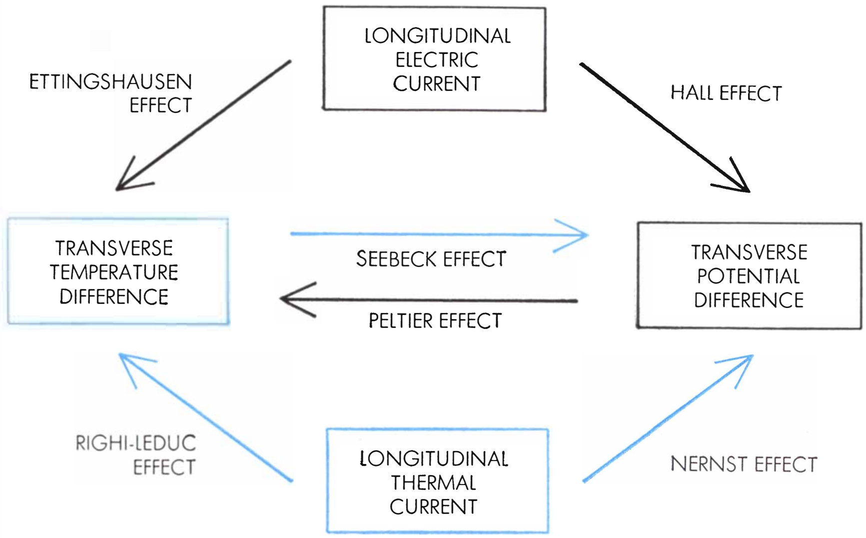
ETTINGSHAUSEN EFFECT is also galvanomagnetic. It is the temperature difference appearing in a direction perpendicular to both the longitudinal electric current and the applied magnetic field.



NERNST EFFECT, or Nernst voltage, is the transverse voltage difference that appears when a magnetic field is applied perpendicularly to a longitudinal thermal current. The effect is thermomagnetic.



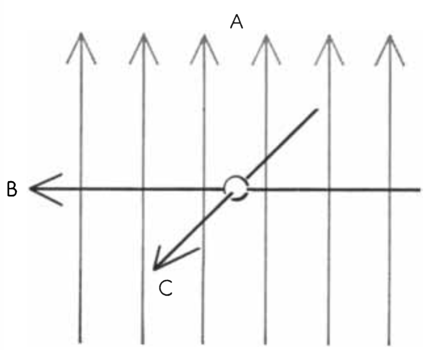
RIGHI-LEDUC EFFECT is the transverse temperature difference that appears when a magnetic field is applied perpendicularly to a longitudinal thermal current. This effect is also thermomagnetic.



EFFECTS AND THEIR CAUSES can be related in this diagram by reading the arrows as "gives rise to." The four galvanomagnetic and thermomagnetic effects (*see illustrations on preceding page*) require a magnetic field; Seebeck and Peltier effects (both thermoelectric) do not. Thus one might read: "A longitudinal electric current in a transverse magnetic field gives rise to a transverse potential difference. This phenomenon is the Hall effect."

length of the strip and to the distance from edge to edge. The direction of the difference reverses with reversal of field or heat current.

Although the thermoelectric effects are not part of the present story, they round out the interrelations among electricity, heat and magnetism. Both have been known since the early 19th century. In one, named for Thomas Johann Seebeck, two unlike metals are joined in two places and the junctions are maintained at different temperatures: a voltage appears between the junctions. The other, named after Jean Charles Athanase Peltier, is the inverse of the Seebeck effect: when electric current is passed through the two conductors, one junction is heated and the other cooled. A pleasing symmetry connects the three types of effect [*see illustration above*].



LORENTZ FORCE (*C*) experienced by an electron (*open circle*) traveling (*B*) through a transverse magnetic field (*A*) is perpendicular to the direction of both motion and field. A reversal of the motion, of the field or of the charge on the particle reverses the direction of the Lorentz force.

Like all atomic phenomena, the galvanomagnetic and thermomagnetic effects can be explained in detail only in terms of quantum mechanics. A simpler "classical" picture, however, can account for them in a general way. Underlying all the phenomena is the Lorentz force, the fundamental interaction between electric charges and magnetic fields. Any charged particle moving through a magnetic field experiences a force that is perpendicular both to its direction of motion and to the direction of the field. The size of the force is directly proportional to the amount of charge, the velocity of the particle and the strength of the field. Reversing the sign (plus or minus) of the charge, the direction of the particle or the direction of the field reverses the direction of the Lorentz force.

If the particle is an electron, both the magnitude and the sign of its charge are fixed. In that case the Lorentz force depends only on the velocity of the electron and the strength of the magnetic field. The direction of the force can be remembered by a kind of left-hand rule: the thumb and first two fingers of the left hand are held at right angles to one another; the index finger is pointed in the direction of the field and the middle finger in the direction of the electron's travel; then the thumb points in a direction *opposite* to that of the Lorentz force [*see illustration at left*].

With the rule in mind, consider the Hall experiment again [*see top illustration on page 130*]. Looking at the metal slab broadside rather than end on, the current flows horizontally. Essentially electric current in a metal is composed of

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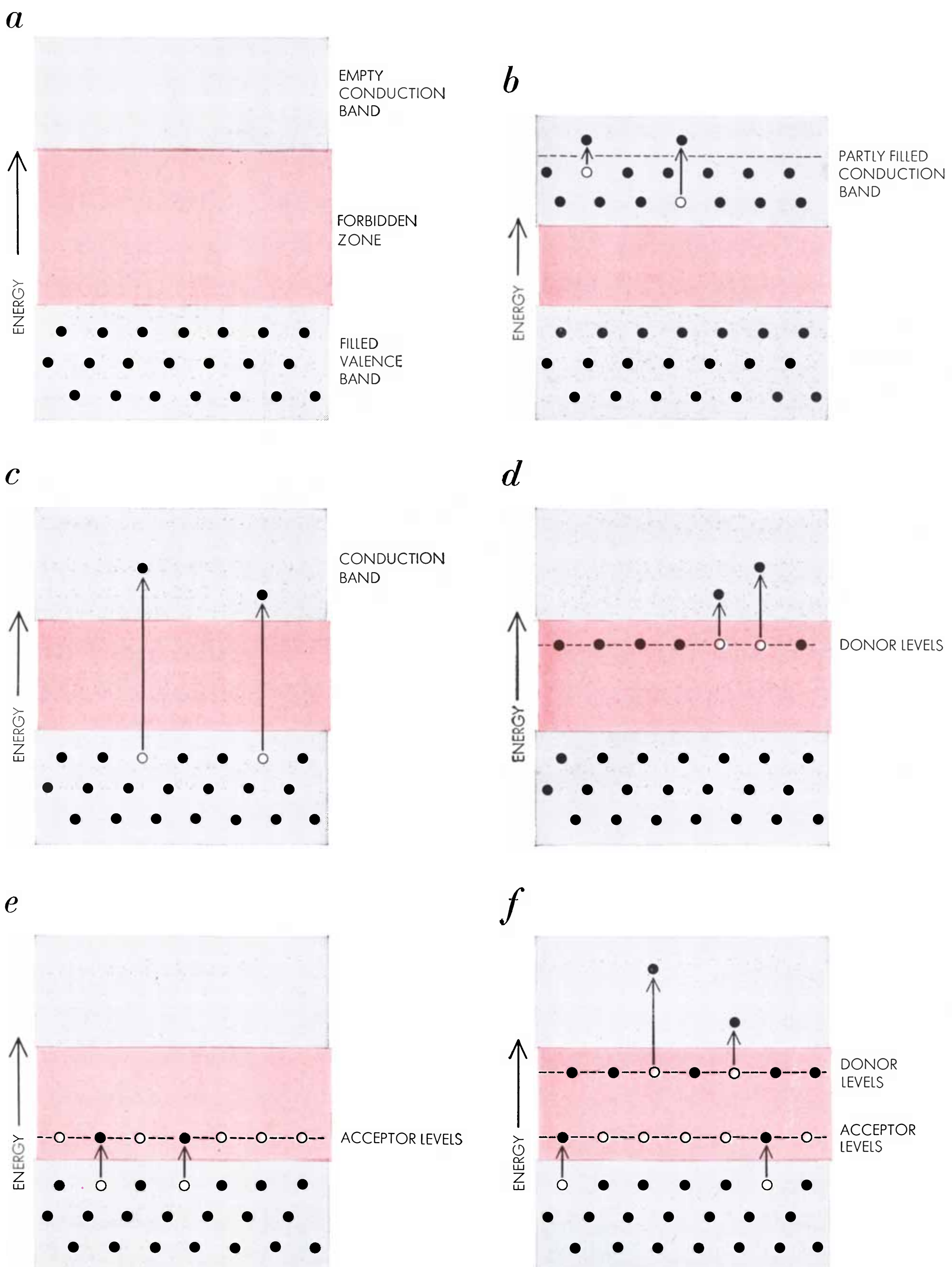


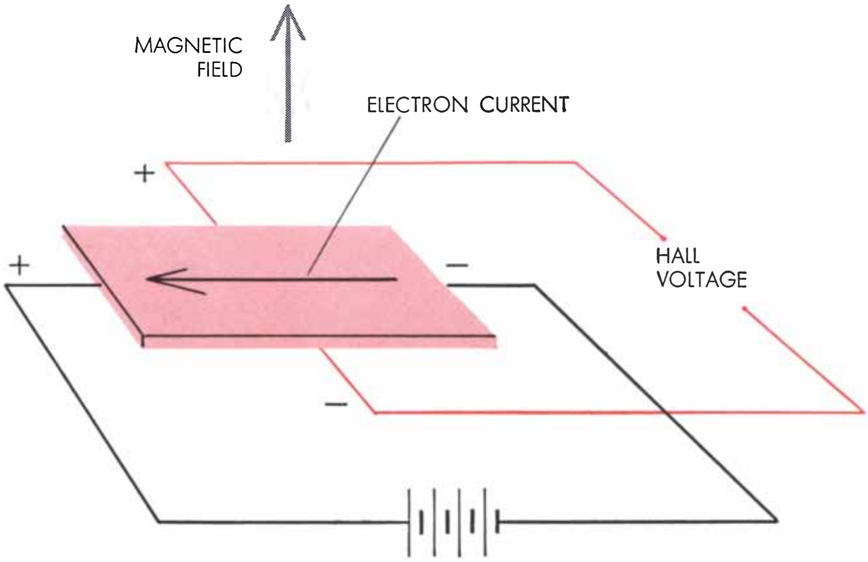
BAND THEORY OF SOLIDS, discussed in the text, describes electrical conduction in terms of allowed and forbidden "bands" (or groups) of energy levels. Represented here are the band schemata of an insulator (*a*), metal (*b*) and four types of semiconductor: intrinsic (*c*), *n*-type (*d*), *p*-type (*e*) and mixed (*f*). Black dots are electrons. An insulator has a wider forbidden zone than a metal or semiconductor. Donor and acceptor levels are energy levels of electrons of donor and acceptor impurities in the semiconductors.

a stream of freely moving electrons. Suppose they move from right to left, as in the illustration. Pointing the left middle finger to the left and the index finger upward along the magnetic field, one finds the thumb pointing toward the back edge of the slab. In other words, the Lorentz force pushes the electrons toward the front edge and they tend to accumulate there, making that edge negatively charged and leaving the back edge positively charged. The diversion of electron flow continues until the negative charge repels electrons from the front edge as strongly as the Lorentz force pushes them toward the edge. From this point on the particles flow parallel to the axis again.

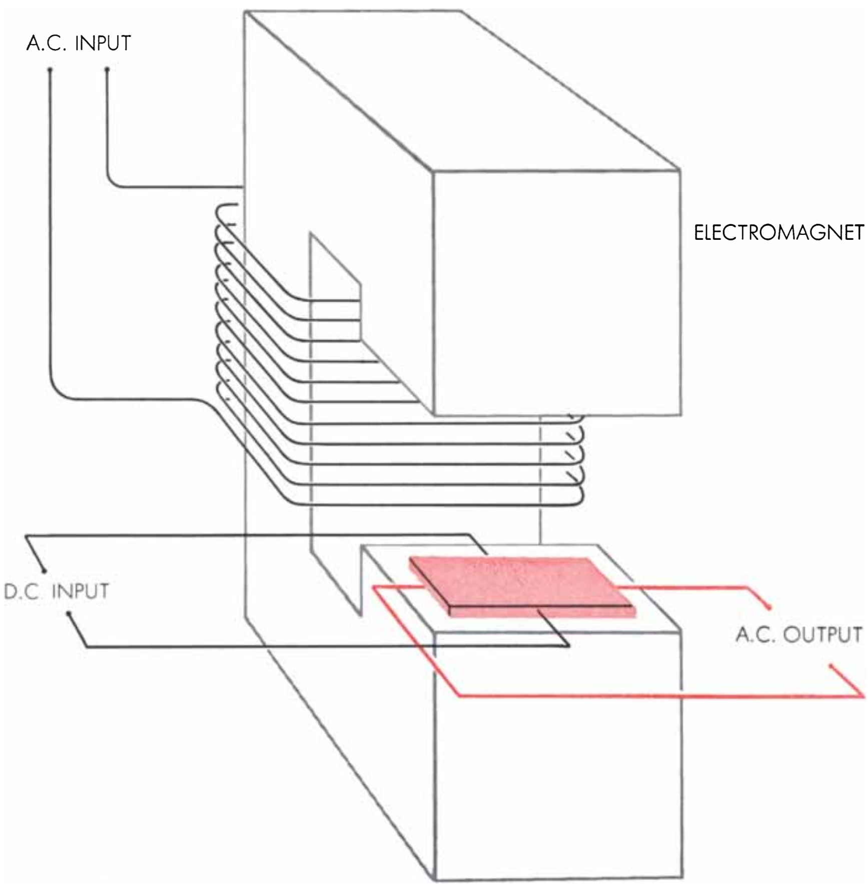
So much for the Hall voltage. How does the same electric current and magnetic field produce the Ettingshausen temperature difference? To account for the latter phenomenon the crude picture of electron flow must be refined. In addition to any motion they may have in response to an applied voltage, the mobile electrons in a metal are always engaged in an irregular, random thermal dance. The actual velocity of any particular electron at a given moment is the sum of its motions due to the electric field and to heat. Therefore, although the average drift velocity of electrons in an electric current is constant, the individual velocities vary over a wide range. Now the faster an electron moves, the greater the Lorentz force a field exerts on it. So the faster-moving particles are pushed more strongly to the edge. Moreover, the faster-moving particles carry more thermal energy. In short, the Lorentz force pushes harder on the "hotter" electrons than on the "colder" ones and builds up a lateral temperature difference.

As for the thermomagnetic effects, the mechanism is very similar to the one just described. In metals heat is conducted largely by a convection current of electrons: the electrons at the heated end are moving faster, on the average, than those farther along, and so energy (that is, particle velocity) diffuses toward the cooler end. Hence a thermal current is in effect a motion of high-speed electrons in the direction of heat flow. The Lorentz force acting on these particles piles up negative electric charge at one edge and leaves the opposite edge positive, producing the Nernst voltage. Moreover, the faster-moving electrons are pushed harder, so that the negatively charged edge is also hotter than the opposite edge. This is the Righi-Leduc temperature difference.

The mechanisms that have just been



HALL EFFECT IN *N*-TYPE SEMICONDUCTOR (*color*) **is the transverse voltage resulting from the deflection of negative electrons toward one edge of the semiconductor. In a *p*-type semiconductor the current direction and Hall voltage are reversed. "Electron current" is to be distinguished from conventional current, which by definition flows from plus to minus.**



AMPLIFIER-CONVERTER depicted here uses the Hall effect to produce an alternating-current (*A.C.*) output from a direct-current (*D.C.*) input. The output (or Hall voltage) is alternating because the Hall crystal (*color*) is subjected to an alternating magnetic field. The output is proportional to the D.C. input and can be further amplified electronically.

described apply to any metallic conductor, but they do not explain why some metals exhibit stronger galvanomagnetic and thermomagnetic effects than others, nor why semiconductors yield much larger effects than any metal. To understand the reason for these differences it is necessary first to look more closely at the process of conduction. According to quantum theory the electrons in a crystalline solid can have certain energies and cannot have certain other energies. On an energy graph the "allowed" energies form a series of virtually continuous bands separated by gaps of "forbidden" energies [*see illustration on page 128*]. The topmost region of allowed energies is called the conduction band; the next allowed region below it, the valence band.

A metal is a solid in which the uppermost occupied energy levels are very close to some unoccupied energy levels; that is, the conduction band is partly filled. This means that if one of the electrons in the band gains energy from an applied voltage, there is a vacant state at a slightly higher energy level waiting to receive it. To put it another way, a partly filled conduction band means that there are mobile electrons, able to accept energy from an external field and therefore to conduct electric current.

In an insulator there are no electrons in the conduction band, and the valence band is full. Moreover, the forbidden gap between the two levels is wide, so that under ordinary conditions a valence electron cannot gain enough energy to jump into the conduction band. And if it cannot get into the conduction band, it cannot accept any energy at all because there is no empty allowed state accessible to it. In short, an insulator has no conduction electrons.

Semiconductors are in some respects like insulators, but in semiconductors the forbidden gap is much narrower. At room temperature or even lower some electrons in the filled valence band have enough thermal energy to jump across the forbidden gap and enter the conduction band. The higher the temperature, the larger the number that will be pushed up. These electrons are then free to accept electrical energy and to move through the material. In addition, the sites, or "holes," left vacant in the valence band become charge carriers in themselves. An electron near a hole can jump in and fill it, leaving a new hole in the place it had occupied. This in turn can be filled by a neighbor farther along, and so on. Current is actually carried by electrons moving in relays, but it can

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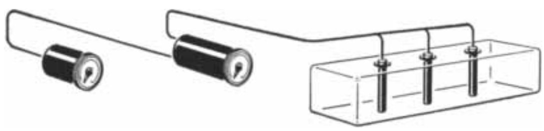

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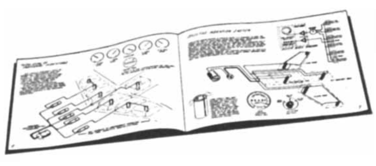

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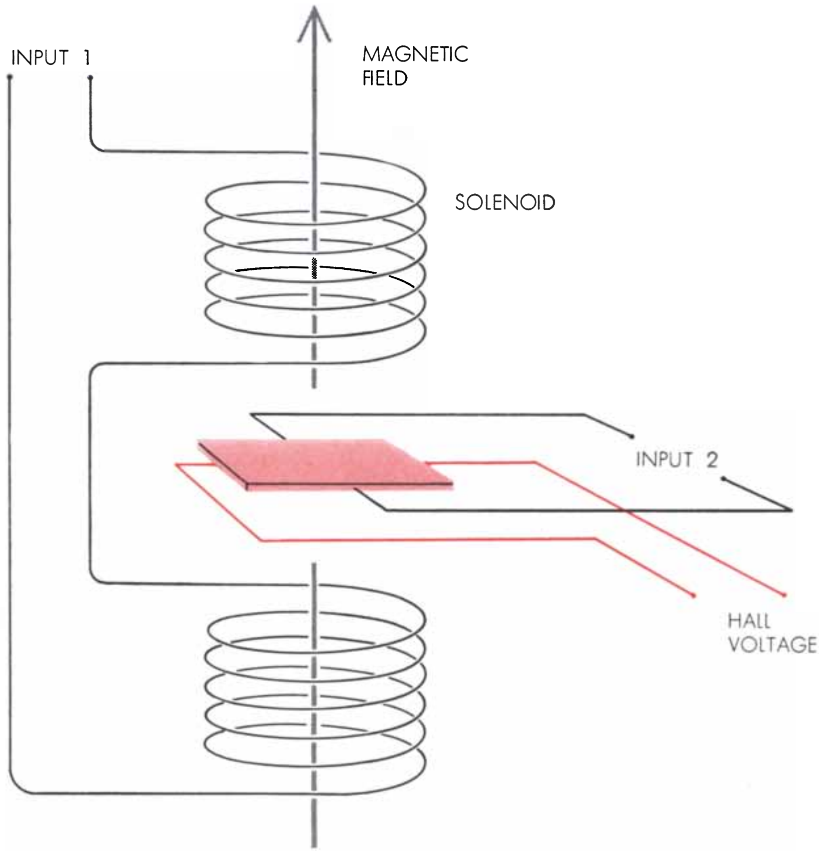
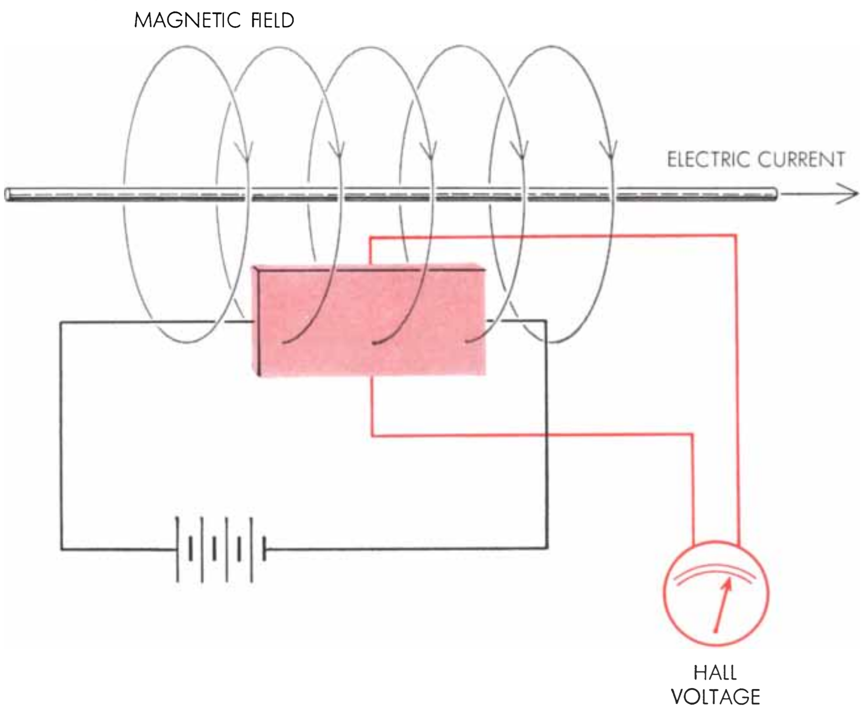


SIMPLE MULTIPLYING CIRCUIT consists of a Hall crystal (*color*) and a solenoid. Since the Hall voltage is proportional to the primary input (*Input 2*) and to the solenoidal current (*Input 1*), which determines the magnetic-field strength, this type of circuit can be used to compute the product of any two quantities that can be represented by an electrical input.



CLIP-ON AMMETER is essentially a Hall crystal (*color*) located to intercept the magnetic field around a conductor. Since the Hall voltage is proportional to the magnetic-field strength and hence to the current in the conductor, this current can be calibrated directly in amperes if the primary input (from a battery) to the Hall crystal is accurately known.

equally well be pictured as a flow of positive holes in the opposite direction. In "intrinsic" semiconductors, such as very pure germanium or tellurium, this is the whole story. Electric current is carried equally by mobile negative electrons and mobile positive holes.

Most semiconducting materials have more free electrons than holes, or vice versa. In these "extrinsic" semiconductors most of the charge carriers are provided by small numbers of impurity atoms. If the impurity atoms have an excess of electrons compared with the atoms of the main material and the electrons have an energy not far below the level of the conduction band, they are easily excited into the conduction band. The impurity acts as a donor of electrons and the material is said to be of the *n* type, meaning that most of its charge carriers are negative. On the other hand, the impurity atoms may lack electrons compared with the base material and have an energy placing them slightly above the top of the valence band. The impurity can then accept electrons raised out of the valence band by thermal energy and so create mobile positive holes. This is a *p*-type semiconductor. Sometimes both acceptor and donor impurities are added to provide a mixed type of extrinsic semiconductor.

Compared with metals, all types of semiconductors are poor in charge carriers. Intrinsic indium antimonide, for example, has about one charge carrier per million atoms at room temperaure; copper has one for each atom. It is precisely this paucity of carriers that makes semiconductors strongly galvanomagnetic and thermomagnetic.

To see why, consider the Hall phenomenon again. The Hall voltage (as well as each of the other effects) is produced by the action of the Lorentz force on moving charge carriers. (The force can be thought of as acting directly on positive holes in a direction opposite to the force on a negative charge. Actually it is exerted on the counterflow of electrons.) The faster the carriers move, the greater are the force and the voltage.

Imagine the Hall experiment performed with two strips of the same dimensions, one copper and the other indium antimonide. The electric current is made the same in each, and they are placed in equal magnetic fields. The number of carriers flowing in the copper is many times greater than the number flowing in the indium antimonide. If the total current—that is, the rate of charge transfer—is the same in each, the

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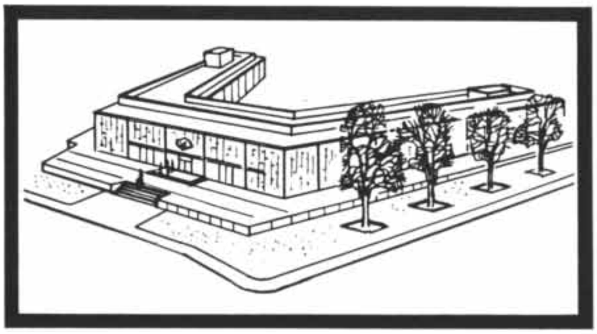

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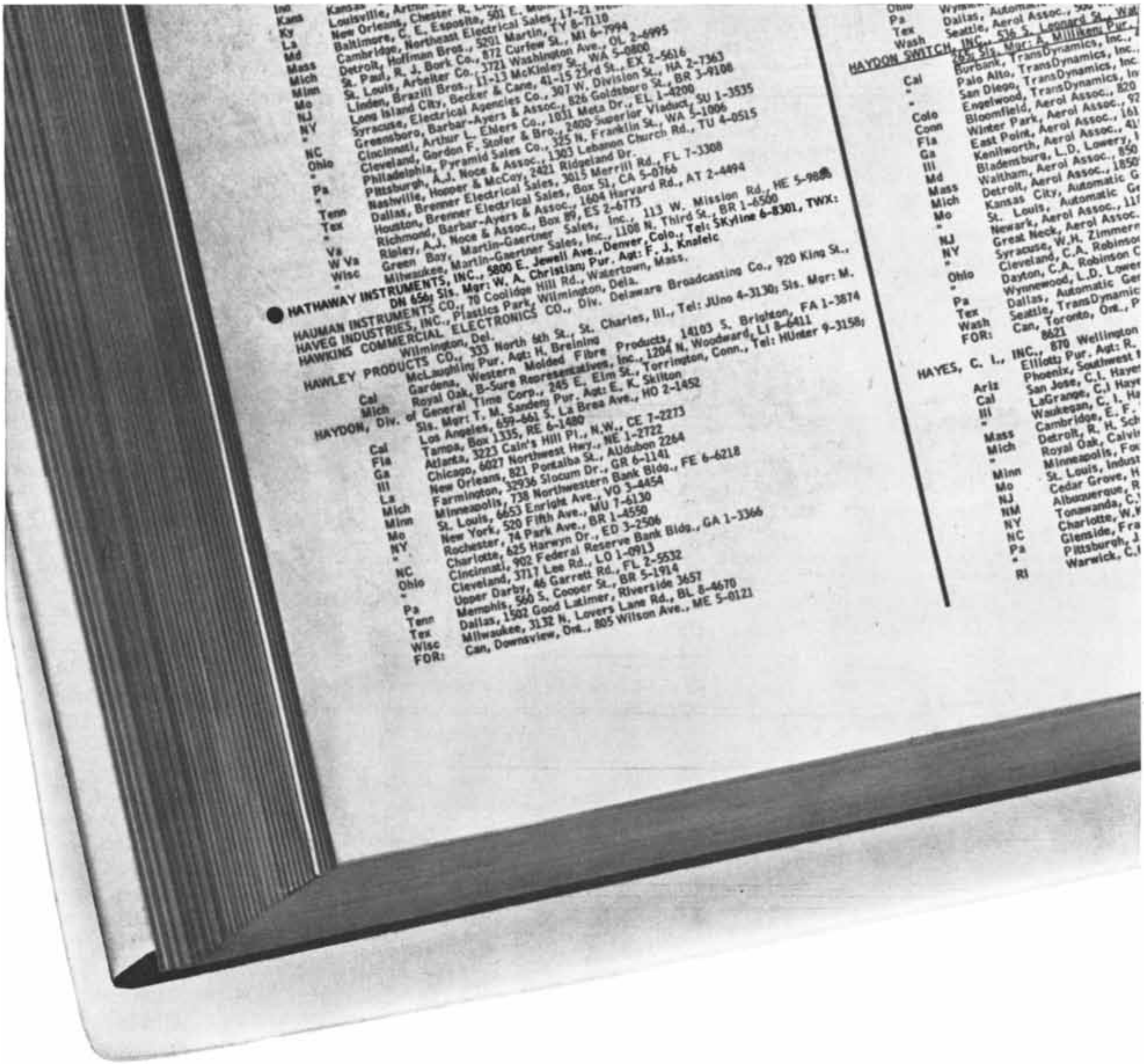
carriers in the indium antimonide must have a much higher drift velocity than those in the copper. For this reason they experience a stronger Lorentz force, and this in turn means a larger Hall voltage at equilibrium. In fact, in indium antimonide the Hall effect is about a million times greater than the effect is in copper. The Ettingshausen, Nernst and Righi-Leduc coefficients are also comparably larger.

If semiconductors have enhanced the importance of the Hall effect, it is also true that the Hall effect provides a powerful means of studying semiconductors. In the first place, almost all the large-scale results of passing a current through a semiconductor are identical regardless of whether it is *n*-type or *p*-type. Not so the Hall voltage. If a current is carried predominantly by electrons traveling, say, from right to left as in the case already discussed, the electrons tend to pile up at the front edge, making it negative and the back edge positive. But if the same current is carried chiefly by holes moving from left to right, the force on the holes is in the same direction—toward the front. This is because both the sign of the charge carrier and its direction of motion have been reversed. Therefore positive charge now builds up at the front and the direction of the voltage is reversed. By observing the polarity of the Hall voltage it is possible to distinguish between *n*-type and *p*-type materials.

As has been mentioned, the number of available charge carriers in a semiconductor increases with temperature; the more charge carriers, the lower the Hall voltage. Measuring the Hall effect at different temperatures is a way of determining the number of free carriers at these temperatures, and therefore the energy required to activate the donor or acceptor atoms.

In addition to its use as an experimental tool, the Hall effect has already found a number of practical applications. Perhaps the most obvious is in measuring the strength of magnetic fields. A semiconductor strip is placed in an unknown magnetic field with its plane perpendicular to the field direction, and a small, accurately known current is sent through it. The Hall output voltage is then proportional to the unknown magnetic field. The voltmeter on which the output is read can be calibrated directly in units of magnetic-field intensity.

Devices operating on these effects have an inherent advantage over other semiconductor arrangements: they can



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isolate the input or control circuit from the output circuit. Just as in a transformer, a magnetic field connects input and output, which are electrically separate. An example of this type of application is a converter-amplifier [*see bottom illustration on page 130*]. A direct current is fed as an input to a semiconductor strip located in the field of an electromagnet. The coils of the magnet carry an alternating current of constant amplitude, giving rise to an alternating magnetic field. The Hall voltage taken off the strip is therefore an alternating voltage, the size of which is proportional to the direct-current input. The output can be fed into an electronic amplifier, and the result is a high-gain, low-noise, stable, direct-current amplifier with no moving parts such as are present in mechanical commutating devices.

Since the Hall voltage is proportional to both the primary exciting current and the magnetic field strength, it in effect multiplies these two quantities together. This fact can be put to use in analogue computers. A Hall element is placed inside a wire solenoid, and two direct currents are fed in, one to the solenoid and the other to the element itself. The magnetic field is proportional to the solenoid current and therefore the Hall output voltage is proportional to both currents; in other words, to their product.

One of the simplest Hall-effect instruments is a clip-on ammeter. It operates on the magnetic field that is set up around any current-carrying conductor. The ammeter is located so that it intercepts this induced field while a small, accurately known primary current from a battery is supplied to the device. The Hall output voltage is proportional to the magnetic field, which is in turn proportional to the current in the conductor. The output meter can be calibrated directly in amperes. Both alternating and direct currents, ranging from one milliampere to thousands of amperes, can be measured by Hall effect ammeters.

Recent studies in both the U.S. and Australia suggest the possibility of utilizing the Ettingshausen effect as a practical means of refrigeration. The work is still in its early stages, but with the advances that are being made in materials and construction technology, an Ettingshausen refrigerator should be realized in the next few years.

Probably the most obvious application of all is one that would make use of the Nernst effect as a means of converting heat directly into electricity. This exciting possibility awaits exploration by the many engineers and scientists now working in the field of direct conversion.

PREHISTORIC SWISS LAKE DWELLERS

For a century it has been widely accepted that the early Swiss built their houses on stilts over a lake. New excavations at the Lake of Burgäschi have shown that this quaint picture is mythical

by Hansjürgen Müller-Beck

Nearly everyone has heard about the lake dwellers of prehistoric Switzerland, who are said to have built their houses on stilts out over the water. There they were, in the land of the Alps, living like South Sea Islanders!

One man is primarily responsible for this rather romantic idea. In 1854 Ferdinand Keller, a reputable Swiss archaeologist, reported on a field of upright wooden pilings extending a few inches above the shore of the Lake of Zurich and exposed to view by a fall in the water level. Ethnologists had recently described whole villages in the Pacific islands that were built over water, the houses standing on platforms supported by logs driven into the water bed. With this image in mind, Keller proceeded to enlarge on the Zurich pilings. In prehistoric times, he wrote, Switzerland had been inhabited by people who lived in villages built on platforms over lakes [*see top illustration on opposite page*]. The statement found such immediate and widespread support that it was passed on virtually unaltered for nearly 100 years, not only in popular books on archaeology but in professional works as well. Tourists visiting southern Germany can still explore a life-size reconstruction of a pile dwelling that gives them a vivid and "authentic" view of this peculiar culture.

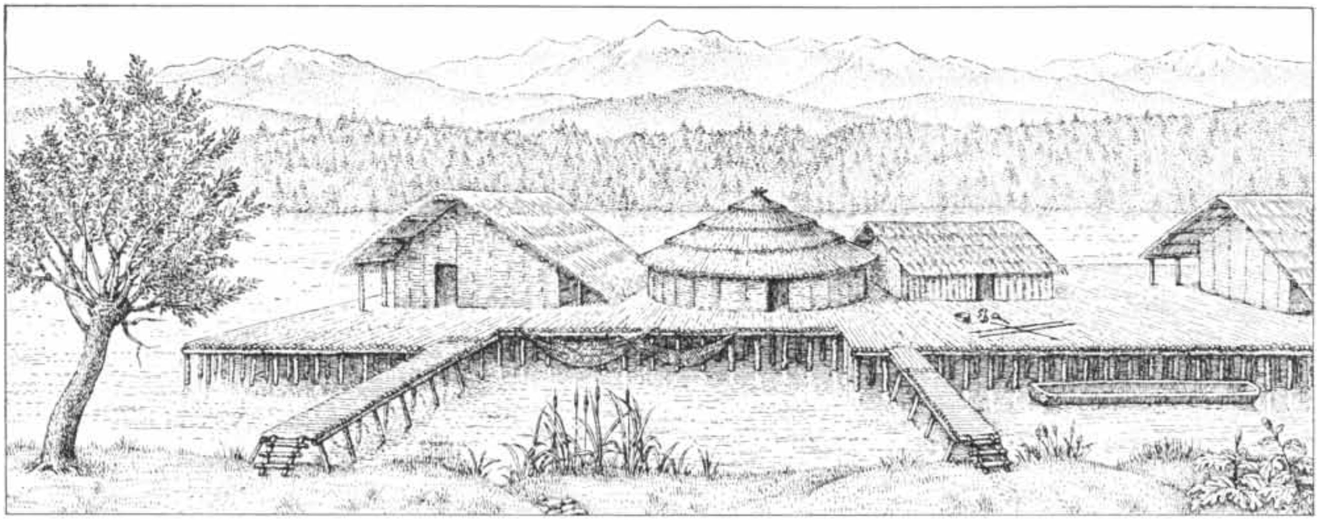
Nonetheless there is increasing evidence that Keller was wrong and that his less well-known colleague, Albert Jahn, was closer to the truth. Four years before Keller published his views Jahn had written about another pile field, this one a few yards off the shore of the Lake of Bienne and completely submerged beneath its waters. Like Keller, Jahn believed that the pilings had once served as part of a settlement. In Jahn's opinion, however, they had provided foundations for houses standing on the ground. The lake, he suggested, had advanced in the intervening centuries; where there now was water there had once been shore.

But Keller's hypothesis was not only more attractive; it also seemed to be supported by an abundance of evidence. Everyone interested in archaeology and ethnology was familiar with the pictures of South Sea island villages in travel books. What was more natural than to assume that prehistoric people should have lived like contemporary preliterate ones? Pile fields were discovered in great numbers as a result of the irrigation projects carried out in Switzerland between 1860 and 1880. Keller's pile field on the shore was an exception; in virtually every other case the upright logs were found in areas previously covered by lake water.

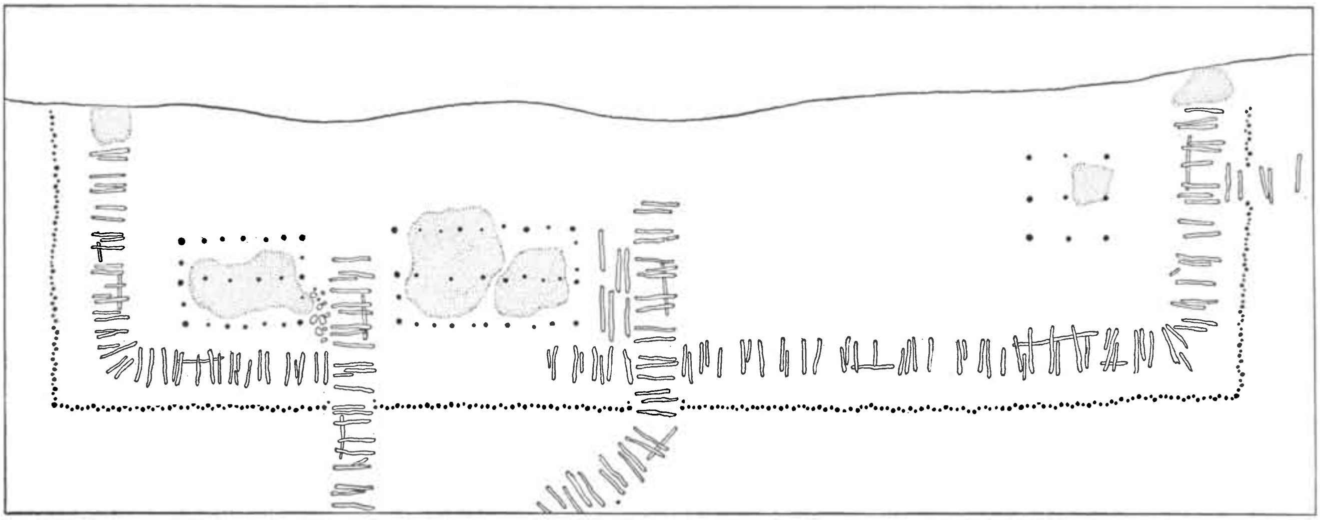
Keller's hypothesis was in fact just as speculative as Jahn's. But speculation was about all that archaeology could offer at the time. The methods of geological investigation then in use could not accurately determine dates for the construction of the pile fields. No one knew how to read the evidence in the layers of soil, lake sediment and rubble in which the piles stood. Such "culture layers" usually represent the floors of ancient dwellings; in Keller's interpretation they were made up of the refuse thrown into the lake from the platforms of the pile dwellings. But the techniques of archaeology did not yet allow detailed examination of the pile fields without such disturbance of the evidence they contained as to render almost worthless any judgment that might be made. Not until the 1920's, when systematic excavations were undertaken in a group of pile fields in southwestern Germany, did it become possible to make a genuinely scientific appraisal of the situation. From that time on the Keller hypothesis was thrown open to serious question, and the "pile-dwelling problem," as it is called, became the subject of lively debate among archaeologists. As techniques of investigation were refined, it became clear that Jahn's view conformed far better to the facts than Keller's. By now it is widely agreed that the pile dwellers of prehistory lived on the shores of lakes, not on platforms over their waters.

My own concern with the pile-dwelling problem dates back to 1957, when, under the auspices of the Bern Historical Museum, I began excavations on the shores of the Lake of Burgäschi, in the Swiss midlands. This is a small lake, with a diameter of only about a third of a mile. Nevertheless, four separate and distinct Neolithic settlements have been found on its shores. One, excavated in the 19th century, was so badly disrupted that its archaeological value was completely destroyed. Two others have been only partially excavated in more recent times. The fourth, on the south shore of the lake, was the object of our investigation. We have studied it in detail and, although a final report of the findings will not be completed until 1963, the major outlines are clear. Our work has served two important purposes. It has helped to fill in the picture of Neolithic life in Europe north of the Alps and it has contributed significantly to a solution of the pile-dwelling problem.

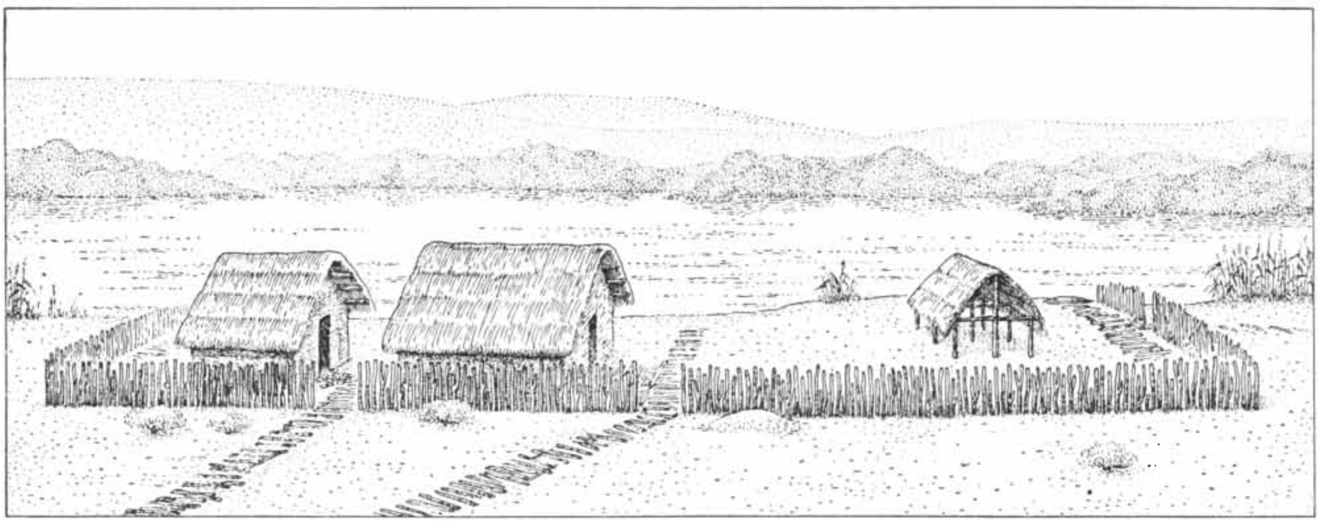
Our first view of the south site was of a reedy shore behind which, at a distance of from five to 10 yards, begins the growth of bushes and trees that gradually deepens into true forest. A few piles protrude from the lake bed near the shore, but none reach as high as the sur-



PREHISTORIC SWISS PILE DWELLINGS were thought to have stood on platforms over lakes, like villages in certain Pacific islands. This drawing is based on a reconstruction that was proposed in 1854 by Ferdinand Keller, who originated the notion.



PILES AT BURGÄSCHI, found on lake shore, are shown as dots on this schematic representation of the top layer of the excavation. Shapes with irregular outlines are mounds of loam and rubble. Strips are remains of corduroy log road of the settlement.



PILE DWELLINGS at excavation site stood on the lake shore, as this reconstruction shows. Piles were driven into the ground to support houses and roads of the settlement. Pile dwellings here, among the most primitive excavated, date from Neolithic period.

face of the water. Nor are any visible along the beach; all are hidden beneath the layers of topsoil and lake sediments that have been laid down during the thousands of years since the area was occupied. Under these layers we found piles in profusion, more than 3,000 of them. Most are the trunks of alder, ash and young oak trees, and they measure from about three to seven and a half feet in length and from five to six inches in diameter. Originally set in the ground in a vertical position, they are now tilted at an angle, with their upper ends pointing out toward the lake. The logs that formed the roads of the settlement are still lying in the horizontal position in which they were originally placed. In addition to the piles, our excavations revealed parts of the walls and roofs of buildings and the mounds of loam, branches and rubble that served as their floors. What is more, we have uncovered artifacts and other remains that have helped us visualize the culture of the people.

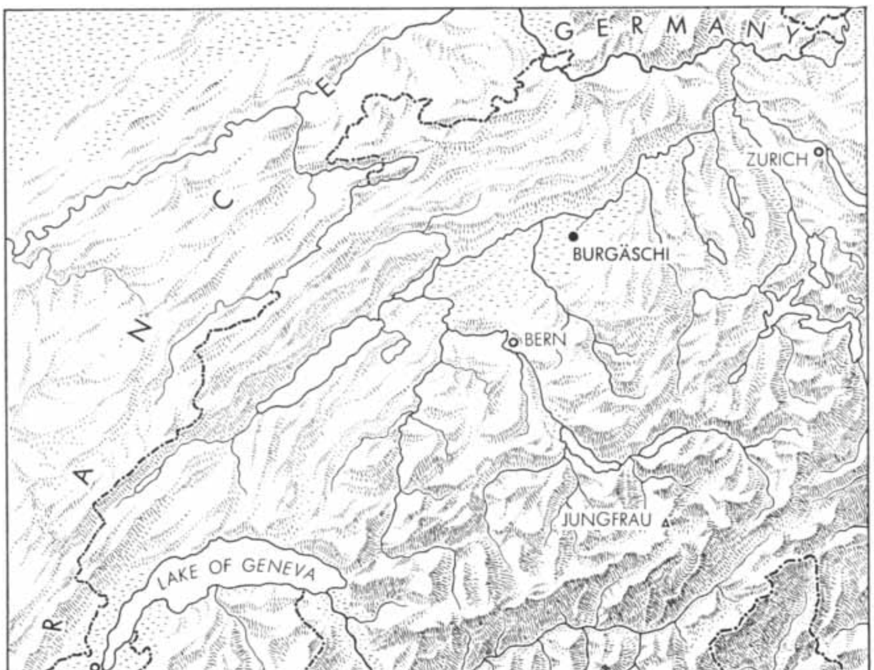
Radiocarbon measurements show that the pile dwellers lived at the south site in the first quarter of the third millennium B.C. and remained there approximately 100 years. When they arrived, they found a broad and treeless strip of land that was ideal for cultivation. The lake, of moderate size when it was formed in the last ice age, had been gradually retreating, leaving on its shores mollusk shells and the deposits of carbon and lime that form around the roots of water plants. The soil cover was still too light to permit trees to take root and grow, but it was quite heavy enough for the demands of primitive agriculture, and its mineral-rich substratum was a guarantee of fertility.

If this stretch of virgin land was ideal for farming, it had serious drawbacks as a living place. The subsoil was wet and far too weak to hold the weight of houses. Structures built on it would have sagged and tilted within a short time if the builders had not found ways to secure the foundations. To make floors for their houses the settlers employed the older mesolithic technique of putting down layers of rubble, branches and soft earth, which they pounded into a smooth, firm surface. They then secured the underpinning of these floors by driving piles through the sediment down to the underlying gravel of bedrock.

Only a small fraction of the upright logs we uncovered at Burgäschi had formed part of the framework of the rectangular houses. By far the greatest number were anchor posts, driven into the ground to provide a firm base for the houses, for their loam floors and for the corduroy log roads of the settlement. But the anchor posts that were sunk when the settlers first arrived do not seem to have been adequate to support the community for the entire span of its occupancy. Whether the lake level rose with the passage of time or whether the buildings gradually sank into the wet ground despite the anchor posts is not known. In any event, it is clear that the settlement was often in need of repair. The floors sank in the middle as the earth beneath them gave way. For a while they could be leveled by the addition of new layers of rubble, branches and loam, and for as long as this expedient served, the houses were safe. But eventually more drastic action became necessary and the entire settlement had to be moved a few feet back from the lake, onto drier land. Each time the move was made, new anchor posts were sunk to support the new constructions. The piles that represent building foundations are disposed in overlapping layers, one behind and beneath another, in much the same manner as roofing tiles. Each layer is evidence of a new move back from the shore.

It was from the last layer, closest to the surface and consequently easiest to distinguish from the others, that we were able to reconstruct the appearance of the settlement during its final stage [*see middle and bottom illustrations on preceding page*]. At that time the entire settlement measured about 50 yards long by 10 yards wide. Among the piles we found were those that represented the remains of the palisade fence that enclosed this area on all but its lake side. Both outside and inside the settlement were a number of piles that had served as anchor posts. These supported two corduroy log roads, the remains of which we also found. The roads ran through two openings in the fence on the inland side and branched to lead to the fronts of the houses and to traverse the inner boundaries of the settlement. The fence had still a third opening, on the narrow side of the settlement near the shore. The road through this opening was only lightly reinforced, secured by fewer anchor pilings than the others.

Inside the settlement were three struc-



BURGÄSCHI is shown as black dot on this map of Switzerland. Lake of Zurich (*upper right*) is site of early discovery leading to idea that pile dwellings were built over lakes.

EXCAVATION AT SOUTH SITE revealed loam floors of houses and piles supporting them. Seen here is part of the floor of the larger house. Four-meter rule shows its size. Light area around floor is chalk, which lies immediately under the culture layer.

WOODEN HOE was found resting on chalk layer after excavation of the culture layer. The wet subsoil of the lake shore at Burgäschi acted as a barrier to air and so preserved logs and wooden implements of the settlement in good condition for more than 4,000 years.

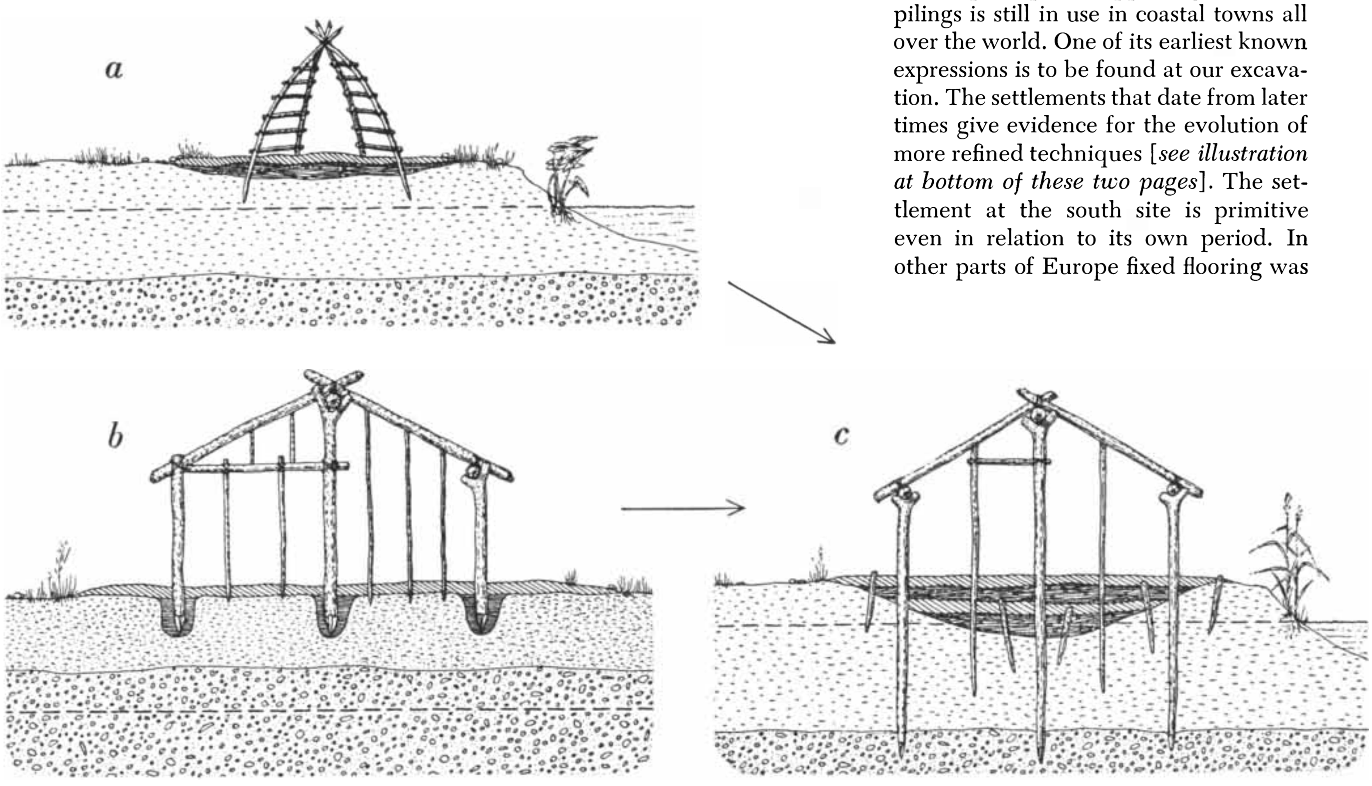
tures. One, on the eastern side, was very small. There is no evidence that it had walls; only posts seem to have supported its roof. From this fact and from the fact that its loam floor was rather thin, we deduce that it was not used as a dwelling but for some other purpose. It may have been a granary, a working place or possibly an enclosure for small domestic animals.

The two larger structures were obviously dwelling places. The roof of the smaller of them was partially preserved, as were parts of the walls of both and the logs that served as their framework. This evidence makes the structure of the houses clear. They had pointed gable roofs, made of grass and reed. The unplastered walls were made of wickerwork and well-finished board about half an inch thick. On each of the thick loam floors was a fireplace, the position of which seems to have been changed several times. The doors of the houses faced away from the prevailing wind and gave on the corduroy roads that led outside the settlement. Since the walls were no more than three feet high, the houses must have been close and dark. But they were adequate as shelters against the night and bad weather.

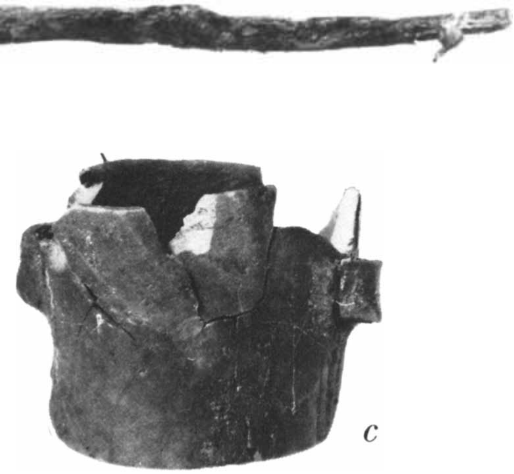
The construction of the houses thus combined common primitive techniques with an innovation dictated by the peculiarities of the lakeside terrain. As far back as 5000 B.C. men were using branches and loam to form a thick flooring for the crude, dome-shaped huts they built on the shores of lakes. By 4000 B.C. the inhabitants of southern Europe knew how to construct a rectangular house with a gabled roof and a framework of logs driven into the ground. The people who lived at the south site combined these two old principles and so produced a new kind of structure. Their gabled houses had log frames and loam floors and were secured by pilings driven deep into the ground.

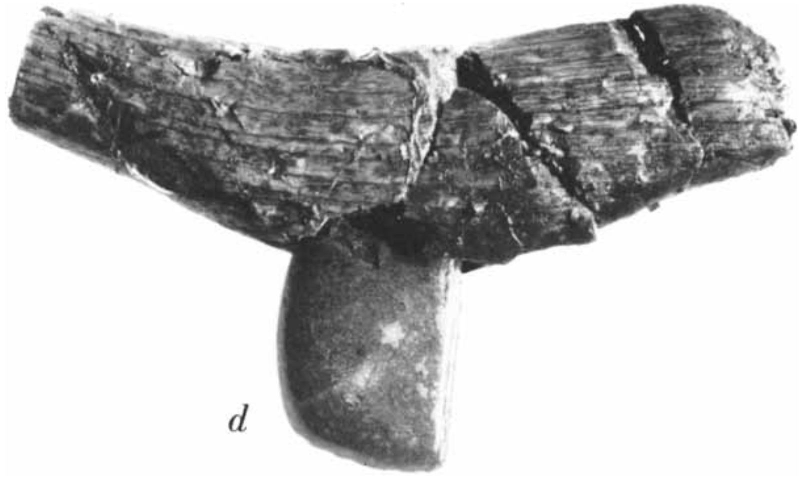
This principle of supporting houses on pilings is still in use in coastal towns all over the world. One of its earliest known expressions is to be found at our excavation. The settlements that date from later times give evidence for the evolution of more refined techniques [*see illustration at bottom of these two pages*]. The settlement at the south site is primitive even in relation to its own period. In other parts of Europe fixed flooring was

IMPLEMENTS found at Burgäschi, seen here about half-size, showed differences in care of workmanship that were probably intentional. The arrow (*a*), with a wooden shaft and a



EVOLUTION OF SWISS PILE DWELLINGS is outlined in these drawings. In 5000 B.C. floors of mound-shaped lake-shore huts were reinforced with loam and rubble (*a*). By 4000 B.C. gabled rectangular houses with framework of posts driven into the ground were built in southern Europe (*b*). At Burgäschi, occupied approximately 1,000 years later, these techniques were combined to





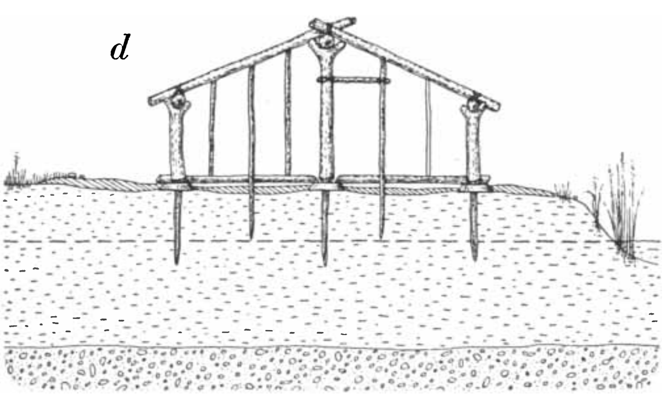
stone head, is the first such weapon discovered at a Neolithic site in Switzerland. The bone blade set in unworked wood (*b*) is highly polished. The cylindrical vessel (*c*) is made of well-finished wood. The ax (*d*) has a stone blade and a broken wooden shaft.

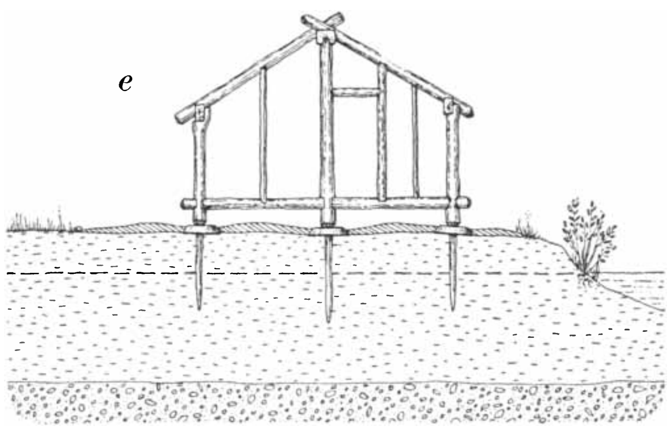
already in use. By the time of the Copper Age and the Bronze Age the pile dwellers of Switzerland knew of it too. By then they also had metal tools with which to work wood. Their lake-shore settlements were constructed with wooden floors and supported by piles driven into the earth at one end and at the other into wooden plates, called ground plates, that served as the base for the flooring.

It is even possible that in time the pile dwellers learned to raise their houses slightly above the ground, as houses are today elevated in coastal communities in order to prevent the floor boards from rotting quickly. Since the ground level at different sites dating from the Copper Age and Bronze Age has not yet been fixed, it has not been determined whether or not the more sophisticated pile dwellings elsewhere in Switzerland really reflect this refinement. Such a construction, if it was used, may sound reminiscent of the Keller hypothesis. Actually it has nothing to do with it. Keller had in mind entire settlements built on platforms over lakes. The present view is that the pile dwellers lived on the shores of lakes in houses with foundations reinforced by pilings.

The sealed, wet layers of clay, loam and lake sediments that preserved the piles at the south site also preserved other evidence of the life and culture of its people. Within the boundaries of the settlement was a layer of buried rubble, and scattered profusely through this culture layer were artifacts and objects of all kinds. There were the bones of animals, more than 80 per cent of them the bones of such wild species as deer, aurochs, boar, fox, beaver and bear. The remainder represent the remains of domesticated species such as pig, goat, sheep and dog. From this it is clear that although the settlers were stockbreeders, the hunting tradition was still strong. There were also flax and grains of cereal, as well as hazelnuts, berry seeds and mushrooms. This again is evidence that, whereas the settlers knew how to raise crops, they still obtained a good part of their food supply by the more primitive methods of gathering.

In these respects the people here were less advanced than contemporaneous peoples in Switzerland and other sections of Europe north of the Alps who





produce gabled rectangular houses with loam floors supported by underground pilings (*c*). By about 2000 B.C. wooden floors were in use and lake-shore houses were supported by pilings driven into the ground through wooden plates beneath the floors (*d*). It is possible that in later times pile dwellings may have been elevated a little above the ground, as they are in coastal towns today (*e*).

were joined with them in the same pottery tradition. Our work uncovered hundreds of crudely shaped, unornamented ceramic pots of a type called Cortaillod, after the site on the Lake of Neuchâtel where they were first found. Other people who made this ware were primarily farmers and stockbreeders; the hunting and gathering component of their culture was far less important.

We uncovered many other artifacts: stone hatchets and knife blades, flint arrowheads, bone chisels and awls, harpoons and drinking cups made of deer horn. Among the most interesting of our finds were wooden implements, preserved for more than 4,000 years in the wet, airless ground. There were handles of hatchets, knives and sickles; clubs, mallets, short lances and drills used to make fire. There was also the shaft of an arrow with a stone arrowhead still fixed on it.

Perhaps the most interesting find was a string of copper beads, which had been placed near the wall of the smaller of the two houses. The beads, graduated in size and strung on thin cord, were

CLAY POTS were found at Burgäschi by the hundreds. All were crudely shaped and undecorated. Such ware, called Cortaillod, is the most common type found at excavations of Neolithic sites in Switzerland.

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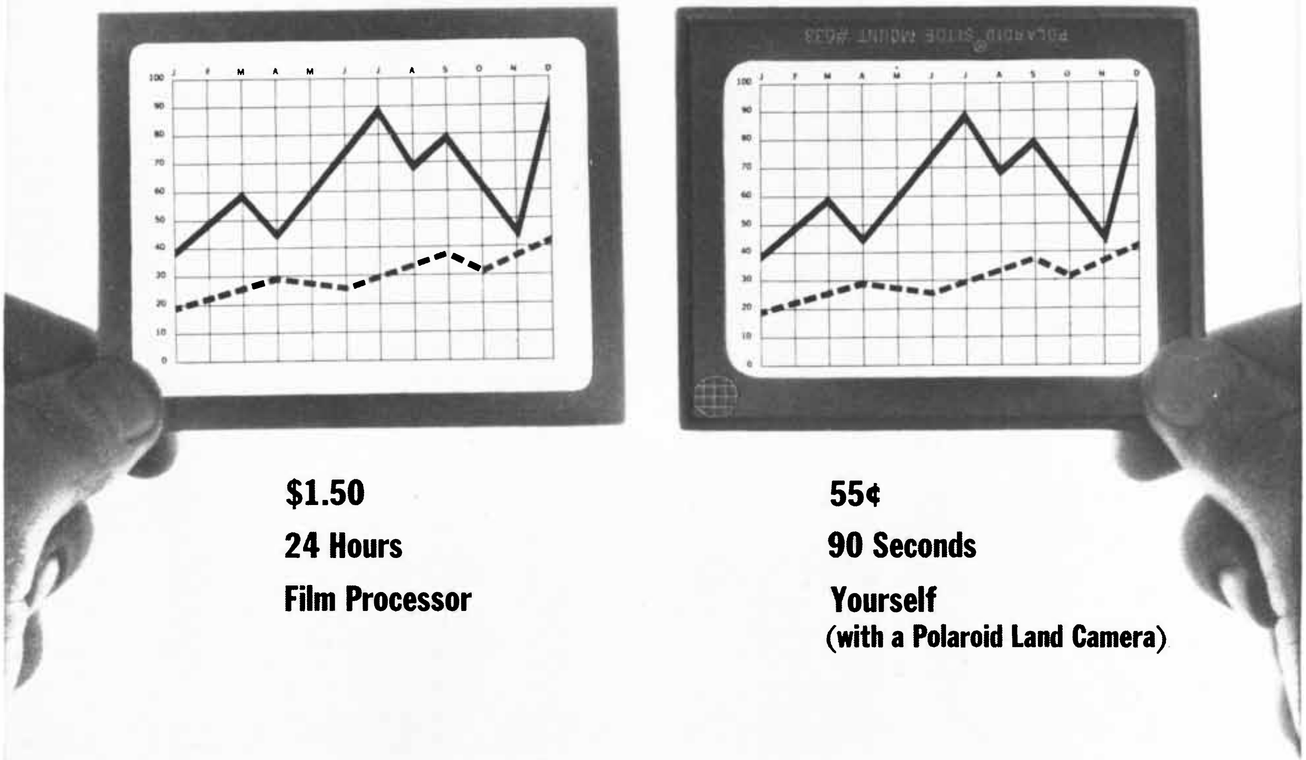

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made of a material rare in this part of Europe during the Neolithic period. Copper ore was commonly found much farther south, east and west. The beads are a strong argument for the beginning of trade that was to link the hinterlands of the Alps with the high civilizations of the Mediterranean.

We found some human teeth but no human bone at all. This is somewhat unusual for an agricultural Neolithic settlement, where archaeologists generally recover both the skeletons of buried dead and isolated bones often considered to be evidences of cannibalism. Our failure to find any human bone is another indication of the strength of the hunting tradition among these people. Hunters are rarely cannibals, and they seldom bury their dead. They leave the bodies in the open air, where scavenging and decomposition cause all traces of them to disappear.

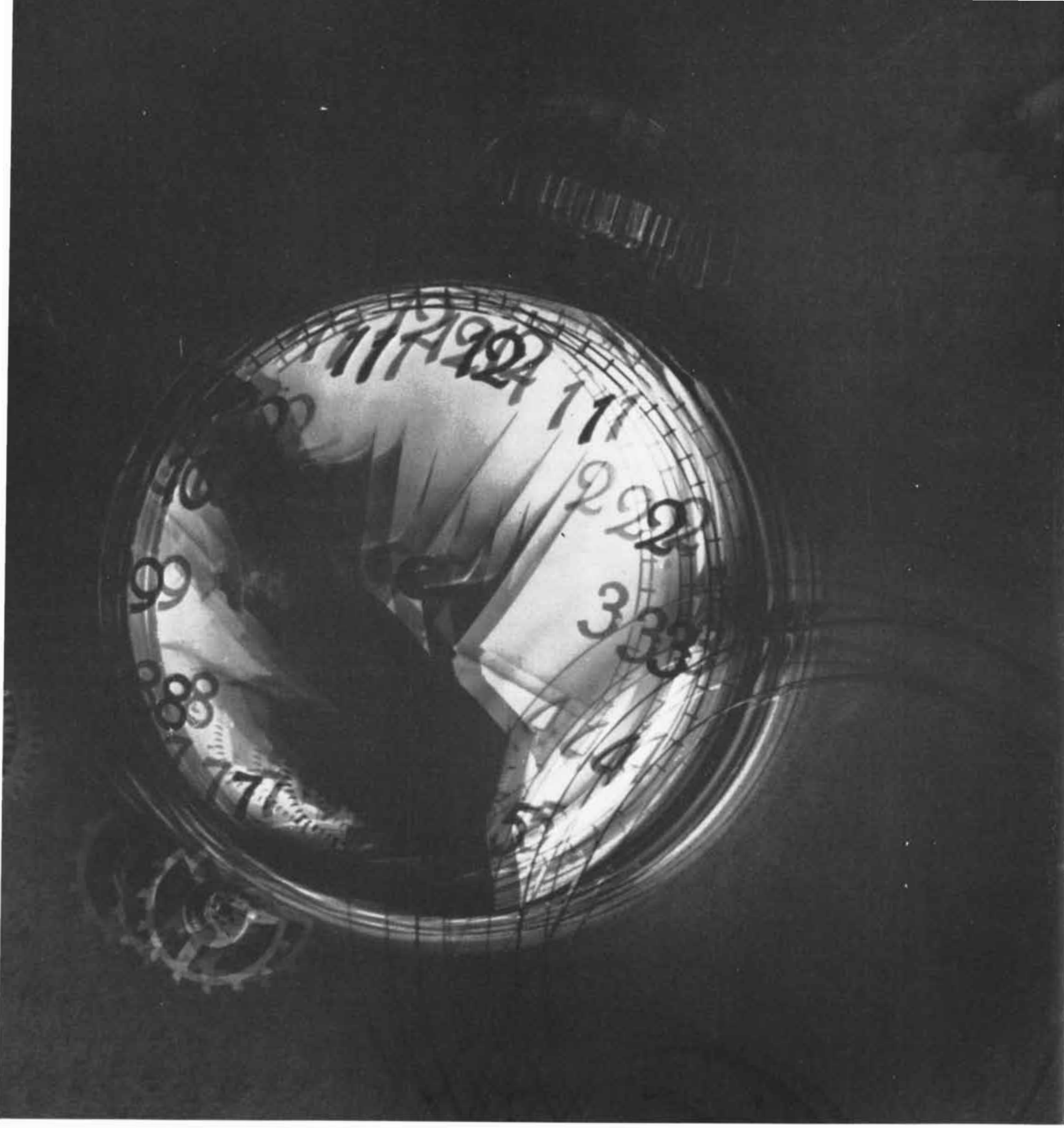
From the size of the settlement and from what we know about the size of hunting groups we deduce that the entire community at the south site consisted of no more than two or three families, perhaps three generations in lineal descent. There may have been as many as 40 people; the number of animal bones we found suggests that the food supply was adequate for a group of this size. But it is more likely that the total population was between 20 and 30.

In such small groups social organization is generally loose, and the evidence suggests that the members of this community lived together on a basis of equality, with people coming and going as they chose. The separate entrances in the fence that surrounded the settlement and the separate roads to the houses within it would not have been found in a larger community, where relatively tight regulations usually govern the behavior of its members.

Yet such tight social organization was already operative in many parts of the world. The great temples and pyramids of Egypt are contemporaneous with the tiny settlement we excavated. Beyond the Alps and across the Mediterranean a complex culture was reaching a zenith at the same time that the modest culture of the pile dwellers was beginning to emerge. Switzerland, in a sense, was a backwater, but it was a corner of the world in which people could enjoy social individuality, a quality of life that has not been suppressed in this part of Europe even for a short time up to the present day.

The singular innovation in engineering that gives the pile dwellers their name was to provide the stuff of scientific controversy more than four millennia later on. That controversy has given impetus to fruitful investigation into the prehistory of Europe.

COPPER BEADS found at Burgäschi indicate the beginnings of trade with southwestern Europe. Copper ore was very rare in sections north of the Alps during the Neolithic period.



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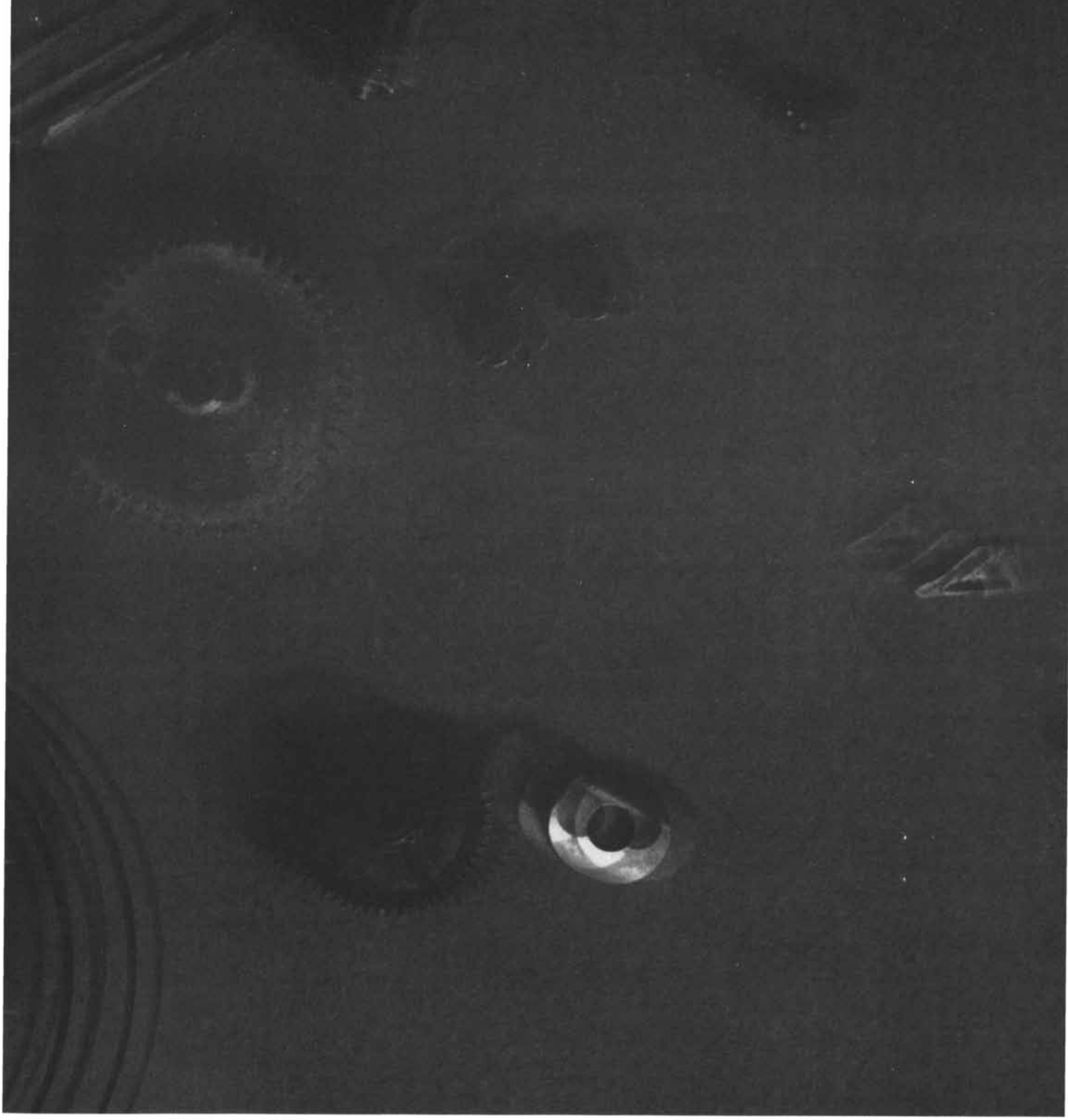

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MATHEMATICAL GAMES

On the theory of probability and the practice of gambling

by Martin Gardner

Conjuring is the art of entertaining people by performing feats that seem to violate the laws of nature. The deception is accomplished by a prodigious variety of subtle techniques, all in good fun because the ultimate intent of the performance is to delight an audience. There are, however, two large fields of public deception in which many of the principles of magic are employed for less wholesome purposes: the fields of gambling and psychic research. A certain false shuffle, for instance, can be equally useful to a card magician and to a card hustler. A technique for secretly obtaining information written on a piece of paper can be equally useful to a magician who performs "mental magic" and to a crooked medium. As a mathematician might put it, the principles of deception in the three areas—magic, gambling and psychic phenomena—form three mutually intersecting sets.

The violation of any natural law, including the mathematical laws of probability, can provide the basis for a magic trick. One of the most famous modern card tricks, known to magicians as Out of this World (it was invented by Paul Curry, a New York City amateur), appears as follows: A shuffled deck is dealt randomly, by a spectator, into two piles. When the piles are turned over, one is seen to consist entirely of red cards, the other entirely of black. The laws of probability have clearly been evaded and everyone is pleasantly amazed. The relation between a trick of this type and deception in the psychic and gambling areas is at once apparent. If a spectator accomplished such a feat by clairvoyance, the feat would move over into the realm of extrasensory perception (ESP). On the other hand, if the magician achieved the results by sleight of hand, who would want to play poker with him?

Techniques of deception in modern psychic research, which relies almost exclusively on experiments that seem to counter the laws of probability, will be dealt with at length by Mark Hansel, a psychologist at the University of Manchester, in a book to be published next year by the Thomas Y. Crowell Company. The techniques of deception in modern gambling, again with a major emphasis on probability laws, receive their most comprehensive coverage in a 713-page book entitled *Scarne's Complete Guide to Gambling*, published last month by Simon and Schuster. The book is well timed. A U.S. Senate subcommittee, before which Scarne was the Government's first star witness, is currently conducting a nationwide investigation of illegal gambling that already has led to new control legislation.

No one alive today is better qualified to write such a book than John Scarne. A native of Fairview, N.J., he developed a passionate interest in magic—card magic in particular—at an early age and quickly became one of the nation's most skillful card manipulators. The magic periodicals of 20 or 30 years ago are filled with references to Scarne's exploits and original magic creations. During the past two decades he has made an intensive study of gambling in all its multifarious and nefarious phases.

In addition to knowing all that one man can know about gambling, and having mastered the most difficult "moves" of the card and dice hustlers, Scarne has also managed to acquire a remarkable knowledge of basic probability theory. This flourishing branch of modern mathematics actually had its origin in gambling questions. Scarne retells in his book the story of how Galileo became interested in probability when an Italian nobleman asked him: When three dice are tossed, why does the total 10 show more often than the total 9? Galileo answered by making a table of the 216 equally probable ways that three dice can fall. Scarne also recounts the more familiar story of how in 1654 Blaise Pascal was asked by Antoine Chevalier de Méré (a French courtier and writer, not at all the professional gambler he is usually made out to be) why he had been losing consistently when he bet even money that

Within the next few years a powerful astronomical observatory will be placed in orbit outside the distortion of the earth's atmosphere. The space observatory will look at interstellar matter, map the sky's ultraviolet light and perform other experiments to help scientists understand how stars and nebulae are born.

IBM is developing an advanced memory system to go aloft in this satellite and store its observations. The system will receive instructions from the ground, help aim the satellite's instruments and hold collected data for periodic radio transmission back to earth.

The new space memory, being developed by IBM for Grumman Aircraft Engineering Corporation and the Goddard Space Flight Center of the National Aeronautics and Space Administration, called for some unusual solutions from IBM engineers. For example, they were able to reduce power demands considerably by designing the memory to read out information over and over without writing it back into memory each time. Another significant accomplishment is the remarkable design reliability of the new system, achieved through new techniques of redundant circuitry.

Solving problems like these in systems development requires imagination that can travel easily back and forth across technical disciplines. At IBM, people with this kind of imagination are making important advances in such areas as semiconductors, microwaves, magnetics and superconductivity. If any of these fields interests you—and you have a degree and experience in engineering, mathematics or one of the sciences—we'd like to hear from you.

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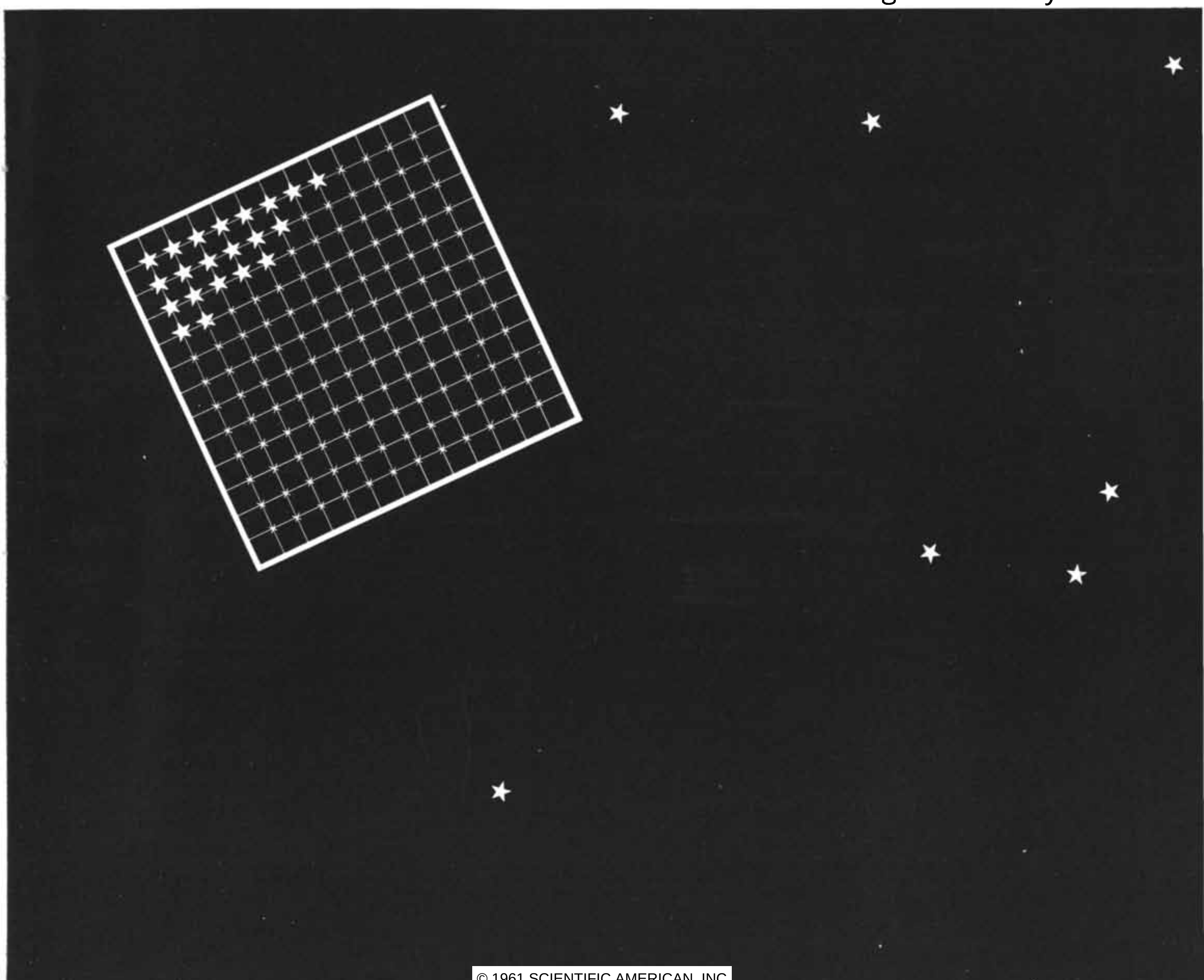

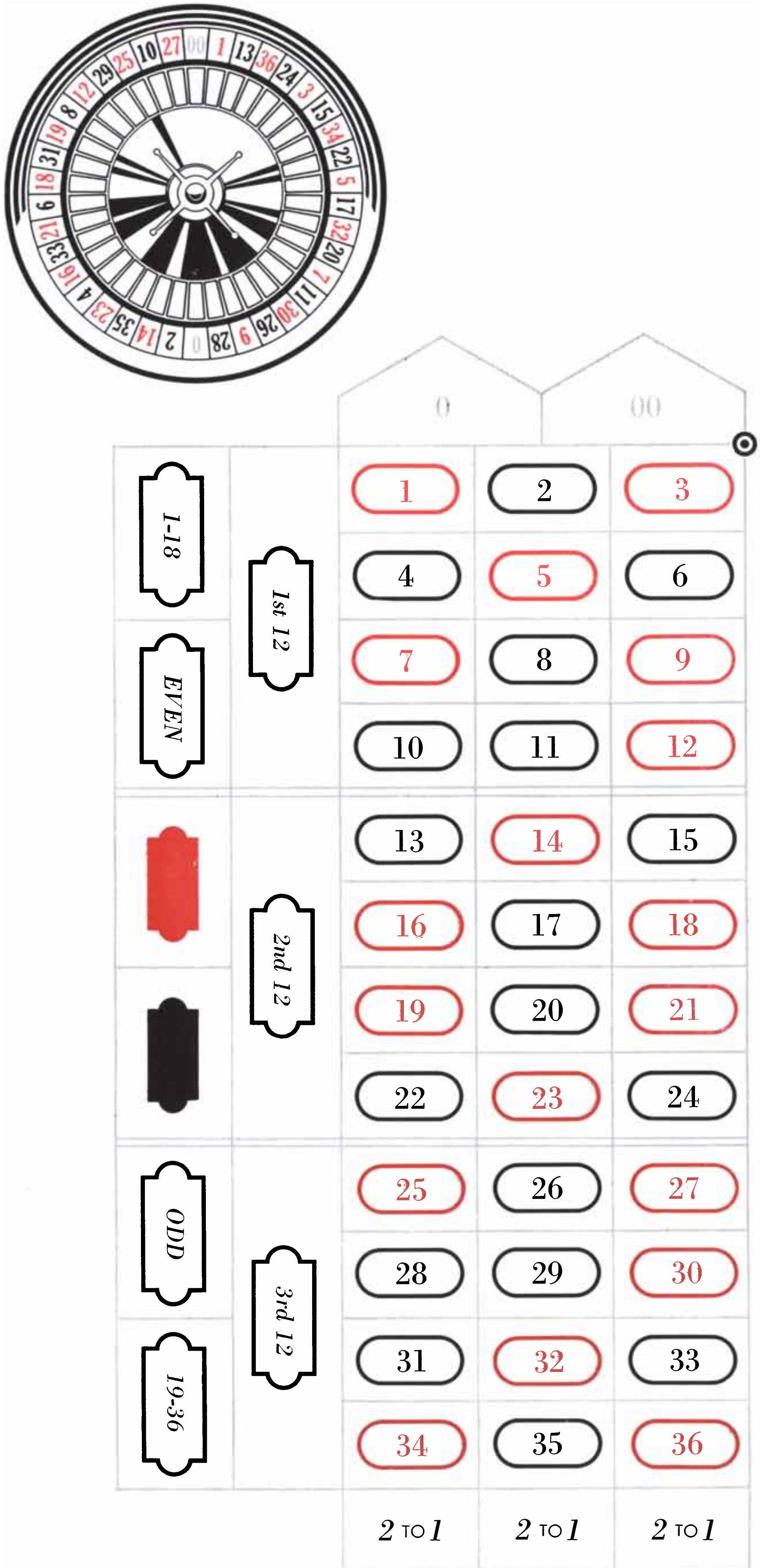

Roulette wheel and a layout with chip on a five-place line bet

a double six would show at least once in 24 rolls of two dice. Pascal was able to show that the odds were slightly against the gambler if he rolled 24 times but would be slightly in his favor if he rolled 25 times.

Scarne's book contains the most complex analysis ever published of blackjack, the only casino game in which, at certain times, the odds actually favor the player. Scarne gives the details of a sound method by which one can beat the house percentage *if* one is willing to spend time mastering the game's mathematics, becoming familiar with casino practices and, above all, learning to "case the deck" (remember every card dealt or exposed). Do you know why it is advantageous for a blackjack dealer to be left-handed? The asymmetrical position of the indices on the cards makes it easier for a left-hander to take an undetectable peek at the top card before he deals it. Another section of the book gives the full and hitherto unpublished history of the famous "rhythm method" by which U.S. slot machines were successfully bilked in the late 1940's of millions of dollars before the manufacturers understood what was happening and added a "variator" to the machines.

The book contains masterly analyses of the mathematics of bingo, poker, gin rummy, the numbers game, craps, horse racing and many other popular forms of gambling. An entire chapter is devoted to the match game, a simple guessing game that has been played every Friday night for the past 20 years at the Artists and Writers Restaurant in New York City. Even carnival games, including the latest swindle, a marble roll-down called Razzle Dazzle, are covered. Is there anyone who hasn't at some time thrown baseballs at those pyramids of six pint-size wooden milk bottles? The "gaff" couldn't be simpler. Three bottles are heavy; three are light. With the heavy bottles on top, one ball will topple all of them off the small table on which they stand. With the heavies on the bottom, a big-league pitcher couldn't do it. Carnival people call this a "two-way store," meaning that it can be set up for the player to win or lose.

One of the book's best chapters is on roulette, certainly the most glamorous of all casino games. "A great part of roulette's fascination," Scarne writes in a bit of purple prose, "lies in the beauty and color of the game. The surface of the handsome mahogany table is covered with a blazing green cloth which bears the bright gold, red and black of the layout. The chromium separators between the numbered pockets on the wheel's rim

glitter and dance in the bright light as the wheel spins. The varied colors of the wheel checks stacked before the croupier and scattered on the layout's betting spaces, the evening clothes of the women, the formal dress of the men, the courteous croupiers—all add to the enticing picture."

So enticing, in fact, that thousands of players, with limited knowledge of probability, each year develop into what Scarne terms "roulette degenerates." Many of them squander their time and fortunes on worthless systems by which they expect to break the bank and retire for life. As almost everyone knows, a roulette wheel has on its rim the numbers from 1 to 36, plus a zero and double zero (European and South American wheels have only the zero). These numbers are not arranged randomly but are cleverly patterned to provide a maximum balance among high-low, even-odd and red-black. The house pays off a winning number at 35 to 1, which would make roulette an even-up game if it were not for the extra 0 and 00. These two numbers give the house a percentage on all bets (except one) of 5 and 5/19 per cent, or about 26 cents on every $5 bet. The one exception is the five-number line bet, in which the chips are placed on the end of the line that separates 1, 2 and 3 from the 0 and 00 spaces on the layout board [*see illustration on page 152*]; in other words, a bet that one of these five numbers will show. Here the bank pays off at 6 to 1 odds that give it a percentage of 7 and 17/19 per cent, or about 39 cents on a $5 bet. Obviously this is a bad bet and one to be avoided.

The fact that every possible bet on the layout is in the bank's favor underlies a very simple proof that no roulette system is worth, as Scarne puts it, the price of yesterday's newspaper. "When you make a bet at less than the correct odds," he writes, "which you always do in any organized gambling operation, you are paying the operator a percentage charge for the privilege of making the bet. Your chance of winning has what mathematicians call a 'minus expectation.' When you use a system you make a series of bets, each of which has a minus expectation. There is no way of adding minuses to get a plus...." For those who understand, this is as ironclad and unanswerable as the impossibility proofs for the trisection of the angle, squaring the circle and the duplication of the cube.

The most popular of all systems, says Scarne, is known as the d'Alembert system. It consists of betting the red or black color (or any other even-money

ASK ALPHA:

What's being done to perfect satellite relay for long-range communications?

Many things. An active development program is making material progress toward low-cost systems for communication by passive reflector satellites. / Another project is development of facilities, techniques, and equipment for ground-space-ground transmission of multiple-channel voice and high-speed data./ There's a new 60-foot diameter antenna of very high precision. ☐ It's all happening as part of a continuous program in communication via satellite being carried out by Alpha Corporation and the parent Collins Radio Company. ☐ The antenna—a steerable, parabolic system—is being installed at Alpha's space communication research station in Dallas. Here, the Space Systems Division is enlarging on experiments which already have used the moon and Echo I as relays in worldwide communication circuits. Next step: to transmit multiple channel voice and high-speed data between the U. S. and England, France, and South America, using active repeating satellites and multiple passive reflector satellites. ☐ There's much more to tell. And it's well worth hearing, if you're seeking new techniques, new facilities, or broad systems capability in space communication. Ask Alpha! Alpha Corporation • Dallas, Texas • A division of Collins Radio Company ☐

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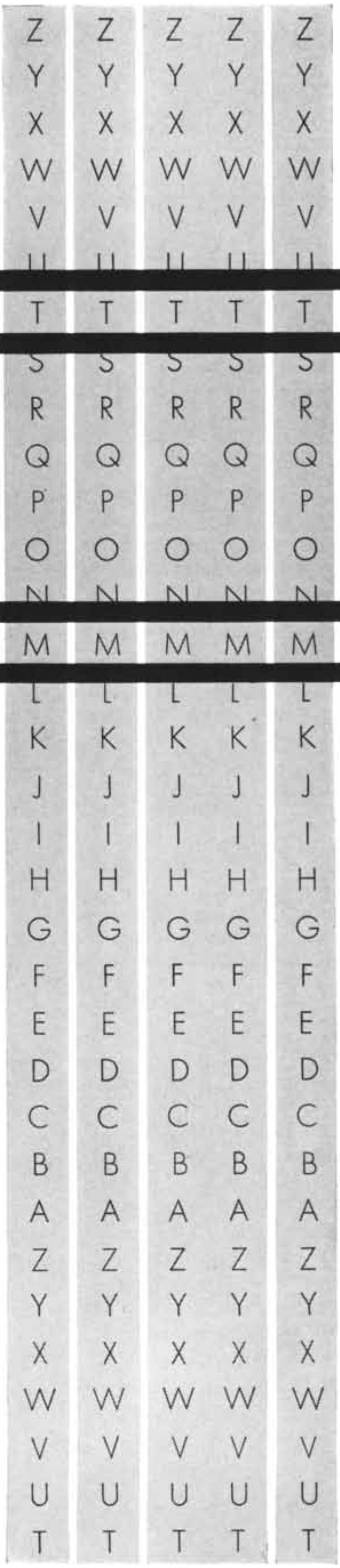

Find the Christmas message

bet), then following with a larger bet after each loss and a smaller bet after each win. The assumption is that if the little ivory ball drops several times into red, it will somehow remember this fact and tend to avoid red on the next spin. Mathematicians know this as the "gambler's fallacy," and of course it gives the player no advantage whatever.

The martingale system, in which bets are doubled until one wins, might work (in a sense) if the house did not have a limit on the size of bets. (The limit is usually the total reached by doubling the minimum required bet about seven times.) It is true that the player of the martingale has a high chance of winning a picayune amount (on even-money bets, $1 for every chain of doubling that begins with $1 and ends before the limit is reached), but this is balanced by the probability of losing a whopping amount. If you start with, say, a $180 bankroll and the bank has a maximum betting limit of $180 on the colors, the odds are greatly in your favor that you will start off a winner with the martingale. But if you continue to play it, you can expect to hit (sooner than you would expect) a seven- or eight-number losing streak that will wipe out your capital. It is as if you charged people 10 cents to watch an exhibition in which you selected a bullet at random from a barrel containing 1,000 blanks and one genuine bullet, put the bullet in a pistol and fired it at your head. The chances are good that you could make a lot of dimes that way, but if you kept at it, you would eventually blow your brains out.

There is a reverse version of the martingale, known in the U.S. as the parlay system (Europeans call it the paroli), in which you continue to bet a dollar after each previously lost bet and double your wager after each winning bet. Instead of making small wins at the risk of a big loss, you sacrifice small losses for the possibility of that one ecstatic moment when a lucky run of wins will pyramid your stake into a fortune of some previously specified amount. Here again, the system has a minus expectation even without the house limit, but the limit makes it even worse. If you started your parlay with a dollar, your doubling procedure would be permitted to go only as far as the seventh win of $128.

Another popular system, called the cancellation system, has lost fortunes for many a mark (sucker) who thought he had something sure-fire. Even-money bets are made (say on red or black) with the amount increased after each loss according to the following procedure. First you write down a column of figures in serial order, say from 1 to 10. Your first bet is the total of the top and bottom figures, in this case 11. If you win, cross out the 1 and 10 and bet the new top and bottom figures, 2 and 9, which also total 11. If you lose, write the loss (11) at the bottom of the row and bet the total of the new top and bottom figures, 1 and 11. This procedure continues with two numbers crossed off at each win and one number added at each loss. Since the losses are about equal to the wins on even-money bets, you are almost sure to cross off all the numbers. When this occurs, you will be 55 chips ahead!

"On paper it looks good," comments Scarne, but alas, it is merely one of the many worthless variations on the martingale. The player keeps risking larger and larger losses to win piddling amounts. But in this case the bets are smaller so it takes longer to be stopped by the house limit. Meanwhile the house's 5 and 5/19 per cent is taking its toll, and the croupier is getting increasingly annoyed at having to handle so many small bets.

The latest roulette system to make a big splash is one that appeared in 1959 in *Bohemia,* a Cuban monthly magazine. For many months it was widely played throughout South America. The system is based on the fact that the third column of the layout [*see illustration on page 152*] has eight red numbers and only four black—a fact that the inventor of the system considers to be a fatal flaw in the layout.

Here is Scarne's description of how the system operates:

"You make two bets on each spin of the wheel. Bet one $1 chip on the color Black, which pays even money. And bet one $1 chip on the third column, which contains 8 red numbers, 3, 9, 12, 18, 21, 27, 30 and 36, and the black numbers 6, 15, 24 and 33. This bet pays odds of 2 to 1.

"There are 36 numbers plus the 0 and 00 on the layout. Suppose you make 38 two-chip bets for a total of $76. In the long run this should happen:

"1. The zero or double zero will appear 2 times in 38, and you lose 2 chips each time—a loss of 4 chips.

"2. Red will appear 18 times out of 38. Each time one of the 10 red numbers listed in the first and second column appears you lose 2 chips—a loss of 20 chips on those 10 numbers. But when the 8 red numbers in the third column appear you win 2 chips on each for a total win of 16 chips. This gives you a net loss on Red of 4 chips.

"3. Black will also appear 18 out of

OPTICAL COMMUNICATIONS Gordon Jacobs, an Electronics Laboratory communications engineer, recently reported that a ruby laser burst system using 350 watts of primary power can provide a range of 10,000 nautical miles at 400 bits per second. In an experimental system development at the Laboratory a KDP crystal was used to modulate the light source frequencies up to 200 mc. The optical receiver utilized a multiplier phototube. Mr. Jacobs stated that future improvements in light sources offer an enormous potential for optical communications. A considerable technical effort is required in many areas: e.g. atmospheric propagation, wide-band modulation and wide-band detection.

ADAPTIVE NEURON COMPONENT Thomas Bray, of the Electronics Devices & Networks group, presented a paper a short time ago describing "An Electro-Optical Shift Register" which employs an adaptive neuron component. This artificial neuron utilizes optoelectronic elements as analog multipliers. (Extremely low volume is an advantage of this Shift Register: a 20-input component consisting of more than 40 analog multipliers and 20 analog memory elements occupies about 2.5 cubic inches.) This work of Mr. Bray's is part of the Laboratory's endeavor in the field of new logic and memory techniques development.

A SCHEME TO CREATE A "RADIOWAVE ATMOSPHERE" NEAR THE MOON ...has been proposed by Dr. Frank Dickey, radar consultant with the Laboratory. He suggested "a powerful earth-based transmitter be employed to beam microwave energy at the moon. The interaction of incident and reflected energy near the lunar surface would create a stationary radiowave pattern...which would be sensed by an incoming spacecraft. This new technique can provide a simple, lightweight device capable of performing all sensory functions needed to achieve soft lunar landings." (First reported at IRE Convention in March 1961, theoretical work is continuing on this concept.)

THE CARDIAC PACEMAKER Electronics Laboratory engineers, headed by Jerome J. Suran, Manager of the Electronic Applications Laboratory, developed this device to control the beat of the human heart. It is the first surgically implantable unit whose rate can be adjusted by the patient to accommodate strenuous activities, such as stair-climbing. Its successful use was described in the May '61 issue of LIFE MAGAZINE. A continuing program of cooperation with medical researchers is now part of the Laboratory effort. It includes work on mechanisms that will stimulate other muscles which have suffered deterioration (from paralytic disease or injury) and the development of new diagnostic techniques.

RESEARCH ENGINEERS AND SCIENTISTS...

Can You Define Boundaries For Electronics?

Investigators at General Electric's Electronics Laboratory believe that no technology is so "remote" that it may not one day contribute to advances in one of the many diverse areas conveniently labeled "electronics" today. The "oneness" of all science is a matter of conviction at the Laboratory, to both Staff Members and Management. The result is an enriching collaboration among individuals trained in many fields, from biochemistry to microwaves, from molecular physics to metallurgy, from geophysics to thermionics ■ Indicative of the breadth of the Laboratory's interests and accomplishments are the above abstracts on recent investigations by members of the staff. Some of this work is now being carried into advance development stages ■ Scientists and engineers (with PhD or MS) attracted by an opportunity to pursue investigations in a stimulating intellectual climate with colleagues from many fields are invited to inquire about opportunities to explore • NEW SOLID STATE DEVICES; APPLICATIONS TO COMPUTER TECHNOLOGY; ADVANCED MICROELECTRONIC CIRCUITRY; MAGNETIC THIN FILMS; SUPERCONDUCTIVE FILMS • NEW APPROACHES TO ELECTRONIC SIGNAL PROCESSING • NEW DATA PROCESSING TECHNIQUES, USING THEORIES OF AUTOMATA, ADAPTIVE SYSTEMS AND OTHERS • PHYSICAL PHENOMENA WITH POTENTIAL FOR MICROWAVE AND COHERENT OPTICAL DEVICES • NEW APPROACHES TO CONTROL SYSTEMS USING NON-LINEAR, ADAPTIVE AND OTHER TECHNIQUES • ORGANIC AND INORGANIC CHEMISTRY: NEW MATERIALS AND PROCESSES (B S degree acceptable) • ADVANCED DEVELOPMENT IN HIGH POWER AND DIGITAL SOLID STATE CIRCUITRY • ADVANCED DEVELOPMENT IN MEASUREMENT INSTRUMENTATION ■ Write in confidence to: Mr. Richard J. Sullivan, Dept. 59-L, General Electric's Electronics Laboratory, Electronics Park, Syracuse, New York.

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GENERAL ELECTRIC

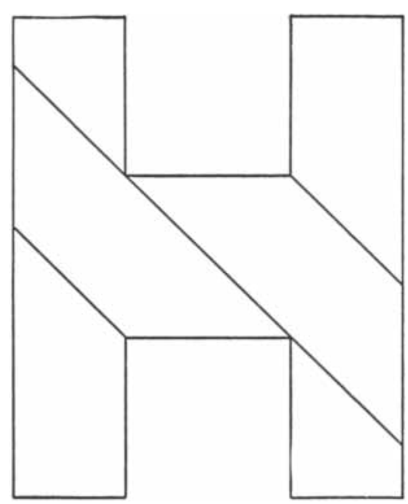
38 times. Each time one of the 14 [black] numbers in the first and second column appears, you lose 1 chip—a total loss of 14 chips. But since you also bet on the color Black, you win 14 times for a gain of 14 chips. This loss and gain cancel out and you break even 14 times. But when the 4 black numbers in the third column (6, 15, 24 and 33) appear, you win 3 chips each time (2 chips on the number and 1 chip on the color) for a profit of 12 chips on Black.

"Having lost 4 chips on the zero and double zero, and 4 chips on Red, and having won 12 chips on Black, you come out ahead with a final profit of 4 chips. Divide your total bet of $76 into your profit of $4 and you find that you have not only overcome the house advantage on the zero and double zero of 5 and 5/19 per cent but have actually supplanted it with an advantage in *your* favor of 5 and 5/19 per cent."

The reader will find it a stimulating exercise in elementary probability analysis to see if he can spot the fallacy in the system. Next month this department will reprint Scarne's explanation.

In keeping with this department's practice of giving a cryptic Christmas greeting each December, the reader is invited to study the device shown in the illustration on page 156. The problem is to slide the four vertical strips of letters up and down until two words conveying the message appear simultaneously, one in each of the two horizontal windows. The puzzle was devised by Leigh Mercer of London.

Last month's problem in dissection is solved as shown in the illustration below.



Answer to last month's dissection puzzle

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A highly sophisticated system, the AN/FCC-17 could be created only by a leading specialist in video, voice and data transmission systems. It is further proof of Lenkurt Electric's mastery in designing, developing and manufacturing quality communication systems of advanced design and proven performance.

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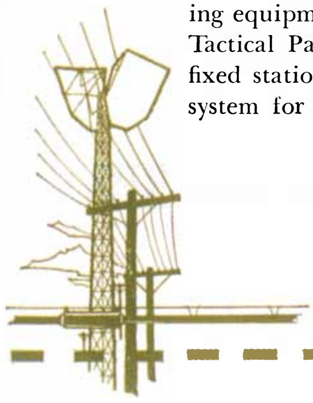

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Today's trend to speed-up in the recording of instrumentation data—with tape speeds up to 120 inches per second—can mean "*Slow Down, Trouble Ahead!*" for tapes that can't cope. On the other hand, "SCOTCH" BRAND Heavy Duty Tapes love to live dangerously—are made for challenging environments where tape speeds are fast and getting faster, where instantaneous temperatures caused by friction between tape and head shoot up. Two new "SCOTCH" Tapes—Heavy Duty Tapes 498 and 499—are especially designed for applications where ordinary tapes soon wear out.

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THE AMATEUR SCIENTIST

A new method that enables the amateur mineralogist to identify various clays

Conducted by C. L. Stong

Few specimens of clay are found in amateur mineral collections, chiefly because they are so difficult to identify. None of the field guides compiled for amateurs even list such interesting clays as anauxite, allophane or montmorillonite. The two most comprehensive guides carry short descriptions of kaolinite, a basic material of the ceramics industry, but discourage its collection by pointing out that clay minerals can be identified only by an intricate combination of X-ray, electron-microscope and chemical techniques that are beyond the capabilities of most amateurs. This was certainly true prior to the last decade. But in recent years the much simpler technique of differential thermal analysis has been successfully applied to the classification of clays, as well as of shales and some uranium ores, by Ralph J. Holmes, Paul F. Kerr and J. Laurence Kulp of Columbia University.

The method is based on the fact that substances absorb heat at characteristic rates. For example, when a bar of iron is heated, within certain limits it gets hotter in direct proportion to the amount of time it spends in the fire. In contrast, when a container of ice is heated, it stays at 32 degrees Fahrenheit until the ice melts. The temperature of the water then climbs steadily to 212 degrees, where it again holds constant until the water boils away. This difference in the heating rate of iron and water constitutes a means, although a trivial one, for distinguishing between the two. In the case of clay minerals, shales and some uranium ores, the temperature fluctuations are more numerous, subtle and definitive.

Part of the apparatus used for making differential thermal analyses at Columbia was designed, constructed and tested experimentally by David Smith, a former student of mineralogy who is now a technical specialist in public relations in New York City. "In essence," he writes, "the method of identifying clay minerals by differential thermal analysis consists in placing the unknown specimen in a furnace along with a relatively inert substance like alumina, and gradually increasing the furnace temperature to about 1,000 degrees centigrade while recording the temperatures of the specimen and the inert substance. A graph made by plotting the temperature fluctuations of the specimen against the constantly rising temperature of the inert substance is uniquely characteristic of the specimen and is roughly analogous to a spectrogram.

"The furnace we used at Columbia was heated by resistance wire of the kind used in electric toasters. With the exception of the furnace liner, a tube of alundum, the furnace can be improvised out of commonly available materials. It should be possible to build an adequate one from a five-gallon paint bucket by replacing the ends with a heat-insulating composition board such as Transite. A tube of alundum some two inches in diameter and as long as the paint bucket can be wrapped with a helical coil of Nichrome wire held in place by a coat of alumina cement (powdered alumina mixed with water glass). This assembly can be supported by holes cut in the centers of the Transite ends to make a snug fit with the tube. The space between the tube and the wall of the bucket should be packed with heat-insulating material such as calcined diatomite or bubble alumina. Leads for connecting the heating coil to the power line can be brought out of the furnace through porcelain tubes of the kind used for house wiring. As a convenience, the furnace should be mounted on a metal frame so it can be raised and lowered while hot [*see illustration on next page*].

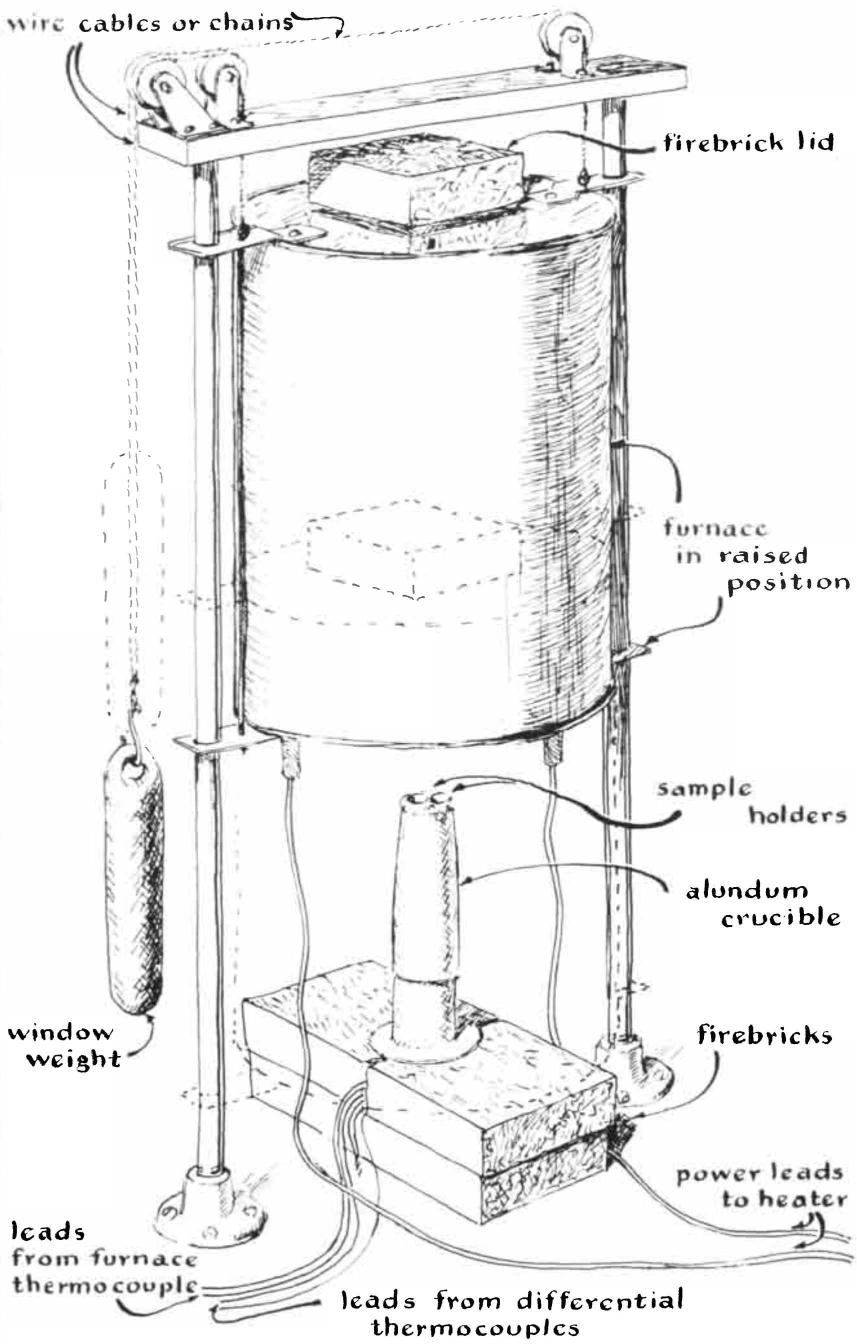
"Our specimen holder was machined from a two-inch length of cylindrical stainless steel three inches in diameter. Twelve ½-inch holes for the specimens were drilled into one face of the block to a depth of one inch. Each hole was then drilled the rest of the way through the block with a ⅛-inch drill as shown at the upper right in the drawing on page 164. An additional ⅛-inch hole was drilled through the center of the block and a second one, about ¼ inch off center, was drilled into it to a depth of one inch from the opposite face, as shown. The small holes admitted thermocouples for measuring the temperature of the specimens, furnace and specimen holder respectively. The specimen holder was supported in the center of the furnace by a hollow cylinder of alundum.

"Thermocouples are easy to make. Twist the ends of two wires of dissimilar metal around each other two or three times. Snip off the excess and clip the free ends to one side of a 110-volt source. Then dip the twisted ends momentarily into a metal bowl of mercury connected to the other side of the circuit. The resulting arc will melt the wire ends into a bead that constitutes a butt weld. The diameter of the bead should be about twice the diameter of the wire. Any two dissimilar metals will exhibit thermocouple action; the most satisfactory are those that develop a relatively high voltage that increases in direct proportion to differences of temperature between the welded junction and the free ends.

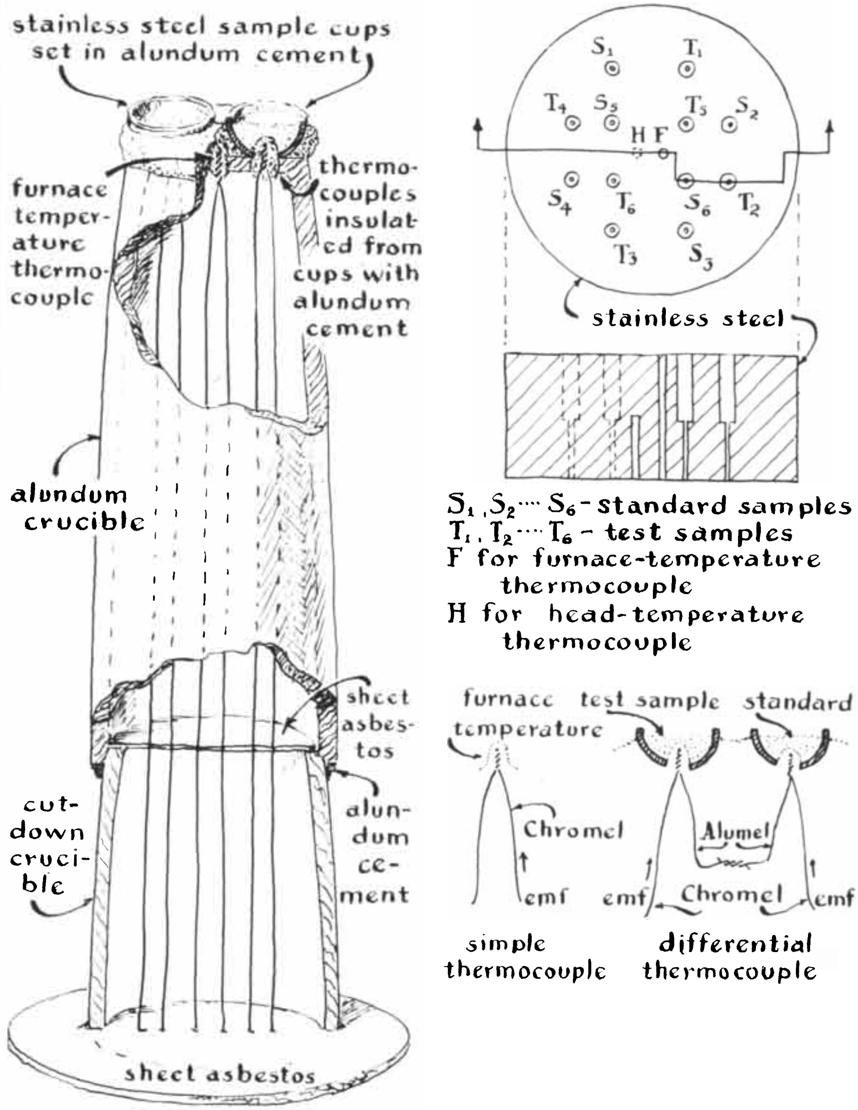
"The analysis of clay requires thermocouples that can withstand repeated exposure in air to temperatures on the order of 1,000 degrees. Ours were made of two special alloys: Chromel-P and Alumel. Chromel-P is 90 per cent nickel and 10 per cent chromium. Alumel is 94 per cent nickel, 2 per cent aluminum, 3 per cent magnesium and 1 per cent silicon. The alloys are produced by the Hoskins Manufacturing Company in Detroit and are available in the form of No. 22 gauge wire from the Edmund Scientific Corporation in Barrington, N.J., in minimum quantity for $1. Chromel-Alumel thermocouples develop a potential difference of approximately one millivolt for each 23.2 degrees C. of temperature difference between the junction and free ends, as shown by the top graph on page 167. Electrons flow from Chromel to Alumel inside the junction.

"Thermocouples can be connected in

pairs to indicate the difference in temperature between two objects by splicing one set of similar leads together, such as the Alumel pair, as shown at the lower right in the illustration on page 164. When the junctions of two thermocouples so connected are at the same temperature, the electrical outputs cancel and no potential difference appears across the Chromel leads. When the junctions are at different temperatures, the thermocouple action of the hotter unit exceeds that of the cooler unit and a voltage appears across the Chromel leads that varies in direct proportion to the temperature difference. Adjacent holes of our specimen holder were equipped with pairs of thermocouples connected for measuring differential temperature. A single thermocouple was installed in the holder for measuring the temperature of the stainless steel block and a second one was extended above the holder for sensing furnace temperature. Care was taken to center the units precisely in the holes so that the junction would not heat unevenly and generate false temperature indications. The Chromel and Alumel leads were insulated by small tubes of alundum and were



Furnace for making differential thermal analyses of clays



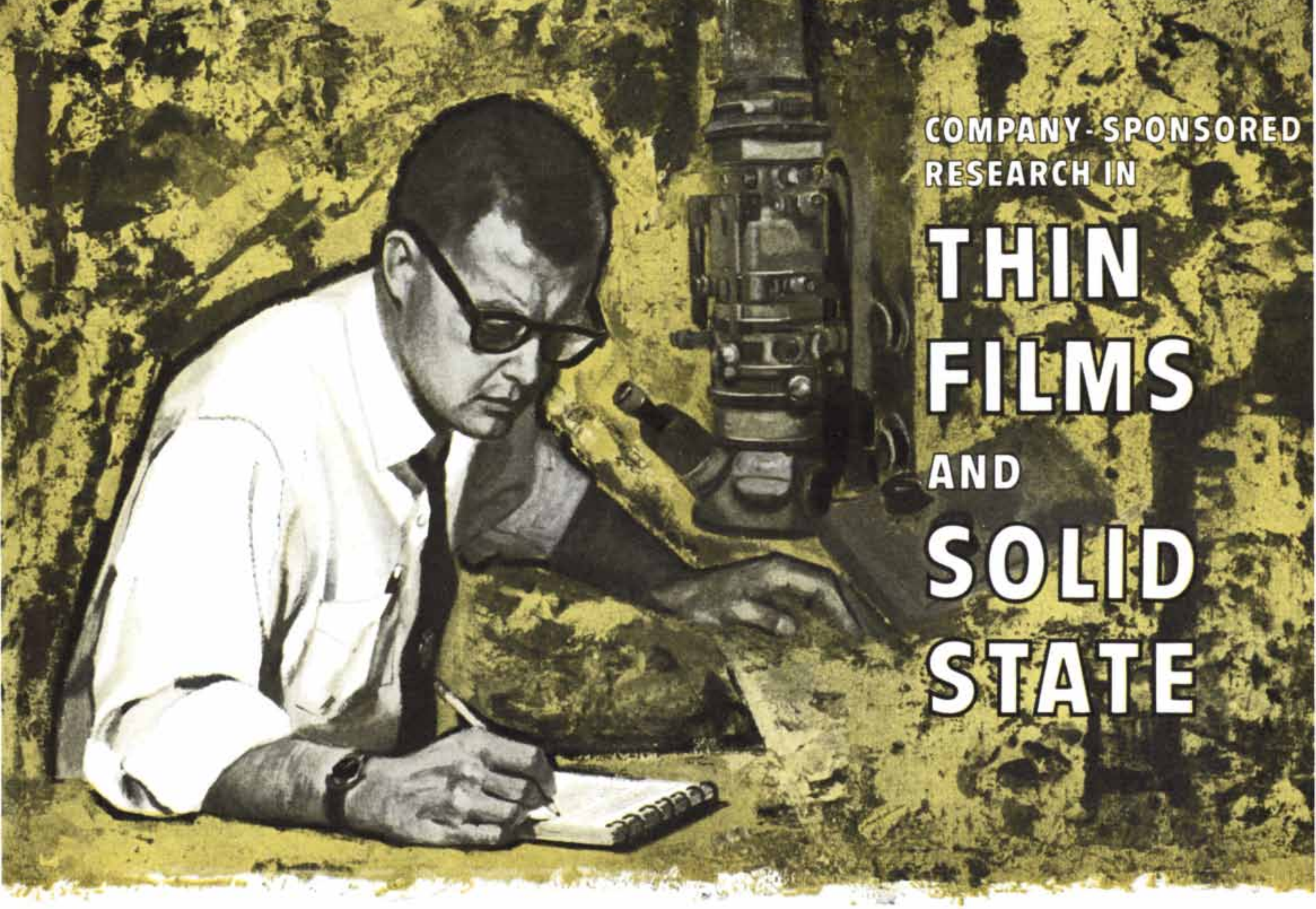
Details of specimen holder for analyzing clay minerals

fastened in the specimen holder by alumina cement.

"The output voltage can be measured either by a voltmeter sensitive to a billionth of a watt and calibrated to 50 millivolts or by pen recorders equipped with appropriate amplifiers, depending on the experimenter's budget. We used a battery of pen recorders and synchronized the speed of the charts with the rate at which the furnace heated by means of an electronic program controller. The controller operated automatically and could be adjusted for any desired rate of heating up to 50 degrees per minute or for holding the furnace at any fixed temperature. A heating rate of 12 degrees per minute resulted in the most clearly defined peaks. Ample information on all specimens appeared in the temperature range from 100 to 1,050 degrees C. Higher temperatures added little of interest to the graphs and reduced the life of the coil and the thermocouples.

"The operating procedure is simple. Specimens are prepared by dry grinding with a mortar and pestle. The specimen holders are filled with ground material that passes through a sieve consisting of 50 crossed wires per inch—a standard 50-mesh screen. The powder is poured into the holes loosely; tamping appears to have little effect on the results, and tightly packed specimens are difficult to remove at the conclusion of a run. The companion hole associated with each specimen is charged with inert comparison material. We used powdered alumina that passed a 60-mesh sieve. Once the samples are inserted and the thermocouples are connected, the furnace can be started.

"We adopted a standard procedure for plotting and interpreting the curves. Temperature fluctuations are plotted upward when the specimen emits heat



SENIOR SCIENTISTS are needed for immediate openings in the General Dynamics | Astronautics Electronics Research Laboratories.

A large, company-sponsored program in thin film and solid state research for applications to *Microminiaturization, Solar Energy Conversion,* and *Magnetic Computer Components* is in progress. Included are: (1) studies of the kinetics and structures of films using advanced electron microscope techniques; (2) epitaxy studies using pyrolytic vapor decomposition and ultra-high vacuum deposition of thin film crystals; (3) materials research for thin film passive and active components prepared by vacuum deposition, sputtering, anodization and electron beam graphics and cathodolysis; and (4) techniques for accurately monitoring and controlling the fabrication conditions and film characteristics for thin film microcircuit and large area energy conversion device fabrication.

If you are interested and have experience in these tasks and are trained in solid state physics, metallurgy and ceramics, physical chemistry or electronics, inquire now. Advanced degree preferred but not necessary if talent and experience in these areas are indicated.

Please write to Mr. R. M. Smith, Industrial Relations Administrator-Engineering, Dept. 130-90, General Dynamics | Astronautics, 5711 Kearny Villa Road, San Diego 12, California. (If you live in the New York area, it may be more convenient to contact Mr. T. Cozine or Mr. E. Hart, General Dynamics | Astronautics, 1 Rockefeller Plaza, New York City, CIrcle 5-5034.)

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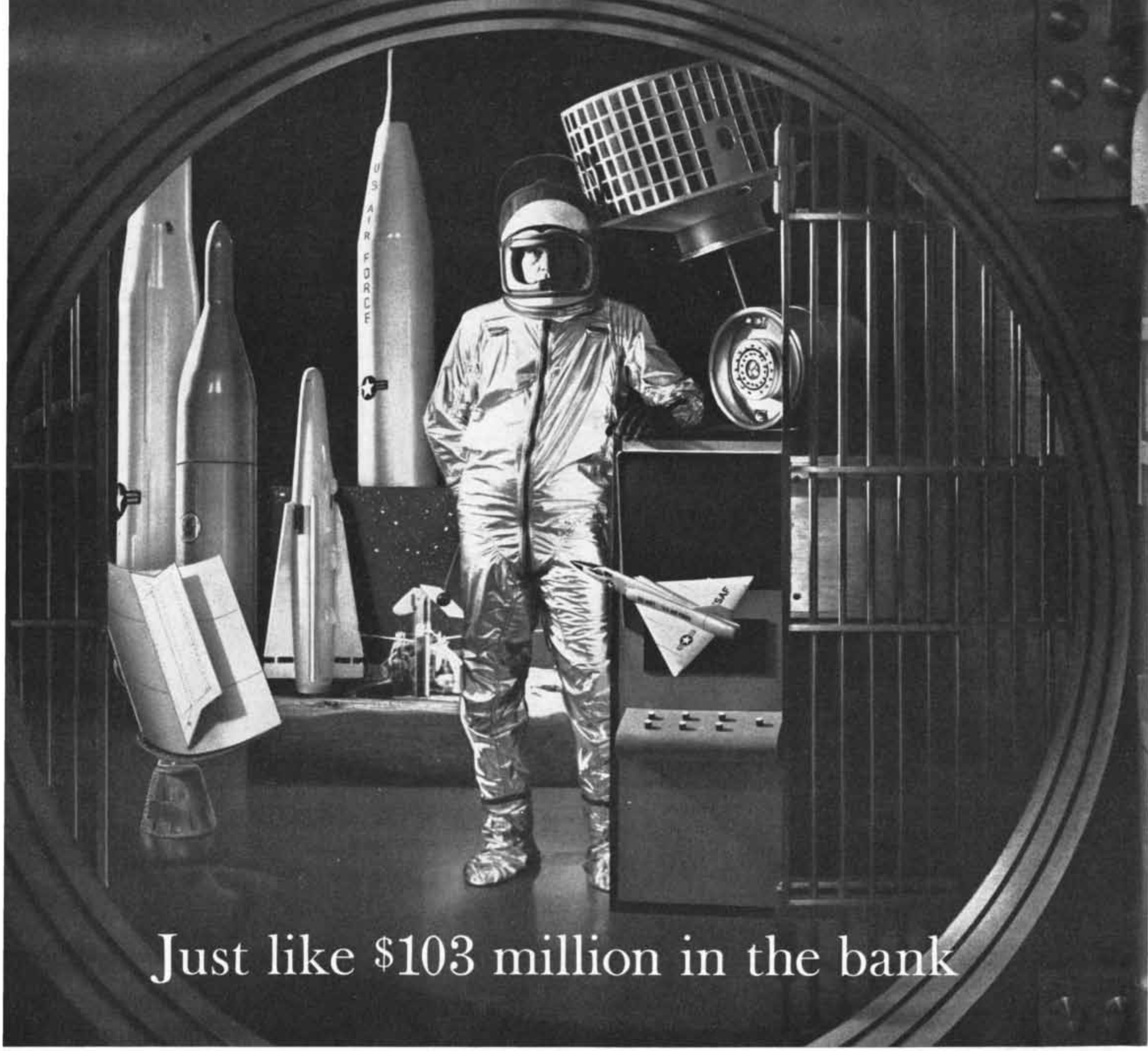

In the past 4½ years, Hughes has put more than 7,000 cost improvements into practice—saving $103 million in defense and space dollars. Prudent management *avoided* these expenditures.

Savings like these in money, materials, time and human energy don't just happen. At Hughes, cost improvement is a corporate way of life. From top to bottom, in all plants and departments, employees submit ideas and suggestions without thought to personal gain. A comprehensive, fully organized program encourages these ideas, evaluates them and makes them work.

Typical ways in which cost improvements were applied: Machining time on a wave guide was cut from 3½ hours to 32 minutes each—saving $41,201. Application of a Preferred Parts Program simplified specifications and rationalized tolerances and performance standards—result, $40,000 saved the first two months. One radar reflector dish was redesigned to fit two different units—saving $117,000.

Each improvement results in lower contract costs. Some of the major defense programs that benefit include the Polaris, Titan, Falcon and Mauler missiles, new 3-D radar-computer systems now in service on Navy ships and automatic armament controls for Air Force interceptors.

And new Hughes space projects—the Surveyor moon landing vehicle, the Syncom communications satellite, the ion engine for long space journeys—all will deliver full value for every dollar.

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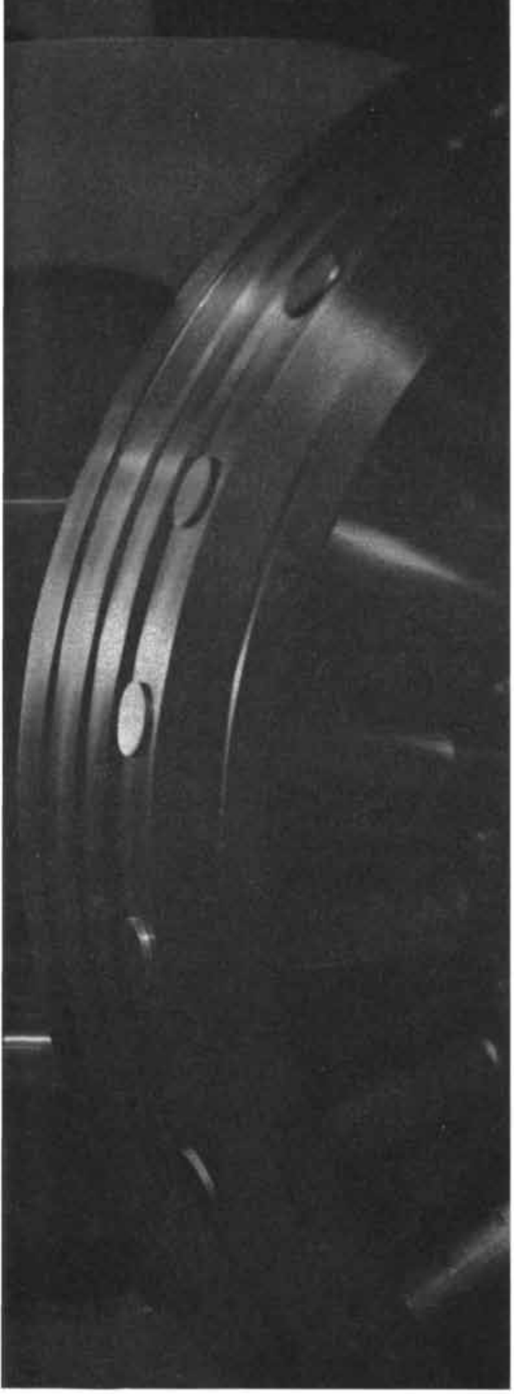
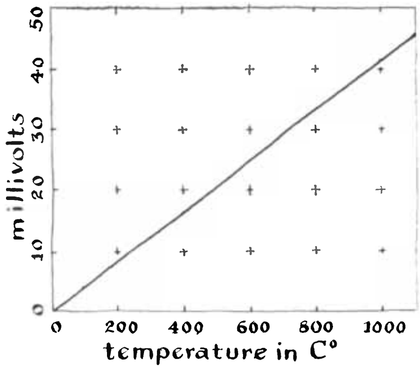


and gets hotter than the comparison material, as a consequence of exothermic (heat-emitting) reactions, and are plotted downward when it absorbs more heat than the comparison material, during endothermic (heat-absorbing) reactions.

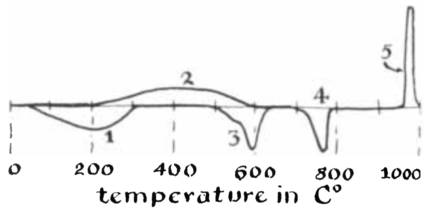
"Reactions of one type or the other may occur for a variety of reasons, including loss of absorbed water and water of crystallization, release of the hydroxyl radical (OH) from the crystal lattice, transitions in the structure of the crystal lattice, the loss of carbon dioxide from carbonate compounds, the devolatilization of coals and oil shales, and the oxidation of sulfide compounds and uranium-bearing shales. The temperature of the furnace is plotted horizontally on the graph; fluctuations of specimen temperature are plotted vertically. The area enclosed by fluctuations or peaks in the graphs varies in proportion to the amount of thermally active mineral involved in the reaction. Mixed specimens can be analyzed by measuring the area enclosed by a selected peak and dividing it into the area of an equivalent peak of a pure specimen that has been measured with the same apparatus. The ratio represents the amount of the known mineral that is present in the mixed specimen.

"At least five basic types of temperature fluctuation occur, each of which produces a typical curve [*see second graph from top at right*]. Broad, low endothermic variations between 100 and 300 degrees C. (*1*) indicate loss of absorbed water. Broad exothermic curves (*2*) signify the oxidation of organic matter in clays between 200 and 600 degrees. The loss of lattice water between 450 and 700 degrees yields curves (*3*) with a broad base. Carbonate reactions show large asymmetrical deflections (*4*) between 450 and 900 degrees. The comparable narrow, high-amplitude exothermic peaks that correspond to transformations in the structure of the aluminum-based part of the molecule occur near 1,000 degrees (*5*).

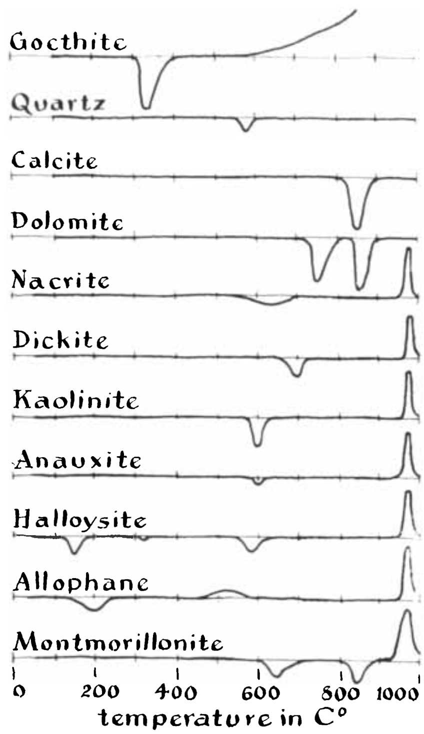
"A number of the gangue minerals (waste materials in ore deposits) also exhibit interesting reactions [*see third graph from top at right*]. The crystalline structure of quartz, for example, undergoes an abrupt endothermic transformation at 575 degrees C. that appears as a dip in the differential curve so sharp and reproducible that it can be used for calibrating thermocouples. (Fairly pure quartz sand for calibrating thermocouples can be taken from the little sandglasses sold as egg timers by novelty stores. Colored sand may also contain quartz, but the impurities often intro-



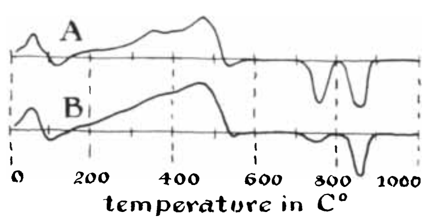
Curve of thermocouple output



Temperature deflections of clay minerals



Reactions of gangue and clay minerals

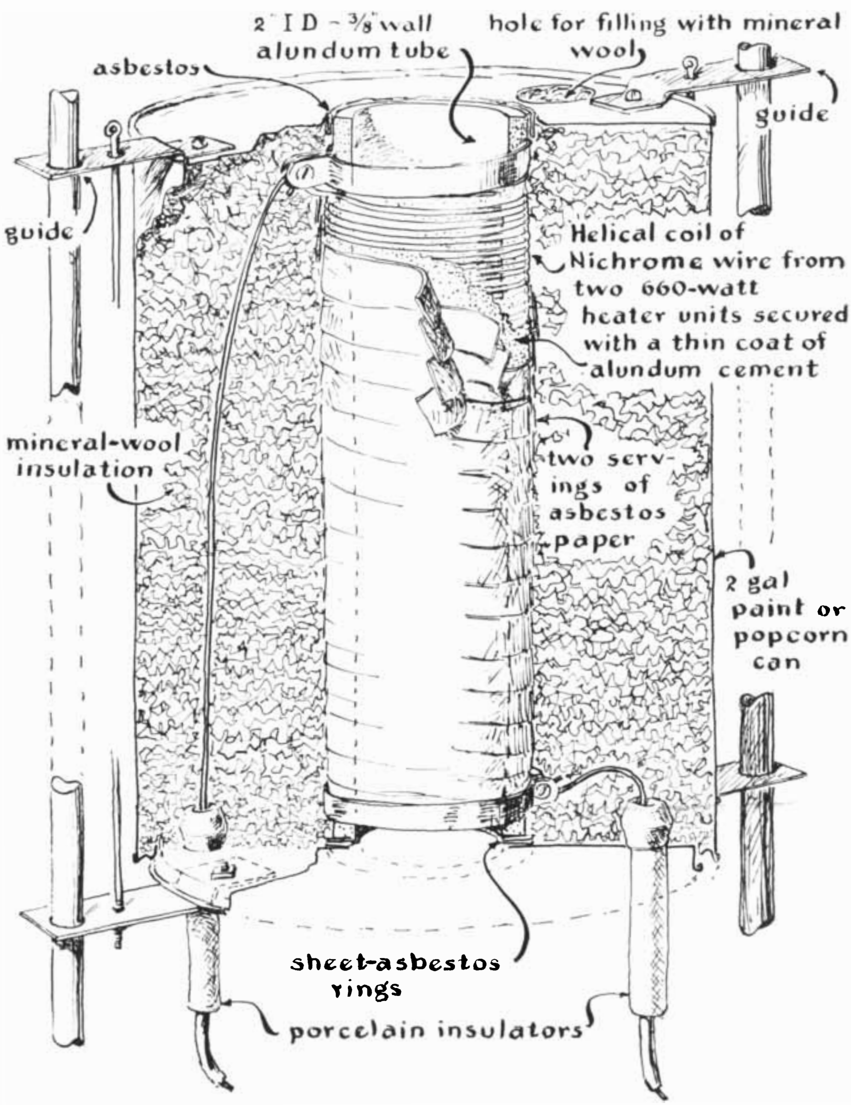


Thermal reactions of two shale specimens duce reactions that mask the endothermic peak at 575 degrees.) Calcite, also a gangue, shows an endothermic peak between 800 and 900 degrees when carbon dioxide is evolved. Two peaks characterize dolomite, one indicating the release of carbon dioxide from the magnesium ion in the vicinity of 750 degrees and another from the calcium ion at 860 degrees.

"The clay minerals all undergo a typical exothermic reaction at 980 degrees, the point at which amorphous alumina adjusts to what is known as its alpha-alumina form. In addition, each member of the clay family is uniquely characterized by one or more endothermic reactions and at least one member by an exothermic reaction. Adjacent curves of the third graph from the top on the preceding page show the characteristics of three kaolin minerals: nacrite, dickite and kaolinite. The graph for anauxite resembles kaolinite except for a smaller area under the endothermic peak that appears during the decomposition of two crystal types into amorphous silica and alumina. Halloysite can be distinguished from other kaolin minerals by two extra low-temperature peaks, one at 150 degrees and a substantially smaller one at 325 degrees. Allophane is so fine-grained that it can almost be considered amorphous. One reaction that has a peak at 180 degrees extends across nearly 100 degrees, and another, at 510 degrees, spans 200 degrees. Neither is clearly defined. Montmorillonite minerals are characterized by two endothermic peaks.

"The graph of talc, which is not included in the illustration, shows a pronounced endothermic peak at 990 degrees, indicative of the strength of the hydroxyl bonds in the talc crystal lattice.

"The temperature of some shales fluctuates almost continuously through a



Details of furnace construction

span of 1,000 degrees. Two of them, arbitrarily designated *A* and *B*, are graphed at the bottom of page 167. Most of the carbonates in shale *A* were in the form of dolomite. Those in shale *B* were mostly limestone. This composition is indicated by the double endothermic reactions between 700 and 900 degrees in the case of shale *A* and the one large peak between 800 and 900 degrees in *B*. The exothermic reaction between 400 and 500 degrees in both shales arises from the combustion of carbonaceous material and the oxidation of marcasite. It is tempting to conclude that the exo-endothermic peaks between 100 and 150 degrees are a consequence of the simple drying of the shale. But dehydration of mechanically held water never occurs exothermically in clays, and the reaction actually signifies the transformation of tridymite quartz. The reactions are typical of illite shales that contain less than 50 per cent illite.

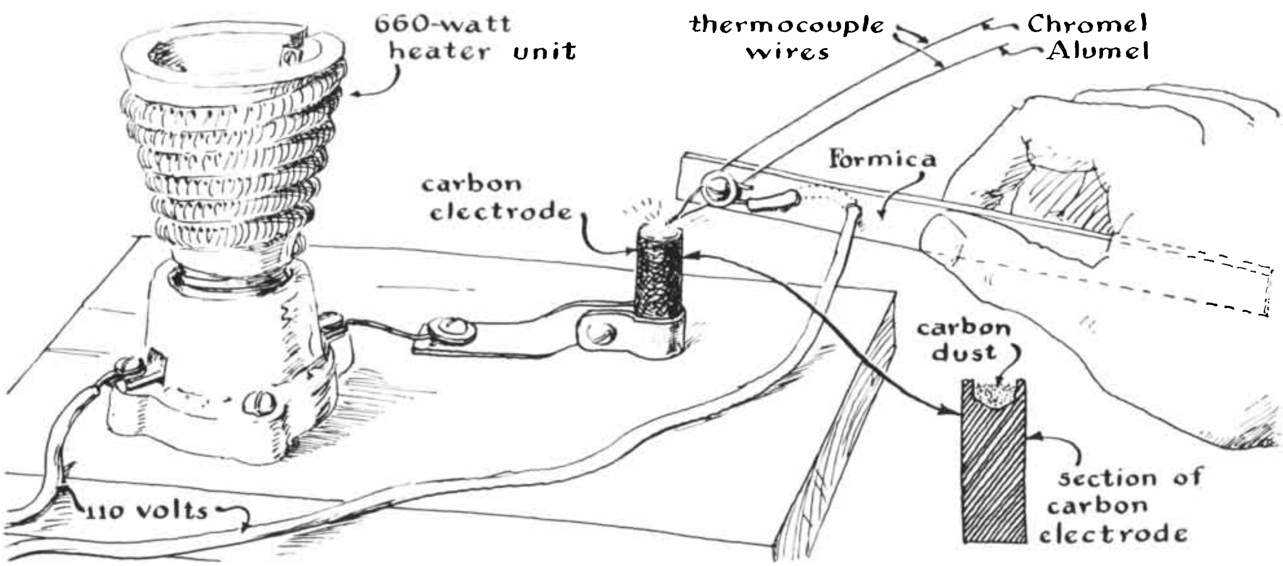
"Characteristic differential thermal reactions of these mineral classes are listed in recently published reference texts [*see "Bibliography," page 192*]. Still others await analysis, and amateurs can help to fill in the gaps. Problems have a way of arising, however, when the technique is applied to unfamiliar materials. Oxides, sulfides and arsenides react with thermocouples, for example, and can ruin them during a single run. Organic impurities tend to mask other reactions when they oxidize. This is particularly true in the case of uranium-bearing shales. Sometimes thermocouples can be protected by a ceramic covering. If the metal specimen holder is attacked, a ceramic cup can be substituted to hold the sample. It is possible to prevent the oxidation of organic materials by running specimens in an atmosphere of an inert gas, such as helium, a procedure that requires the furnace to be enclosed in an airtight bomb.

"At the conclusion of a run the powdered specimens should immediately be blown from the specimen holder by a blast of compressed air. Some specimens tend to cake if permitted to cool in the containers; they must then be dug out and the thermocouples are ruined."

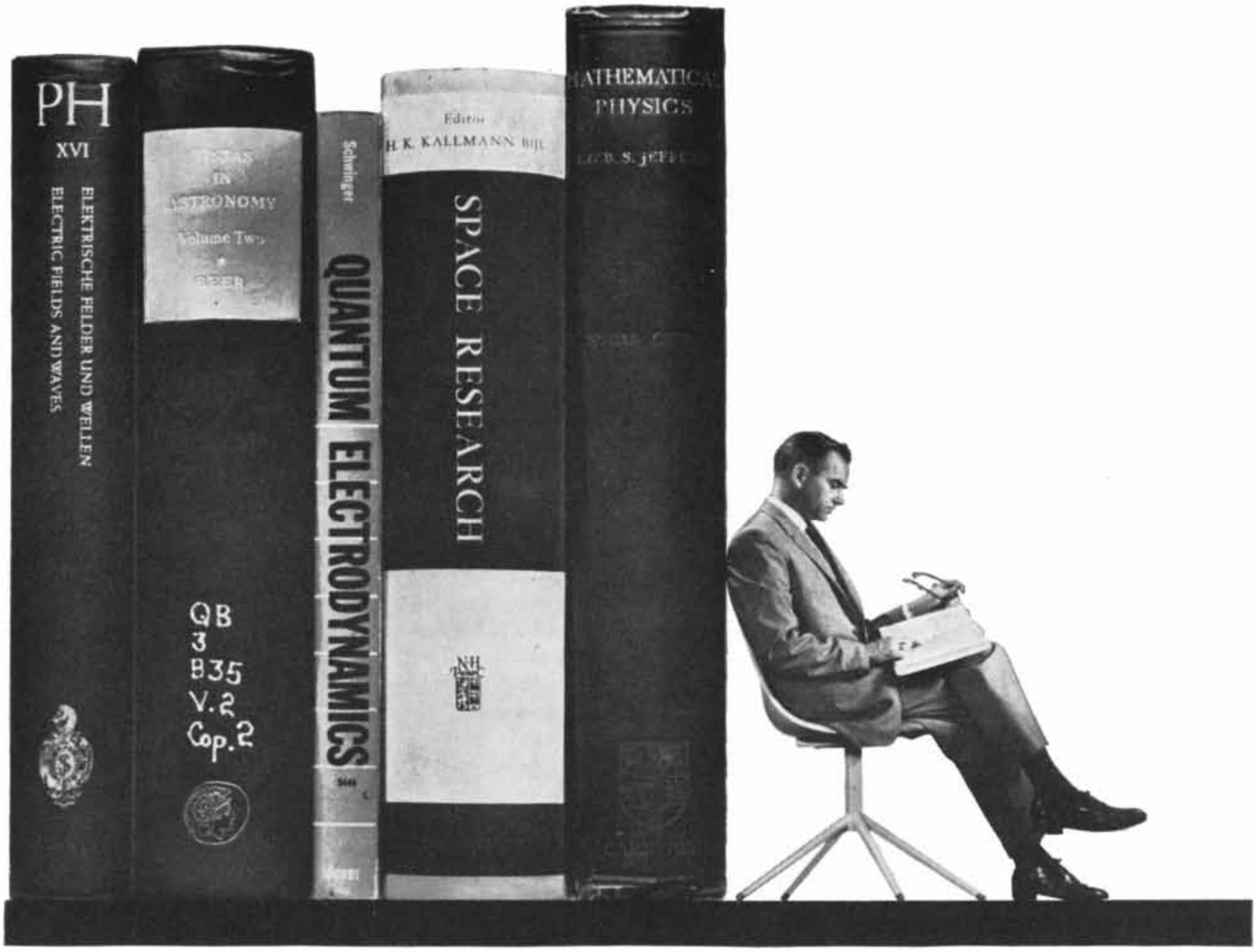
This department shares Smith's enthusiasm for differential thermal analysis. It is a fascinating experiment, both to set up and to run. Not all of us have access to electronic programmers and expensive pen recording systems, however, and even such prosaic materials as three-inch cylinders of stainless steel are not easy to pick up. Nonetheless, with a few tips from Smith I have just built a primitive model of his apparatus. It cost only $20 and it worked very nicely. The principal outlay went into a piece of two-inch alundum tubing for the furnace liner (obtained from the Fisher Scientific Company, 633 Greenwich Street, New York 14, N.Y.) and thermocouple wire.

All Smith's suggestions for constructing the furnace were adopted except one: the paint bucket was not equipped with Transite ends. This was a mistake. Heat buckles the tin and pulls it away from the muffle, and the ends are now being replaced by Transite. The alundum tubing was wound with Nichrome wire removed from a pair of 660-watt radiant-heater units bought at a local electrical-supply store. Each element has a ⅛-inch helical spiral winding. When the spiral is removed from the element, the wire can be straightened by slipping one end of the helix over the point of a shingle nail (held in a vise) and pulling the free end away from the nail. The straightened wires from two radiant elements are twisted to form a pair, then wound on the alundum tube. The ends of the wound coil are clamped to the alundum tube by narrow metal bands as shown in the illustration on page 168.

I did butt-weld one thermocouple with a mercury arc, as Smith suggests. In making such welds a ballast resistor must be connected in series with one lead to limit the current; I used a 660-watt radiant-heater unit, as shown in the drawing below. But when a mercury arc is struck, a small, yellowish cloud of highly toxic mercury vapor rises, a whiff of which could land the experimenter in the hospital. It is better to make the welds with a carbon arc, a more difficult procedure but one that can be mastered with practice. Remove the carbon rod from a size D flashlight cell and wash it thoroughly in strong soap and water. Since an arc will not be sustained between the wires and solid carbon at five amperes (the current passed by the ballast resistor), first drill an axial hole slightly smaller than the diameter of the rod into one end to a depth of about ⅛ inch. (The rod is so soft that you can make the hole by twisting the bit with your fingers.) Save the drillings and tamp them into the hole. Then strike the arc between the thermocouple wires and the solidly packed carbon dust. The small cloud of carbon dust kicked up by the arc seems to conduct just as well as mercury vapor. The



Carbon-arc device for welding thermocouple wires


PH
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ELECTRIC FIELDS AND WAVES
QB
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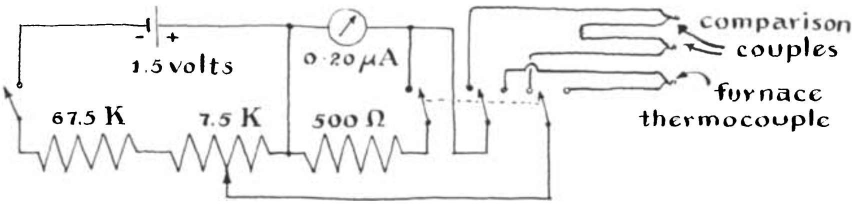


Schematic diagram of the circuit for measuring temperatures

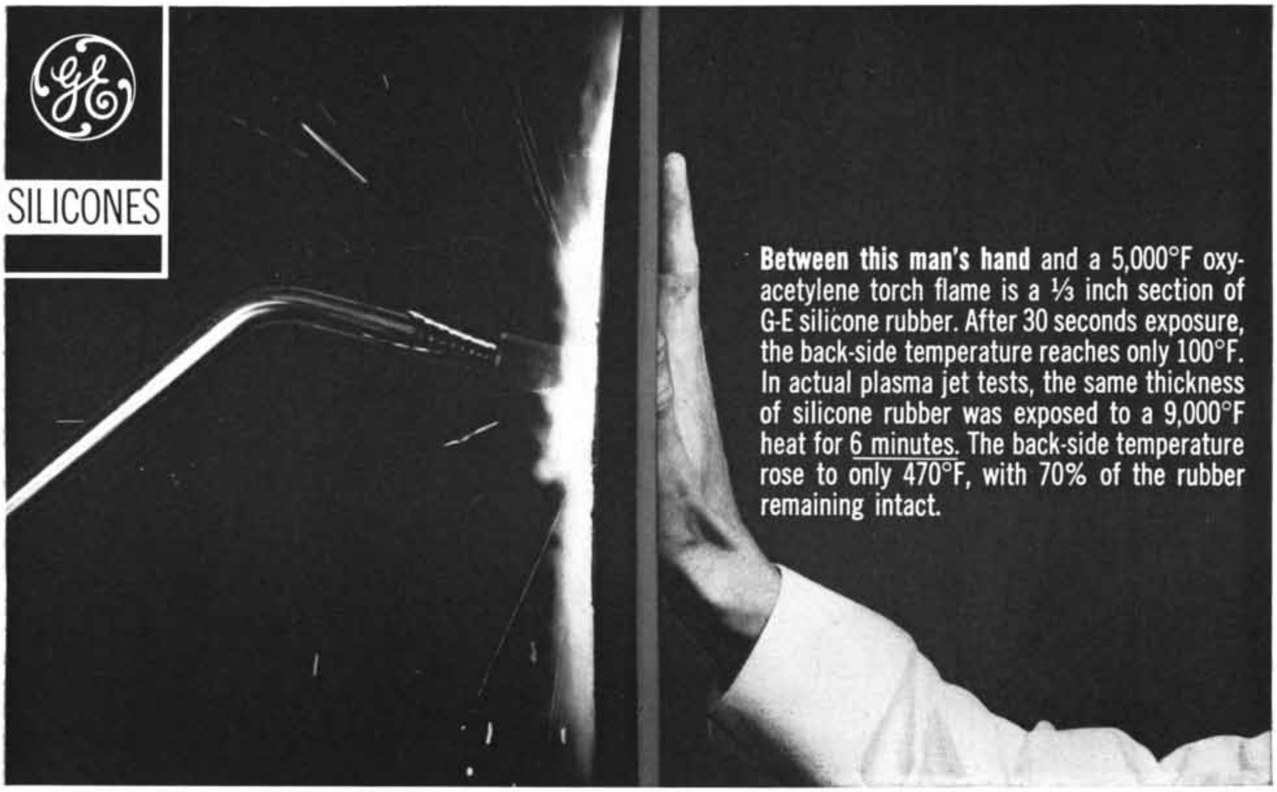
job is made still easier, and better welds result, when a flux of borax is applied to the wires before striking the arc. Just moisten the twisted ends and dip them into powdered borax of the 20 Mule Team variety that is found in most kitchens. Try to control the arc so that the twisted ends melt into a bead about the size of a pinhead. Make a few practice welds with Nichrome wire from a heater unit until you acquire the knack.

The potential difference across Chromel-Alumel thermocouples varies from approximately zero volts at room temperature to 45 millivolts at 1,050 degrees C., as shown by the top graph on page 167. The short-circuit current of the thermocouple reaches a maximum of about 30 microamperes at 1,050 degrees. The maximum output power of the device at this temperature is on the order of one microwatt. To hold costs down I measured the output voltage directly and did not attempt to amplify the current. The measurements were made with the potentiometer circuit shown above. The potentiometer was of the large, wire-wound precision type currently available on the surplus market for $1. The fixed resistor is of the carbon type and rated at ½ watt. The circuit is energized by a single flashlight cell. The voltage of the cell should be determined while under load by an accurate voltmeter. The dial of my potentiometer turns through 270 degrees and is calibrated in 20-minute intervals of arc. A tenth of the cell voltage (.152 volt) appears across the potentiometer. So each scale division equals .00018 volt.

The thermocouples are connected through a double-pole, double-throw switch to the arm of the potentiometer and the positive terminal of the battery so that the thermal current opposes that of the battery. A 0–20 microammeter of the flush-mounted type is included in the common circuit to indicate the direction of current flow. It was converted to function as a sensitive galvanometer by cementing to the pointer a small mirror that reflected a beam of light to a screen 10 yards away. To make the conversion, remove the movement from the case and carefully bend the pointer back over the pivot bearing in the form of a hairpin loop. Center a ⅛-inch square of glass broken from a silvered microscope cover slip above the pivot and cement it there. The movement is then mounted for protection in a box fitted with a window of reasonably flat glass, such as is used for photographic plates. I used a 35-millimeter slide projector as a light source.

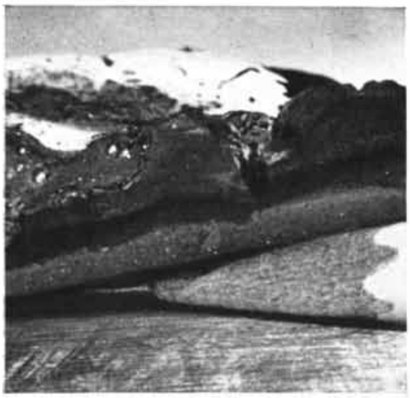
With the potentiometer set at zero, the switch is thrown to connect any cold thermocouple. The position of the beam on the screen is then marked "zero." When heat is applied to the thermocouple, the beam will drift to one side. It is returned to zero by rotating the potentiometer arm. The temperature of the thermocouple is then computed by multiplying the voltage, as indicated by the position of the potentiometer arm, by 23,200. The potentiometer scale can be calibrated directly in degrees centigrade if desired.

I could not locate stainless steel cylinders of the size specified by Smith. So I improvised a one-specimen sample holder out of two stainless steel tablespoons, hammering the bowls into small cups by heating the spoons with a torch and gradually driving the metal into the hole of a ⅝-inch nut with the rounded end of a ⅜-inch bolt. Wrinkles were prevented by alternately hand-forming the cup on an anvil and then driving it a little farther into the nut. The bottoms of the finished cups were drilled for the thermocouples and assembled with alundum cement to an inverted alundum crucible, which had previously been drilled for the thermocouples. Alundum insulating tubes could not be located, so the thermocouple leads were insulated with coatings of alumina cement. The heating rate of the furnace was controlled by a continuously variable auto transformer. A simple rheostat would work as well, although it would run up the light bill a bit faster. Experimenters who duplicate this version of the apparatus will find that cranking the transformer and potentiometer while simultaneously jotting down temperature readings will keep them hopping during the hour of the run. The results, however, will more than justify the effort.



Thermal barrier against 5000°F flame

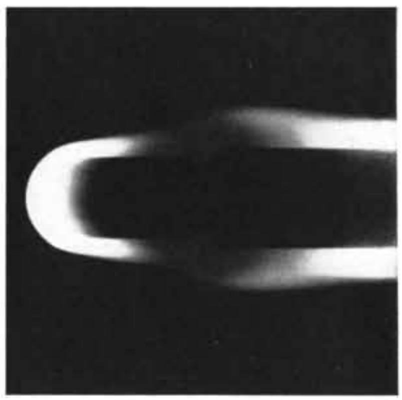
GENERAL ELECTRIC SILICONE RUBBER



RESULTS OF PLASMA JET TESTS AT 9,000°F

Flight Simulation
Vel. = 17,000 ft./sec.
Alt. = 250,000 ft.

Exposure time at 9,000°F	Back-side temperature of ⅓ inch section of G-E silicone rubber
30 seconds	100°F
2 minutes	210°F
3 minutes	300°F
4 minutes	375°F
5 minutes	430°F
6 minutes	470°F



The surface of the tested rubber section forms a hard, carbonaceous crust, while the underside remains flexible and undamaged. Preliminary tests showed the effective heat of ablation to be eight times better than presently used plastics, with one-seventh the rate of ablation and one-fourth the weight loss. Here is an excellent ablative covering with low thermal conductivity.

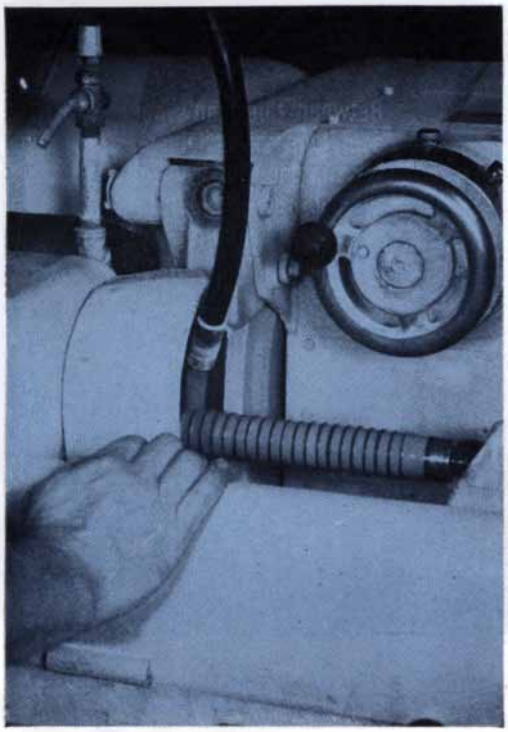
The above chart shows how the high thermal insulation of G-E silicone rubber is maintained during exposure to 9,000°F heat. It is also useful in mechanical and electrical applications at temperatures from —150°F to 600°F, where it remains resilient and flexible. It also maintains its excellent physical and electrical properties over this wide temperature range for extended periods.

Continued high temperature testing goes on at General Electric's Missile and Space Vehicle Department in Philadelphia. Shown above is a typical specimen undergoing plasma jet testing in an electric arc heated supersonic wind tunnel. Continuous testing like this will develop new data on the thermal and ablative uses of G-E silicone rubber.

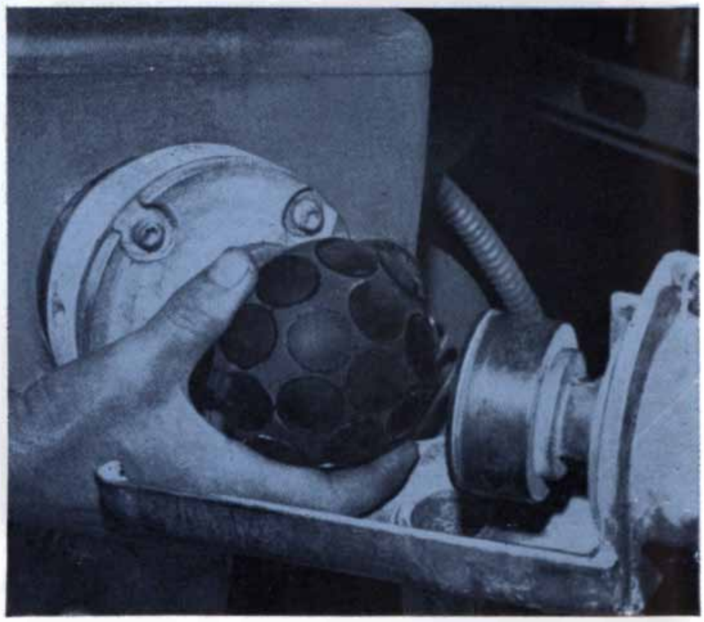
To learn more about G-E silicone rubber, and its uses as a thermal and ablative material, write: General Electric Company, Silicone Products Dept., Section U1261, Waterford, New York.

GENERAL ELECTRIC

Diamonite® Products Mfg. Co., Shreve, Ohio, gang-grinds ceramic rings with natural diamond wheel. The unchanging dimension of the wheel assures uniformity of diameter and surface finish. Only diamonds can give the finish required to meet specified tolerances.



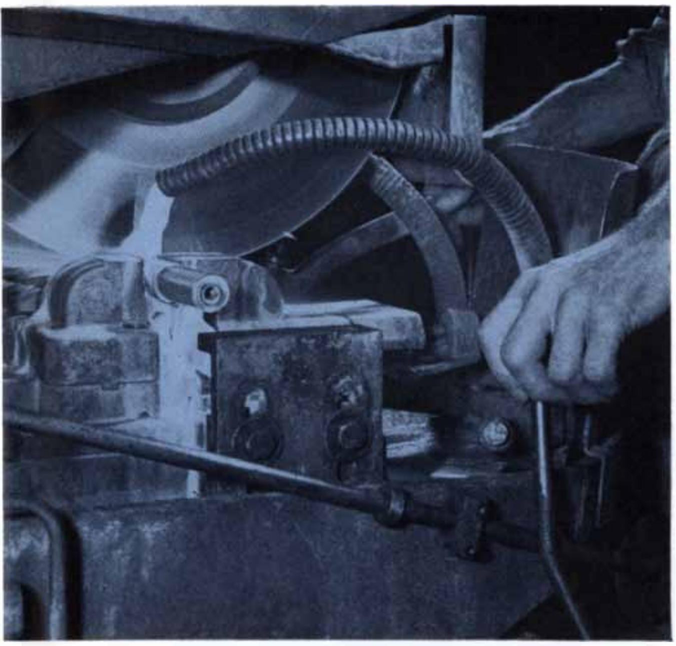
Bell & Howell, Chicago, grinds 13 lenses simultaneously with natural diamonds. Cup-type metal-bond wheel is impregnated with 160-mesh natural diamond particles. Bell & Howell also uses natural diamonds to polish precision parts for their new "zoom" camera mechanism.



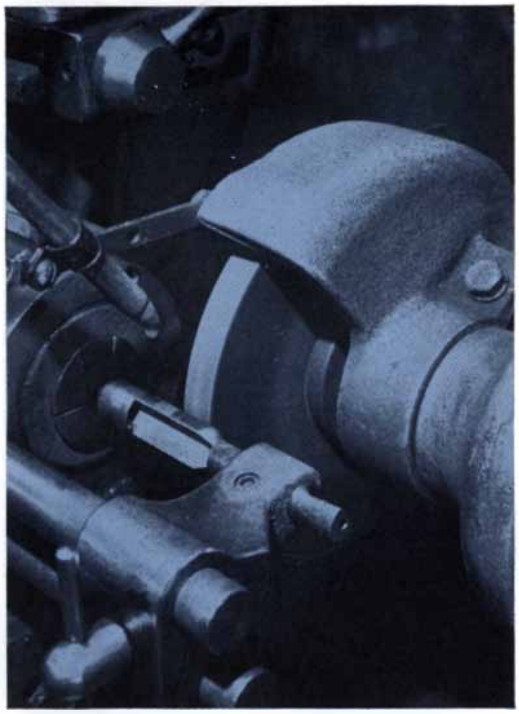
These manufacturers are using natural diamonds to advantage. You can, too.

Industrial diamonds cut practically everything . . . especially your production costs

National Vulcanized Fiber Company, Wilmington, Delaware, cuts glass-reinforced plastic tubing with diamond cut-off wheel. Metal-bond diamond wheel withstands heavy abrasion of glass reinforcement, and leaves a clean, smooth edge without causing delaminations.



Kandu Tool Company, New Haven, Connecticut, grinds carbide gun drills, used to drill deep holes in steel, with natural diamond resinoid-bond wheel. In this operation, .015″ of material is removed in a plunge cut. Only natural diamonds can withstand the impact of the interrupted cut.



The four grinding and polishing jobs shown here span the fields of optics, metalworking and ceramics. But they have one important thing in common: in every case, natural diamonds are doing the job quickly—and economically.

In diamonds, you find this unique combination of properties: excellent cutting ability linked with fantastic endurance.

Result: your diamond tools last longer than any other tools you can use. Your people spend more time producing, less time changing tools.

If you cut, sharpen or smooth in your business, you can probably use natural diamonds to advantage. Test them against the method you're now using. You'll see how efficient—and economical—a diamond can be, especially now.

BEST GRIT FOR METAL-BOND WHEELS DEVELOPED BY THE DIAMOND RESEARCH LABORATORY IN JOHANNESBURG

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CONCEPTUAL SYSTEMS ENGINEERING

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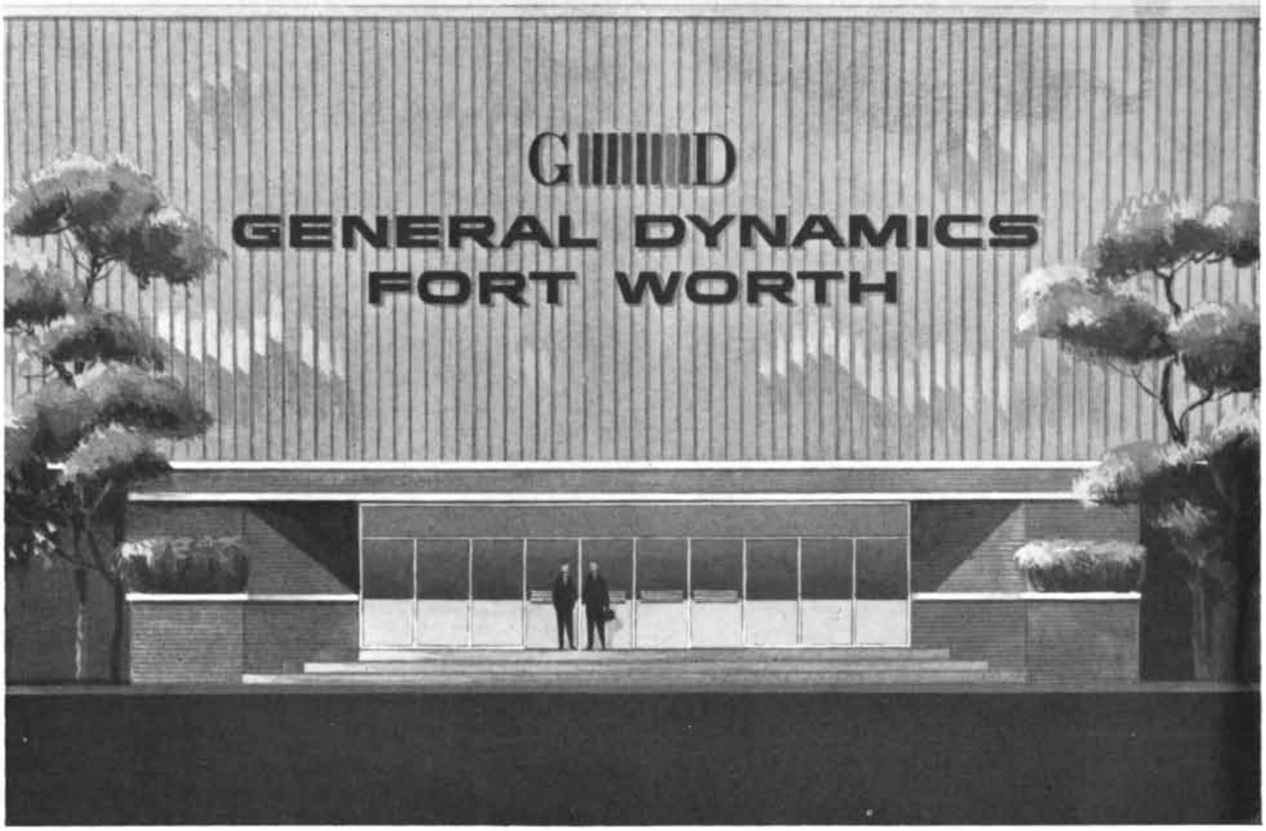

Reconnaissance Systems electronic, photo or infrared reconnaissance systems; photo and infrared instrumentation; Elint simulators • **Radar & Microwaves** advanced radar systems, coherent Doppler data processing radars; satellite tracking and telemetering; communications; MASERS or LASERS; electromagnetic theory; information theory; radar cross section measurements; antennas, RFI • **Computer Design and Data Management** airborne digital or analog computer design for use with navigation and guidance systems, equipment programming, command and control; data recording; data displays • **Advanced Navigation and Guidance** for high performance aircraft and space vehicles; satellite trajectory computation and prediction; satellite re-entry and recovery • **Data Processing and Communications** ground based systems for reconnaissance data processing, point-to-point data transmission and communications network; data processing system display and presentation techniques; computer design • **Advanced Research** PhD's preferred for theoretical-experimental studies in: cryogenic devices, electronic microminiaturization, optics, hyperthermal research, astrogeophysics, applied mathematics, mobility research, nuclear shielding, space radiation, radiation effects • **Operations Research** weapons systems analysis; military operations and logistics planning; managerial and industrial applications; economic analysis, prediction and planning; cost analysis; mathematical probabilistic and statistical model development • **Also current openings in:** structural loads and dynamics, human factors, fluid power control systems.

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GENERAL DYNAMICS | FORT WORTH

BOOKS

A newly translated history of science that traces the rise of the mechanistic concept

by A. Rupert Hall

The Mechanization of the World Picture, by E. J. Dijksterhuis. Oxford University Press ($16.80).

Among the changes in thought accompanying the evolution of modern science, one of the most profound and fertile is singled out for consideration in this penetrating book, the fruit of a lifetime of study in the history of science. The change was that by which mechanistic (or, as men in the 17th century said more simply, mechanical) explanations of phenomena came to be preferred to all others. When it occurred, this change involved a sharply formulated antithesis between what science had hitherto been and what it should be. The science of Greek antiquity and the Middle Ages was accused of accounting for things in nature by means of entities (such as the celestial spheres and Aristotle's four elements) whose existence was not proved, and by the manipulation of concepts that were either esoteric and incomprehensible (such as "form" and "equality") or, still worse, frankly supernatural (such as intelligences responsible for the planetary motions). So long as the investigation of nature had been in the hands of Aristotle and his disciples—the Schoolmen—the answer to the simplest question entailed a hopeless plunge into the unfathomable. It was the ambition of the first modern scientists to explain what was at first sight complex by reference to principles and relationships that were simpler and better known.

At the end of a chain of reasoning, they argued, should be found causes more simple, not more recondite, than the effects they explain. Now the most direct examples of causal relationships are mechanical ones: one end of a lever rises because the other is depressed; a stationary billiard ball moves because it has been struck by the cue. Moreover, if care is taken in defining the circumstances—the billiard table must be level and so forth—it is possible to say of mechanical systems that event *B* will occur if and only if a prior event *A* occurs. Therefore in a given system the occurrence of *B* can be explained only by saying that *A* has occurred, and accordingly a mechanical system may be defined as one governed by a strict and describable rule of causality. It certainly need not be "machine-like" in the crudest (and most pejorative) sense.

This, I believe, is what 17th-century scientists meant by the adjective when they described themselves as "mechanical philosophers." They meant that their mechanistic universe was strictly logical and consistent, and moreover that it was describable because it could be analyzed—that is, broken down into simple components like those of a machine. Using a metaphor rather than a comparison, they could therefore liken the universe to a vastly complex astronomical clock or to a delicate watch. In a rather different sense they could also maintain that their philosophy was mechanical because it began from the premise that everything happening in the universe can be reduced to some phenomenon of matter in motion, so that the science of mechanics (in the modern sense) was the primary and ultimate science. This, however, was an ideal; it was possible to be a mechanical philosopher without being a mathematician, and mechanics itself was unable to say *why* motions of matter occur.

This question was always latent in mechanistic philosophy, intertwined with the problem of determinism. For if there is nothing but inert matter in the universe, and if all the causes of its motions are themselves mechanistic, then it seems that everything happening must be determinate. The word "chance" then merely signifies "hard to calculate." Thus in Descartes's cosmology, since every particulate motion is merely a consequence of the law that the total quantity of motion remains always the same, determinism is complete. Though Descartes writes of a particle of matter "happening" to do this or that, there can be no question of its motion being fortuitous, except in so far as he declares the human soul to be nonmechanistic. With Isaac Newton, in whose work the 17th-century mechanical philosophy attains its peak, the question assumes a new form. For Newton the universe is fully mechanistic, to the extent that its phenomena result from the motions of matter produced by forces, or, as he also calls them, "virtues" or "powers." Of these Newton recognized several kinds, including the gravitational, cohesive, chemical, magnetic, electric and optical. But Newton clearly doubts whether or not forces themselves are mechanical in their origin, for several excellent reasons. Above all, to resolve the forces into further mechanical systems would render the universe utterly "machine-like," without Creator, design or purpose. So Newton declares in a letter to Richard Bentley:

"Gravity must be caused by an agent acting constantly according to certain laws, but whether this agent be material or immaterial, I have left to the consideration of my readers."

From many passages in his writings it is clear that Newton felt bound to resist the mechanization of physical forces *if* this entailed a denial of God and a Design (which he took to be scientifically demonstrable). Since he was unable to define the nature of these forces so that they appeared neither merely mechanical nor (as his critics objected) strangely miraculous in their origin, he left the problem transmuted but unsolved.

So far Newton's attitude was not re-

Editor's Note

Each December since 1949 this department has reviewed a number of books about science for younger readers. The reviews begin on page 183.

mote from that of his Christian predecessors in the mechanization of nature. To men for whom both the Old and the New Testaments were literally exact, mechanism would have been unthinkable had it not been possible to conceive that the universe was God's artifact, a Great Engine constantly under His surveillance. Among Newton's contemporaries, however, there were those who countenanced no limits to mechanism and who accordingly charged Newton with betraying the cause of modern science. The Dutch physicist Christiaan Huygens, for example, declared that "in true science... the causes of all natural phenomena are known from the principles of mechanics. In my opinion this is necessary, or else we must give up all hope of ever understanding anything in physics."

In the opinion of Newton, for whom "to discourse of [God] from the appearance of things, does certainly belong to Natural Philosophy," the limits of mechanization were set by the science of mechanics itself, which does not say how forces arise but tells us rather what their effects are. As defined by Newton, a force is simply that which accelerates a body; in modern classical mechanics force equals mass times acceleration. Neither view says anything about what forces actually exist.

Newton's view prevailed. It was in the limited, Newtonian sense that classical physics established the details of a mechanistic universe. For this universe still admitted Newtonian forces, whereas renewed attempts in the 18th and 19th centuries to replace them by mechanical constructs collapsed as the earlier attempts in this direction by Descartes and Huygens had collapsed. It is true that Newton's force was no longer regarded as an emanant effect of Newton's God; Laplace, as he said in his famous comment to Napoleon, had no need of that hypothesis. But Laplace did not claim to be able to explain gravity. Like magnetism or chemical affinity, gravity had to be accepted as an inexplicable part of the way things are.

To do so did not hinder the development of physics until almost two centuries after the publication of Newton's *Principia*. On the contrary, it enabled classical physics, following the example of the *Principia*, to develop mathematical theories free from the taint of speculation that had clung to the mechanical models of Descartes and Huygens. As a result the Newtonian concept of force, indefinite though it appears, is properly regarded as the last step in that development of mechanistic science through the 17th century which made classical physics possible.

This crucial development has been studied often and from many points of view. The evolution of the mathematical science of mechanics and specifically of celestial mechanics is intimately involved in it. Not less so are the histories of astronomical and atomistic theory. Again, the case for and against a mechanical explanation of events has been much debated by philosophers, with obvious repercussions on religious belief. The scope of *The Mechanization of the World Picture*—the title of the recent English translation of E. J. Dijksterhuis' monumental volume originally published in Dutch 11 years ago—is necessarily wide-ranging and copious. In fact, Dijksterhuis' book is a complete history of physical science from antiquity to the time of Newton, focused on the mechanistic concept. Thoroughly and authoritatively it traverses all aspects of the matter, from philosophical speculation to the mathematical artifices of planetary motion. Dijksterhuis, a senior member of the distinguished Dutch group of historians of science, has taught for many years at the University of Utrecht; he proves himself here a master of his material and its exposition.

Few readers who pick up this solid volume will be deceived by its author's manner of address to the general reader into supposing that this is a trivial work. It is a major contribution to the history of science whose ready availability in English has been eagerly awaited for several years. It should be remarked at once that the translation by Miss C. Dikshoorn is excellent. This is a book for serious study, and one that well repays the effort. Its author expects a fair amount of mathematical and physical understanding on the part of his readers, and by no means fails in respect to his subject by sliding over its difficulties. The reader must be prepared to grapple with ideas, and sometimes terminologies, that demand concentrated attention.

The main steps in *The Mechanization of the World Picture* are not difficult to pick out, though no short summary can do justice to Dijksterhuis' learned and enlightening study of the original texts. The main speculative contribution of the Greeks was their atomistic theory; this was countered, however, by the qualitative physics of Aristotle. The Greek use of mathematics—chiefly in astronomy and statics—furnished another essential element, but, as Dijksterhuis rightly points out, the use remained immature because the Greeks regarded mathe-

matics as capable of representing the phenomena, not of explaining them. Hence their celestial kinematics never developed into celestial dynamics "through an inquiry into the possible efficient cause of the movements traced." Here, of course, there is a vital issue to which Dijksterhuis necessarily returns again and again: so long as mathematics was employed merely to describe, it was inevitably outside the core of scientific thinking, which was indeed dominated during antiquity and the Middle Ages by Aristotle. Passing over Dijksterhuis' careful accounts of the revival of Greek science in Europe and the shaping of medieval philosophy, we find a judicious treatment of the medieval "science of motion," of the idea of impetus and the mathematical analysis of variability. As is now well known, this medieval discussion was the fertile soil from which arose directly the discoveries in mechanics of Galileo and his contemporaries. Then, through Renaissance philosophy and fair, if critical, evaluations of such key figures as Leonardo da Vinci, Paracelsus and Copernicus, Dijksterhuis' story enters its critical and ultimately triumphant phase. From the work of Simon Stevin, Galileo and Kepler in the late 16th century stems the great flow of discovery and innovation in physical science—and above all in mechanics as the paradigmatically mathematical branch of physics—that leads directly to Newton and so to the classical concepts.

Considered as a history of physical science, Dijksterhuis' book deserves nothing but praise. It is full, accurate and acute. If it is unfortunate that the author was unable (as he acknowledges) to refer to important work that has appeared in the dozen or so years since his book was written, it is no less unfortunate that the originality of Dijksterhuis' conclusions has so long been hidden from English readers. For instance, his well-argued contention that Galileo was both less original and less correct than tradition has held him to be is far less striking now than when this book was written. Yet Dijksterhuis is still ahead of the field in criticism of Galileo—perhaps vulnerably so, for he seems to forget that Aristotle was no less Galileo's target than was Ptolemy, and his statement that every one of Galileo's discoveries could have been accounted for in the Ptolemaic system is untrue. (Of course, nothing that Galileo did compelled men to believe in any form of heliocentric system either.) Nor is it quite clear why doubt should be cast on almost every one of Galileo's appeals to experiment when each of

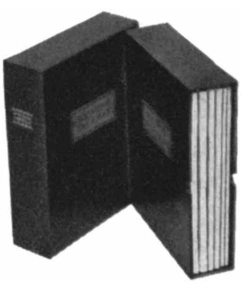
Pascal's bizarre accounts of experiments (of which Robert Boyle was highly skeptical) is accepted without comment. But differences of interpretation such as these are not significant in a long and thoughtful account of physical science.

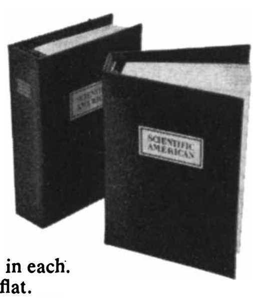
In turning to the specific object of the book—to trace the rise of mechanism in science to its full acceptance (at any rate in physics)—wider and more fundamental criticisms suggest themselves. It may be doubted whether the development of this particular concept of, or attitude to, nature is best brought out by recounting the whole history of physics, even though that history certainly entails the dominance of that concept. A treatment that is at once more analytical and more synthetic than Dijksterhuis' may be required, and one that is more philosophical. That the world is mechanistic is a philosophical concept that has influenced science, that many men have regarded as essential to science and that many also have thought to be justified by science. But the concept can hardly be said to have been produced by science. In fact, when it first became significant, in the 17th century, there was no scientific justification for it. Thus there is a paradoxical sense in which the history of mechanism is outside the history of physics until three centuries ago.

Of course, Dijksterhuis is well aware that scientific activity may be conditioned by the prevailing outlook in philosophy, and, as I have indicated, he puts much effort into reviewing philosophical systems. But he is also well aware that philosophical ideas do not constitute science. In the last analysis, therefore, the mechanization of the world picture is not seen by him as the unfolding in science of a way of regarding nature whose origins and strengths are ultimately philosophical (indeed, metaphysical). It is seen in the closing words of his book as "the introduction of a description of nature with the aid of the mathematical concepts of classical mechanics; it marks the beginning of the mathematization of science, which continues at an ever-increasing pace in the twentieth century." There is much in this final sentence worthy of discussion; here, however, it is only necessary to remark that while Dijksterhuis' definition is perfectly just as applied to the work of mathematical physicists from Newton on, it does not apply to many "mechanical philosophers" who preceded Newton or to some who came after him. Perhaps their view should have been that precise, but in fact it was not; they sought something far more partial and nebulous, being perhaps more at home with pictorial and model representations than with mathematics. It might reasonably be said, for instance, that Dalton's atomic theory mechanized the theories concerning chemical combination that were formulated by Lavoisier and his successors (much as Boyle had attempted, prematurely, to do); but Dalton utilized neither mathematics nor the concepts of classical mechanics. If it is objected that Dalton's was only the first rudimentary step, it can be observed that chemical phenomena never have been described with the aid of the mathematical concepts of classical mechanics, nor was it an endeavor of 19th-century chemists to accomplish this. Nevertheless, one would ordinarily regard 19th-century chemistry as a mechanistic science.

The same kind of difficulty occurs in some of Dijksterhuis' observations on Kepler, of whose discoveries he gives a particularly fine account. He records as the second of the principal features of Kepler's method in science: "Independence of scientific inquiry of all philosophical and theological tenets." He explains further that this "does not of course imply that human thinking had become independent of metaphysical or religious convictions, but only that they were no longer allowed to fulfill any function in the study of science as such." And Kepler, Dijksterhuis points out, was egregiously not independent in the former sense, since his work was inspired by both Christian and Pythagorean ideas. In what sense, then, is Kepler's science nevertheless "independent"? Certainly he did not falsify observations or computations to prove a preconceived, metaphysical idea; nor did he conceal failure of his preconceived ideas to match with the facts. That is to say, he was honest. But he certainly sought and sometimes found things in science because nonscientific considerations led him to believe they must exist. Had he not entertained such considerations he would have acted otherwise; in this sense, at least, they had a scientific function. A man's ideas do not cease to be metaphysical in origin because the most scrupulous scientific inquiry proves them to be true.

The great strength of Dijksterhuis' book is that it brings out very fully both the deficiency of ancient science arising from the lack (indeed, the rejection) of mechanistic analyses of phenomena, and the tremendous theoretical development that followed in the 17th century and later from the use of such analyses. To





go further, to make the most complete exploration of the roots of the mechanistic concept, would be to write another kind of book. Again, a different book would be required to explore the mechanization of the biologist's view of the world—on which Dijksterhuis is completely silent. Other approaches than his have their imperfections. Dijksterhuis' book has the great advantage of following closely the actual events, the problems and their conquest, in the history of physical science. It never loses sight of the specific or of what (at different times) the intellectual horizons of scientists actually included. And above all it is a magisterial history of physico-mathematical science.

Children's Books

VIRUSES AND THE NATURE OF LIFE, by Wendell M. Stanley and Evans G. Valens. E. P. Dutton & Co., Inc. ($4.95). Co-operative books, not to say co-operative popularizations, rarely turn out well. This book is a conspicuous exception. Wendell Stanley and a collaborator, supported by a number of other authorities on virology (Robley C. Williams, Gunther S. Stent, Arthur Pardee, Harry Rubin, C. Arthur Knight, Heinz Fraenkel-Conrat) who are responsible for special chapters, tell the story of viruses better than it has ever been told before. Just as explorers and mountain climbers are frequently able, in spite of the lack of formal training as writers, to tell of their adventures in direct and engrossing fashion, these investigators, experts in their field of research, have put together an always readable, fascinating report of their adventures with flasks, test tubes, Petri dishes, centrifuges, electron microscopes and other laboratory paraphernalia. They explain what a virus is, its dual personality as a molecule and a living organism, its capacity to reproduce itself, its role as an *agent provocateur*, its relation to cancer and other diseases. They clarify the roles of protein and nucleic acid, the chemistry of mutation and the marvelously intricate process by which the genetic material duplicates itself. Photographs and diagrams contribute to the effectiveness of the story. Highly recommended for teen-agers and adults.

GALILEO AND THE SCIENTIFIC REVOLUTION, by Laura Fermi and Gilberto Bernardini. Basic Books, Inc. ($3.50). It is a curious fact that no full-scale modern biography of Galileo has been written. He had a long and full life; he was a

pioneer of physics and astronomy and a founder of the scientific revolution; he was a brilliant writer and an incomparable polemicist; he was persecuted for his ideas, engaged in a long struggle with the Church on behalf of freedom of thought in science, was the central figure in a famous ecclesiastical trial and was condemned to spend the last years of his life in seclusion. The ingredients of a first-class story are all there, but other than Zsolt de Harsányi's biographical novel (1939) and Giorgio de Santillana's study *The Crime of Galileo* (1955), which deals with the intricate and still not fully explained circumstances leading to the Inquisition's charges of heresy, the life of this remarkable man has received scant attention. This book by Mrs. Fermi and an Italian physicist is therefore very welcome. It is not, to be sure, a full-dress performance. It is a 150-page volume appearing in a series addressed to students and general readers; it has none of the solemn (and useful) apparatus of scholarship, and it offers nothing new except an English translation of Galileo's first work in Italian, *La Bilancetta* (*The Little Balance*), written when he was 22 years old, which suggests how Archimedes might have actually performed his famous experiment on Hiero's crown. There is no need, however, to apologize for the book. As an introduction to its subject it has no peer, and as a sketch, not only for teen-agers but also for readers at any age level, of Galileo's personality and achievements it deserves high marks. The writing is simple and pleasant. There is no hero worship. Galileo's ideas and thought experiments are well explained. A good book whose quiet tone is peculiarly effective in bringing out the drama of Galileo's life.

FARADAY AS A DISCOVERER, by John Tyndall. Thomas Y. Crowell Company ($2.75). Michael Faraday died in September, 1867. Four months later John Tyndall, Faraday's associate and later his successor at the Royal Institution, gave a memorial lecture entitled "Faraday as Scientist and Man." The material of the discourse was published as a book in 1868 under the title *Faraday as a Discoverer*. Immensely well received, the volume went through several editions, the fifth in 1893. It is this edition which is here reissued with an introduction and notes by Keith Gordon Irwin and a few additional illustrations. Tyndall's book is a minor classic of the history of science, a keystone of the literature on Faraday. Tyndall was an eminent physicist and a graceful writer, and he knew Faraday well. The account of his incomparable experiments in chemistry and electricity and magnetism, of his broader speculations on gravity, lines of force and the nature of matter is lucid and altogether admirable. Only one other writer, Silvanus P. Thompson in his long-out-of-print book *Michael Faraday, His Life and Work,* covered the material so skillfully; his account is more detailed and has the advantage of examining Faraday's achievements from the vantage point of increased scientific and technical knowledge, important parts of which grew out of Faraday's discoveries. Tyndall's book, however, has lost none of its interest and can be enjoyed by any student or general reader who wishes to learn about one of the greatest "experimental philosophers" the world has ever seen.

ATOMIC PHYSICS TODAY, by Otto R. Frisch. Basic Books, Inc. ($4.50). Since this book is based, as the introduction points out, on a number of broadcasts and popular articles written during the past few years, it does not at first sight seem a very promising package. But the reader is in for an agreeable surprise. Frisch is Jacksonian Professor of Physics at the University of Cambridge, known for his collaboration with Lise Meitner in 1939 in the identification and explanation of the phenomenon of nuclear fission. He gives a clear, well-paced, comprehensive survey of the main topics of atomic physics, which loses little, if anything, by being a collection of independent articles rather than a systematic exposition. Among the subjects dealt with are fission, radioactivity, energy from hydrogen fusion, the nature of atoms, waves and particles, how atomic particles are made visible and counted, the atomic nucleus, high-energy accelerators, fundamental particles, the neutrino, parity, causality. High school students and adults interested both in what is known about the atom and in the great unsolved problems of physics will find this a stimulating volume.

REALM OF ALGEBRA, by Isaac Asimov. Houghton Mifflin Company ($3). Asimov has done an excellent job of explaining the building blocks of algebra, the rudiments that are so often badly taught and that so many youngsters, even the bright ones, don't quite get the hang of. The result is that, while they are able to go on and take the required mathematics courses in high school, they perform with about the same understanding of what they are doing and why as trained seals. The book discusses the meaning of equations, why things are set equal, how to maneuver fractions, the vagaries of negative numbers, mixing different operations, the relations between equations and figures, the use of parentheses, extraction of roots, solving quadratics, simultaneous equations. A final chapter demonstrates the uses of algebra in determining the behavior of moving bodies, the law of gravitation, the weight of the earth. The whole thing is handled so well one is sorry to see the book come to an end and regrets that Asimov is not at hand while one is struggling with more advanced topics. For ages 12 and up, and for anyone who would like to make a fresh start in the realm of algebra.

MATHEMATICS IN THE MAKING, by Lancelot Hogben. Doubleday & Company, Inc. ($9.95). With *Mathematics for the Million* Hogben broke new ground in the popularization of the subject. There had, of course, been other good simplifications long before his time. In the 18th century, for example, the great Leonhard Euler broke open the mysteries of algebra in his *Letters to a German Princess;* in the 19th century Adolphe Quételet wrote charmingly (for a duke) about the meaning of statistics, and Augustus De Morgan published several first-rate mathematical primers; in this century Silvanus P. Thompson's celebrated little *Calculus Made Easy* and Alfred North Whitehead's *Introduction to Mathematics* were among the books which helped the student and general reader to grasp mathematical concepts and to taste the intellectual excitement of the foremost science. Hogben, however, made his own distinctive contribution, not only in the range of topics with which he dealt, the detailed treatment and the skillful use of illustrations, but also in style and interpretation. In Hogben's view mathematics is and always has been a tool, an instrument, a means of communication. While he is not indifferent to its elegance and beauty, nor insensitive to mathematics as a form of art, his primary concern is with its service to man in achieving understanding of and control over the physical world. Man made mathematics to help him as an accountant, surveyor, architect, explorer, carpenter, merchant, stargazer, bridge builder, physicist, biologist, gambler, underwriter, soldier, clockmaker, economist—and as a student of human affairs and human behavior. This view of the subject strongly flavored *Mathematics for the Million* and continues to flavor, though perhaps somewhat less strongly, the present volume. What is now offered is a "humanistic" account of the growth of mathematics, an attempt to describe by selected major achievements "a facet of the history of the technique of human communications." In a text strongly supported by a variety of visual aids—ingenious diagrams, photographs, facsimiles, colored illustrations—Hogben spans the development of mathematical ideas from the beginnings of counting and measurement to the sophistications of Gödel's proof. This is not always an easy book for the beginner or even the beginner-over-again. It compels concentration and presses the reader to work through the methods and examples. It is also opinionated and designed to affront orthodox opinion; he says, for example, that Aristotle was pre-eminent in stifling human inventiveness, and that if he and Plato were truly representative of the intellectual achievements of Greek civilization, "we might reasonably write off the Greek contribution as a prolonged setback." But Hogben naughty is still Hogben, which is to say an able scientist and a lucid popularizer, with a gift for illuminating mathematical ideas, tracing their origins and exhibiting astonishing relationships between apparently unrelated concepts. For teen-agers and adults.

THE WONDERFUL WORLD OF ENGINEERING, by David Jackson. Doubleday & Company, Inc. ($2.95). Excellent books have appeared in this series, among them Ritchie Calder's on medicine and John Boyd-Orr's on food. This one is no earth-shaker, but it is colorful, pleasant and mildly informative. It gives a scattering of facts about laying railway tracks, building dams, river control and irrigation, digging canals, mounting large radio telescopes, pushing roads through difficult terrain, tunneling under mountains and water, constructing tall buildings, bridges, harbors and breakwaters, and so on. Good illustrations of all types, some in color.

RADIOASTRONOMY AND RADAR, by J. G. Crowther. Criterion Books, Inc. ($3.50). The very same device that played a critically important role during the war—radar—was almost immediately afterward transformed into a major tool of astronomical research, the radio telescope. This book, for teen-agers, gives a concise and clear account of the origin and principles of radar, its present-day uses in navigation and surveying, airfield control, weather forecasting; and a similar survey of radio astronomy, including descriptions of the scientific knowledge which has been gained and of the research programs being carried out with the immense new radio telescopes in Britain, the U.S. and elsewhere. Crowther is an able popularizer, skilled in making intricate mechanisms understandable and engrossing. Illustrations.

TEN LITTLE HOUSEMATES, by Karl von Frisch. Pergamon Press, Inc. ($3). The title is cute and so is some of the writing, but this is a most engaging little book. It deals with the incivilities and the charms (if any) of 10 small creatures, several, if not all, of which are apt to be our lodgers. The 10 housemates are the housefly, the gnat, the flea, the bedbug, the louse, the clothes moth, the cockroach, the silverfish, the spider and the tick. They are, with the possible exception of the spider, detested and despised; we know their names and we exterminate them on sight if we can; and that is about the range of our knowledge and our feeling for them. Yet each is wonderful in its way, and it is Frisch's purpose to tell us something about their structure, function and habits. It must not be supposed, however, that in providing this information he seeks to make nonresisters of us—to persuade us, say, to be soft on bedbugs and cockroaches. On the contrary, in each case he gives specific instructions on the latest and best methods to get rid of the pests. Samples from Frisch: There are 40,000 different species of fly; more flies are killed by fungus threads which attack them (fly mold) than by cold or insecticides. Gnat bites itch because when the gnat settles to have a meal off us it deposits through its proboscis a tiny drop of irritant liquid, a dripping from its salivary glands, which literally make the gnat's mouth water in anticipation of delights to come. Fleas, like crickets, have sound-making organs, but the music can be heard only by other fleas. Bedbugs have on their undersides two tiny sacs which are filled with bacteria that live in symbiosis with the bugs; the bacteria have a cozy home, in return for which they supply certain of the bedbug's nutritional requirements by producing vitamins necessary for its healthy growth. A "well known" zoologist has reported that in 1915 he removed 3,800 living lice from the shirt of a Russian prisoner of war. Moths don't eat cotton because they lack the enzymes that are necessary to digest the lignin of vegetable products. Cockroaches have been around this distracted globe, little changed, for about 300 million years. They have hard chitinous teeth in their stomachs with which they rechew their food. Since nobody likes cockroaches, they are in each area named—as was the case with syphilis—after the hated neighbor alleged to be responsible for their appearance; for example, in western Germany they are called "Frenchmen," in eastern Germany "Russians," in Russia "Prussians." Ticks have no eyes; they have a sense of smell, the organs being located in small hollows near the "toes" of the first pair of legs. This explains why a tick sits with its forelegs raised, atop a blade of grass, waving its legs slowly about in the air. In the chapter on spiders Frisch gives a superb step-by-step description of the engineering involved in spinning a web. It is astonishing how little the inborn skill of these animals is bound to a rigid system, how greatly their action differs in detail according to local conditions and according to "the weaver's character." This chapter alone makes the book worth reading. Good drawings. A fine book for anyone 12 or over.

MAN AND POWER, by L. Sprague De Camp. Golden Press, Inc. ($4.95). Man gets his living by scratching things from the surface of the earth and moving them around. Both activities require energy. Until comparatively recently this energy came from his own muscles or from those of domesticated animals. But in the past 200 years or so he has learned to harness other forms of power, devising ingenious, increasingly larger and more elaborate machinery for the purpose. This book is an illustrated survey of the evolution of these devices. Beginning with the crude machines that were used long before the Industrial Revolution, the story moves through the ages up to the present time, covering power derived from such sources as wind, water, steam, internal combustion, chemical reactions, electricity, nuclear processes. The text is sensible; the illustrations are abundant, colorful and informative. Agreeable and instructive reading for teen-agers and adults.

THE DOUBLEDAY PICTORIAL LIBRARY OF NATURE: EARTH, PLANTS, ANIMALS, edited by James Fisher, Sir Julian Huxley, Sir Gerald Barry and J. Bronowski. Doubleday & Company, Inc. ($9.95). This is the second volume in an attractive series, the first having dealt with chemistry, physics and astronomy. Various specialists have written sections on the structure of the earth, how living things work, the mechanism of heredity, the past ages of life, evolution, animal behavior, the geography of life, the web of life, man's place in nature, man as a social animal. The material is clearly presented and easy to read. A remarkable amount of information is compressed into this single volume, yet there is no sense of haste or superficiality. Open the book at any page and there are well-captioned illustrations that arrest the eye and invite further study. The pictures—of which there are hundreds, some in color, some photographs, some diagrams—are not conspicuously well executed, but they perform the right service at the right time. Altogether, a much better than average introduction to the study of nature, suitable for teen-agers as well as adults.

WHAT IS RELATIVITY? by L. D. Landau and G. B. Rumer. Basic Books, Inc. ($1.95). This popularization by two leading Soviet physicists has merit. A B C relativity is a subject on which many lances have been tried and almost as many broken. The ingenious analogies never quite reach; the trains and clocks and rods and lanterns, harmless and familiar things with which the reader is quite comfortable at first, begin as soon as the plot thickens to behave preposterously, like props in a haunted house. Then, to make matters worse, mathematical equations and formulas appear, which are usually simple but, alas, not simple enough for the many intelligent people who are able to function splendidly in the intricate engagements of life but collapse when confronted by fractions and indices, which they had hoped never to see again after the school traumas of elementary algebra. C. V. Durrell wrote a first-rate primer, *Readable Relativity*, noted in these columns before, but it required working through and is not for those who blanch at a square-root sign. There are few other introductions that even half-fulfill their purpose. Landau and Rumer come closer than most. They have no really new ideas; all the old paraphernalia is used. Still, they strive for and achieve a most commendable plainness. Simple words, no jargon, no slurring over subtleties, no cheating; one or two square roots, no fractions. Everything is here that is needed, even to understand the flummery about those space travelers who daintily nibble at time while we stay-at-homes lose our quenchless feud with it at a headlong rate. It is worth mentioning that the publisher describes this little book as suitable for readers of 14 and older. Very proper. For the fact is if you can't grasp the fundamentals at 14, the chances are you never will. The brain gets no better as one gets older, especially in casting off the prejudices and preconceptions which are the main obstacles to understanding relativity.

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BIBLIOGRAPHY

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

NATIONALITY AND CONFORMITY

CROSS-NATIONAL RESEARCH. *The Journal of Social Issues,* Vol. 10, No. 4; 1954.

NATIONAL CHARACTER: THE STUDY OF MODAL PERSONALITY AND SOCIOCULTURAL SYSTEMS. Alex Inkeles and Daniel J. Levinson in *Handbook of Social Psychology,* edited by Gardner Lindzey. Addison-Wesley Publishing Co., Inc., 1954.

THE STUDY OF CULTURE AT A DISTANCE. Edited by Margaret Mead and Rhoda Métraux. University of Chicago Press, 1953.

STUDYING PERSONALITY CROSS-CULTURALLY. Bert Kaplan. Row, Peterson & Company, 1961.

THE EAST PACIFIC RISE

THE EAST PACIFIC RISE. H. W. Menard in *Science,* Vol. 132, No. 3441, pages 1737–1746; December 9, 1960.

THE FLOORS OF THE OCEAN. I: THE NORTH ATLANTIC. Bruce C. Heezen, Marie Tharp and Maurice Ewing. The Geological Society of America Special Paper 65; 1959.

HEAT-FLOW VALUES FROM THE SOUTH-EASTERN PACIFIC. R. Von Herzen in *Nature,* Vol. 183, No. 4665, pages 882–883; March 28, 1959.

THE RIFT IN THE OCEAN FLOOR. Bruce C. Heezen in *Scientific American,* Vol. 203, No. 4, pages 98–110; October, 1960.

SERPENTINES, OROGENY, AND EPEIROGENY. H. H. Hess in *Crust of the Earth,* pages 391–407. The Geological Society of America Special Paper 62; 1955.

SATELLITE CELLS IN THE NERVOUS SYSTEM

BIOCHEMICAL CHANGES IN GLIAL CELLS AND NERVE CELLS AT VARYING ACTIVITY. Holger Hydén in *Official Proceedings of the International Congress of Biochemistry, Vienna,* Vol. 3, pages 64–89; 1960.

MASS, LIPIDS, PENTOSE NUCLEOPROTEINS AND PROTEINS DETERMINED IN NERVE CELLS BY X-RAY MICRORADIOGRAPHY. Sven-Olof Brattgård and Holger Hydén in *Acta Radiologica,* Supplement 94; 1952.

THE NEURON. Holger Hydén in *The Cell,* Vol. 4, edited by Jean Brachet and Alfred E. Mirsky, pages 215–323. Academic Press Inc., 1960.

THE EÖTVÖS EXPERIMENT

BEITRÄGE ZUM GESETZE DER PROPORTIONALITÄT VON TRÄGHEIT UND GRAVITÄT. Roland von Eötvös, Desiderius Pekár and Eugen Fekete in *Annalen der Physik,* Vol. 68, No. 9, pages 11–66; 1922.

GRAVITATION WITHOUT A PRINCIPLE OF EQUIVALENCE. R. H. Dicke in *Reviews of Modern Physics,* Vol. 29, No. 3, pages 363–376; July, 1957.

IDEAS AND OPINIONS. Albert Einstein. Crown Publishers, Inc., 1954.

THE MEANING OF RELATIVITY. Albert Einstein. Princeton University Press, 1955 (fifth edition).

PRINCIPLE OF EQUIVALENCE AND THE WEAK INTERACTIONS. R. H. Dicke in *Reviews of Modern Physics,* Vol. 29, No. 3, pages 355–362; July, 1957.

THE THREE-DIMENSIONAL STRUCTURE OF A PROTEIN

BIOPHYSICAL CHEMISTRY. Edited by John T. Edsall and Jeffries Wyman. Academic Press Inc., 1958.

THE CRYSTALLINE STATE. Edited by Sir W. H. Bragg and W. L. Bragg. G. Bell and Sons Ltd., 1933.

THE MOLECULAR BASIS OF EVOLUTION. Christian B. Anfinsen. John Wiley & Sons, Inc., 1959.

X-RAY ANALYSIS AND PROTEIN STRUCTURE. F. H. C. Crick and J. C. Kendrew in *Advances in Protein Chemistry,* Vol. 12, pages 133–214; 1957.

THE FIGHTING BEHAVIOR OF ANIMALS

AGGRESSION. J. P. Scott. University of Chicago Press, 1958.

KAMPF UND PAARBILDUNG EINIGER CICHLIDEN. Beatrice Oehlert in *Zeitschrift für Tierpsychologie,* Vol. 15, No. 2, pages 141–174; August, 1958.

STUDIES ON THE BASIC FACTORS IN ANIMAL FIGHTING. PARTS I–IV. Zing Yang Kuo in *The Journal of Genetic Psychology,* Vol. 96, Second Half, pages 201–239; June, 1960.

STUDIES ON THE BASIC FACTORS IN ANIMAL FIGHTING. PARTS V–VII. Zing Yang Kuo in *The Journal of Genetic Psychology,* Vol. 97, Second Half, pages 181–225; December, 1960.

ZUM KAMPF-UND PAARUNGSVERHALTEN EINIGER ANTILOPEN. Fritz Walther in *Zeitschrift für Tierpsychologie,* Vol. 15, No. 3, pages 340–380; October, 1958.

GALVANOMAGNETIC AND THERMOMAGNETIC EFFECTS

GALVANOMAGNETIC AND THERMOMAGNETIC EFFECTS. L. L. Campbell. Longmans, Green & Co., Inc., 1923.

AN INTRODUCTION TO SEMICONDUCTORS. W. Crawford Dunlap, Jr. John Wiley & Sons, Inc., 1957.

THE PROPERTIES, PHYSICS, AND DESIGN OF SEMICONDUCTOR DEVICES. John N. Shive. D. Van Nostrand Company, Inc., 1959.

THE SCIENCE OF ENGINEERING MATERIALS. J. E. Goldman. John Wiley & Sons, Inc., 1957.

SEMICONDUCTORS. R. A. Smith. Cambridge University Press, 1959.

THE SOLID STATE FOR ENGINEERS. Maurice J. Sinnott. John Wiley & Sons, Inc., 1958.

PREHISTORIC SWISS LAKE DWELLERS

DIE AUSGRABUNGEN IN DER SPÄTBRONZEZEITLICHEN UFERSIEDLUNG ZUG-SUMPF. Josef Speck in *Das Pfahlbauproblem,* edited by W. U. Guyan *et al.,* pages 275–334. Birkhäuser, 1955.

PFAHLBAUSTUDIEN. Emil Vogt in *Das Pfahlbauproblem,* edited by W. U. Guyan *et al.,* pages 119–219. Birkhäuser, 1955.

REVIEW OF DAS PFAHLBAUPROBLEM. H.-G. Bandi in *Bonner Jahrbücher,* No. 155–156, Part II, pages 623–631; 1955–1956.

MATHEMATICAL GAMES

THE AMAZING WORLD OF JOHN SCARNE. John Scarne. Crown Publishers, Inc., 1956.

ON CARD TRICKS. John Scarne. Crown Publishers, Inc., 1950.

SCARNE ON DICE. John Scarne and Clayton Rawson. Military Service Publishing Co., 1945.

THE AMATEUR SCIENTIST

DIFFERENTIAL THERMAL ANALYSIS: THEORY AND PRACTICE. W. J. Smothers and Yao Chiang. Chemical Publishing Co., Inc., 1958.

MULTIPLE DIFFERENTIAL THERMAL ANALYSIS. Paul F. Kerr and J. L. Kulp in *The American Mineralogist,* Vol. 33, Nos. 7 and 8, pages 387–419; July–August, 1948.

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