SCIENTIFIC AMERICAN

FRACTURED METAL

FIFTY CENTS

February 1960

Photographed with the cooperation of Columbus Coated Fabrics Corp., Columbus, Ohio

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Surprising as it may seem, you're looking at a fabric supported vinyl upholstery. It's called *Milano* and, for the first time, combines the soft shimmer of moiré silk with the washability, wearability and general durability of vinyl.

There's no single reason for the distinctive eye- and touch-appeal of this upholstery. It results from a combination of fine skills and materials. But among these materials, Pliovic, the basic vinyl resin used, plays a key role.

The primary advantages of using Pliovic are: 1. It blends readily, fuses at low temperatures, is generally easy to process. 2. It embosses easily and faithfully. 3. It helps assure lasting adhesion to the knitted fabric backing. Other benefits: Excellent heat- and light-stability plus good over-all physical properties.

Improving the appearance and performance of supported upholstery sheeting is but one of many possible uses for Pliovic. How can it help your product? For the answer plus full details on Pliovic write: Goodyear, Chemical Division, Dept. N-9457, Akron 16, Ohio.

GOODYEAR
CHEMICAL DIVISION

Pliovic—T. M. The Goodyear Tire & Rubber Company, Akron, Ohio

Milano—T. M. Columbus Coated Fabrics Corporation, Columbus, Ohio

Basic Research at Honeywell
Dr. Finn Larsen
Vice President for Research, Honeywell

Thermoelectricity, Electrical Resistance and Electron Scattering in Metal Alloys

How does the scattering of electrons affect the thermoelectric behavior and the conduction of electricity in metals? Physicists at Honeywell have been able to successfully predict certain features of this behavior on the basis of a simple mathematical model.

Everyone is familiar with the fact that metals are good conductors of electricity and also good conductors of heat. All of the electrical current and most of the heat is carried ordinarily by the electrons in a metal. The flow of electricity is intimately associated with the flow of heat or energy, and we can say that the heat flow "interacts" with the electrical current flow. Whatever gives rise to one of these flows will also give rise to the other. Thus if we connect a wire across a battery we get a flow of energy (heat) as well as a flow of electricity; conversely, if we place one end of a copper wire in a flame, heat will pass down the wire and at the same time an electrical current will flow momentarily so as to "readapt" the electrons to the new situation in the wire—one end of the wire is now hotter than the other. The electrical current flow is only momentary because there is no "return path" by which the electrons can flow around in a closed circuit.

If we connect an iron wire to the copper wire at the hot end, and connect the two free ends to a sensitive voltmeter, there will be a flow of heat (energy) in both wires, of course, and there will also be a flow of electrons in both wires. But now, since the electrons are free to traverse a closed loop (through the voltmeter), the electrical current flow is sustained as long as we keep the hot junction in the flame.

The experimental facts that heat flow in a pair of wires (called a *thermocouple*) can cause electricity to flow has been known for over a century and is called the Seebeck Effect; the reverse phenomenon, that electrical current flow through a junction of dissimilar metals will cause heat to flow toward or away from the junction, depending upon the *direction* of the current, has been known for nearly a century and is called the Peltier Effect. The Seebeck Effect is used in thermocouples to measure temperature, to detect radiation (which simply heats the junction), to generate electricity from heat, and for many other related applications which involve the conversion of heat into electrical current flow. The Peltier Effect has only recently come into prominence in thermoelectric refrigerators, and in these applications as well as in thermoelectric generators it has been found that semiconductors are often more suitable than metals.

Although the general connection between heat flow and electrical current flow is now well known, the detailed *mechanisms* of electrical and heat conduction in metals is only poorly understood. The extent to which a particular metal conducts electricity or heat is determined in part by the number of electrons which can contribute to the conduction process, and in part by the opposition or "resistance" which these electrons meet as they move along the wire. This resistance results from the presence of various kinds of "obstacles" or "irregularities" in the wire and can be treated as a *scattering* of the electrons from their normal forward motion along the wire. For example, a "perfect" crystal lattice consisting of only copper atoms at *fixed* positions would present no resistance to the flow of electrons; but at any temperature above absolute zero the copper atoms vibrate about their normal positions and behave as "obstacles" to the conduction electrons.

A very effective kind of obstacle or scatterer is an atom of a kind different from that of which the crystal itself is made. Thus if we place a gold atom in a copper lattice, the electrons are confronted with an "oddity" in the otherwise "pure" copper lattice and are thereby scattered: the more gold atoms, the larger the total scattering and the larger the electrical resistivity. Also, some atoms are more effective scatterers than others; thus iron atoms in copper are nearly twenty times more effective than gold atoms. Finally, the scattering ability of a given atom usually depends upon the temperature of the crystal.

Our understanding of the facts just described is at best only qualitative, and the specific *interactions* between heat flow and electrical flow which give rise to the Seebeck and Peltier thermoelectric effects are even more of a mystery! Nevertheless, we have been successful in predicting the thermoelectric behavior of *ternary* alloys on the basis of empirical information on *binary* alloys. We have thus contributed some small amount of order into a technological field (metal thermocouples) which for a century has been within the exclusive domain of alchemy.

But our motivation in this work has not been *primarily* the development of "bigger and better" resistance and thermocouple materials—rather it has been a desire to understand specifically how electrons interact with various kinds of imperfections in a crystal. Together with physicists, chemists and metallurgists in other laboratories throughout the world, we look forward to a more thorough understanding of this very small facet in the fascinating study of matter.

If you wish to have more details of our work in the field of thermoelectricity in metal alloys, we will be happy to provide them. Simply write to Honeywell Research, Minneapolis 8, Minnesota.

Honeywell
First in Control
H HONEYWELL SINCE 1885

Established 1845 SCIENTIFIC AMERICAN February, 1960 Volume 202 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover depicts an experiment in fracture (*see page 94*). Bolted into the jaws (*top and bottom*) of a special test apparatus at the Naval Research Laboratory in Washington, D.C., an eighth-inch aluminum plate has cracked under a tension of 200,000 pounds. Before the tension had been applied, a hole with a slot to its left and right had been made in the plate. Under the tension the crack slowly grew out from the slots; then the plate suddenly fractured. The dial at lower right shows that a tension of 15,000 pounds remained when the slow cracking had ended; the timer at upper right, the time in seconds during the extension of the crack.

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Cover painting by Walter Murch

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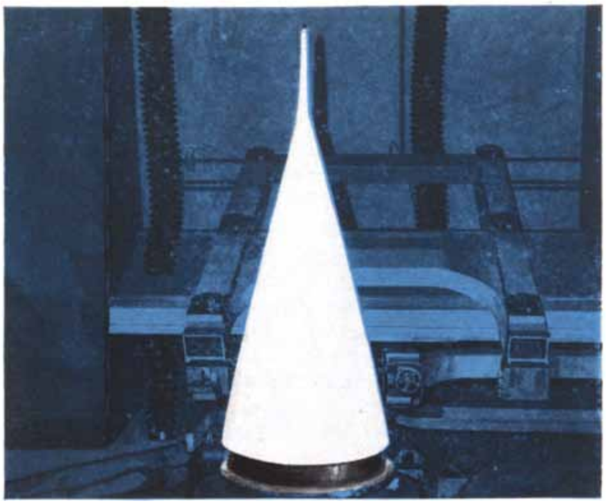
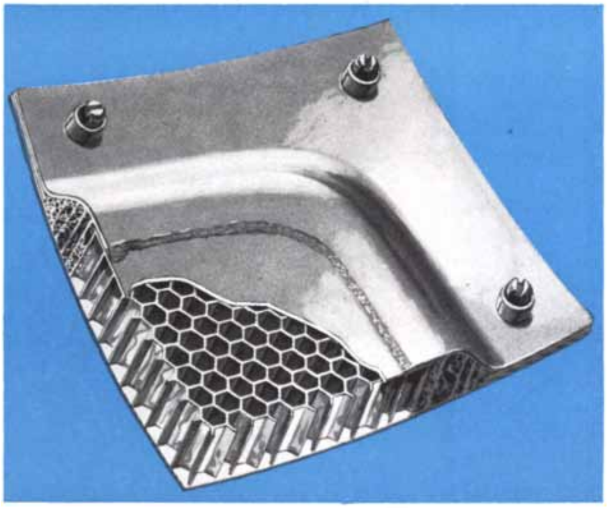
Brunswick technology leads the way in three critical space-age components

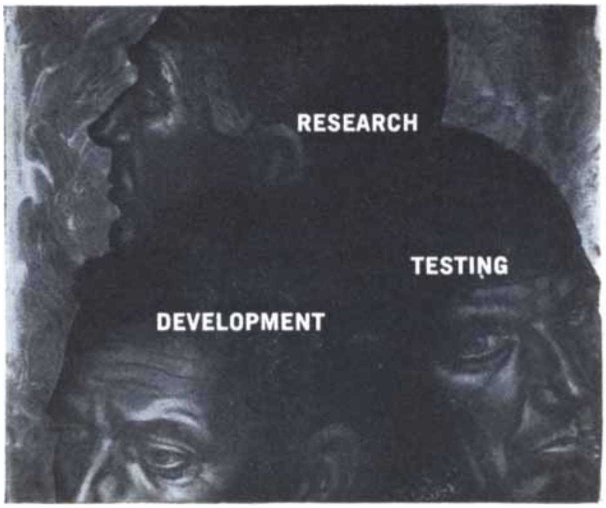
PRESSURE VESSELS AND MOTOR CASES, fabricated by Brunswick's exclusive Strickland "B" Process, now have the highest strength-to-weight ratio ever obtained in filament-wound components. Brunswick is *now* producing these virtually leak-proof pressure vessels. Brunswick also fabricates motor cases capable of withstanding extremely high pressures and temperatures.



RADOMES AND NOSE CONES, created by Brunswick's outstanding research and development efforts and filament winding process, are being used on supersonic aircraft such as the advanced Convair F-106 and McDonnell F4H, as well as on missiles such as the Boeing Bomarc, Lockheed Q5 and similar missiles. And, of course, Brunswick capabilities include complete electronic design and test facilities.



HONEYCOMB ASSEMBLIES, now developed by Brunswick can support two million times their own weight. Brunswick research has created honeycomb assemblies of paper, fiber glass, aluminum and stainless steel as well as conventional forms. Using the most advanced adhesive systems, these assemblies can be formed in compound curvatures with extremely close tolerances.



RESEARCH, DEVELOPMENT AND TESTING—carried on by Brunswick teams have contributed heavily to space-age technology . . . most notably in solving problems of increasingly high operating temperatures (600°–4,000°F.) for critical components and new heights in strength-to-weight ratios. For full information on how this leadership can help you, write or call Brunswick today!

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What you should know about Analog Computers

The Donner 3400 Desk-top Computer functions as a compact, versatile electrical model of a dynamic system.

Judging from the literature, most discussion of analog computers turns on form rather than function.

Every computer manufacturer, including Donner, is ready to tell you all about their designs, right down to the last microvolt. Few spend their literary effort in telling you how to use them and what kind of problems are amenable to analog computer solution. Not too strangely, this is what you, the prospective user, wanted to find out in the first place.

HOW AN ELECTRONIC ANALOG COMPUTER SOLVES PROBLEMS

A mathematical expression which defines the dynamic behavior of a particular physical system also describes the behavior of all other analogous systems. A general purpose analog computer can be programmed to behave as one of these analogous systems. So programmed, it can be used to explore the characteristics of the system or to "solve" the describing equations. Typical problems range all the way from explaining the laws of classical and modern physics to the physiological relations of life itself. Here are some of the fields where analog computers are in use: antenna design, medical research, cybernetics, electron trajectories, nuclear reactor design, fluid mechanics, heat transfer analysis, aerodynamics, meteorology, classical and nuclear physics, chemical kinetics, petroleum, engineering, servo system analysis, auto- and cross-correlation, and economic forecasting.

Assembly of Donner 3100 series high accuracy medium size analog computers in quantity lots provides the user with more value at lower cost. Complete Donner 3100 Computer Consoles start at just under $11,000.

Basic computing elements in an electronic analog computer are dc amplifiers, precision components (resistors, capacitors, and potentiometers), and non-linear accessories (multipliers, function generators, and transport delay simulators).

By interconnecting the computing elements at a patchboard, varying voltage amplitudes can be integrated, summed, differentiated, multiplied, divided, altered in non-linear fashion, and otherwise operated on as directed by a mathematical equation. The answer, which appears as a varying voltage, can be visually observed on a voltmeter or an oscilloscope and permanently recorded by any one of several plotting devices.

The analog computer user can take an equation, change the coefficients at will, and get whole sets of solutions with amazing ease and speed. He can get these results to accuracies of 0.1% or better for a very modest investment. Small Donner computers begin at just over $1,000.

ANALOG OR DIGITAL

The chief advantages of the analog technique are speed, economy, and flexibility. With the analog computer, you get a genuine insight into the response of the system to both internal and external stimuli. No other approach can bring the investigator into such intimate contact with the system.

Digital computers sometimes provide more accurate results, but they seldom give the user the same knowledge because they are at best only machines that compound arithmetic information. Unlike digital computers, analog computers actually behave just like the simulated systems.

TWO NEW PUBLICATIONS PROVIDE MORE INFORMATION

If you are interested in learning more about the application of analog computers, copies of Donner Tech Notes #1 and #2 are available from your nearby Donner engineering representative or directly from the factory. Tech Note #1 is titled "How to Simulate a Non-Linear Control System with an Analog Computer;" Tech Note #2, "How to Use and Program Analog Computers."

Donner Scientific specializes in the manufacture of accurate fixed and general purpose analog systems designed to analyze, measure, and control dynamic inputs. Complete technical information and informed applications assistance can be obtained from your nearby Donner engineering representative or writing Dept. 70.

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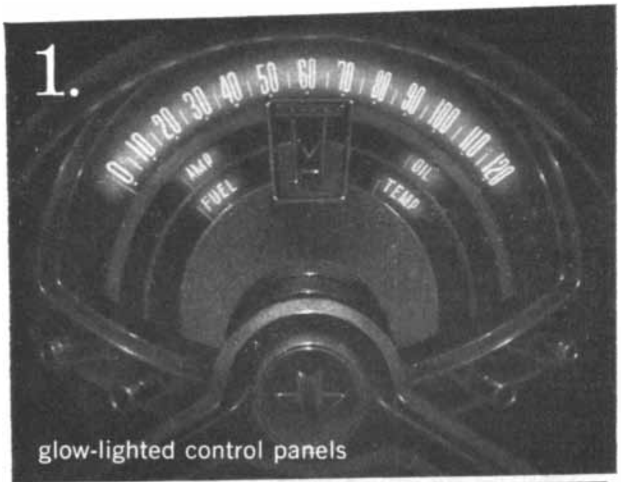
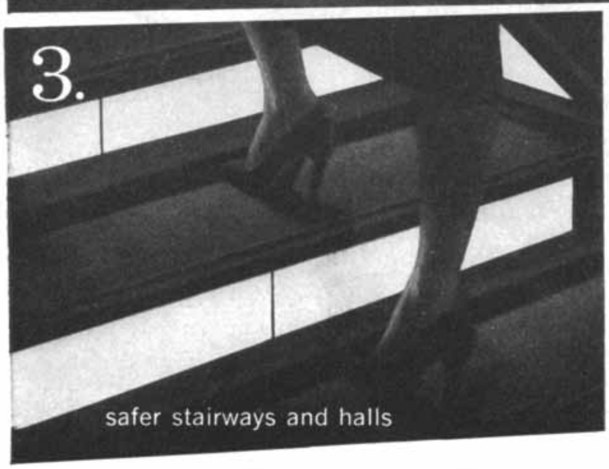
4 bright ideas...

WITH SYLVANIA PANELESCENT® LAMPS



glow-lighted control panels

easy-to-read dials



safer stairways and halls

Here's imagination to challenge your own—the first new light source in fifty years.

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Today you can create easier-to-read dials for clocks, radios and other appliances. You can design glow-lighted dashboards for automobiles, and stairs and halls for homes and hotels that are safer at night. Tomorrow you may be designing walls and ceilings that come alive with gentle radiance. Soft whites, refreshing greens, cool blues, and warm yellows.

Do you feel an idea coming on? Would you like more information to spark your thinking? If so, write to Sylvania Lighting Products, a Division of Sylvania Electric Products Inc., Dept. 51, 60 Boston Street, Salem, Mass. *In Canada:* Sylvania Electric (Canada) Ltd., P.O. Box 1190, Station "O," Montreal 9.

SYLVANIA

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Coating of a TFE-fluorocarbon resin is used on filler barrel of the Parker 61 pen, a product of The Parker Pen Co., Janesville, Wisconsin

THE INSIDE STORY: How a finish put an end to an inky problem

The inner barrel of the new Parker Pen is dipped into ink and fills by capillary action. Puzzling to the designers at first was how to make it easy to clean the wet barrel. *Solution:* A coating of the TFE resin sheds the ink so well, that it is not necessary to wipe the cell case.

Unless special techniques are used, nothing sticks with any strength to a TFE-fluorocarbon resin surface. Moreover, TFE resins resist heat to 500°F., are unaffected by almost all chemicals, and have lower coefficients of friction than any other solid material.

Special techniques can however be used to bond TFE resins. Sheets of TFE resins are often applied via these techniques to hoppers, conveyors and chemical vats. The exposed surfaces of the resins remain slippery and "anti-adhesive".

We've just issued a 20-page illustrated booklet entitled "TEFLON TFE-Fluorocarbon Resins in Mechanical Applications", packed with facts on uses of TFE resins. Send for your copy today. **E. I. du Pont de Nemours & Co. (Inc.), Polychemicals Department, Room T-392, Du Pont Building, Wilmington 98, Delaware.**

In Canada: Du Pont of Canada Limited, P.O. Box 660, Montreal, Quebec.

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LETTERS

Sirs:

In the brief review of Isaac Asimov's *Words of Science, and the History behind Them* ["Books," SCIENTIFIC AMERICAN, December, 1959] we read that the word "ellipse," coming from the Greek for "defect," indicated a defective circle. This is not at all the origin of the word. In the *Conics* of Apollonius, the originator of the name in this connection, the words "ellipse" (defect), "parabola" (equality) and "hyperbola" (excess) were applied to the three curves now known by these names because of the relationships $y^2 < px$, $y^2 = px$ and $y^2 > px$, respectively, where p is the parameter (*latus rectum*) of the curve which is so placed upon a coordinate system that a vertex is at the origin, and the axis of the curve lies along the axis of abscissas. One sees that Apollonius applied the name "ellipse" to indicate not a defective circle but a defective parabola.

CARL B. BOYER

Brooklyn College
Brooklyn, N. Y.

Sirs:

In the article "Molecular Motions," by B. J. Alder and Thomas E. Wainwright [SCIENTIFIC AMERICAN, October, 1959], you reproduced a photograph that W. E.

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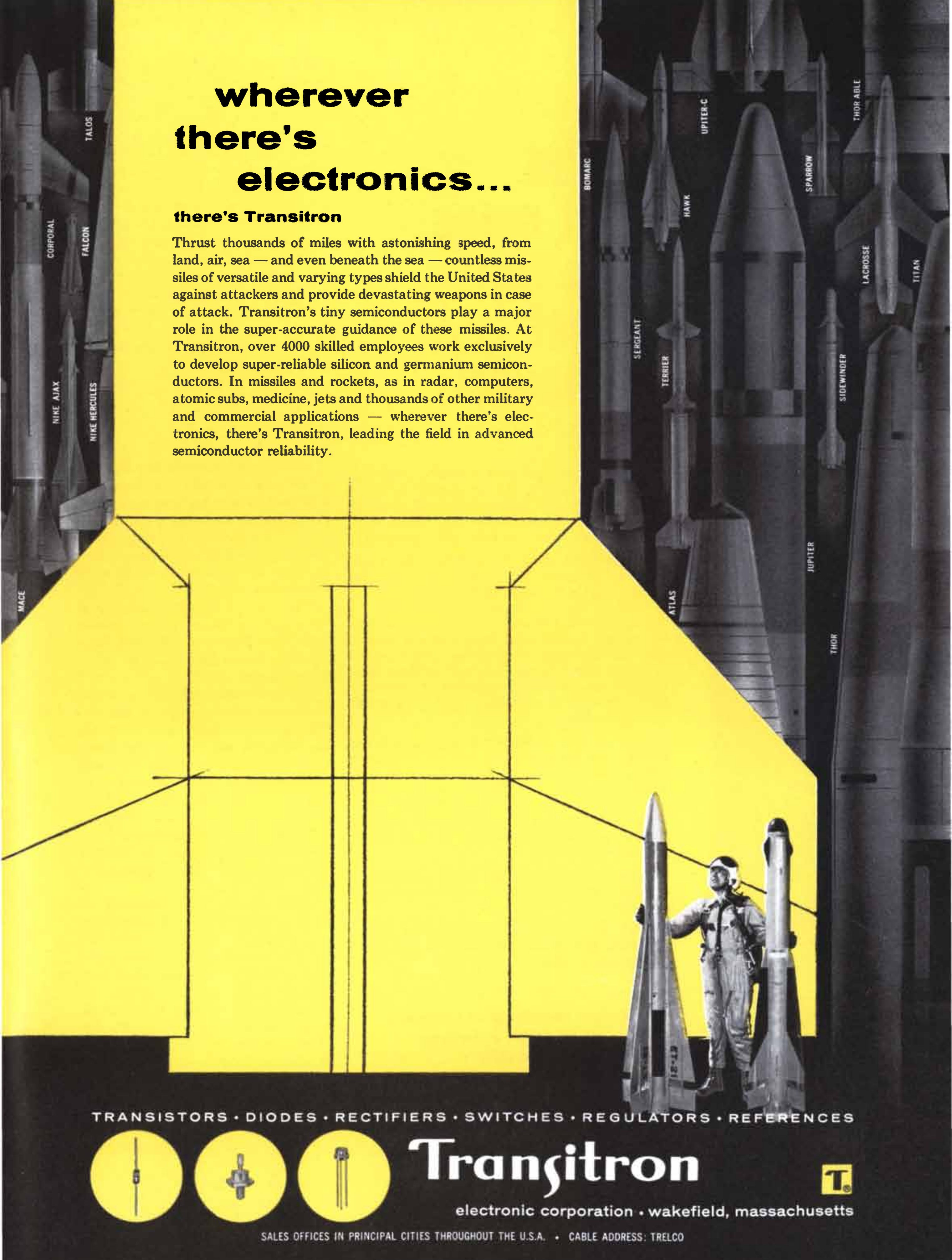
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Morrell and I had published in 1936 of a model designed to represent the distribution of molecules in a liquid. In referring to it, the text states: "They suspended gelatin balls in a tank of liquid whose density was equal to that of the gelatin, so that the gravitational force was canceled by buoyancy."

Omitted from that statement was an additional essential factor: The suspending liquid must have the same refractive index as the gelatin balls. Both conditions were achieved by using as the suspending-phase liquid a gelatin solution that had been boiled to prevent gelling.

JOEL H. HILDEBRAND

University of California
Berkeley, Calif.

Sirs:

I have just taken up the October issue of *Scientific American* and have read with great interest the brief autobiographical remarks of George Wald in your section "The Authors." It is such a beautiful statement that I read it out loud to my wife, and then I was reminded of what others have said.

Wald says: "I think this is the way it always goes in science, because science is all one." Then we have what René Descartes says in his *Regulae ad Directionem Ingenii* (1629):

"Hence we must believe that all the sciences are so interconnected, that it is much easier to study them altogether than to isolate one from all the others. Therefore, if anyone wishes to search out the truth of things in earnest, he should not select any one special science; for all the sciences are conjoined with each other and interdependent."

And then, too, we have the words of Herbert Spencer in *The Genesis of Science* (1854):

"Without further argument it will, we think, be admitted that the sciences are none of them separately evolved—are none of them independent either logically or historically; but that all of them have, in a greater or less degree, required aid and reciprocated it. Indeed, it needs but to throw aside hypotheses, and contemplate the mixed character of surrounding phenomena, to see at once that these notions of division and succession in the kinds of knowledge are simply scientific fictions."

JULIUS SUMNER MILLER

El Camino College
El Camino, Calif.

SYNCHRONOUS D.C. MOTOR

Globe Industries has developed a control circuit for our d.c. permanent magnet motors which causes the motor to run synchronously with a reference frequency while getting full power from a d.c. source. Thus now you can have, in one package, the high torque per weight and size advantage of our d.c. motors combined with precise speed regulation. The system does not disturb the speed-torque performance of the motor even during starting.

The control is fully transistorized. No contacts or other moving parts are used, so that long reliable speed regulation is assured.

One version of this control, in a two cubic-inch package, provides speed regulation of +.1%/−.5% over load and/or voltage variations. (The motor runs in exact synch with the built-in reference frequency but the frequency generator also has a .1% error over the range −20°C to 50°C.)

Speed regulation with accuracy measured in parts per million is being approached through development of a very stable separate frequency generator to be fitted into a five cubic-inch package.

We are ready to discuss your application problems. Our wide experience in making motors for literally thousands of military applications—involving the fullest range of environmental requirements—assures you of a quick solution to specific problems. Globe Industries, Inc., 1784 Stanley Avenue, Dayton 4, Ohio, Telephone BAldwin 2-3741.

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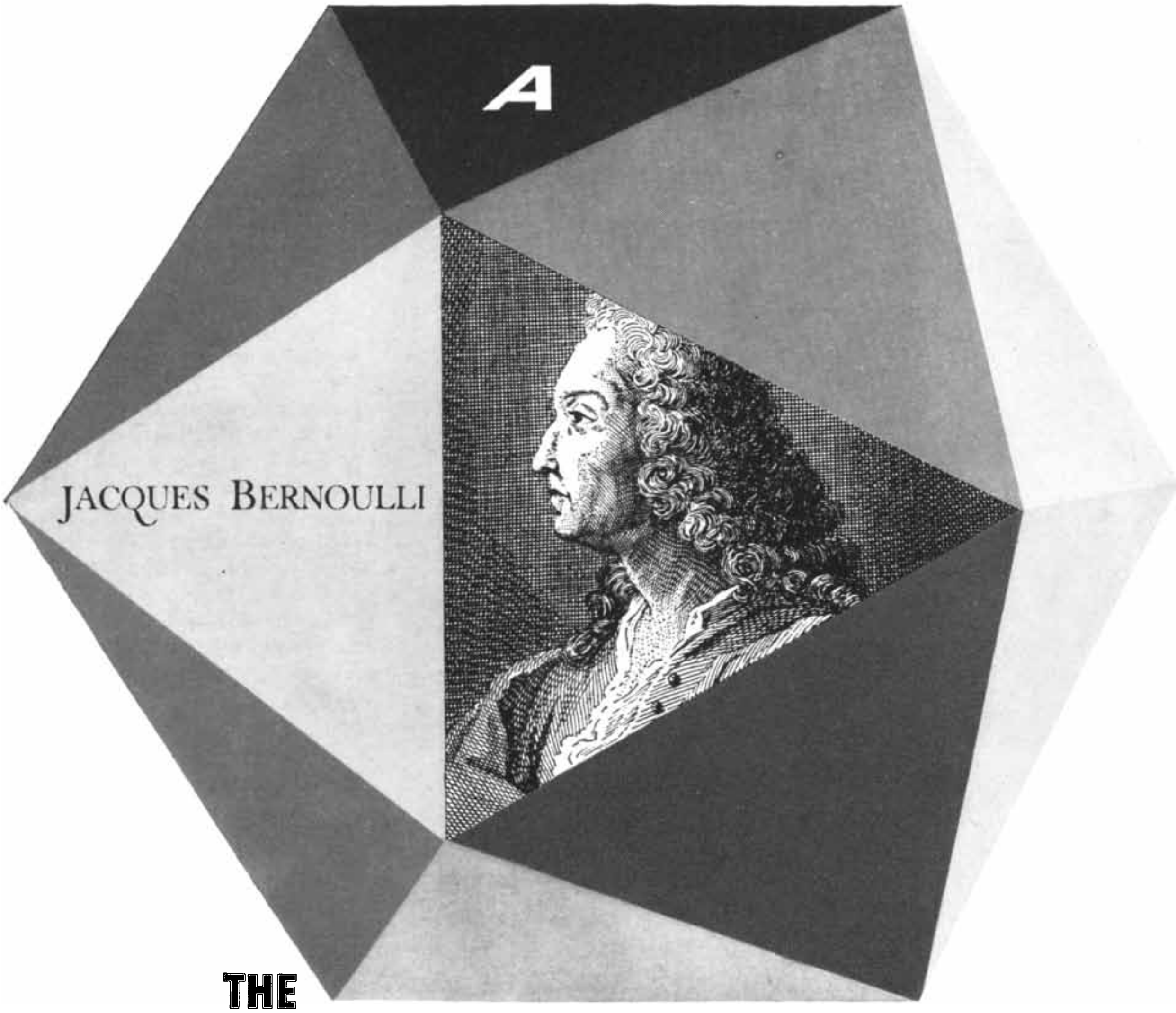
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1910: "The first spectroscopic observations of Halley's comet, made at Meudon by Deslandres and Bernard, reveal clearly marked discontinuities in the spectrum of the comet. The faint continuous spectrum is crossed by distinctly stronger lines, especially in the ultraviolet region. On December 6th the comet showed a nearly circular nucleus from which extended two curved rays of feeble brilliancy, resembling the antennae of an insect. The direction of these rays was such that it appeared scarcely possible to attribute them solely to the repulsive force of the sun. These first observations show that the comet is already self-luminous and that its light is due partly to incandescent gases."

"The infectious nature of poliomyelitis has been assumed rather than proved; it would now seem that complete demonstration of infectivity will presently be forthcoming. Early in 1909 two German experimenters, Landsteiner and Popper, successfully inoculated two monkeys with spinal cord taken from two fatal human cases of poliomyelitis. In both the monkeys lesions of the spinal cord were found similar to those in man. In September of 1909 Dr. Simon Flexner and his colleague, Dr. Paul A. Lewis, of the Rockefeller Institute in New York City, similarly inoculated monkeys with emulsions of human spinal cord and later with emulsions of the cords of monkeys that had developed paralysis after injection of the first emulsion. In one series, seven monkeys were each successively inoculated with the virus from the cord or cortex of its predecessor, the disease regularly resulting. Flexner and Lewis have found that the virus of infantile paralysis is of the same nature as that of smallpox; it belongs to the class of the minute and filterable viruses. There should be no reason in science why a vaccine or an immunizing agent against poliomyelitis should not in good time be forthcoming."

"In recognition of the culmination of his life work in the discovery of the



THE WIZARD OF ODDS *He solved a telephone traffic problem two centuries ago*

Jacques Bernoulli, the great Swiss mathematician, pondered a question early in the 18th century. Can you mathematically predict what will happen when events of chance take place, as in throwing dice?

His answer was the classical Bernoulli binomial distribution—a basic formula in the mathematics of probability (published in 1713). The laws of probability say, for instance, that if you roll 150 icosahedrons (the 20-faced solid shown above), 15 or more of them will come to rest with side "A" on top only about once in a hundred times.

Identical laws of probability govern the calls coming into your local Bell Telephone exchange. Suppose you are one of a group of 150 telephone subscribers, each of whom makes a three-minute call during the busiest hour of the day. Since three minutes is one-twentieth of an hour, the probability that you or any other subscriber will be busy is 1 in 20, the same as the probability that side "A" of an icosahedron will be on top. The odds against 15 or more of you talking at once are again about 100 to 1. Thus it would be extravagant to supply your group with 150 trunk circuits when 15 are sufficient for good service.

Telephone engineers discovered at the turn of the century that telephone users obey Bernoulli's formula. At Bell Telephone Laboratories, mathematicians have developed the mathematics of probability into a tool of tremendous economic value. All over the Bell System, the mathematical approach helps provide the world's finest telephone service using the least possible equipment. The achievements of these mathematicians again illustrate how Bell Laboratories works to improve your telephone service.

BELL TELEPHONE LABORATORIES

World center of communications research and development

North Pole, the Senate has passed a bill making Commander Robert E. Peary a Rear Admiral on the retired list. This signal recognition of the explorer followed closely upon the recent gathering, presided over by the Governor of the State of New York, at which Peary received a gift of $10,000, which, by the way, he immediately contributed to the proposed U. S. expedition for the discovery of the South Pole."

"On the 10th instant Wilbur and Orville Wright were presented with the Langley medals of the Smithsonian Institution by Chief Justice Fuller at Washington. Dr. Alexander Graham Bell and Senator Henry Cabot Lodge made brief addresses. Wilbur Wright announced that as soon as he and his brother get their American company under way, they expect to devote their time to research work in aviation. The two gold medals were designed by J. C. Champlain, a member of the French Academy, the reverse being from the seal of the Institution, which was designed by St. Gaudens."

"Madame Curie has obtained a tenth of a grain of polonium and has been experimenting with it. Polonium is a radioactive element discovered by Madame Curie as early as 1898, but not obtained before in sufficient quantities for elaborate experimentation. From the brief reports which have been received, it would seem that polonium in its earlier stages is more radio-active than radium, but it loses its power very much more rapidly. It seems reasonably certain that polonium is identical with radium F, one of the series of metals produced by the decomposing of radium."

"The Aeronautic Show held in Mechanics Hall, Boston, Mass., from the 16th to the 23rd instant, although fairly representative of the different experimenters, was somewhat of a disappointment in that none of the motor-driven heavier-than-air machines exhibited has actually flown, and half were shown without motors. Upon entering the hall the visitor saw the Blériot and Antoinette type monoplanes of the Scientific Aeroplane and Airship Company. The former of these machines has lately been experimented with upon ice by Mr. Stanley Y. Beach and is in a fair way of making a flight in the near future. Opposite these two machines were two Wright-type biplanes, one of which had movable flaps upon the rear edges of the wings instead of the warping arrangement used by the Wrights. The finest

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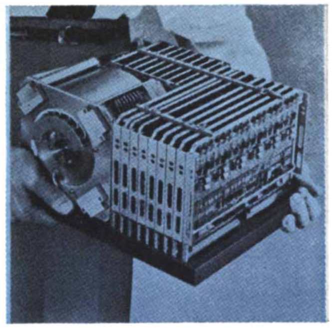
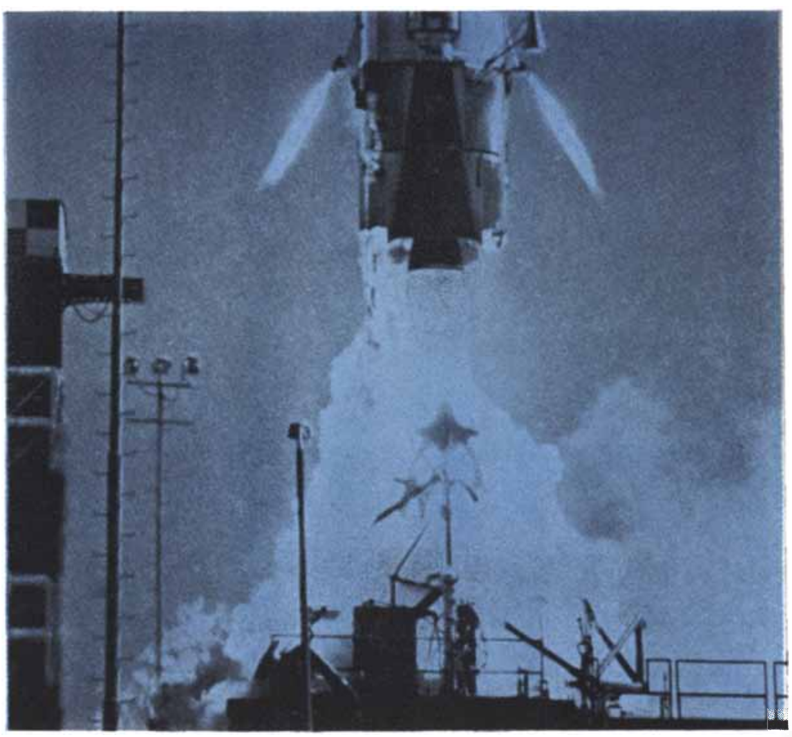


computers that pace man's expanding mind



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piece of construction on exhibition was the Herring machine built by the Starling Burgess Company, a well-known boatbuilding concern. This machine, in general appearance resembling the Curtiss biplane, was mounted upon three round skids, no wheels being used. The machine, complete with a Curtiss motor, weighed less than 400 pounds. There were also several gliders on view, and a large number of models of all kinds, most of which were built by boys."

Scientific American.

FEBRUARY, 1860: "Colonel Colt has invented a revolving shot gun. It is said that upon a late trial of this valuable gun, at a distance of 30 yards, it put 175 pellets in a circle of 12 inches diameter, penetrating 75 sheets of ordinary brown paper. The gun is a five-shooter."

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"A very distinguished English inventor has recently gone the way of all the earth, and under circumstances which call forth our sympathies. This man was James Boydell, the inventor of the steam traction engine for common roads. He was in the very prime of life, and had made an appointment with some of the government snobs to test his engine in the Woolwich marshes, and was kept waiting in vain for their attendance during a severely inclement day in December, by which he caught a severe cold, from the effects of which he never recovered. His peculiar locomotives are not adapted for quick traveling, but for drawing heavy loads, such as would require 10, 12 and even 20 horses. They are invaluable, and will yet come into more general use. English papers complain that James Boydell was murdered by government routine."

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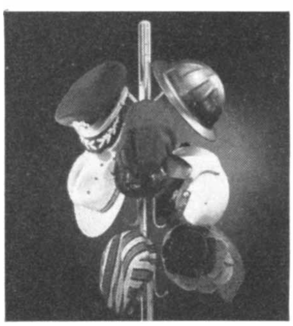

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working

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Because of Aero's all encompassing interest in controls, its engineers have for years been working in the area of human factors engineering. The speed and complexity of space age machines demand an optimum interaction (within parameters of reliability, weight, cost) between man and the machine. One of several techniques for measuring the optimum man-machine relationship is SSOA (Second-by Second Operational Analysis) . . . an analysis of perceptual inputs and motor outputs for each second of a mission; a basis for later workload analysis.

Techniques such as SSOA and achievements such as electrically suspended gyros, adaptive flight control systems, guidance and control systems for space vehicles are examples of Aero's interest in airborne controls. Their competence has been demonstrated by contributions to Mercury, Scout, X-15, Sergeant, Thor, Atlas, Titan, and others.

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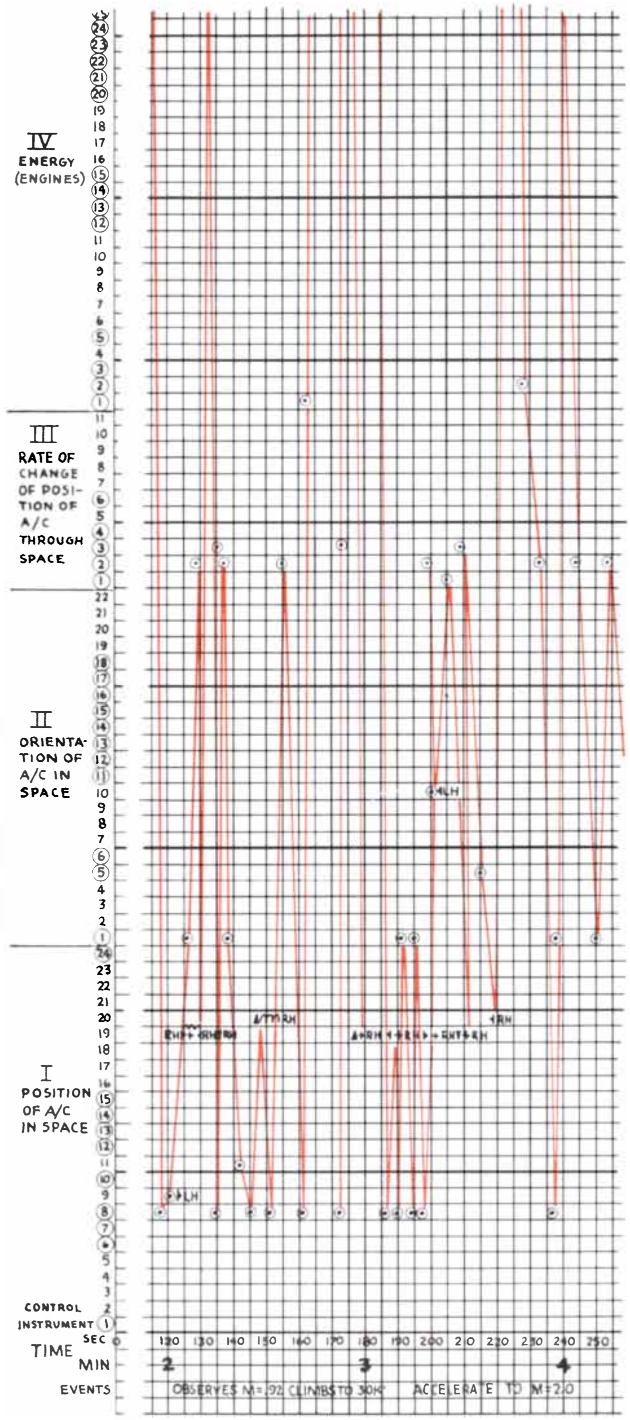

SECOND BY SECOND OPERATIONAL ANALYSIS

SYMBOLS USED:

DIRECTIONAL:

- ▲= UP, INCREASE, ON, OPEN, ADVANCE, IN, FORWARD
- ▼= DOWN, DECREASE, OFF, CLOSE, RETARD, OUT, BACK
- ◄= LEFT
- ►= RIGHT
- += CENTER, NEUTRAL, NORMAL

PERCEPTUAL:

- -O- = OBSERVE OUT
- ⊙ = OBSERVE IN
- ↄ = LISTEN
- ᗰ = SENSE BY TOUCH

MOTOR:

- LH = LEFT HAND
- RH = RIGHT HAND
- ┘= LEFT FOOT
- └= RIGHT FOOT
- ∽= SPEECH

living

season by season

Honeywell engineers and their families experience wide variations in climate—and their activities vary as much as the climate. Some spend winter in hibernation-type activities such as reading by the fireplace. More enterprising souls enjoy outdoor activities like skating, skiing, ice fishing, ice boating, sleigh-riding. Griping about the weather seems to be a universal pastime, and Minnesotans are no exception. Yet, ask a Minnesotan who has moved away what he misses most—he'll tell you it's the seasonal changes. The foot-and-a-half snowfalls, the melting springs when everything begins to turn green again, the warm, pleasant summers, the colorful autumns. Such pronounced changes seem to stimulate mental as well as physical activities. It's a good place to live and a good place to raise a family. And it's part of the living that Honeywell engineers and their families enjoy.

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THE AUTHORS

OLIVER LA FARGE ("The Enduring Indian") is an author, anthropologist and archaeologist who is currently president of the Association on American Indian Affairs. He was born in New York City in 1901 and took his B.A. and M.A. degrees in anthropology at Harvard University. He went on a total of six archaeological expeditions to Arizona, Mexico and Guatemala for Harvard, for Tulane University and for Columbia University. He left anthropology and archaeology in order to write, and he has published numerous novels, as well as many works of nonfiction. One of his novels of Indian life, *Laughing Boy*, won the Pulitzer prize. He has held two Guggenheim fellowships in writing.

DAVID E. GREEN ("The Synthesis of Fat") is professor of enzyme chemistry and co-director of the Institute for Enzyme Research at the University of Wisconsin. A native of New York City, he graduated from New York University in 1930 and took his Ph.D. at the University of Cambridge. He stayed there as a research fellow for seven years, returning to the U. S. in 1940. He spent a year in research at the Harvard Medical School and then became head of the enzyme laboratory of the College of Physicians and Surgeons of Columbia University. In 1948 he went to Wisconsin.

HORACE W. BABCOCK ("The Magnetism of the Sun") is Assistant Director of the Mount Wilson and Palomar Observatories. Even while he was an undergraduate at the California Institute of Technology, which together with the Carnegie Institution of Washington operates the Observatories, he spent his summers as a volunteer assistant in their optical shop and on Mount Wilson. After his graduation from Cal Tech in 1934, he went on to the University of California, where in 1938 he acquired his Ph.D. Subsequently he worked at the Lick, McDonald and Yerkes observatories, and during World War II he did research on radar at the Radiation Laboratory of the Massachusetts Institute of Technology and on rockets at Cal Tech. In 1946 he officially joined the staff of Mount Wilson and Palomar, where he has investigated variable stars, the rotation of spiral galaxies, the light of the night sky and, most notably, the magnetism of the sun and other stars. Babcock has also had a keen interest in the instrumentation of

astronomy. He supervises the ruling of optical diffraction gratings at Mount Wilson and Palomar, where many of the world's finest gratings have been made. He has developed a precise automatic guider for the 200-inch Hale telescope, and integrating exposure meters for spectroscopy. Babcock became interested in astronomy through his father, Harold D. Babcock, a physicist on the Mount Wilson (later Mount Wilson and Palomar) staff from 1909 to 1948. Although the elder Babcock is officially retired, he is still active; father and son have collaborated on the development and use of the solar magnetograph, which produced the new results on solar magnetic fields described in this issue.

C. WALTON LILLEHEI and LEONARD ENGEL ("Open-Heart Surgery") are respectively a noted heart surgeon and a science writer. Lillehei was born in Minneapolis in 1918, and received his M.D. from the University of Minnesota Medical School in 1942. For three years thereafter he was an Army doctor; he won a Bronze Star for his work under fire at the Anzio beachhead. He returned to Minneapolis in 1946 to take a four-year academic residency in surgery under Owen H. Wangensteen, and during this period he also earned a Ph.D. Cardiac surgery has been a major interest in Wangensteen's department for two decades, and Lillehei entered the field in 1951. He now heads the first team to achieve consistent success in this frontier of surgery. Engel met Lillehei while working on a book about recent developments in surgery. One of the country's leading science writers, Engel is an alumnus of Columbia University and the University of Chicago. His articles have appeared in some 40 publications, including *Harper's*, *The New York Times Magazine* and SCIENTIFIC AMERICAN.

JOHN J. GILMAN ("Fracture in Solids") is a metallurgist with the General Electric Research Laboratory in Schenectady. He was born in Saint Paul, Minn., in 1925 and took his B.S. and M.S. degrees at the Illinois Institute of Technology. He acquired his Ph.D. at Columbia University in 1952. He has taught at Illinois Tech and at Rensselaer Polytechnic Institute, and was with the Crucible Steel Company before working at the General Electric Research Laboratory. He has won several high awards from the American Institute of Mining, Metallurgical and Petroleum Engineers, the latest being the 1959 Mathewson Gold Medal for the outstanding contribution to metallurgy for the preced-

One of a series

On the riddle of rolling friction

It doesn't take much to roll a hard ball across a hard, smooth, level surface — actually only about 0.00001 times the normal force acting vertically on the ball. But by careful measurement of this tiny rolling force, scientists at the General Motors Research Laboratories are helping to unravel the riddle of rolling friction.

An important relationship recently uncovered in this fundamental study: the rolling force is proportional to the volume of material that is stressed above a certain level. As a result, a GM Research group have not only confirmed the hypothesis of *how* a rolling ball loses energy (Answer: elastic hysteresis) but also have learned *where* this lost energy is dissipated (Answer: in the interior of the material, not on the surface). Mathematical analyses have indicated the exact shape of the elastically stressed volume in which all the significant frictional loss takes place.

The purpose of friction research at the GM Research Laboratories is to learn more about the elastic and inelastic behavior of materials. This knowledge — of academic interest now — will eventually give GM engineers greater control of energy lost through friction. This is but one more example of how General Motors lives up to its promise of "More and better things for more people."

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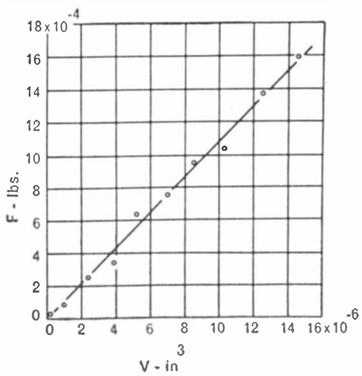

Relationship of rolling force to elastically stressed volume.

ing three years. He has also been honored with the A. H. Geisler Award of the American Society for Metals.

STANLEY D. BECK ("Insects and the Length of the Day") is associate professor of entomology at the University of Wisconsin. He obtained his B.S. degree in entomology at the State College of Washington in 1942, and his M.S. and Ph.D. in zoology at the University of Wisconsin. Since 1948 he has been teaching and doing research in insect physiology at Wisconsin. His main avocation is writing, and his book, *The Simplicity of Science,* was published last year. Beck is editor of the annual *Transactions of the Wisconsin Academy of Sciences, Arts and Letters.*

HANS PETTERSSON ("Cosmic Spherules and Meteoritic Dust") is professor of oceanography at the University of Göteborg in Sweden, and from 1939 to 1956 was director of the University's Oceanograph Institute and of the Bornö Oceanographic Station (which was founded by his father). He studied physics in Uppsala under Knut Angström and at University College London under Sir William Ramsay. He graduated from the University of Stockholm and joined the Göteborg faculty in 1914. One of his early research projects involved the study of the radium content in the deep-sea sediments gathered by the voyages of the *Challenger* and the Prince of Monaco. From 1923 to 1930 he was head of a team at the Radium Institute of Vienna studying artificial atomic disintegration by alpha particles. He returned to a professorship in oceanography at Göteborg, and in 1947 and 1948 he led the Swedish Deep-Sea Expedition around the world. He edited all the reports of the expedition. In 1957 he was visiting professor of geophysics at the University of Hawaii, and while there he undertook the studies that are reported in this issue.

ANTHONY H. ROSE ("Yeasts") lectures on microbiology at Heriot-Watt College in Edinburgh. In 1950 he took a degree in industrial fermentation at the University of Birmingham. He acquired his Ph.D. there in 1954 in applied biochemistry, and received a King George VI Fellowship of the English-Speaking Union to study at the Institute of Microbiology at Rutgers University. He has also held a fellowship in fermentation in the National Research Council of Canada. He was the author of the article entitled "Beer" in the June, 1959, issue of this magazine.


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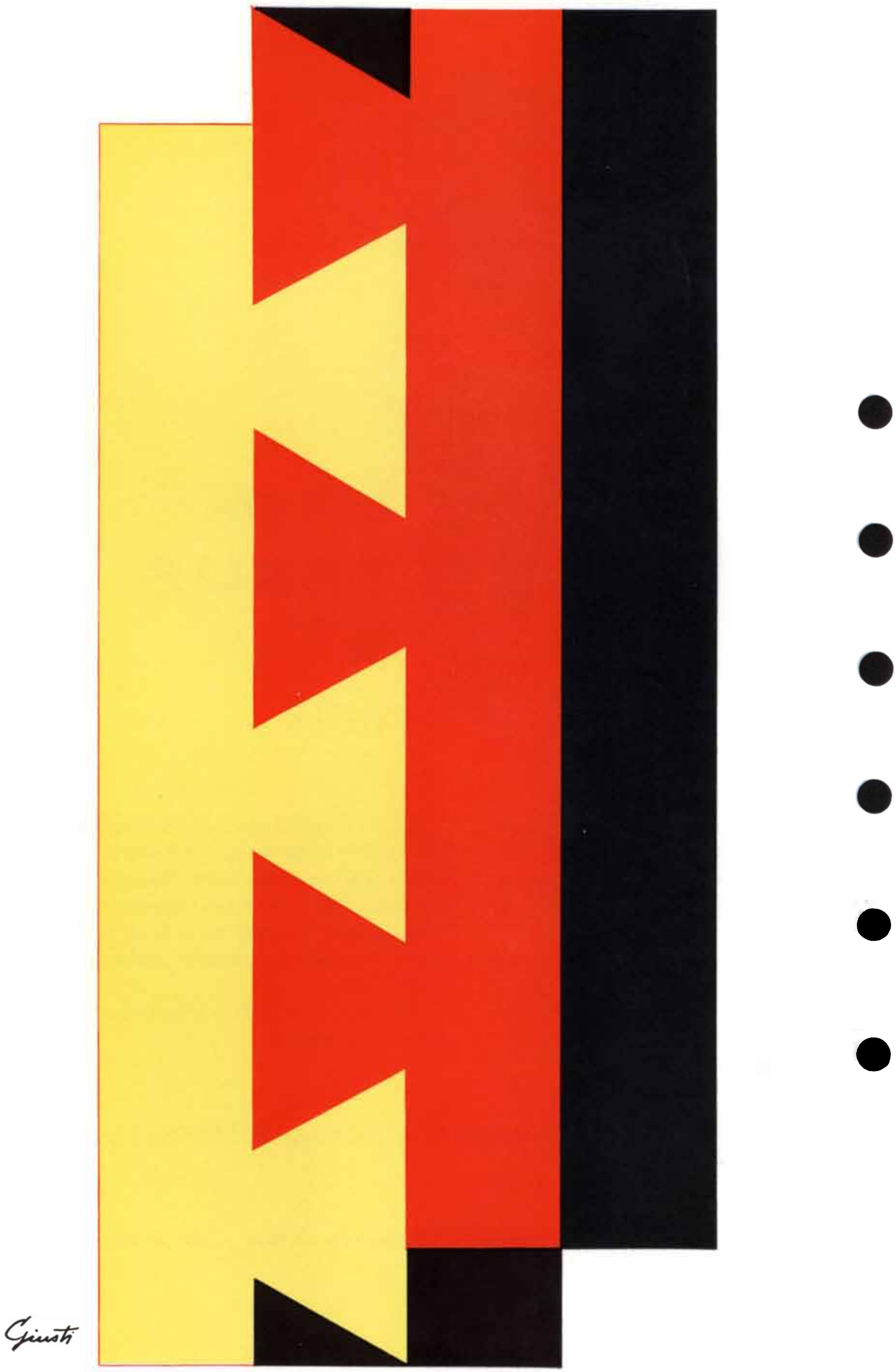
Giusti

George Sarton...on dreamers

"Men understand the world in different ways. The main difference lies in this, that some men are more abstract-minded, and they naturally think first of unity and of God, of wholeness, of infinity and other such concepts, while the minds of other men are concrete and they cogitate about health and disease, profit and loss. They invent gadgets and remedies; they are less interested in knowing anything than in applying whatever knowledge they may already have to practical problems; they try to make things work and pay, to heal and teach. The first are called dreamers (if worse names are not given to them); the second kind are recognized as practical and useful. History has often proved the shortsightedness of the practical men and vindicated the "lazy" dreamers; it has also proved that the dreamers are often mistaken. The historian of science deals with both kinds with equal love, for both are needed; yet he is not willing to subordinate principles to applications, nor to sacrifice the so-called dreamers to the engineers, the teachers, or the healers." — *A History of Science, 1952*

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Established 1845 SCIENTIFIC AMERICAN February, 1960 Volume 202 Number 2

The Enduring Indian

Americans of European descent have always believed that the original Americans would somehow vanish. But despite slaughter, assimilation, disease and dislocation, Indians continue to maintain their identity

by Oliver La Farge

In 1954 a group of anthropologists, two of them American Indians, held a conference in Chicago. Their topic of discussion was the American Indian of today, and they considered in particular the idea (as they put it) "that assimilation of the American Indian into the normal stream of American life is inevitable, and that Indian tribes and communities will disappear."

On the basis of current and historical evidence they concluded: "This prediction is unwarranted. Most Indian groups in the United States, after more than 100 years of Euro-American contact and in spite of strong external pressures, both direct and fortuitous, have not become assimilated in the sense of the loss of community identity and the full acceptance of American habits of thought and conduct. Nor can one expect such group assimilation within any predictable time period, say one to four generations. The urge to retain tribal identity is strong and operates powerfully for many Indian groups."

The vanishing Indian, in other words, is not vanishing.

The general adherence to the contrary view has several motives. One is simple good will—the belief that there is no better fate for any group than to be melted down and totally fused into the general community, and that Indians must desire and eventually follow the same course as the Irish or the Italians. Another is wish-fulfillment. The white men who conquered what is now the U.S., with the exception of the Spanish of the Southwest, came here to settle, to occupy and use the country for all it was worth. They found an alien, primitive, sparse population holding the land. That population had to be evicted. It still holds land. It owns good pasture in areas where pasture is scarce, valuable timber, minerals and water. There are still large numbers of white men who desire this property and accordingly are inclined to believe that the Indians will, or must be made to, vanish.

More important in the thinking of the majority of Americans is the actual history of the decline in Indian population. In 1600 the Indian population of the area now embraced by the 49 states of the continental U.S. was, according to the best estimate, between 900,000 and one million. At its lowest ebb, around 1920, the Indian population was perhaps 350,000. This shrinkage was caused by European diseases, by conflict and, to a small degree, by assimilation.

The first European settlers on the Atlantic Coast, in New England and Virginia, needed and sought the Indians' friendship. Their racial attitude was tolerant; stable marriages between whites and Indians could occur, the most famous of which was that of John Rolfe and Pocahontas. But new settlers were constantly arriving, and the settlements were expanding. Pocahontas's father, Powhatan, found his people being crowded from their land. He attacked, but too late. The English counterattacked, and the Powhatan confederacy was shattered. In New England, Metacomet, commonly called King Philip, son of the Pilgrims' loyal friend Massasoit, organized a still more powerful attack, in the conviction that there was no hope for his people unless the white men were driven out. He too was defeated, after heavy fighting. He had tried for total war; the white men did the same. In a large region that was mostly wilderness, actual genocide was not possible. The Yankees nonetheless had a good try at it.

As settlement increased, the Indians became involved in the imperial wars between the European nations, the most important of which were between the French and the English. Warfare between tribes had usually been sporadic and to some extent a sporting proposition; now it became constant and deadly. Tribes on the losing side suffered heavily; some were wiped out. Throughout the Colonial period, moreover, colonists attacked individual Indian villages, often wantonly, killing everyone they could find.

War and disease eliminated a number of the Eastern tribes. In the North simple intermarriage helped the process along. In the South, however, the importation of Negro slaves raised the shibboleth of racial purity and brought the assimilation of Indians to a stop. An interesting indication of the change can be seen in the laws of Virginia, which forbid miscegenation between whites and Indians, and define an Indian by a proportion of Indian descent that, at the time the law was enacted, was just large enough not to include those who claimed

INDIANS OF FOUR TRIBES appear in these photographs made by Helen M. Post. At the far left is a young Navaho woman in tribal costume. Second from the left a member of the Crow tribe addresses a tribal fair. Third from the left is an old man of the Blackfeet

descent from Pocahontas. In many New England communities there are white men who are proud to claim an Indian ancestor; in the South there are separate communities of "Indians," for example, the Lumbees of North Carolina, who recently became famous for shooting up the Ku Klux Klan.

The once-powerful Narragansetts of Rhode Island no longer exist as a tribe; the Wampanoags are extinct; of the Pequots and Mohicans there remains a tiny handful in Connecticut. The Natchez nation of Mississippi and Louisiana is entirely gone. Still, when you call the roll of Eastern tribes, the surprising thing is that traces of so many of them still exist, some *in situ*, more of them west of the Mississippi.

These latter Indians were among the subjects of the "Indian removals," by which, in the first half of the 19th century, the young republic set out to clear the Indians from all the country east of the great river. Tribe after tribe was dumped across the river, or removed itself westward. A large concentration of them landed in what is now Oklahoma, to the surprise and distress of the Indians then occupying that region. West of the Mississippi, from Wisconsin to Texas, can be found what is left of one Eastern tribe after another, and in Oklahoma itself are some of the tribes that moved out of the very states in which these others were settled.

The Indian removals were accompanied by naked force, brutality and fraud. Before the Revolution the British Crown endeavored to honor the treaties and alliances it had made. But after the Revolution its Indian allies found themselves abandoned, their lands wanted by frontiersmen against whom they had fought all too well. Both Washington and Jefferson strove to check the frontiersmen, who were already going on the slogan that the only good Indian was a dead one, and for many years the Federal Government maintained at least the appearances of decency. The West moved ever farther from the seat of government and became ever more powerful politically. Getting Indians to sign treaties when blind drunk was standard practice; so was it to set up sham chiefs, sign treaties with them, and use these as an excuse for applying force. A rough and hardy people had to have that territory to expand into and intended to get it by whatever means.

The great pressure at that time was to clear the South of the powerful "Five Civilized Tribes": the Cherokees, Choctaws, Creeks, Chickasaws and Seminoles. The finding of some gold in Cherokee territory in Georgia intensified the drive. The Cherokees sought legal redress, leading to a famous decision by Chief Justice John Marshall in the case of Worcester *v.* Georgia. This decision, which found solidly for the Indians, was the cornerstone of later Indian law. But Andrew Jackson, himself a frontiersman and Indian fighter, was President. He said: "Marshall has made his decision; let him enforce it." The President commanded the troops; the troops marched in and moved the Cherokees, and after them the rest. Thousands died in the course of these removals; not a few were killed trying to defend their homes, or simply to encourage the others to hurry.

The intent was to settle all Indians on land white men would not want. But the white man kept moving westward, wanting new land. The Delawares, for instance, moved from the coast to the interior of Pennsylvania, then to Ohio. From there some wandered as far as Texas, hoping for better faith from the Spanish Government, then returned. In 1835 the main body was settled in Kansas on a reservation purchased with money paid for lands they had given up farther east. They were Christians. They fenced the land, built houses and a church, raised cattle and planted. But Kansas, it turned out, was fertile; in 1867 the Delawares were removed to Oklahoma and much poorer soil.

During the 1840's the white men's westward movement jumped over the "Great American Desert" to the West Coast, in the south gold-bearing, in the north richly fertile, in places both. There history repeated itself, with local varia-

tribe. At far right is a young woman of the Cheyenne tribe. The Navaho reservation is in New Mexico, Arizona and Utah; the Crow, in southern Montana; the Blackfeet, in northern Montana; the Cheyenne, in southern Montana (*see map on next two pages*).

tions, and with the important difference that it was becoming more and more impracticable to try to settle all Indians in Oklahoma. Instead there developed the practice of giving them reservations in their native territories.

After the Civil War white men began to settle the Great Plains and the mountain country. As they closed in on the tribes of these regions they outdid them, on the whole, in treacheries and outrages. But it was no longer possible to be as openly ruthless with the Indians as it had been with the tribes that had been broken earlier. When gold was found in the Black Hills of South Dakota, country pledged to the Sioux by treaty, the Army honestly tried for a while to keep goldseekers from going in. Removals to Oklahoma did occur, as in the case of the Cheyennes of Montana, but the majority of the Western tribes received reservations where they had always lived.

In Arizona and New Mexico there were special circumstances. That region had been conquered by the Spanish. The Spanish did not come to colonize, to till the soil, but for imperial conquest in the grand manner. They did not break treaties, because they did not make them. They looked upon the Indians as their labor force and as souls to be won to God; they did not want to exterminate them, but needed them to make their empire pay. The Spanish Crown gave definite rights and protections to its Indian subjects. These were fully recognized by the Mexican Republic, and when the U. S. annexed the region after the Mexican War, they were written into the Treaty of Guadalupe-Hidalgo. Thus many of the sedentary, farming tribes of the Southwest are protected, especially in title to their land and in rights of self-government, by an international treaty.

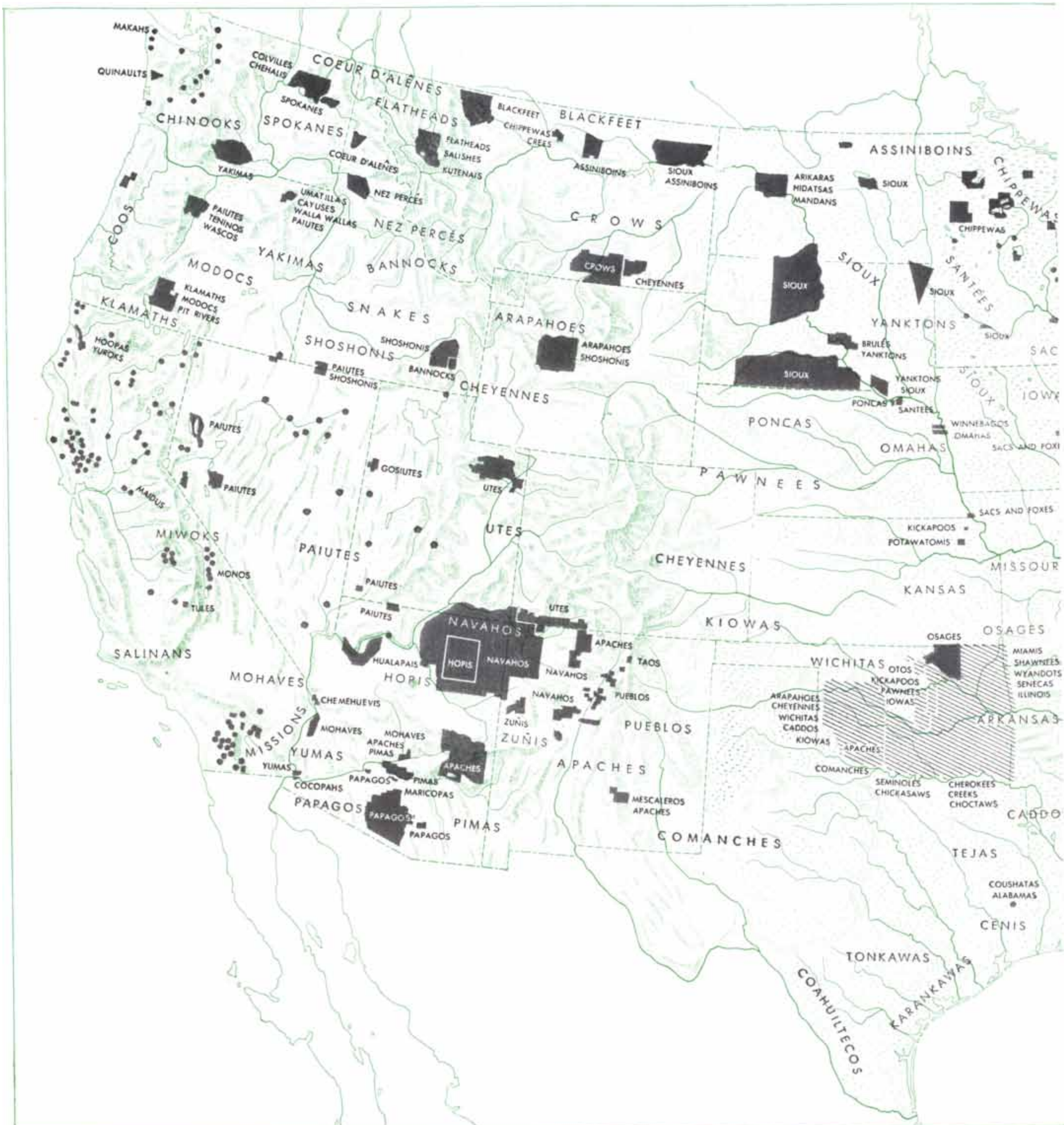
The wilder, hunting tribes of that region occupied semidesert, or country that seemed hopelessly remote. Many of these, such as the Navahos and Apaches, had a high nuisance value, as did the strong Plains tribes, at a time when the East was beginning to balk at the cost of Indian wars. The demand for land in the Southwest was relatively weak until recently. As a result of all these factors the Indians of the Southwest received fairly ample reservations in their native territories.

By 1880 the major Indian wars were over, and most tribes were located on the reservations where they are now. There were hostilities after that. Some tribes were moved; some had yet to receive reservations, but the big job was done. The reservation and along with it the status of the Indian have changed considerably since 1880, but the essential terms of this arrangement still play a part in the lives of Indians today.

A reservation is a tract of land—part of a tribe's original territory or given in exchange therefor—set aside for the exclusive use of a tribe or group of Indians, and held in trust for them by the Federal Government. At first white men also conceived of reservations as areas within which a dangerous, hostile people could be confined. Most Indians were not citizens of the U. S.; as "Indians not taxed" they were excluded from the provisions of the Fourteenth Amendment to the Constitution. Whatever their theoretical rights may have been, they were *de facto* wards and subject to astonishing arbitrary controls over their personal and public lives. They could be, and occasionally were, punished for leaving their reservations; to this extent these areas could be considered as concentration camps of a very roomy kind, but even that is a past condition.

A long series of court decisions, going back to Chief Justice Marshall's Cherokee decision, has firmly established that, within the boundaries of the reservations, civil and criminal jurisdiction belong to the Federal Government and the tribe, with the states and territories excluded. Citizenship was extended to Indians gradually until 1924, when in recognition of their services in World War I Congress made all of them citizens. Since then it has been amply proven in the courts that there are no more "Indians not taxed," and that the Fourteenth Amendment applies to them all.

The courts have established that Indians are not wards, that they are American citizens endowed with all the rights deriving from their status as the original occupants of this country, including local self-government under Federal jurisdiction and Federal responsibility for their health and education while they reside in what is legally termed "Indian country." This combination of Federal and autonomous jurisdiction the Indians hold to be their most valuable and necessary right. When an Indian leaves "Indian country," his status is theoretically the same as anyone else's. But some states or local units frankly refuse to extend normal services to the Indian. Unless he goes far from home he usually encounters the prejudice, the discrimination, the unequal justice before the law that help explain why Indians have feared recur-



ORIGINAL AND PRESENT LOCATIONS of the principal American Indian tribes are shown in this map of the U.S. The general original location of the tribes is indicated by the large type; the present location (or locations) is given in small type. Indian reserrent moves to turn them over to state governments.

Indian trust-land cannot be alienated or rented without the consent of both the trustee and the beneficiary. It is tax-exempt, and so is income derived from it by its Indian owners, an enormous advantage. It is also called "restricted land," because it is inherent in the nature of the trust that the owners are not perfectly free to do as they like with it, beginning with losing it to satisfy debts. The trustee (the Government) is responsible for the proper use of the land and its conservation, which is no easy responsibility. There has been one case in which a tribe persuaded the Bureau of Indian Affairs to approve an arrangement it wanted for the sale of its timber. The arrangement was bad, and the tribe lost a great deal of money, whereupon it turned around and successfully sued its trustee for more than $1 million in damages.

vations are denoted by areas or points in gray. Hatched area in Oklahoma was once reservation. Many Indians now live there with certain rights guaranteed by special legislation.

All that has been said so far makes reservations and the status of a federally recognized Indian sound highly desirable, and in fact there are few such Indians who do not want to see their reservations and their Indian status continued. The restrictions, however, can be burdensome. The trustee is not an individual but a large bureaucracy that changes policy with almost every change of administration. The Government is trustee of a large part of Indian funds as well as of property. Its officials are educated, experienced; the beneficiaries are ignorant, inexperienced. Most Indians, although theoretically literate, are unable to handle the papers of quite simple business transactions without help. It is easy for the trustee, for technical reasons, to withhold funds, to block or promote Indian enterprises, to refuse assistance. Thus the Indians' legal situation has been partly negated by the realities.

As of 1880 the Indians owned 155 million acres of land, mostly guaranteed by treaties. As the West filled up, this land was coveted. The allotment system, culminating in the Allotment Act of 1887, became the device for subtracting land from the Indians' domain. Under this system tribes were high-pressured into surrendering title to their reservations, accepting instead individual allotments of land and ceding the "surplus" to the U. S. for a song. The trust periods on the individual allotments were limited, and when trust was removed, those tracts too could be obtained by non-Indians. The humanitarians of the time supported this system in the belief that individual ownership would break up the tribes and lead to assimilation. Outside the Southwest, between 1887 and 1933, when the process was temporarily halted, the Indians lost 93 million acres, with economically disastrous results in many places.

Allotment vests still further power in the trustee; it can extend or refuse to extend the trust period when it is due to expire. Once an allotment goes out of trust it becomes subject to taxation, and experience shows that it soon passes into

NAVAHO FAMILY is photographed at its home on Navaho Mountain, in a remote part of the Navaho reservation. At the left is the entrance to the family's hogan, a structure built of wood and earth. This photograph is reproduced through courtesy of *Farm Quarterly*.

NAVAHO SCHOLARSHIP COMMITTEE interviews Emily Roanhorse, who wishes to obtain schooling outside the reservation. The tribe has a trust fund of $5 million for this purpose, and each year sends some 200 students to colleges, universities and trade schools.

white ownership. There is also the matter of "key allotments," that is, tracts of land whose ownership controls the use of surrounding tracts. The key piece of land may have the only water in a large area of grazing land, or it may be the only means of access to a stand of timber. When a non-Indian gets hold of a key allotment, there is little the surrounding Indian owners can do but sell or lease to him at his price. For many years prior to 1953 Indian Bureau regulations established special safeguards over such parcels of land. Under the present administration, however, the field officials concerned were instructed to ignore the "key" consideration entirely when land was in line to be sold. This harsh injunction has recently been somewhat softened.

Indians sell their lands for various reasons. Many allotments are owned by persons, usually of mixed blood, who have permanently left their reservation and no longer care what happens to the tribe. They receive lease money, but prefer to get a lump sum in cash and have done with it. Many try to sell their land in order to obtain at least temporary relief from destitution, or because the states in which they live will not give old-age payments or other relief to persons owning property. Perhaps the principal cause is heirship: an allotment may now be owned by the numerous grandchildren and even great-grandchildren of the original allottee. There are actual cases of heirs who receive only one cent per annum in lease money. The natural tendency of the trustee and of the heirs is to get rid of the mess by selling the land outright.

As the land base dwindled, so did the Indian population, tactfully fulfilling white expectations. In this there were two principal factors. One was disease, fortified by malnutrition, entire lack of sanitation, and little or no medical or public-health service. The other was plain hopelessness, reflected in a declining birth rate. After the 1920 nadir, when the Indian population (including a few thousand Eskimos and Aleuts) had fallen to 350,000, the Indians began to increase. No improvement in their condition explains this development. One can only speculate that a new generation had come along that had made at least a partial adjustment to its wretched mode of life and was therefore less despondent and more inclined to reproduce than its predecessors had been.

The upturn was followed by developments that favored it. A major overhaul in the Indian health service was undertaken in 1926 under President Coolidge and was reinforced during the Hoover administration. During the Eisenhower administration Indian health was made the responsibility of the Public Health Service, and that transfer, with certain other innovations, leads to the hope that before too long health services to Indians will be comparable to those received by other Americans.

The Hoover administration also initiated reforms in education. Most education for Indians had been vocational; Indians were expected to be farmers, herders, manual workers and domestic servants, and they were schooled accordingly. Indian schools were places of virtual imprisonment, of harsh discipline, hard labor, hunger and a minimum of learning. Under President Hoover the schools actually became schools. To mention just one item, the provision of sufficient food for the children—initially by raising the allowance in 1931 from 11 to 28 cents a day—has meant a change in the physical potential of an entire generation. Further improvements have been introduced by succeeding administrations. The picture is still not perfect; there are still too many Indians who never get to school at all. But it is no longer surprising to find Indians in college, and one can detect the spread of a new self-confidence and new competence, still beginning, still uncertain, among the Indian people.

In the grievous problem of trust lands the Hoover administration adopted the policy of automatically renewing the trust periods as they expired. Under the administration of Franklin D. Roosevelt the Indian Reorganization Act offered all tribes authority to form recognized local governments with clearly defined powers and, if they wished, to become corporations under Federal charter, with financing available in a $10 million revolving loan fund. Further allotment of land was stopped; tribes were given all possible encouragement to buy land coming up for sale and to recapture ceded lands that had never been occupied. For the first time in history the total Indian estate increased, from 47 million to slightly more than 50 million acres. There was a distinct upturn in the Indian economy, and a quite dramatic increase in the number of Indians in professional positions, both in the Indian Bureau which administers their affairs and in private life. By and large the Federal Government seemed to accept the idea that Indian communities would continue, had a right to continue and that Indian progress should be based upon them.

In the second Truman administration Indian policy swung around abruptly, both in the Executive Branch and in Congress. Once again the Federal trustee set out to diminish the Indian land base, which one major official, speaking of an irritatingly persistent tribe, said was "a millstone around those Indians' necks." Once again it was hoped that the tribes, divested of their land, would disperse and that the individuals would disappear into the general population. The drive reached its peak during the first Eisenhower administration. But throughout this period one could see that the white men were uncertain. Thousands of acres of lands in various categories were added to a number of reservations by Congressional action, while administrative action caused disastrous thousands of acres to be lost to others.

Dispersal of the tribes was further promoted during this period by the device of "termination," in essence the passing of an act of Congress declaring that a given group of Indians is no longer Indian. All trust land then goes out of trust; local jurisdiction, self-government, all Indian rights are ended; and the early dissipation of the tribe is comfortably sure. Actually only a few tribes were terminated before Congress, reversing itself again, balked at the process. The most important of the terminated tribes are the Klamaths of Oregon and Menominees of Wisconsin, both of which were owners of large tracts of valuable timber.

In 1958 Secretary of the Interior Frederick A. Seaton announced what amounts to at least a three-quarter return to the policies of the Roosevelt period. Since then the Department of the Interior has given many tribes substantial help in holding their land and starting sound programs for self-advancement. The subordinate Indian Bureau, however, has not clearly identified itself with the new turn in policy. In the field one finds the superintendent and the tribal council on one reservation happily working out an effective program for retention and consolidation of land and for economic development, while on the next reservation the superintendent is facilitating the loss of land and blocking efforts to stop this loss. All in all, it must be rather bewildering to be an Indian.

Despite everything, the tribes are still here. The Indian population now numbers close to half a million, and is increasing by nearly 5 per cent per annum. In this half million I include an estimated 50,000 people east of the Appalachians who are not recognized as Indians by the Federal Government, but are so recognized by the states in which they live. By and large, the Indians are extremely poor. They live in scattered communities, few of which exceed 50,000 and many of which number less than 1,000. Their health is worse than that of any other racial group in the country—the average life-expectancy of the Papago Indians of Arizona, in a most salubrious climate, is 17 years. Yet the Indians and most of their communities are going to continue into the future.

This retention of identity is not rigid, nor is it necessarily antiprogressive. Except for a small and ever diminishing number of extremists who somehow dreamily hope to wave the white men away, Indians desire functional equality with other Americans. They are selective about the Indian cultural items to be retained; they want education; they want to progress as individuals and as communities. There is a constant movement of individuals out into the general society, as indicated by the presence of the two Indian anthropologists at the conference to which I have referred. On the other hand, prejudice in the white community is an important factor, often ignored, in fostering Indian identity. In most parts of the country where there are considerable concentrations of Indians, they suffer from discrimination that ranges from mild to violent. In many communities far from the South, Indians are flatly segregated, and even in the past 10 years white men have killed Indians with impunity.

Present Indian culture could be represented by a parallelogram of forces, in which the current attitudes, emotions, and ways of responding to situations are the product of the action upon each other of the aboriginal culture and the culture that the white man has brought or imposed. The Indians' old way of life differed enormously from that of the present. It was a rhythmic alternation of activities—hunting, fighting, planting, cultivating, harvesting, performance of ceremonies—with intervals of leisure. What they did went by the seasons, the positions of the sun, the occurrence of need. Those ways have been shattered, and little has been available to replace them. With some exceptions, especially in the Southwest, the outward manifestations of their cultures have been abandoned except as reminiscent public functions, assertions of identity, such as the pasteurized sun dances staged annually by many Plains tribes. Deep down the cultural stream runs strong and, it seems, cannot be choked off. An educated modern Sioux tribal official may tell you confidentially that some of the old men say he is *wakan*—touched by the influence of God—and that sometimes he wonders if this is not so. In the old days many tribes were contemptuous of the accumulation of property and of individual self-assertion; this pattern still inhibits Indians in competition for jobs and promotion, or in reciting and asking questions in college classrooms. When white advisers have had the sense to work with this trait, instead of fighting it, they find that it leads to strength in community endeavors and progress.

One effect of the Indians' historical experience has been a development of frustration, resentment and dependency—qualities that can too often be observed in modern Indians. At that conference of anthropologists the participants agreed that most Indians concur in these assumptions about their situation: "that Indians can expect no long-term consistency in policies affecting them; that the interests of the dominant society will take precedence over their own in any policy decisions; that Indians can do little to affect decisions concerning themselves; that the turning over of Indian affairs to the states is inevitable; and that state administration is more likely to be hostile to Indians than is the Federal administration."

These assumptions, although pessimistic, are realistic; in them I find a quality of despair. The Indians have been pushed around for anywhere from one to two centuries; they are despised and discriminated against; they are baffled, angry, frustrated. The last time they had something like an even break was in King Philip's War.

Yet the Indians have not given up. They strive for the right to be themselves. Unlike any other American minority, they did not come here seeking freedom and a good life; they were here and had both until white men arrived and took these from them. They are our ultimate aristocrats, and as a whole have no more intention of losing their identity than have the members of the Daughters of the American Revolution. They remain surprisingly good-natured and have extraordinarily little of the monolithic prejudice toward white men that white Americans commonly feel toward the dark races. They want tolerance, time and reasonable opportunity, and they absolutely refuse to vanish.

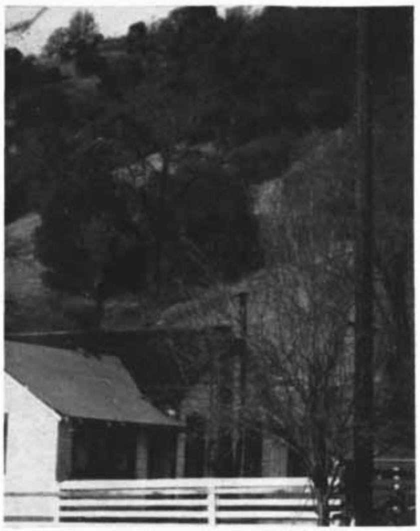
LIGE REEVES is one of three northern California Indians whose status is depicted in

BILL FRAZIER is also a resident of Round Valley. Younger than Lige Reeves, he has

ERNIE MARSHALL is a member of the Hoopa tribe, which lives 200 miles north of

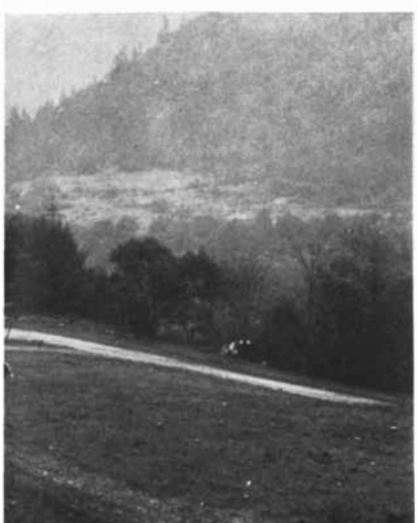
these photographs by John Collier. Reeves's home (*left*) is in

Round Valley, into which remnants of seven tribes were driven. At right he sits with a daughter and a grandchild. Too old to do heavy farming, he lives mainly on relief. His allotted land is tax-free.



been able to develop his land into a thriving stock farm (*left*).

He and his wife (*right*), like other Indian residents of the valley, worry that their government-allotted land will be "terminated." This would force Indians who were unable to pay taxes to sell their land.



Round Valley. The Hoopa land, unlike that of the Indians of

Round Valley, has not been allotted to individuals but is owned by tribe. Rich in timber, it provides a good living to tribe members. At left is Marshall's home; at right he sits with son and grandson.

The Synthesis of Fat

When the way in which fat molecules are broken down was worked out, it was assumed that they are built up by the same steps in reverse. Now it has been found that the synthetic process is quite different

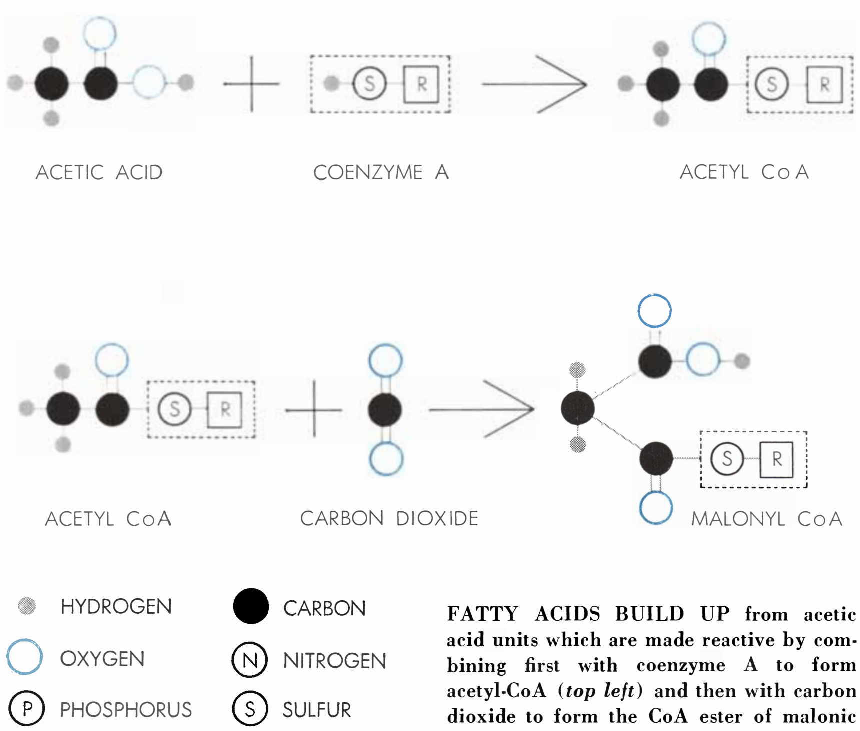
by David E. Green

Fat, along with sugar, is the body's fuel. How the body burns the carbon chains of fat and sugar to yield carbon dioxide, water and energy is now well understood; these were, in fact, the first biochemical processes to have been worked out in their many-staged entirety. But the body also manufactures fat: as is well known, men and animals may fatten on a starchy diet. The different kinds of fat molecules synthesized in the cells of the body serve a variety of functions more sophisticated and no less fundamental than that of fuel. One measure of the importance of fat in these functions is the fact that the leading causes of death in our society—arteriosclerosis and degeneration of the heart—are identified with faulty fat metabolism. As biochemists have investigated the combustion of fat, they have been no less concerned to understand its synthesis. The process is not yet completely understood, but it is now possible to describe in general terms how the fat molecule is put together in the body.

The architectural plan of the molecule is simple enough. The characteristic structural unit is a fatty acid: a straight chain of carbon atoms, usually 16 or 18 in number; it is shaped like a matchstick, with a carboxyl group (COOH) as the head. To form a fat molecule the fatty acid is attached to an alcohol. Together a fatty acid and an alcohol make an "ester," a kind of organic salt in which the "acidic" carboxyl group has reacted with the "basic" hydroxyl (OH) group of the alcohol to throw off a molecule of water and establish an oxygen or ester bond. There are many possible combinations of alcohols and fatty acids; most of them have been exploited in the make-up of the fats—or, as the biochemist terms them, lipids—found in nature.

In plants as well as in animals glycerol is the most important fat-building alcohol; it has three hydroxyl bonds for attachment to three fatty acids, or to two fatty acids and a third group of another sort that gives the fat in question its chemical identity. In animals cholesterol is an alcohol around which certain important fat molecules are built. No matter how diverse or complicated the structures of the innumerable fat molecules, all are variations on the same basic theme. The synthesis of lipids in the body therefore comes down to two questions: the build-up of fatty-acid chains and the assembly of these chains around an alcohol.

Fatty acids of natural origin almost invariably have an even number—from four to 22—of carbon atoms in their chains. The odd-numbered chain is a biochemical freak that can be ignored. It does not require great mathematical insight to recognize in this situation a clue to the synthesis of fatty acids: the only simple way to build up an even-numbered chain is by the addition of successive two-membered units. In 1926 Ida Smedley-Maclean of the Lister Institute in London demonstrated that the building stone of fat in yeast is the two-carbon unit of acetic acid (CH_3COOH). Later, with the help of radioactive car-



FATTY ACIDS BUILD UP from acetic acid units which are made reactive by combining first with coenzyme A to form acetyl-CoA (*top left*) and then with carbon dioxide to form the CoA ester of malonic

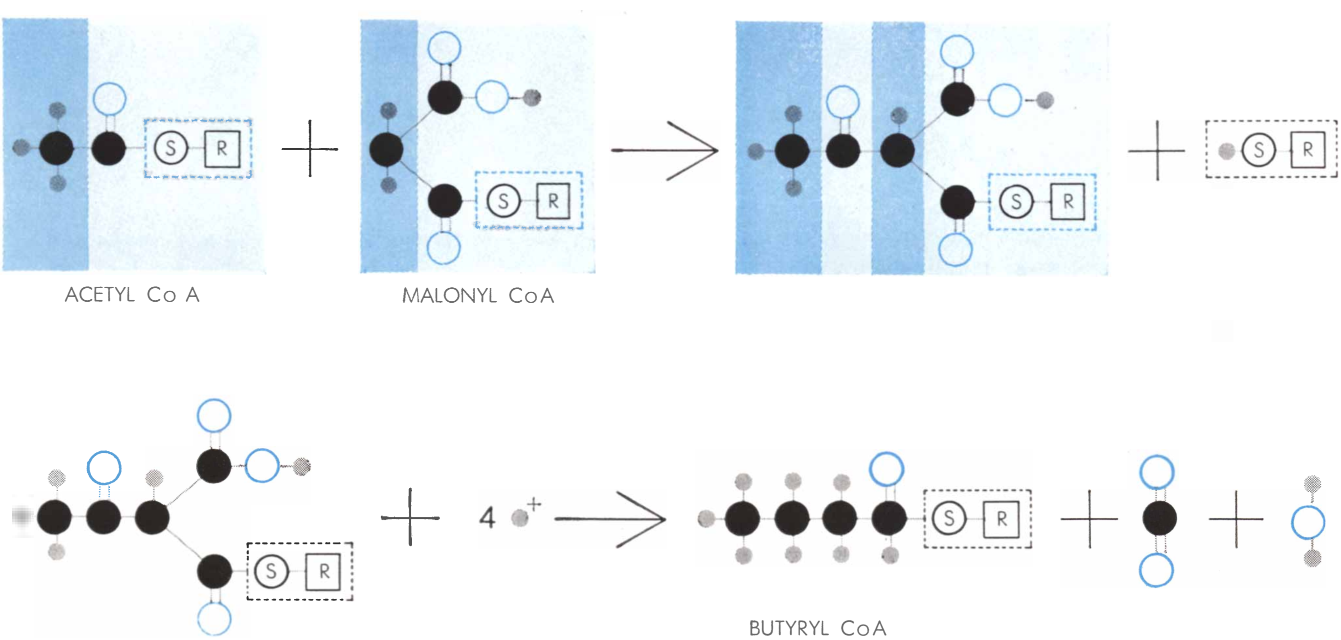
bon, a group of investigators at Columbia University's College of Physicians and Surgeons established with certainty that all of the carbon atoms in a long-chain fatty acid come exclusively from acetic acid. They proved further that the chain is hooked together in just one way: by the joining of the carboxyl head of one acetic acid to the methyl (CH_3) tail of another. The fatty-acid chain may thus be regarded as a polymer in which the repeating unit is acetic acid.

This understanding explains how it is that the consumption of fats, carbohydrates and even proteins can give rise to fat in the body. In the assimilation process all three classes of foodstuff may be broken down to the same ultimate common denominator: the two-carbon unit of acetic acid.

A crucial step in the unraveling of the combustion of fat in the body was the discovery, two decades ago, that fat is oxidized or degraded two carbon atoms at a time and that in the process a substance equivalent to, if not identical with, acetic acid is peeled off. Now if acetic acid is not only the starting material but also the breakdown product of fatty acids, does this mean that synthesis represents merely the reversal of the breakdown process? It was tempting to think so in the days before either process was well understood. In the early 1930's, moreover, this idea gained support from the discovery that the biochemical machinery of a certain species of bacterium could either break fatty acids down to acetic acid or build them up from acetic acid. This organism, *Clostridium kluyverii*, a mud-flat relative of the deadly bacterium that causes botulism, grows in the absence of air and derives its energy by oxidizing ethyl alcohol to acetic acid. It uses some of this energy to combine acetic acid molecules into short-chain fatty acids made up of four or six carbon atoms. In the laboratory of Horace A. Barker of the University of California it was found that in the presence of oxygen this organism, or extracts from it, could degrade the four- or six-carbon fatty acids back to acetic acid.

A few investigators insisted, however, that there is an important difference between the process in the bacterium and that observed in higher animals. The bacterial system deals only with short-chain fatty acids, but animal systems involve long-chain fatty acids. Furthermore, it was pointed out, such animal systems as isolated liver-cells can synthesize and degrade fatty acids at one and the same time. If the processes were merely the reverse of each other, one or the other, but not both, could be expected to go on under a given set of conditions. The existing data could not settle the question, and significant progress toward the resolution of synthesis had to await the elucidation of the breakdown process.

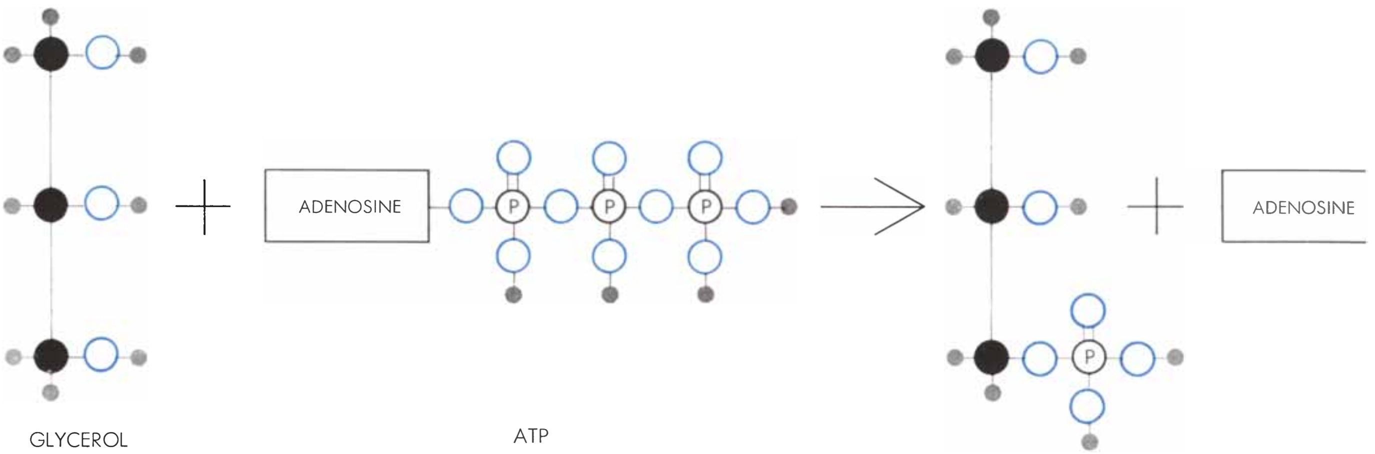
At last, in 1953, two groups of investigators, one in the laboratory of Feodor Lynen at the University of Munich and the other in our laboratory at the Institute for Enzyme Research of the University of Wisconsin, worked out the details of the mechanism by which fatty acids are degraded [see "The Metabolism of Fats," by David E. Green; SCIENTIFIC AMERICAN, January, 1954]. The most striking feature of this process is that the free fatty-acid is not oxidized as such. It is first converted to a more reactive form by combination with coenzyme A (CoA), the mediator of a number of significant reactions in all living cells. The reactive part of the coenzyme is a "thio" group (SH), which resembles the hydroxyl group but has a sulfur atom instead of an oxygen. Like the hydroxyl group, the thio group can join with a carboxyl to link two molecules into a so-called thiol ester. Coenzyme A thus activates the fatty acid, forming a thiol ester with it. At a later stage in the process additional coenzyme A then degrades the coenzyme-A ester of an oxidized form of the fatty acid (the beta-ketoacyl CoA ester), chopping off two carbon atoms at a time to produce molecules of acetyl-CoA, the coenzyme-A ester of acetic acid. Each chop in-



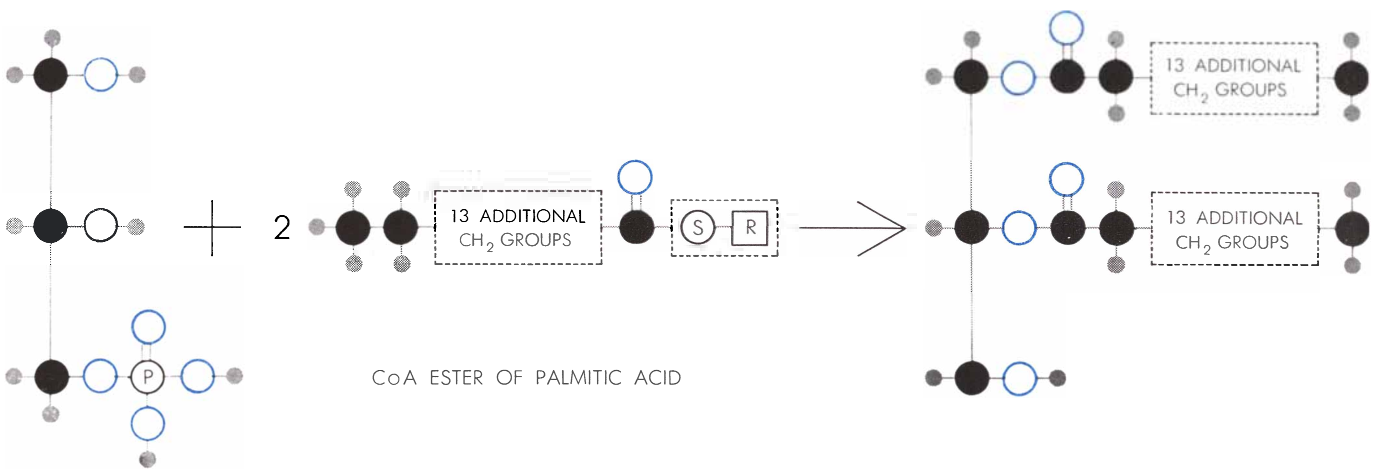
acid (*bottom left*). Malonyl-CoA and acetyl-CoA can condense (*top right*) into an intermediate compound. Further reactions not yet fully explained then reduce the intermediate to the CoA ester of a four-carbon fatty acid (*bottom right*). This, like acetyl-CoA, can condense with a molecule of malonyl-CoA, ultimately giving the ester of the six-carbon fatty acid; the chain thus lengthens by successive steps. The molecules always join head (*lighter colored rectangles*) to tail (*darker colored rectangles*), the carboxyl head of the fatty acid joining the methyl tail of the malonyl-CoA. The letter R symbolizes the 82 atoms in coenzyme A other than sulfur.

volves a series of four consecutive reactions, two of which are oxidations. It was found that in addition to coenzyme A the oxidation of fatty acids required various other factors, such as certain pyridine nucleotides, groups of enzymes and adenosine triphosphate. This last substance, better known as ATP, is the universal transducer of chemical energy in cells.

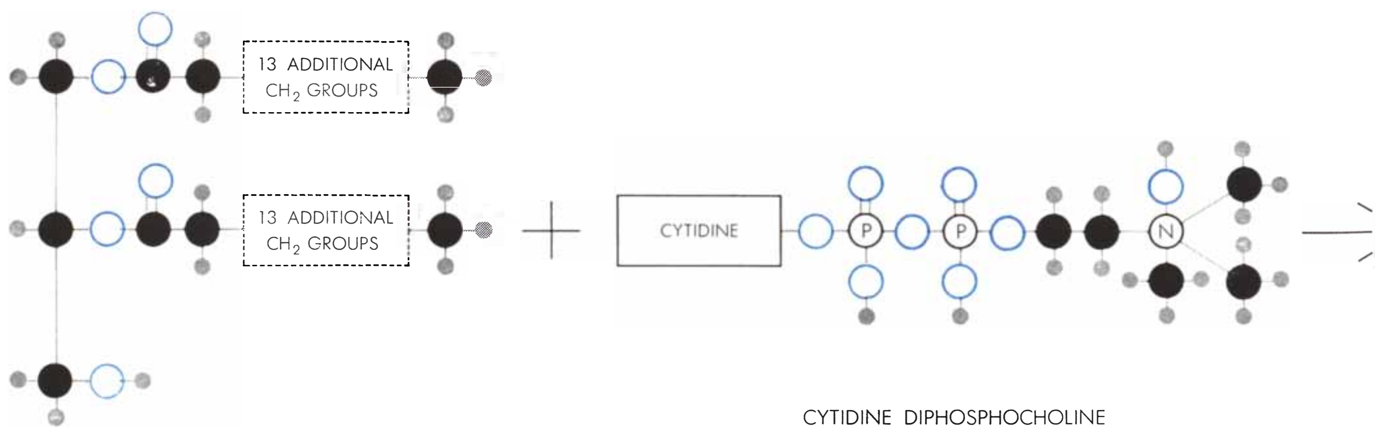
It was now possible to decide whether the process of synthesis did or did not proceed by the reversal of the degradation pathway. At the outset the identification of the essential biochemical agents of degradation—in particular coenzyme A, ATP and the pyridine nucleotides—virtually convinced the biochemical world that the two processes are identical. The same agents had been found at work in the synthesis of fatty



FIRST STEP IN ASSEMBLING A LECITHIN is the joining of a phosphoric acid group from ATP (adenosine triphosphate) to one of the hydroxyl (OH) groups of the alcohol glycerol, leaving ADP (adenosine diphosphate) as a residue. The alcohol and acid



SECOND STEP IN ASSEMBLING A LECITHIN links two fatty-acid groups to glycerol by means of ester bonds; the phosphoric acid group drops off. The fatty acids used must be in the form of esters of coenzyme A (*broken rectangle*). Lecithins may have vari-



LAST STEP IN ASSEMBLING A LECITHIN requires the aid of the coenzyme cytidine diphosphocholine to deliver the combination of phosphoric acid and choline to the vacant hydroxyl group. The phosphoric acid is linked to glycerol and to choline by ester

acids. Such difficulties as were experienced in attempts to achieve synthesis by the reversal of oxidation were attributed to simple technical deficiencies in the experiments. But the deduction still stood unproven.

In 1955 our group at the Institute for Enzyme Research decided to put aside all assumptions about the relation of fatty-acid synthesis to other processes and to set out to isolate the system of enzymes, coenzymes and accessory factors involved. Samuel Gurin and his colleagues at the University of Pennsylvania School of Medicine had already carried out pioneer investigations on a cell-free preparation from pigeon liver that converted acetic acid into long-chain fatty acids. We used their system as the starting point for our studies.

It is difficult enough to isolate a single enzyme or coenzyme from crude material, but the isolation of a system with a dozen or more enzymes and cofactors is a brutal research experience. A team of five workers (D. M. Gibson, Salih Wakil, A. Tietz, J. Porter and E. B. Tichener) gave three years of intensive work to eliminating the extraneous factors and identifying the necessary ones. They finally determined that two enzyme complexes and four cofactors—adenosine triphosphate, manganese ions, reduced triphosphopyridine nucleotide and carbon dioxide—are the rock-bottom requirement for synthesizing fatty acids. If any one of these six factors is missing, the system fails to work.

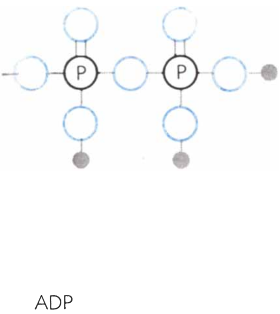
Even in advance of a full elucidation of the steps in the process, this listing of the factors involved showed that synthesis is something more than a simple reversal of oxidation. It is true that acetic acid, as the starting material, enters the cycle in the same coenzyme-A ester form in which it comes from the degradation process. The cofactor requirements also bear some resemblance to those for oxidation. But there are major differences. The oxidative process requires magnesium ions and reduced diphosphopyridine nucleotide; in synthesis these are replaced by manganese ions and reduced triphosphopyridine nucleotide. Carbon dioxide is essential to synthesis; it has no place in oxidation. To complete the contrast, our two highly purified enzyme preparations do not contain appreciable amounts of any of the oxidative enzymes. Synthesis was therefore a different process. The next step was to determine how it proceeds.

The requirement for carbon dioxide in synthesis was baffling at first; it was difficult to imagine what role this substance could play. Since all the carbon in the fatty-acid chain was known to come from acetyl-CoA, it was clear that the carbon of carbon dioxide could not actually be incorporated into the chain. Did carbon dioxide perhaps serve as a catalyst? A relatively simple experiment answered the question. When acetyl-CoA was mixed with one of our two enzyme preparations, together with ATP, manganese ions and carbon dioxide, the carbon dioxide was trapped in the resulting compound. This compound was then added to the second enzyme preparation, together with the cofactor triphosphopyridine nucleotide; it was thereupon converted to a long-chain fatty acid, and the carbon dioxide was released. Evidently carbon dioxide, as part of an intermediate compound, does serve a catalytic function.

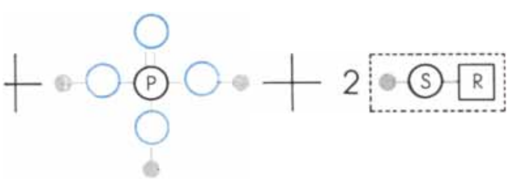
The intermediate compound itself proved to have an interesting identity. Wakil, now at Duke University, found it to be malonyl-CoA, the coenzyme-A ester of malonic acid. Organic chemists discovered more than 100 years ago that malonic acid is a lively substance, and they now use it as the basis for a vast number of syntheses. It is like an acetic acid molecule with an extra carboxyl group added to its tail. The middle carbon atom, being situated between two carboxyl groups, is highly reactive.

The formation of malonyl-CoA by the addition of carbon dioxide to acetyl-CoA is a rather improbable reaction; it is mediated by still another remarkable catalyst. This catalyst is biotin, one of the B-vitamins. Gibson and Wakil observed that the first enzyme preparation which brought about the incorporation of carbon dioxide in malonyl-CoA was rich in biotin, and that its activity in fact ran parallel to the biotin content. The activity, moreover, disappeared upon addition of avidin, an enzyme found in egg white that specifically combines with and inactivates biotin. This proved conclusively that biotin, firmly bound to the enzyme, supplies the catalytic activity.

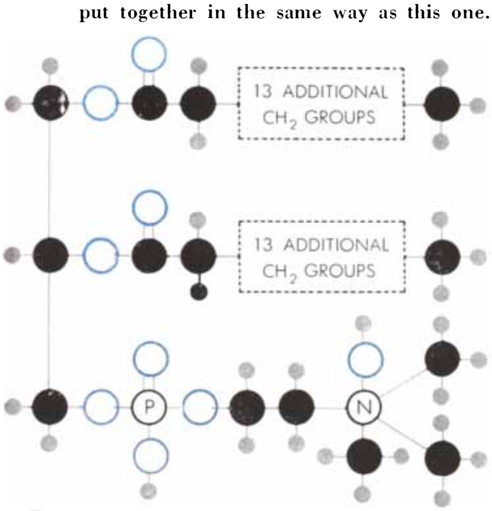
The fact that adenosine triphosphate is necessary to this reaction gave us a clue to its character, because the many biosynthetic reactions that are energized by ATP tend to follow the same pattern. By analogy we may assume that the malonyl-CoA synthesis takes place as follows: The ATP provides the energy or driving force by transferring its terminal phosphate to biotin, making phosphoryl biotin. Carbon dioxide then replaces the phosphoryl group to produce carbonyl biotin, which is essentially an activated form of carbon dioxide. In this state the carbon dioxide combines with acetyl-CoA and forms the second carboxyl group of what is now malonyl-CoA. Some recent studies by Lynen on the mode of action of an analogous biotin-containing enzyme involved in the carboxylation of isopentenyl CoA sug-



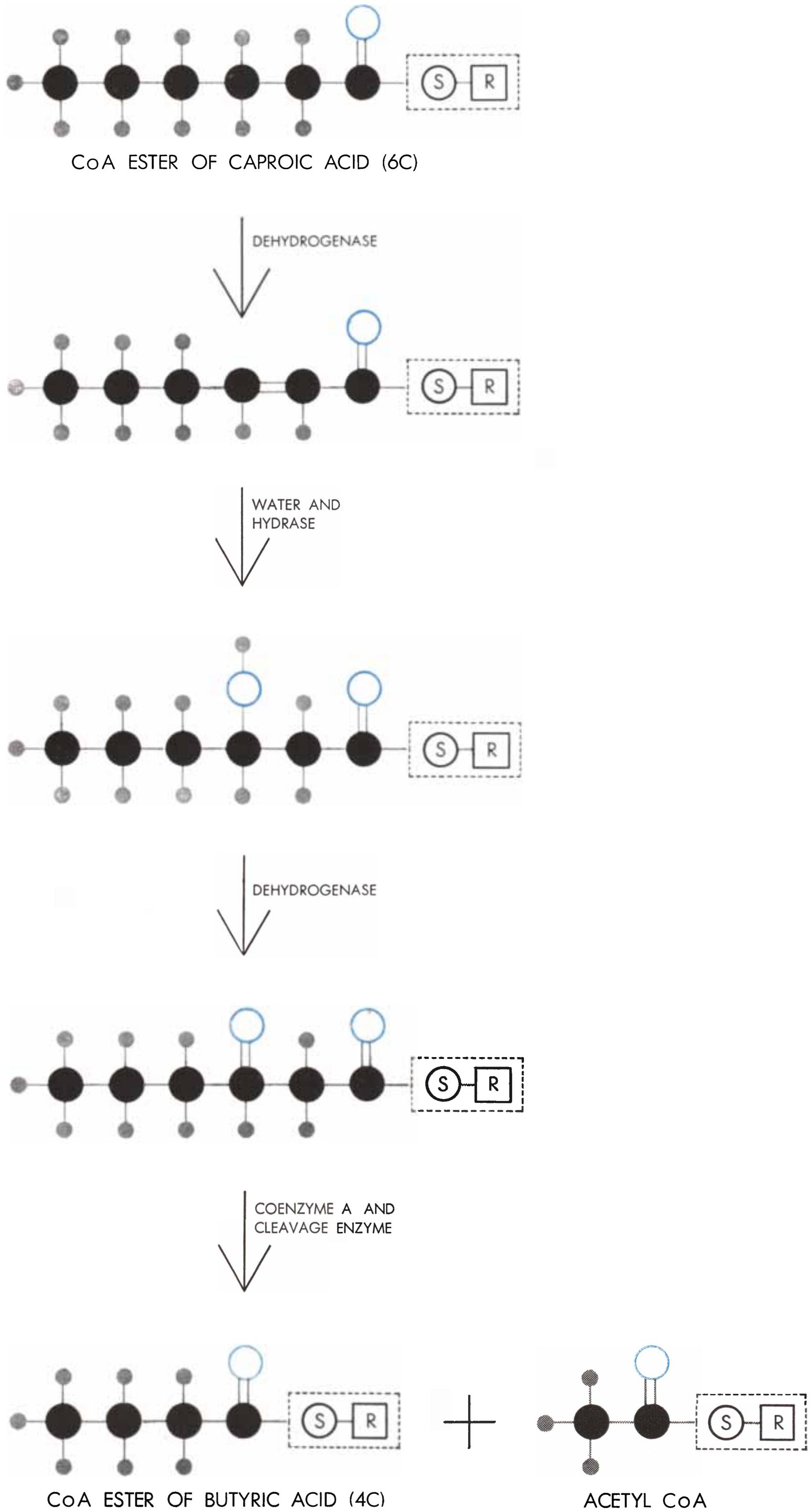
are joined together by an oxygen, a kind of linkage that is known as an ester bond.



ous combinations of fatty acids, but all are put together in the same way as this one.



bonds. Cytidine monophosphate, the coenzyme remnant, is not shown in the equation.



BREAKDOWN OF FATTY ACID is an oxidative process, that is, hydrogens are removed by the actions of enzymes (dehydrogenases). The fatty acid (here caproic acid, which has a chain of six carbon units) is not broken down in its free form but in the form of an ester of coenzyme A (*top*). After oxidation and hydration (*first three steps*), two carbon units split off from the chain in the form of acetyl CoA (*last step*). The remaining chain, still in the form of a CoA fatty-acid ester (here the ester of the four-carbon chain, butyric acid) can go through the whole process again for further degradation. Thus a fatty acid of any length can be disassembled two units at a time until it is all reduced to acetyl CoA.

gest that the intermediate may be adenosine diphosphoryl biotin rather than phosphoryl biotin.

Up to this point, in explaining the synthesis of malonyl-CoA, our work had shown how just one carbon atom is added to the original two carbons of acetic acid. From here on it was clear that the build-up of the fatty-acid chain must involve three main processes. First, additional carbon units must be fastened to the chain; second, the carbon dioxide must be eliminated; third, the oxygen or ester link in the intermediate compound must be eliminated by hydrogenation.

At the outset it seemed possible that the chain might build up by polymerization of malonyl-CoA. In line with this idea one would expect two units of malonyl-CoA to join together to form a six-carbon intermediate. Upon hydrogenation and elimination of carbon dioxide, the intermediate would give a five-carbon product; this product would combine with another unit of malonyl-CoA and so on. Fatty acids or intermediates with odd numbers of carbon atoms would thus dominate the process, and fatty acids with an even number of carbon atoms would appear only at the end. It turned out, however, that the chain builds up in quite a different way. Malonyl-CoA condenses not with another molecule of its kind but with acetyl-CoA. It thus forms an intermediate with five carbon atoms. This is transformed, by the addition of hydrogen and the elimination of carbon dioxide, to a four-carbon fatty-acid coenzyme-A ester. The four-carbon product reacts with a malonyl-CoA to form a seven-carbon compound, which in turn yields a six-carbon coenzyme-A ester, the process repeating itself until a 16-carbon fatty acid is reached.

Malonyl-CoA is thus in effect the source of the two-carbon units. It combines only with the even-numbered fatty-acid coenzyme-A esters, and these are generated after each addition by the processes of hydrogenation and elimination of carbon dioxide. The details of the processes have not yet been worked out. There are apparently two hydrogenating steps for which the cofactor, reduced triphosphopyridine nucleotide, provides hydrogen (or electrons). Carbon dioxide is probably eliminated after the hydrogenation, but the evidence is still incomplete.

Although our analysis of fatty-acid synthesis was based on the process found in pigeon liver, this is not the only tissue that synthesizes fatty acids through the malonyl-CoA pathway. Indeed, it appears that this method is used universally in oxygen-respiring cells, whether of animals, plants, insects or microorganisms. *Clostridium kluyverii* belongs among the anaerobic organisms (*i.e.*, those that grow in the absence of air) and hence is the exception and not the rule. As luck would have it, the exception set the mode of speculation and hypothesis for more than a decade and postponed recognition of the differences between the mechanisms of oxidation and synthesis. Evidence is multiplying that life processes almost never follow the same pathway in building up and in degrading a complex molecule. Readily reversible processes are rarely suitable for synthesis; the trick is to pick reactions that go almost exclusively in one direction.

One of the most intriguing aspects of fatty-acid synthesis is the fact that in practically all cells synthesis stops sharply at the stage of the 16-carbon acid. Only traces of the 14- or 12-carbon acids and literally none of the 18-carbon acids form. It is not yet possible to account for this strong bias in favor of the 16-carbon acid, and to explain how it is established with such a complete cutoff of the 18-carbon acid and with negligible spillage of the 14- and 12-carbon chains. Clearly the specificity of enzymes must permit a continuous process to break off sharply in a way that the organic chemist could only dream of duplicating.

We have not yet separated our two purified enzyme preparations into their individual enzymes. At a conservative estimate fatty-acid synthesis must involve at least a half-dozen different enzymes and four coenzymes. In the cell these are probably arranged in a sort of molecular assembly line to permit the orderly build-up of the fatty-acid chain. One may imagine that the reactive coenzyme-A esters of malonic and acetic acid come in at one end and palmitic acid (the 16-carbon fatty acid) comes out at the other.

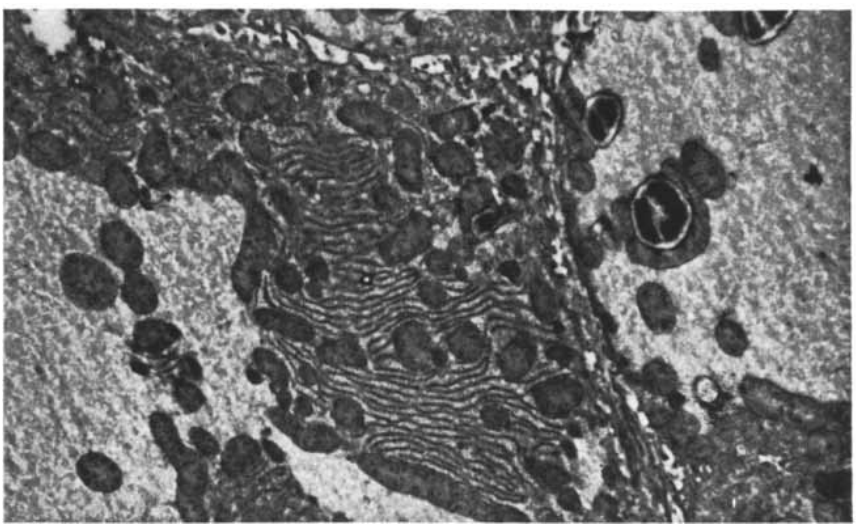
In what part of the cell are fatty acids synthesized? All the available evidence indicates that the system is not in the mitochondria, where the enzymes for degrading fatty acids are located. Instead the synthetic process appears to be associated with the much smaller particles broadly designated as cytoplasmic membranes or microsomes. Thus the two systems for oxidation and synthesis are physically separated. Such compartmentalization permits both processes to go on simultaneously in the same cell without mutual interference.

The process of synthesizing the fatty-acid chain is, however, just one of several operations in the construction of fat molecules. The fatty-acid chains must be linked to an alcohol and to other accessory groups in the various combinations of this rich family of substances. It appears that the mitochondria in the cell have the major role in the final assembly of the component parts of the lipid molecule, even though they play no role in fatty-acid synthesis.

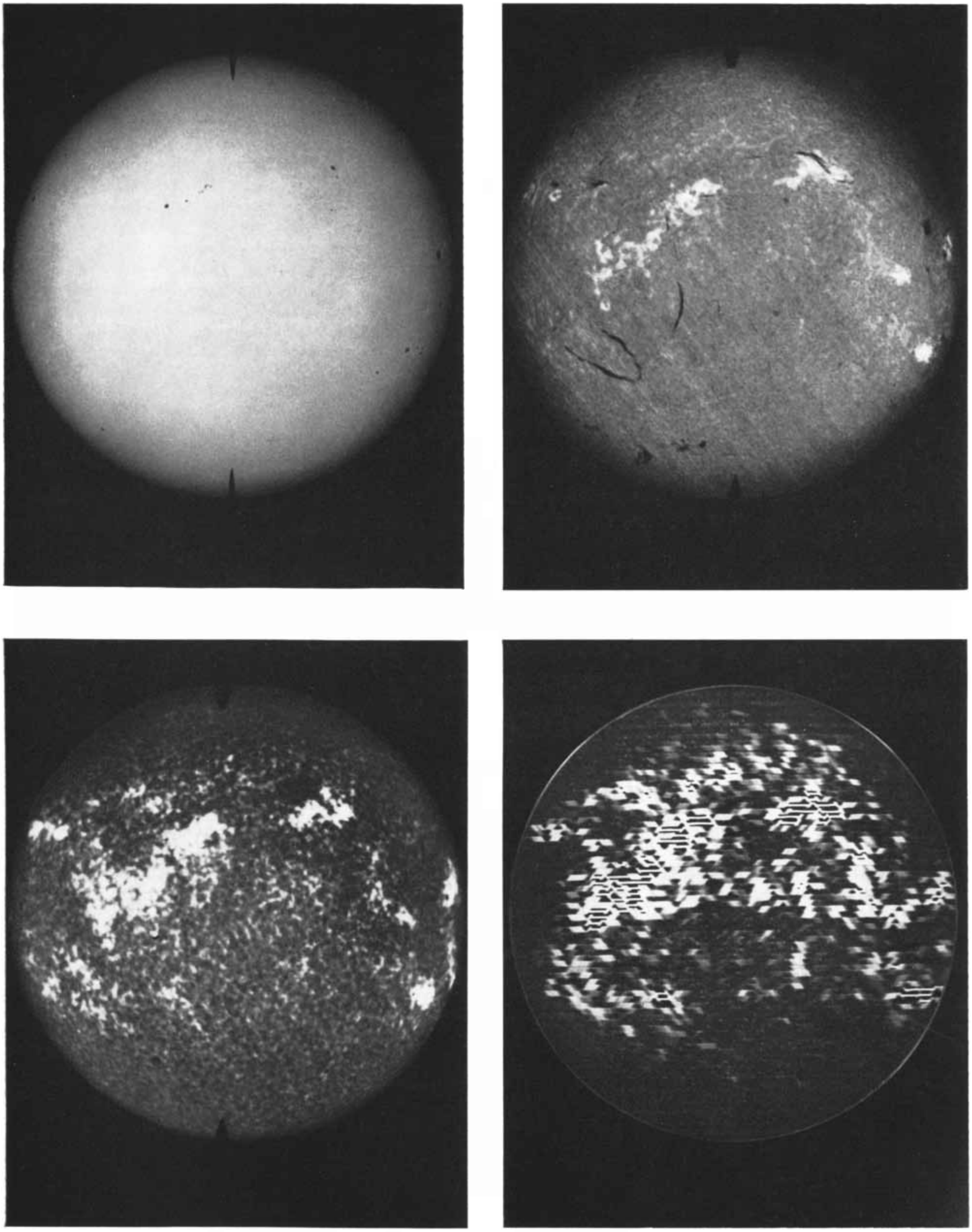
There are some dozens or more of lipids, each with its distinctive chemical pattern. One of the most important is the lecithins, which are built around a glycerol molecule. Two of the hydroxyl prongs of the glycerol are occupied by fatty-acid chains; the third forms its ester linkage with a phosphoric-acid choline group. In what order are these units put together? The enzymatic strategy underlying the synthesis of lecithin was discovered by Eugene P. Kennedy of the University of Chicago in the course of a brilliant series of investigations. First a hopped-up phosphate group transferred from ATP pre-empts one of the three hydroxyl groups on the glycerol. The "phosphoglycerol" now reacts with two fatty-acid molecules in the form of their coenzyme-A esters, and two ester bonds are established, filling the remaining two prongs on the glycerol. But then the unexpected happens: the phosphate group is kicked off, leaving one glycerol prong free. Meanwhile a phosphoric-acid choline combination has formed from choline and ATP with the aid of an enzyme. Fitting this piece into place is, chemically speaking, a sticky operation, but it is nonetheless effected by one of the cell's typical catalytic stratagems. The phosphoric-acid choline group is picked up by a special coenzyme called cytidine diphosphocholine, which delivers it to the vacant glycerol hydroxyl, completing the lecithin molecule.

The synthesis of lecithin is representative of the processes that put together other types of lipid. Most of them were understood before the synthesis of the seemingly simpler fatty-acid chain was worked out.

With the major questions of fat synthesis settled, biochemists are shifting their attention to the fascinating medical and biological problems connected with the function of fat molecules in the cell and organism. Some of the most fundamental activities of life are inextricably entwined with the properties and structure of the lipids. The red-blood-cell membrane which regulates the inflow and release of sugar, salt and other small molecules; the nerve-cell membrane which controls the transmission of nerve impulses; the mitochondrion which provides the power for the cell; the plant chloroplast which fixes radiant energy in the form of chemical energy—these are only a few examples of living systems in which lipids are the warp and woof of function.



MITOCHONDRIA AND MICROSOMES can be seen in this electron micrograph of liver cells made by George E. Palade of the Rockefeller Institute. The microsomal particles (*parallel strands*) are probably the sites of fatty-acid synthesis; the mitochondria (*small oval structures*) are the sites of both fatty-acid breakdown and of assembly of alcohols and fatty acids into fats. Lipid droplets (*dark blobs*) lie adjacent to mitochondria at upper right. Fats are also present as functional parts of mitochondrial membranes and cell walls (*whitish boundaries at top and right center*). Structures are magnified some 5,700 diameters.



SOLAR DISK is viewed in four different ways, demonstrating correlation between visible features and magnetic fields. Ordinary photograph (*top left*) contains sunspots. "Spectroheliograms" made with the light of the hydrogen-alpha spectral line (*top right*) and a violet spectral line of ionized calcium (*bottom left*) show, respectively, dark filaments of cool hydrogen and bright regions called faculae. "Magnetogram" (*bottom right*) is a record of surface magnetism, with brighter regions indicating greater field strengths.

THE MAGNETISM OF THE SUN

Changing magnetic fields, local and general, play continuously across the solar surface. They account for many of its visible features and furnish a hint of the motions in the sun's interior

by Horace W. Babcock

The four pictures on the opposite page are all representations of the sun. Three of them were made by exposing photographic plates to solar light of different wavelengths. The fourth, at the lower right, is a "magnetogram"—a record (on a cathode-ray tube) of the magnetic fields at the surface of the sun.

As a glance at the pictures will show, the magnetic pattern has a close connection with the visible details of the solar surface. This is not surprising; the new discipline of magnetohydrodynamics tells us that the highly ionized gaseous material of the sun must be intimately coupled to the magnetic fields within and around it. When the ionized material moves, the fields tend to move with it, and vice versa. Hence from the variations of the magnetic fields at the surface of the sun we can deduce the patterns of fluid motions and thus perceive what lies behind the sun's ever changing visible features. In addition, magnetic studies provide clues to the nature of the turbulent activity of the sun's interior.

Magnetic fields are of course invisible, and lines of force are purely imaginary constructs. How can we "see" them on the sun? The answer lies in their effect, discovered by the Dutch physicist Pieter Zeeman, on the interaction of light waves and atoms in a gas.

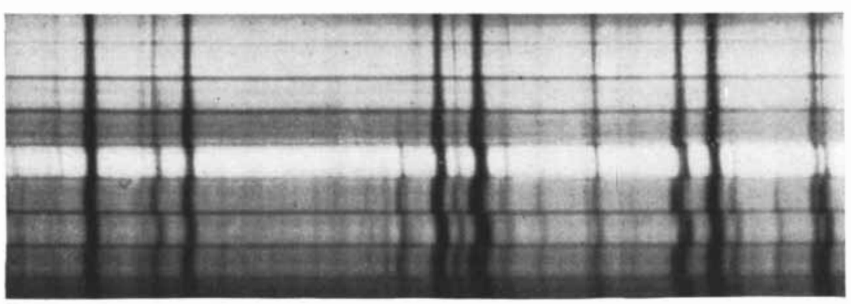
In the absence of a magnetic field every kind of atom emits (and absorbs) light at a number of distinct wavelengths. The wavelengths can be separated by the spectroscope into a series of lines characteristic of the element that is emitting or absorbing the light. Zeeman showed that when atoms are placed in a magnetic field, their spectral lines are split. In other words, each single line becomes a group of lines with slightly different wavelengths. Furthermore, the light at each of these wavelengths is polarized. The amount of splitting, that is, the spread between the longest and shortest wavelength in a group, depends predictably on the strength of the field. The directions of polarization depend on the direction of the field.

Quantum theory explains the Zeeman effect in terms of the behavior of atoms in magnetic fields. Each line in the ordinary spectrum of an atom represents a transition between two of its possible energy levels. In a magnetic field these levels are themselves split. The atom is a tiny magnet which, according to quantum theory, can take only certain distinct positions in relation to an external field. These positions differ in energy. Hence every energy level takes on two or more values, corresponding to the various possible orientations of the atom in the field.

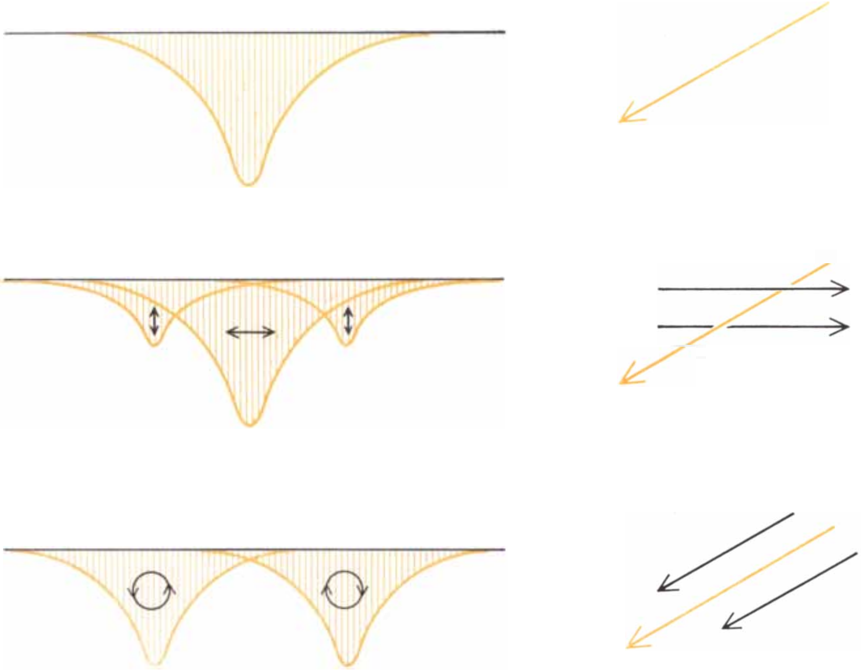
Within a few years of its discovery in the laboratory the Zeeman effect was demonstrated in astronomy by George Ellery Hale at the Mount Wilson Observatory. In 1908 he showed that spectral lines in the light from sunspots are split and that the light is polarized. Thus at one stroke he had for the first time detected and measured an extraterrestrial magnetic field and had related it to a visible phenomenon.

Hale immediately recognized the importance in the sun of what we now call magnetohydrodynamic phenomena, and he prepared to study them thoroughly. He saw to the building on Mount Wilson of a 150-foot tower telescope equipped with a large diffraction-grating spectrograph. Realizing the inadequacy of existing gratings, he set the instrument shop to developing machines of extreme precision to produce bigger and better ones. Instruments were built to record solar features such as prominences, flares and faculae (regions that appear bright in the light of the main emission-line of calcium) and to establish their connection with magnetic fields.

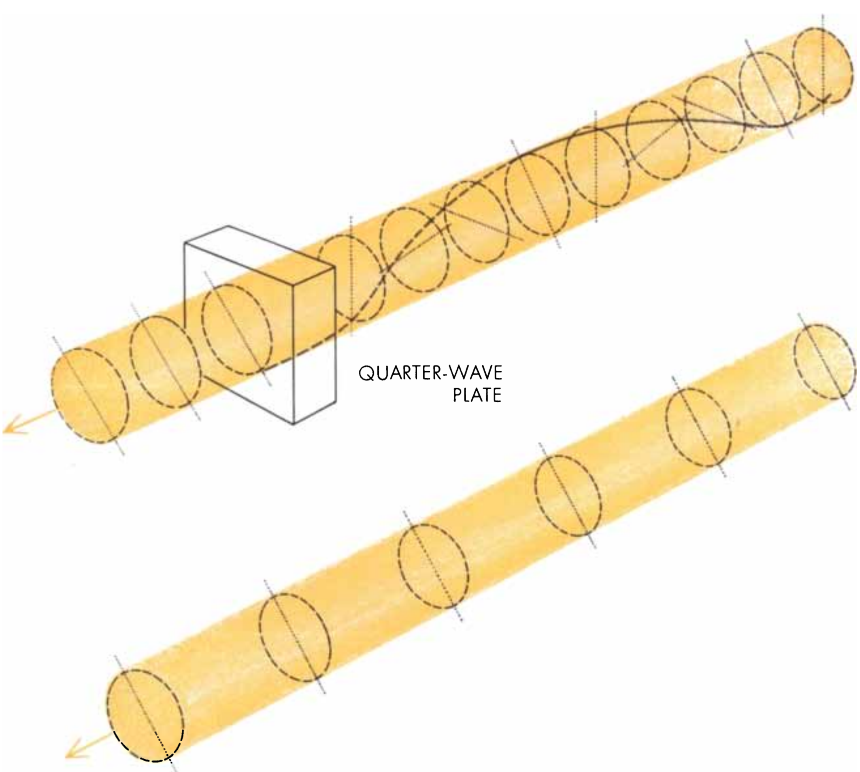
A systematic investigation of sunspots soon disclosed that they invariably have strong magnetic fields, ranging from a few hundred to about 3,800 gauss. (The earth's field is approximately .6



SUNSPOT SPECTRUM shows Zeeman effect, or splitting of the spectral lines. The photograph was made through an analyzer that passes right-circularly polarized and left-circularly polarized light in alternate narrow strips. Spectral lines arising in sunspot regions are seen to consist of two components, both oppositely displaced and oppositely polarized.



ZEEMAN EFFECT is illustrated diagrammatically. Curve at top represents a spectral absorption line from atoms in a region of no magnetic field. Lower curves show splitting of the line by field perpendicular to line of sight (*middle*) and along line of sight (*bottom*). Two-headed arrows on curves indicate directions of polarization; colored arrows at right, the direction in which light is traveling; black arrows, the directions of the magnetic fields.



POLARIZATION OF LIGHT can be circular, as in upper beam, or plane, as in lower. Ellipses are cross sections through the beams, with straight dotted lines indicating the direction of vibration of the electric field in the light wave. In circularly polarized light the direction twists as the wave advances, as indicated by helical line around upper beam. When such a beam passes through a quarter-wave plate, it is converted to plane-polarized light.

gauss.) As time went on a number of other important facts emerged.

It had long been known that sunspots usually appear in pairs or groups. Now it developed that the leading and trailing members of a group, in the sense of their apparent motion across the solar disk as the sun rotates, have opposite magnetic polarity. (A region where the lines of force come out of the surface is said to have positive polarity; one where the lines go in, negative.)

Perhaps the most familiar characteristic of sunspots is the cyclic variation in their number, which has so fascinated some students of business cycles and other human ups and downs. Restricting ourselves to purely solar matters, we can say that the number of spots (and of other features of surface activity) rises and falls fairly regularly, in a cycle of roughly 11 years. Moreover, the average position of the spots shifts during the period: the zone of activity moves from the intermediate latitudes at the start to the equatorial regions at the end.

There are indications that, from the physical point of view, 11 years make up not a full cycle but a half-cycle. For one thing, the total number of spots is systematically larger and smaller in alternate 11-year periods. For another, the rate at which individual spots migrate from higher to lower solar latitudes seems to be alternately faster and slower. But magnetic data—Hale's laws of sunspot polarity—have provided the most striking evidence. During the half-cycles beginning in 1913, 1933 and 1954 the leading spots in the groups in the northern solar hemisphere had positive polarity; the trailing spots, negative. On the southern hemisphere the leading spots were negative; the trailing, positive. During the alternate half-cycles the situation was reversed!

As we shall see later, these observations fit into a consistent, though still very sketchy, dynamical model of the sun. However, they are only the beginning of the story. In addition to the strong magnetic fields associated with sunspots there are weaker fields covering vast areas and a faint general field that behaves in a quite unexpected way.

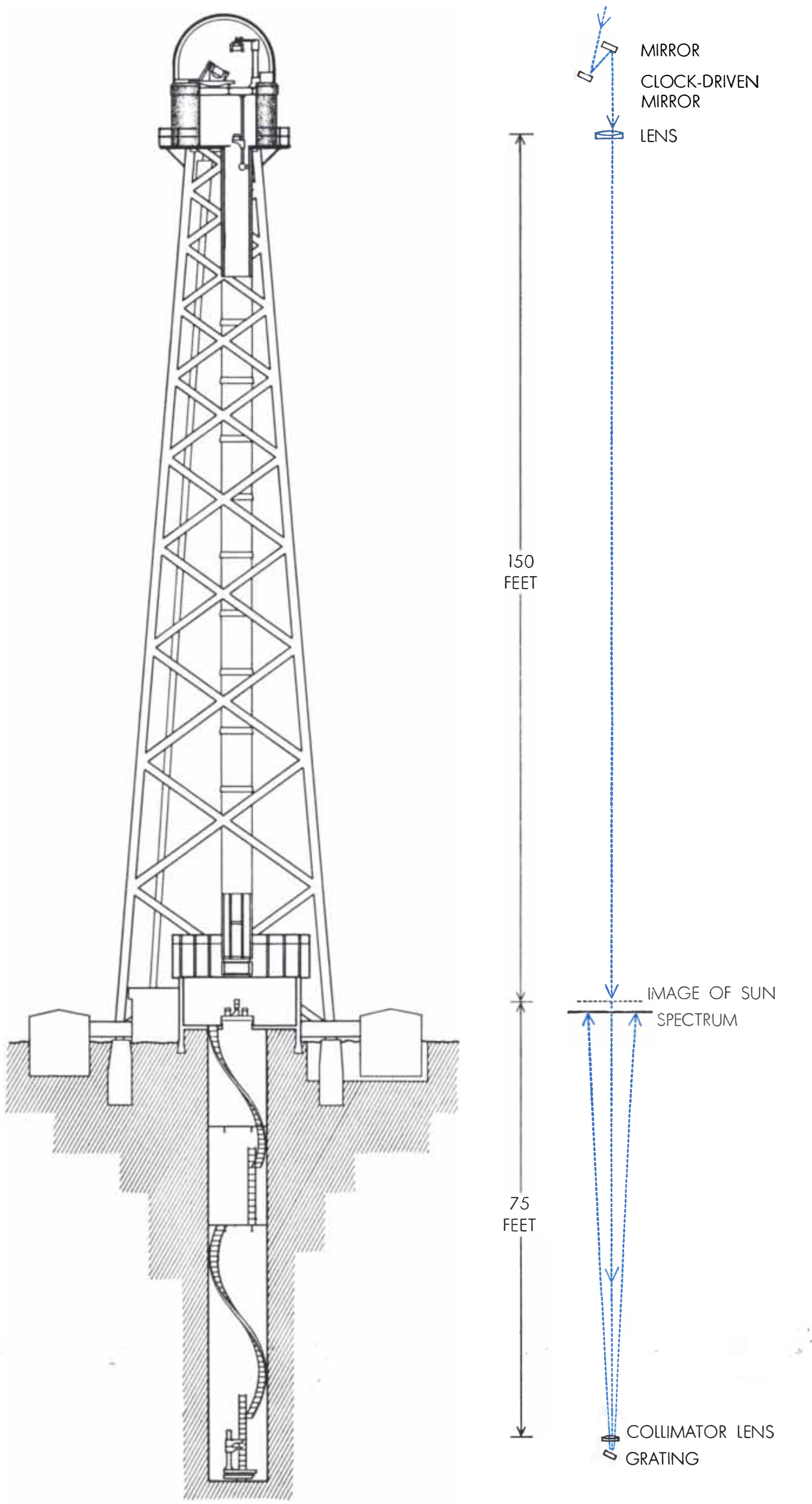
The search for weak solar magnetism was started by Hale in 1912. He was particularly interested in finding out whether the sun has an over-all magnetic field, a matter that had been the subject of speculation for some time. The form of streamers in the sun's corona, seen during total eclipses, suggested that the sun might have a dipole field like that of the earth. Hale and his colleagues looked for this field with every means at their command. They were unable to obtain clear and convincing data, although they did detect some weak, sporadic effects that they thought might be connected with the general field. It now seems probable that these were transitory local phenomena.

Efforts to detect weak fields and to record them systematically have continued without interruption at Mount Wilson. Since the middle 1930's the work has been largely carried on by Harold D. Babcock (the father of the author). Only in the past 10 years have instruments and techniques become equal to the job. Large, high-quality diffraction gratings, the fruition of Hale's early plans, and an ultrasensitive technique for measuring Zeeman splitting have at last brought success.

The central problem that had to be overcome was that the Zeeman effect is essentially very difficult to detect. The range of wavelengths in the visible spectrum is from 3,900 to 7,500 angstrom units, and to split a line in the spectrum by one angstrom unit requires a magnetic field of most 100,000 gauss. Thus the strongest sunspot field produces a separation of only a few hundredths of an angstrom. If such a small displacement is to be measured accurately, the spectrum must be greatly dispersed, or fanned out, and the details must be rendered very sharply, or with high resolution. The present grating in the Mount Wilson magnetograph gives a dispersion of 11 millimeters per angstrom. On this scale the entire visible spectrum would be spread over a distance of 35 yards.

But mere dispersion, no matter how great, cannot provide the sensitivity needed for really fine measurements. In solar studies we deal with magnetic fields as weak as a fraction of a gauss. The corresponding Zeeman separation is a hundred thousandth of an angstrom. But each line in the unsplit spectrum is itself about a tenth of an angstrom wide. Thus the parts into which a line is split almost completely overlap.

The magnetograph distinguishes the overlapping lines and measures their tiny separation by virtue of the fact that their light is polarized. To understand how the apparatus works we must say a little more about polarization in the Zeeman effect. When the light from the atoms in a magnetic field is observed from a direction perpendicular to that of the field, the spectral lines are split (in the simplest case) into three components. Each component is plane-polarized, that



TOWER TELESCOPE used for magnetic observations at the Mount Wilson Observatory is diagrammed at left; its optical system, at right. Clock-driven mirror tracks the sun. Solar image is formed at ground level, selected light rays passing to a diffraction grating at the bottom of the shaft beneath the tower. The light is reflected upward from the grating and is dispersed into a spectrum, which falls on a screen that is also located at ground level.

is, the electric vibrations of the light waves are restricted to a single direction. The middle component of a given line is polarized parallel to the field; the components to either side of it are polarized perpendicular to the field [*see top illustration on page 54*].

When the direction of observation is parallel to the magnetic field, the line is split into two parts, each exhibiting what is known as circular polarization. In a circularly polarized beam the direction of the electric vibration rotates as the wave advances [*see bottom illustration on page 54*]. The two parts of the split line are polarized in opposite directions: the rotation is clockwise ("right circular") for one and counterclockwise ("left circular") for the other. It is these circularly polarized beams that are detected by the magnetograph, so that the instrument measures the component of the magnetic field that is parallel to the line of sight.

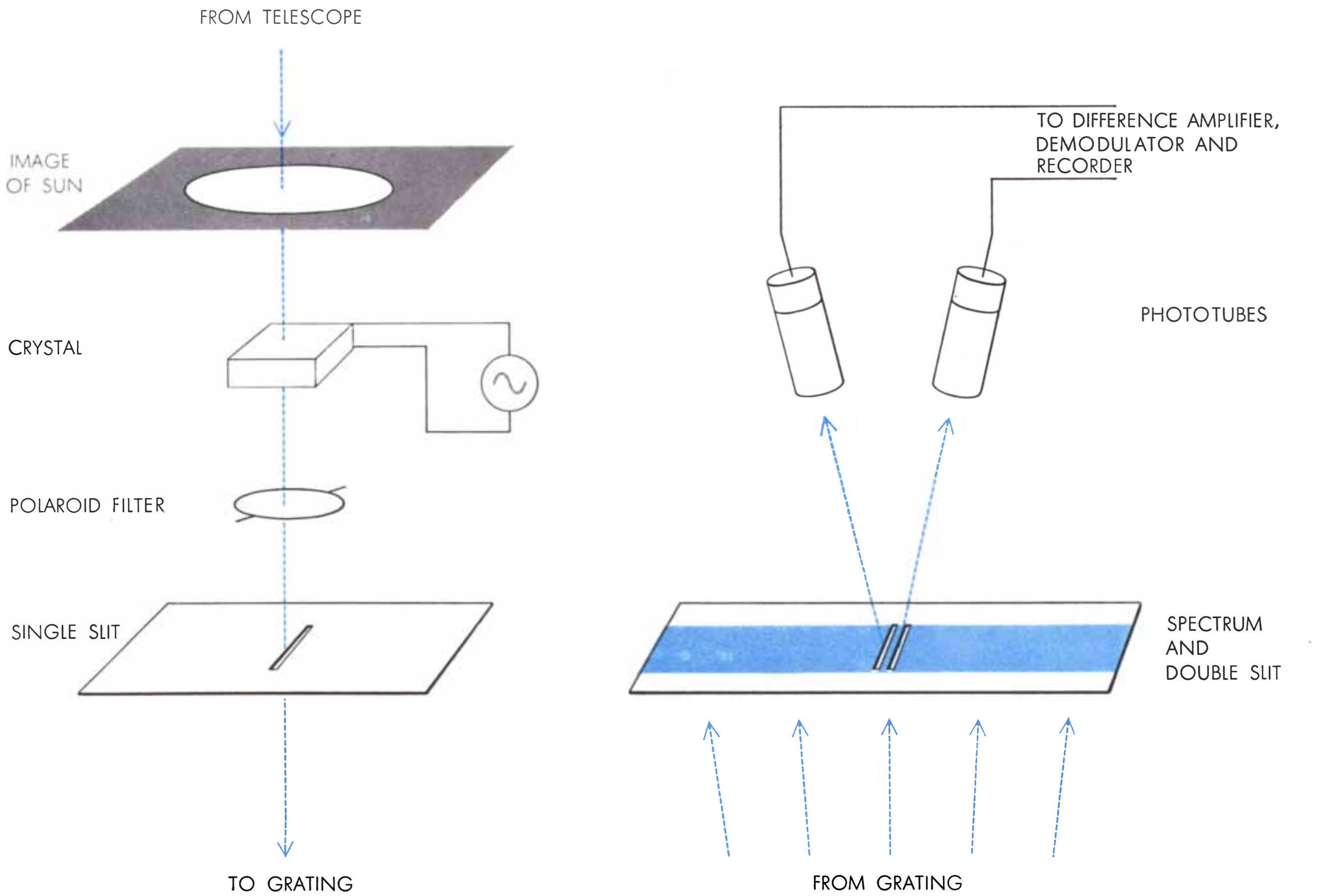
To analyze circularly polarized light it is first converted into plane-polarized light; this is done by passing it through a device known as a quarter-wave plate. Then the direction of vibration can be determined in the ordinary way, for example with a Polaroid filter.

In the magnetograph this principle is applied in a special manner to provide high sensitivity [*see illustration below*]. Serving as a quarter-wave plate is a crystal of ammonium dihydrogen phosphate; when a voltage is applied to this substance, it becomes in effect a quarter-wave plate for either right- or left-circularly polarized light, depending on the direction of the voltage. With an alternating voltage the crystal passes the right-circular beam and suppresses the left-circular beam on one half-cycle, and reverses on the other.

Thus the magnetograph separates the two overlapping components of a split line by viewing them one at a time and alternately. The image of the line therefore oscillates back and forth over a tiny distance, the displacement depending on the strength of the magnetic field that produced the splitting. The relation between the direction of the jump and the polarity of the crystal depends on the direction of the field—whether it points toward or away from the observer.

The oscillating image of the line falls on a screen perforated with two parallel slits. As the image moves back and forth it sends more light first through one slit and then through the other. A separate photomultiplier tube picks up the light from each slit, converting it into a varying electric current. The difference between these signals is amplified and converted to a single direct current whose size varies with the strength of the detected magnetic field and whose direction reflects the polarity of the field.

Information contained in the electrical output is translated into a visible record on a cathode-ray tube. As the sun's image is scanned by the turning of the main mirror of the magnetograph, the electron beam of the cathode-ray tube



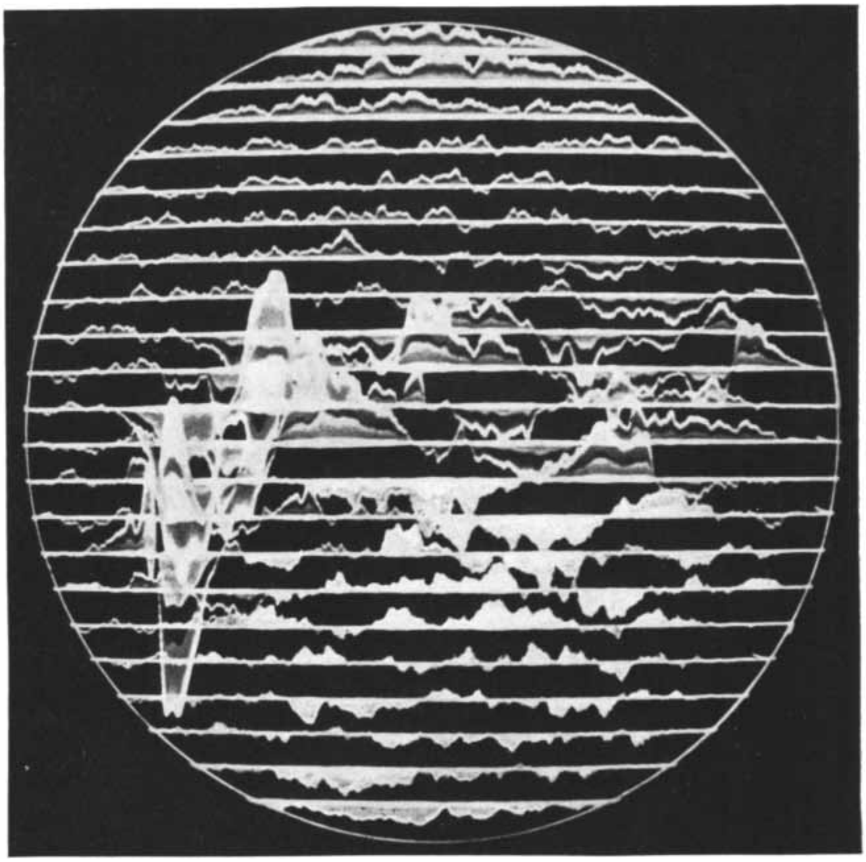
SOLAR MAGNETOGRAPH, depicted schematically, produces a magnetic map by scanning the sun's surface. At left light rays (*colored arrow*) from solar image pass through crystal which is subjected to an alternating voltage and alternately transmits right-circularly and left-circularly polarized light. Beam passes single slit to diffraction grating. At right dispersed light from grating forms a spectrum, with one of its lines centered on double slit in a screen. Light from slits passes to separate phototubes, which convert it into electric currents that vary as line oscillates. These currents are used to vary the brightness of the trace on a recording oscilloscope.

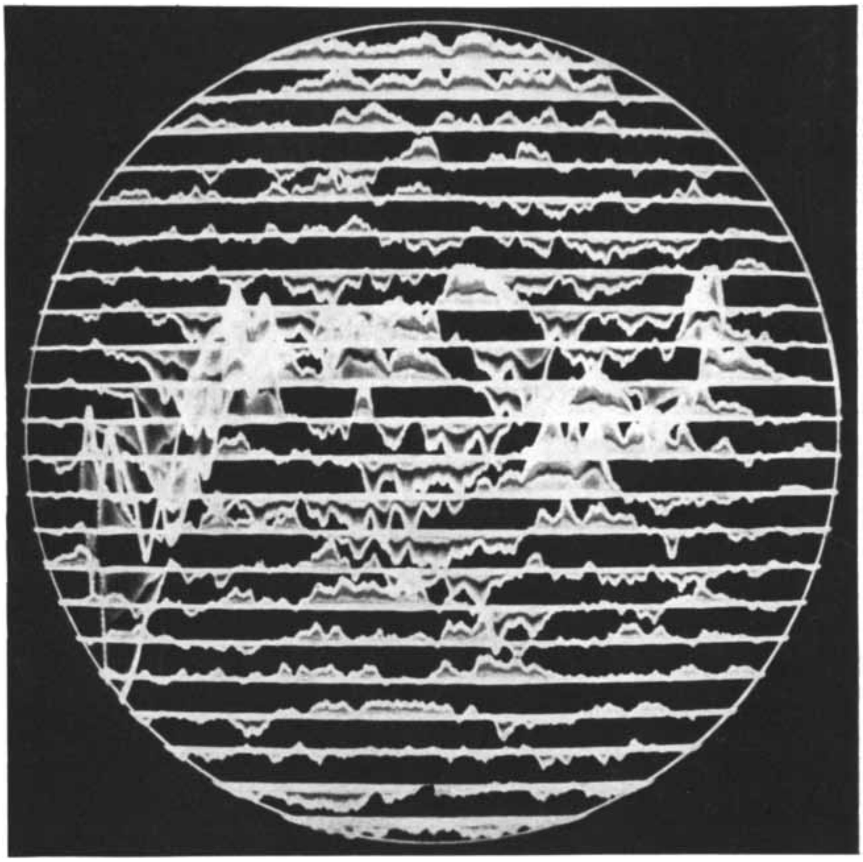
sweeps across the tube-face in a series of horizontal lines. In the original version of the instrument the photomultiplier output was applied to deflect the beam vertically from its scanning path, giving a series of curves that represents the magnetic field [*see illustrations at right*]. In the present recording setup the current modifies the intensity of the beam, making the trace brighter for greater field strength. The scanning beam does not form a spot on the tube, but a short vertical line. For fields of positive polarity the line is made to slant upward to the right, and for those of negative polarity it is made to slant upward to the left. When the field strength exceeds a chosen quantity, the scanning segment collapses to a spot and the trace becomes a horizontal line. Thus the magnetograms consist of parallelograms of varying brightness, with horizontal lines where the field is strongest.

The magnetograph at Mount Wilson scans the whole of the sun's disk once an hour, with a resolution of 23 seconds of arc (an 80th of the sun's diameter). The usual working range is one to 50 gauss or more, although magnetic fields as weak as .3 gauss can be measured. It is also possible to scan a small region of the disk with higher resolution. The fine-scanning arrangement covers a square five minutes of arc on a side (140,000 miles at the sun's surface), with a resolution of five seconds of arc, in a period of 15 minutes.

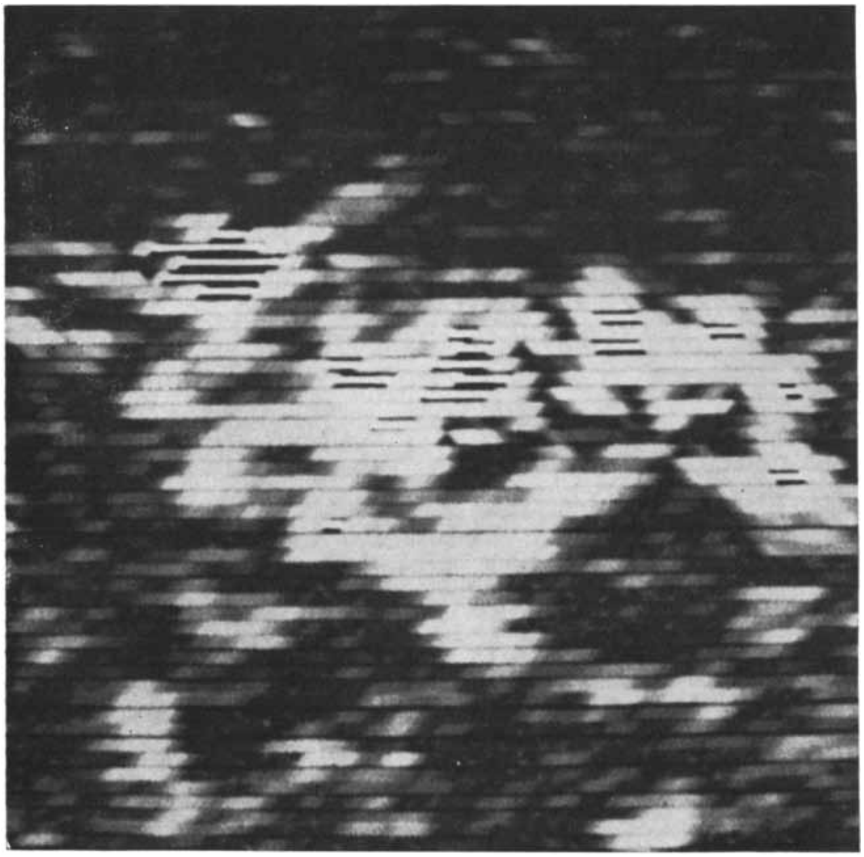
Fine-scanning is useful in studying localized, rapidly developing effects such as solar flares. (These features have become especially interesting since John R. Winckler of the University of Minnesota found that they emit low-energy cosmic rays in such copious amounts as to constitute a serious threat to space travel.) By studying the changes in the magnetic-field patterns during the progress of flares it may be possible to discover the source of their energy. The first astronomer to carry out such an investigation was A. B. Severny of the Crimean Astrophysical Observatory in the U.S.S.R., where there is a magnetograph like the one at Mount Wilson.

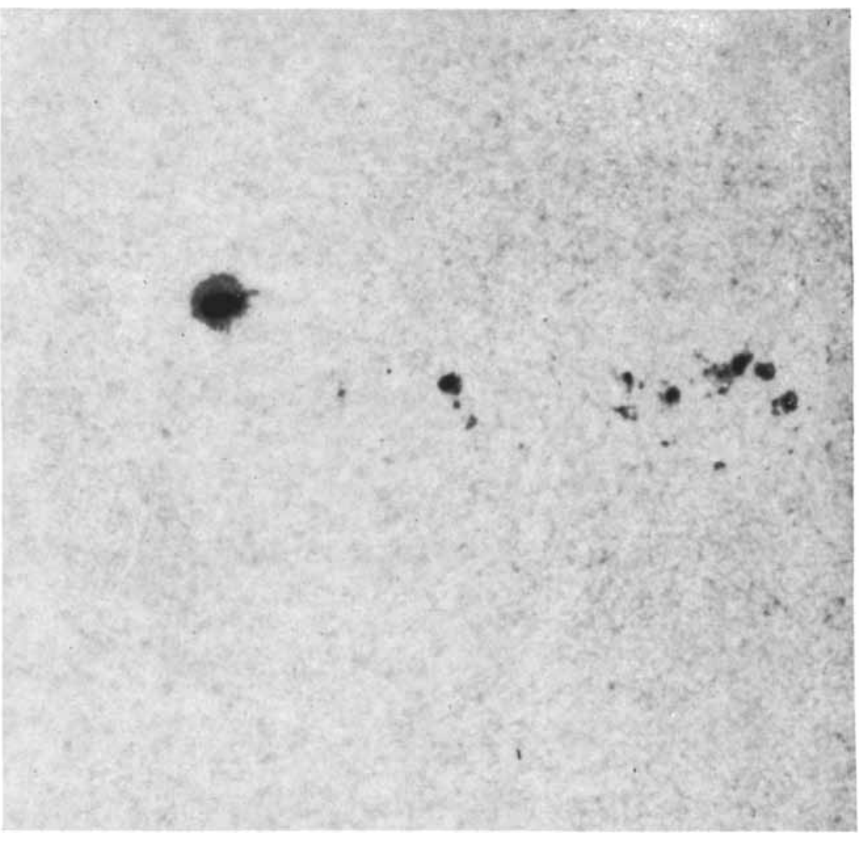
Recently a photographic technique that supplements the magnetograph has been developed by Robert B. Leighton of the California Institute of Technology. He makes two monochromatic photographs of the sun: one in right-circularly polarized light and the other in left. The wavelength selected by the slit of his spectrograph is just on the edge of a spectral line. When the line splits, one





GENERAL POLOIDAL FIELD on successive days in 1953 appears near top and bottom of these magnetograms. Field strength is indicated by distance of curves from horizontal lines; positive polarity by upward displacement; negative polarity, by downward displacement.





BIPOLAR MAGNETIC REGION appears just above the horizontal center line in magnetogram (*top*). Left-hand, or leading, portion has positive polarity; right-hand, negative, as shown by traces slanting up to right and left respectively. Bright horizontal lines indicate strongest fields. Photograph at bottom shows sunspots contained in this bipolar region.

component moves farther into the slit; the other, farther away. Thus the density of the two photographs differs in magnetic areas. By superimposing a negative of one photograph on a positive of the other, Leighton obtains a picture in which magnetic fields show up as bright or dark regions, depending on their polarity [*see top illustration on page 60*]. The method gives excellent resolution but it cannot detect fields weaker than about 20 gauss.

What has the magnetograph revealed about the sun's magnetism? One of the earliest findings was that there are usually numerous extended regions on the solar disk where fields can be detected, with intensities ranging from a fraction of a gauss to several tens of gauss or more. The fine details of these patterns change appreciably from day to day. Larger features vary more slowly, and with more regularity and underlying symmetry. The changes result from the hydromagnetic flow of material coupled to the magnetic lines of force. On the small scale the motions reflect convection and turbulence; on the larger scale they are related to the rotation of the sun and to an over-all pattern of slow circulation or oscillation.

A great majority of the magnetic regions are bipolar: they are divided into two parts, usually contiguous, of opposite polarity. The same laws that govern the polarity of leading and trailing sunspots apply to the parts of bipolar-magnetic regions. Some regions are more complex and are better termed multipolar.

Although they vary greatly in size, field intensity and details of life history, bipolar regions follow the same general line of development. At first they are quite compact. Then they expand gradually, and for a time their total magnetic flux increases. Eventually the flux reaches a maximum, but the region continues to expand, so that the intensity of the field grows weaker. So long as a region is well defined, the outgoing flux from the positive part of the field appears to equal the ingoing flux in the negative. Since magnetic lines of force are continuous, we envision them as forming arches that loop upward into the solar atmosphere. The feet of the arches are anchored in the two parts of the bipolar region, with the lines of force passing through the surface more or less perpendicularly.

When their maximum field-intensity is less than about 20 gauss, bipolar regions are not accompanied by any obvious visual changes on the sun's disk.

Above 20 gauss they produce faculae, or brightening of the light emitted by ionized calcium atoms in the region. Still stronger and more concentrated regions often produce sunspots while they are young. Indeed, every sunspot is a part of a bipolar or multipolar region where the lines of force are crowded especially close together.

For the two or three years (1953-55) of minimum activity during the present sunspot cycle the bipolar regions were weak and usually small. Even then, however, there were only a few days when no such regions could be found on the sun's surface.

A very much rarer type of solar magnetic area is the so-called unipolar-magnetic region. Only three examples have been unambiguously identified, all in the declining years of the last sunspot cycle. The strongest unipolar region, which had positive polarity, appeared in 1953. It lasted through some six rotations of the sun, its average field-intensity never rising above three gauss.

Where do the magnetic lines of a unipolar region go? We can only assume that they extend up from the surface more or less radially, perhaps to great distances, and eventually return to the sun diffusely in areas that have not been identified.

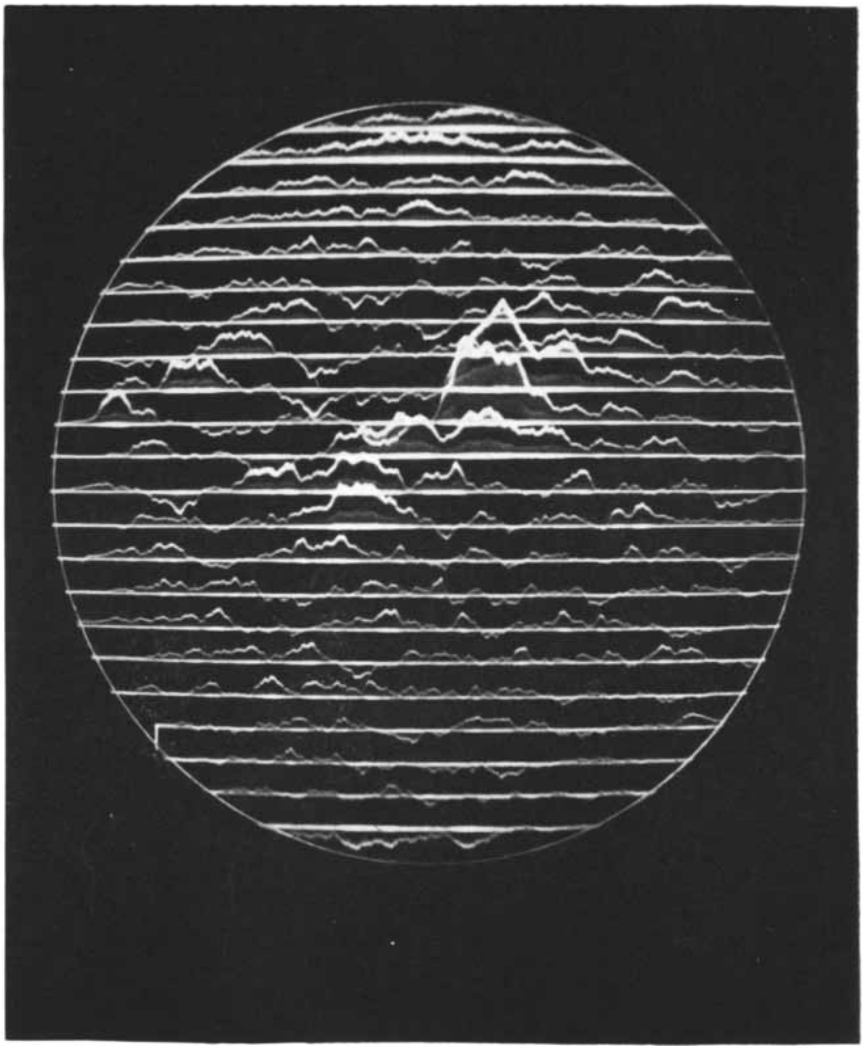
None of the unipolar regions so far identified produced faculae or other surface disturbances. However, each time the strongest one crossed the center of the sun's disk, cosmic-ray counters registered increased activity, and, about three days later, there followed a disturbance in the earth's magnetic field. Magnetic storms that repeat after 27-day intervals have been known for a long time, and have been attributed to streams of ionized hydrogen ejected from the sun. But the source of these streams had not been identified. Now it appears that they may come from unipolar magnetic regions that are carried around by the rotation of the sun. For confirmation of this idea we shall have to wait for the declining years of the current sunspot cycle, when the 27-day storms should show up again and the sun's magnetic pattern may quiet down enough so that unipolar regions can form and be identified with certainty.

The localized magnetic features mentioned thus far are generally confined to latitudes within 40 or 50 degrees of the solar equator. Nearer the sun's poles there are sometimes no fields at all. But in 1953 the magnetograph detected a widespread weak magnetism that may be termed the poloidal field of the sun. This is the elusive "general field" that Hale looked for so assiduously. It turns out to be much weaker than he suspected, differently distributed and remarkably variable. Not only does its intensity change and its distribution shift; its polarity even reverses!

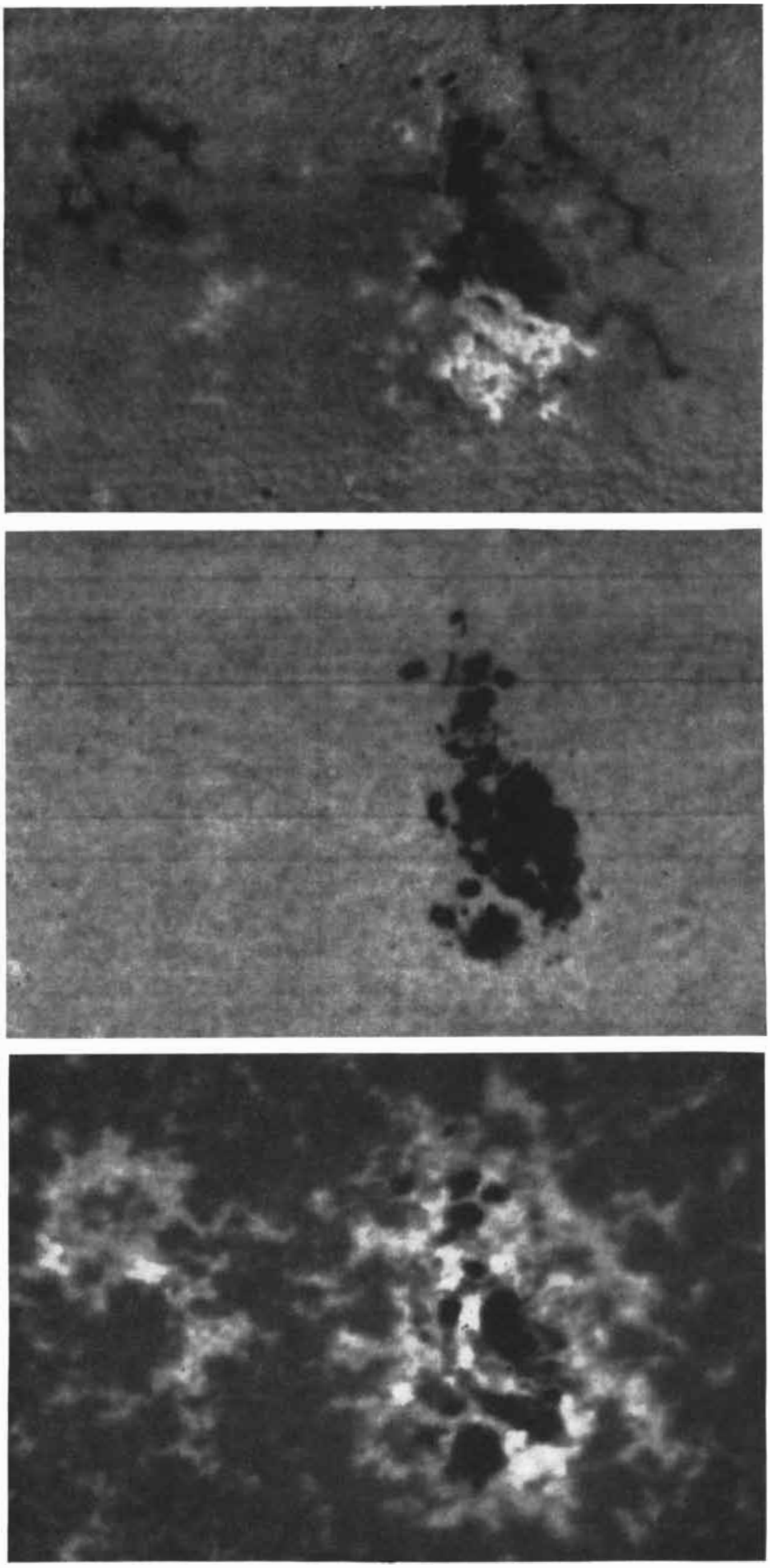
Magnetograms made in 1953 clearly indicated a positive field in the high northern latitudes of the sun and a negative field in the far southern latitudes [*see illustrations on page 57*]. The intensity of the fields was one or two gauss. In the next few years the fields grew weaker and eventually could not be detected. Then, in 1957, the field of the southern polar region reappeared with reversed polarity. For nearly a year there were weak positive fields near both poles. Finally, in November, 1958, the northern field also reversed. Prior to 1957 the poloidal fields were restricted to very high latitudes. Since the reversals they have been most evident in zones closer to the 50th and 60th solar parallels. Currently we can detect hardly any fields in the extremely high latitudes, and the southern poloidal field seems to be weakening again.

The reversals of the poloidal field occurred near the time of maximum activity of the sunspot cycle. It seems quite likely that this phenomenon is another aspect of the 22-year magnetic cycle.

From all the evidence it now appears that the general magnetic field of the sun has two components. One is the poloidal field; the other is a submerged toroidal (ring-shaped) field running parallel to the equator in the northern and southern hemispheres [*see illustra-*



UNIPOLAR MAGNETIC REGION of positive polarity, which persisted for more than six months in 1953, appears in this magnetogram as a series of upward-displaced traces near the center of the solar disk. No neighboring downward displacements indicate a negative pole.



PHOTOGRAPHIC METHOD, described in the text, shows solar magnetic fields as light or dark areas (depending on polarity) against a uniform background (*top*). Same region of sun is photographed in ordinary light (*center*) and in light of calcium emission (*bottom*).

tion on next page]. This toroidal component presumably accounts for most of the localized surface magnetic effects and their accompanying visible features as well as for arching lines of force that loop far out above the surface.

To understand the role that the toroidal field plays, recall that the highly conducting material of the sun can slide easily along lines of magnetic force but cannot move readily across them. If a convection current carrying gas from the interior to the surface crosses the ring of magnetic lines, it will carry those lines with it. When the field reaches the surface, some of the lines can break away from the associated matter and arch up into the sun's atmosphere. Thus is born a bipolar magnetic region. The ring may undulate like a sea serpent, looping up through the surface at several places and forming a number of bipolar regions at the same latitude.

Assuming that the field directions are opposite in the northern and southern rings, the reverse polarity of leading and trailing regions in the two hemispheres is explained. Moreover, we envisage a new pair of rings forming in the higher mid-latitudes at the beginning of each 11-year half-cycle. They then migrate slowly toward the equator and disappear at the end of the period.

Once the toroidal fields break through the surface, their interaction with matter can produce a variety of visible effects. Sunspots are formed when the nearly vertical lines of force leaving or re-entering the surface are tightly crowded together. The small, roughly circular convection currents that carry hot gases toward the surface and cooler gases back to the interior are inhibited. They can move vertically up or down, but not horizontally across the lines to complete the circuit. Hence the transfer of heat toward the surface is reduced and the area cools and darkens, producing a sunspot.

Prominences, the peculiar cloudlike formations of relatively cool hydrogen gas observed high above the surface, must owe their support to the magnetic fields that arch above bipolar regions. Long, thin, relatively stable prominences have been found to lie along the imaginary line that runs at right angles to the lines of force and divides a bipolar region into two parts of opposite polarity. Apparently the gas has collected and cooled near the tops of the magnetic arches and pushed them down into a sagging or hammock-like shape. Thus precariously supported, the prominence may exist for days or weeks, perhaps eventually to be propelled outward at high speed by an increase in the field.

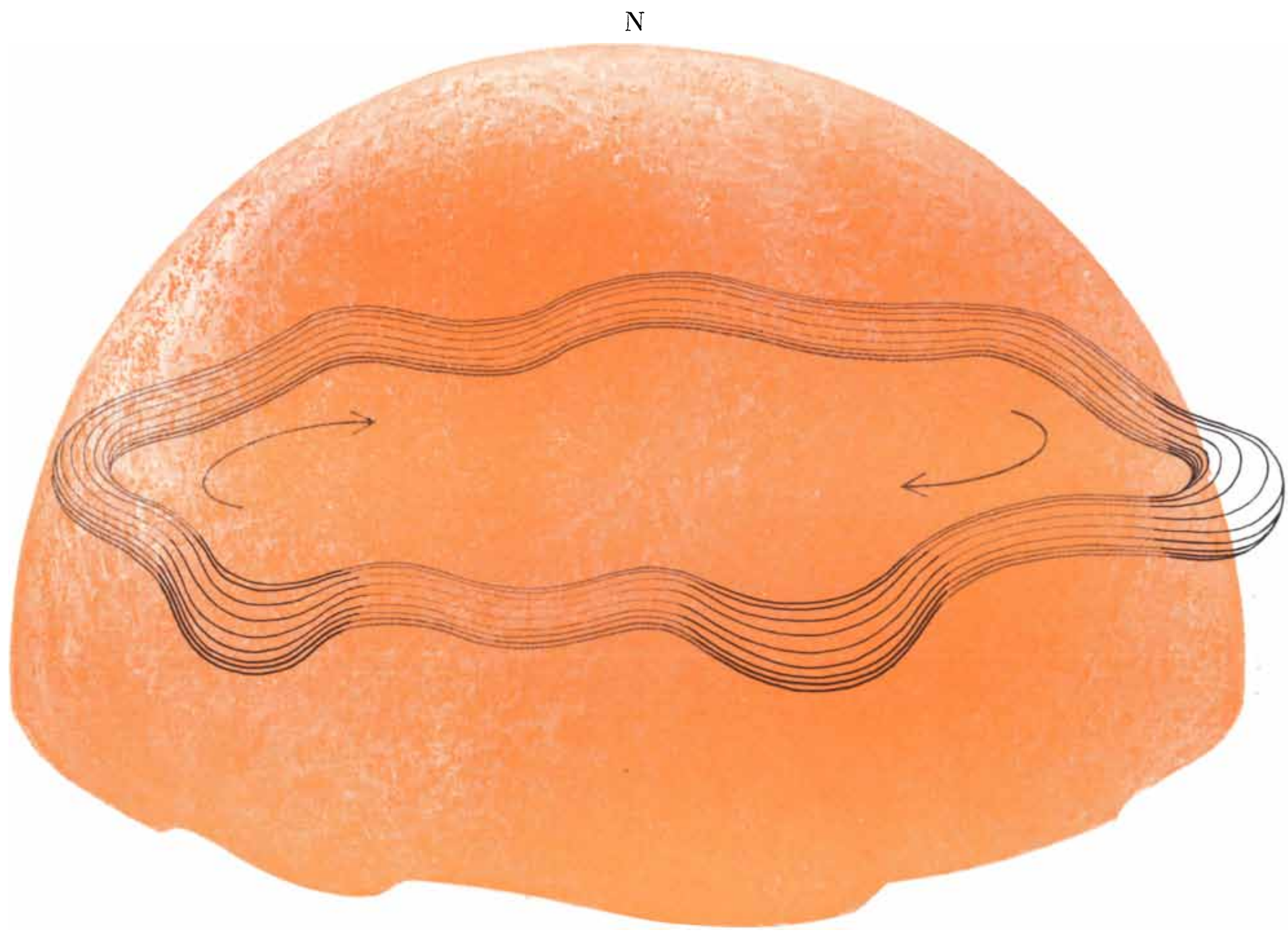
The bright calcium clouds, or faculae, just above the photosphere are also a product of the magnetic fields. According to magnetohydrodynamic theory, turbulent motion in the material around the bottom of the arches continually jostles and crowds the magnetic lines of force. This generates transverse hydromagnetic waves that travel upward along the lines of force, increasing in amplitude as they rise owing to the decreasing density. The magnetic oscillations in the waves act on charged particles, causing them to vibrate. And the energy of the vibrations is converted to thermal energy when the charged particles collide with neutral atoms in the gas. The heating excites various special radiations, particularly those of ionized calcium, that characterize faculae.

There is empirical evidence that protons and electrons are also accelerated upward along magnetic lines of force, and probably attain moderately high energies. This process is thought to occur wherever lines of force emerge: in bipolar and unipolar regions and near the poles of rotation. Above bipolar regions particles coming up on both sides of the arching lines of force would collide at the top. It is generally believed that such collisions, in the presence of a magnetic field, would generate radio noise. And indeed radio telescopes have picked up increased levels of radio noise in the direction of bipolar regions.

Finally let us consider briefly the physical conditions that underlie the sun's magnetism. What maintains the fields? What governs their intensity and controls their changes? How are the toroidal and the poloidal fields connected? What, in fact, causes the 22-year solar magnetic cycle, and how can we explain the migration of the toroidal fields and the reversal of the poloidal field? These questions constitute one of the great problems of solar physics. At present the theoretical picture is little better than fragmentary. However, some of the principles that have been developed for explaining the earth's magnetic field in terms of a self-sustaining "dynamo" can probably be applied to the sun. There are two essentials in this picture: rotation and the rise and fall of fluid material through convection [see "The Earth as a Dynamo," by Walter M. Elsasser; SCIENTIFIC AMERICAN, May, 1958].

The sun does not spin uniformly as does a solid body. The polar regions complete a rotation once every 34 days, while the equatorial zone requires only about 25 days. Under the influence of this differential rotation, an initial poloidal field (very probably primeval) could be drawn out so that the lines of force are nearly parallel to the equator, and are amplified as the rotation continues. Thus we can visualize a possible origin of the toroidal fields.

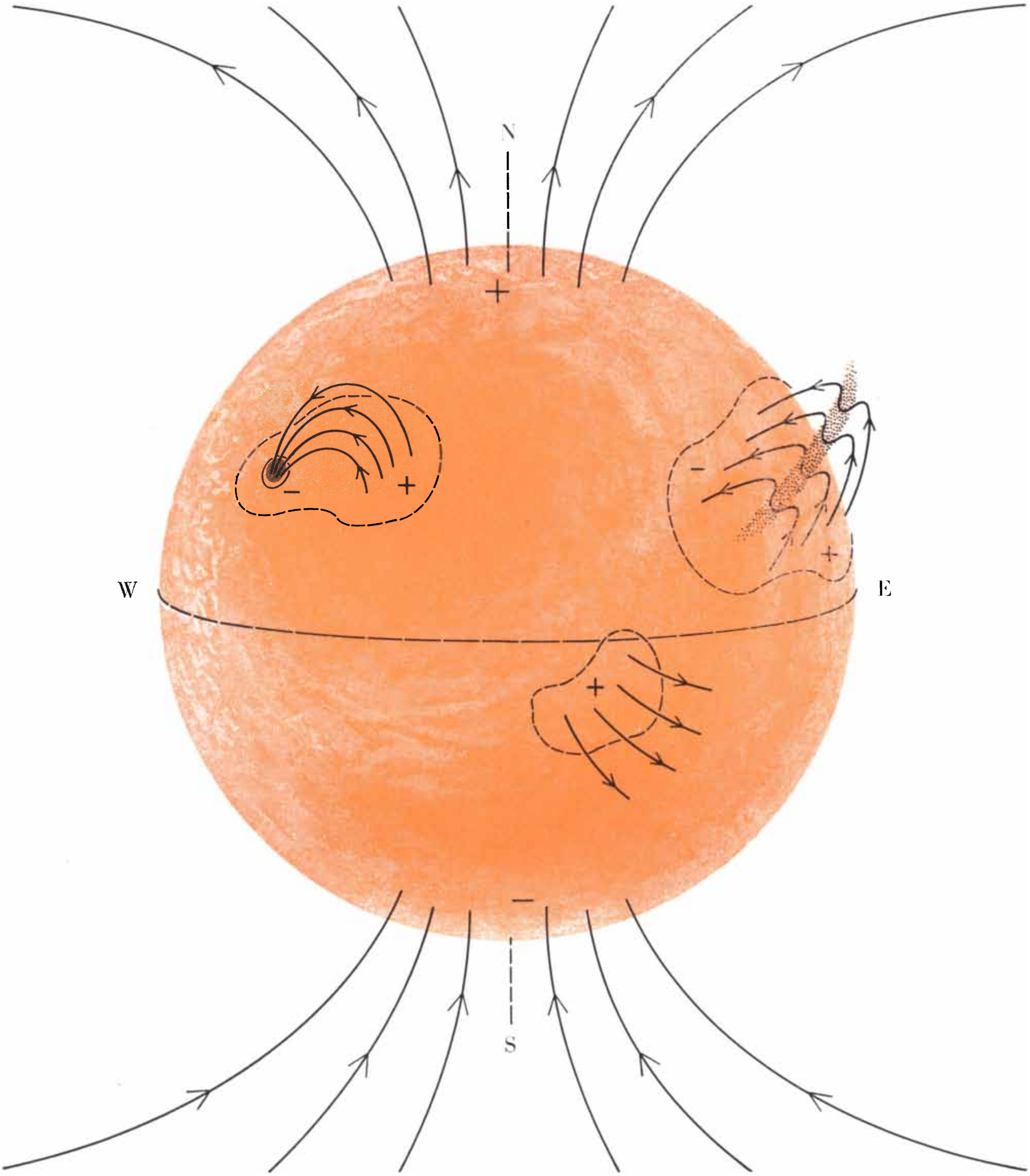
Superimposed on the differential rotation there is probably a very slow torsional oscillation. If the rotation were removed, a great equatorial belt would be seen to twist forward and back with respect to the remainder of the sun,



TOROIDAL MAGNETIC FIELD is thought to lie beneath the surface of the sun in both northern and southern solar hemispheres. When the northern ring, shown here, has the magnetic direction indicated by the arrows, southern ring has opposite direction.

swinging around its north-south axis through an angle of about 340 degrees once every 22 years. When combined with the spinning motion, the effect is to cause a small, cyclic change in the rate of rotation. Such a change is too small to observe directly, but Robert S. Richardson and Martin Schwarzschild have shown at the Mount Wilson and Palomar Observatories that the torsional oscillation would explain the different rates at which sunspots migrate toward the equator in alternate 11-year cycles.

Obviously the magnetohydrodynamic processes of the sun are extremely complex, and our understanding of them is meager. The development of an adequate theory will almost surely require a body of data that can be obtained only through long-term, continued observation of the sun's magnetism.

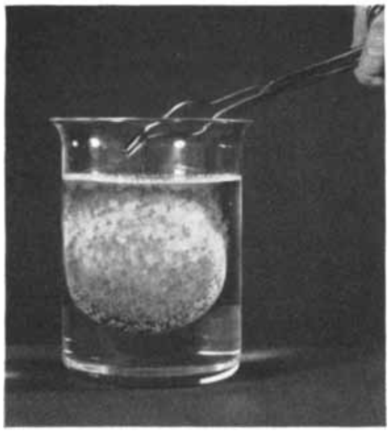


SUN'S MAGNETIC-FIELD PATTERNS are diagrammed schematically. Curved lines at top and bottom represent the general or poloidal field. Northern hemisphere has two bipolar regions, one with a sunspot (*left*), the other supporting a cloud of cool hydrogen. Unipolar region is shown in southern hemisphere. Unipolar regions are rare; bipolar regions are almost always found.

Kodak reports on:

a simple-minded stunt with a little honest fudging . . . a little something for the taxpayers . . . what the big wheels do

A tough window for the infrared



Here represented is a nice piece of infrared technology. We take pride in it, even though they tell us it will never replace the foot-soldier.

Our simple-minded stunt photo demonstrates that a 3-inch flat of the new *Kodak Irtran Optics, Type AB-1* can be fused so securely into a stainless steel mounting that plunging it at 200°C into tap water generates steam but does no harm.

We have developed this *Irtran* material for transmitting in structurally adequate thickness more than 90% of impinging energy from 3 to 6μ. Not only does it withstand thermal shock, weathering, humidity, and abrasion, but, defeating the emissivity of "hot windows," it retains its high transmittance at 800°C and, possessing a refractive index less than 1.4, requires no coating to cut reflection losses.

The only fudging was a bit of detergent in the water. We justify this on the grounds that dividing the steam among a cloud of bubbles made the test more severe by increasing the cooling rate.

For the dope on what we can make in Kodak Irtran *lenses, domes, prisms, flats, and substrates for interference filters, write Eastman Kodak Company, Special Products Division, Rochester 4, N. Y.*

Microelectronics

Ever hear of the Diamond Ordnance Fuze Laboratories? It's a Department of the Army agency in Washington. To support DOFL, the average citizen shells out the federal tax on, let us say, several gallons of gasoline a year or a little tobacco. Since a fuze is a device which times an explosion to blow up his enemy, he probably wouldn't mind the expense if it were explained to him. But, *mirabile dictu* and happy day, prospects brighten that the piddling investment will pay off beyond the dreams of avarice!

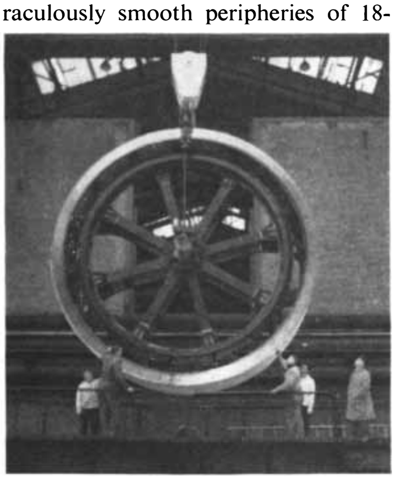
DOFL has spawned "microelectronics," the shrinking of electronic assemblies to 1/100 normal size. DOFL became involved through the proximity fuze program, which requires very small and exceedingly rugged components. We are involved through certain light-sensitive products for the microfabrication of conductive, semiconductive, and dielectric materials.

Send to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y., for a reprint of "The DOFL Microelectronics Program." Thus we nudge you toward great undertakings.

A kind word for triacetate tape

The time has come for a few carefully framed remarks from us about recording tape, a product which we do not offer in the United States, even though Kodak Pathé has done well with tape in France for about a decade. In this country we do make base for magnetic tape. This we sell to several competent organizations who practice their respective rival methods of depositing iron oxide on it.

Our base is cellulose triacetate, the same as in Kodak Aerographic Films for precision mapping from aloft. We cast it from solution on the nigh miraculously smooth peripheries of 18-



foot wheels like this one. In the 330° of rotation allotted for preliminary evaporation of the solvents before stripping off as sheet, the thickness—along with any thickness errors—shrinks by 4/5. This situation favors the maintenance of thickness with great uniformity. Except for infrequent replating, these prodigious wheels have been rotating with stately unbroken angular momentum night and day, winter and summer, week ends and workdays for a full generation of mortal man.

Not only do our tape-making customers rival each other in excellence of deposition, but our cellulose triacetate has a rival of its own in polyethylene terephthalate, which is known as polyester. Because of the slightly higher price of polyester tape, it has often been assumed on all counts superior. This misconception hurts us.* The price difference at least partially stems from the higher salable yield that the tape manufacturer gets from cellulose triacetate. He has to reject less tape for deformation or "skew" and has the inherent thickness uniformity of the solvent-evaporation method to thank.

Though most of the tape being bought today is our beloved cellulose triacetate, there is a place for polyester. That we admit. It's very good for humidity amplitude and devilishly strong.

Cellulose triacetate, on the other hand, has only 15% ultimate residual elongation, not 45%. It does not go on stretching and stretching when overloaded by apparatus design that leans too heavily on strength of the tape base. In many applications a stretch of large and unknown magnitude could have a sneaky effect on the results.

One other factor puts cellulose triacetate high with the man to whom the word "dropout" is an expression of horror. A dropout is caused by an inhomogeneity. Our cellulose triacetate, by the nature of its manufacture, is not likely to contribute inhomogeneity. Believe us.

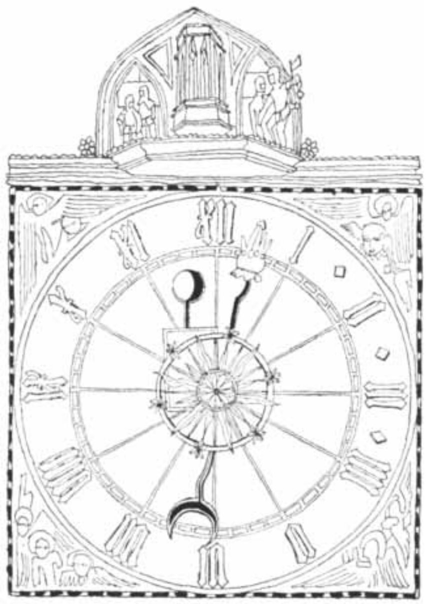
Don't write to us about the foregoing unless you just happen to be in a mood for correspondence. All we ask is that you bear our assertions in mind when the occasion arises to specify magnetic recording tape.

*Another thing that disturbs us is inclusion of cellulose triacetate under the generic term "acetate." Fortunately, cellulose *di*acetate is fast disappearing from the tape market.

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

Kodak
TRADE MARK

SCIENCE AND



Agreement on Space

The cohesive impulse that produced the International Geophysical Year appears to retain its force. Having recently agreed to join together in antarctic research, the nations of the world have now made a start toward a similar understanding on space. The General Assembly of the United Nations has adopted unanimously a resolution setting up a permanent 24-nation committee to organize international cooperation in space research. The resolution, drafted jointly by the U. S. and the U.S.S.R., also authorizes an international scientific conference "for the exchange of experience" in space matters, to be held this year or next. Western countries are to occupy 12 of the 24 committee seats, with seven going to members of the Soviet bloc and five to neutral nations.

Disagreement on Testing

The problem of distinguishing underground explosions from earthquakes continues to obstruct progress in the Geneva talks on outlawing nuclear-weapons tests. What level of uncertainty would necessitate on-the-spot inspections to determine the source of doubtful "seismic events"? How many doubtful cases would arise through the use of the 180-station seismic-detection network proposed by a committee of experts in 1958?

A second committee of experts from Great Britain, the U. S. and the U.S.S.R., convened late last year to consider these and related questions, has left matters where it found them—with the U. S. and the U.S.S.R. at loggerheads. The group's report was classified shortly after its submission. From published excerpts and official comments it was difficult to determine how much the experts had disagreed on the political consequences of technical data and how much on the data themselves.

"The Soviets agreed on all things that make the control system look better and on nothing that makes the system look worse," said James B. Fisk of Bell Telephone Laboratories, leader of the U. S. delegation. President Eisenhower spoke of "the recent unwillingness on the part of the politically guided Soviet experts to give serious scientific consideration to the effectiveness of seismic techniques for the detection of underground nuclear explosives." "Indeed," he added, "the atmosphere of the talks has been clouded by the intemperate and technically unsupportable Soviet annex to the report of the technical experts."

This annex accused the U. S. scientists of being "on the brink of absurdity" in proposing inspection criteria that would "leave under suspicion the overwhelming majority of the earthquakes registered by the control system." It "categorically repudiated" U. S. interpretations of data from the "Hardtack" series of underground nuclear tests in 1958. According to these interpretations the ability of the 180-station network to recognize nuclear detonations would be much less than originally supposed. The Soviet experts, however, maintain that criteria can be established that would "unquestionably insure the detection of truly suspicious events, on which the control system's future activity will be concentrated." "Shortcomings" in the U. S. data, said the annex, cannot be regarded "as resulting from carelessness or coincidence," and the Soviet experts "have come to the conclusion that there has been tendentious use of one-sidedly developed material for the purpose of undermining confidence in the control system, whose basic characteristics were determined by the 1958 Geneva conference of experts."

In addition to the Hardtack results the U. S. presented theoretical studies indicating that underground explosions can be very largely muffled by "seismic decoupling," *i.e.*, setting them off in very large, hollow chambers. The theory, dismissed by the Soviet group as unproved and of no practical importance, was discussed in some detail at the winter meeting of the American Physical Society in Pasadena, Calif. A panel of physicists and seismologists reported that the disturbance set up in the solid earth by a subterranean explosion might be reduced 300 times by a sufficiently large chamber. To muffle an explosion equivalent to 100,000 tons of TNT would require a spherical hole some 3,000 feet deep and 800 feet in diameter. Assuming that such an enormous excavation could be made (it would involve scooping out a 20th as much earth and rock as was removed in digging the Panama Canal) and the factor of 300 could actually be realized, one physicist asserted, a 100,000-ton explosion "would not even be detected and located by the proposed Geneva network."

Negotiations are continuing at Geneva, but "no satisfactory agreement is yet in sight," President Eisenhower declared. As of the beginning of 1960 the U. S. feels "free to resume nuclear weapons testing," he added, but advance notice will be given of any such resumption.

Smashing Success

Late last year, several months ahead of schedule, workers at CERN, the European Organization for Nuclear Research in Geneva, brought the biggest of all atom smashers up to its full design-energy of 24 billion electron volts (Bev). Even more remarkable than the enormous voltage was the intensity of the beam extracted from the brand-new machine: a pulse of 10 billion protons 20 times a minute. "A breathtaking, historical achievement," said a U. S. physicist. By comparison the Bevatron at the University of California delivers a six-Bev pulse containing 20 billion protons once every six minutes. The 10-Bev accelerator in the U.S.S.R., after two years of tinkering by its designers, still gives only a billion protons per pulse.

Like the others, the CERN machine is a synchrotron. It employs a varying magnetic field to hold the accelerating particles in a fixed circular orbit as they are boosted to higher and higher energies. But the break-through to 24 Bev was achieved with the help of the additional principle of strong focusing. Alternate sections of the ring-shaped magnet spread and concentrate the circling protons, with the net result of a narrower beam, and hence a thinner magnet. The magnet iron in the CERN accelerator weighs 3,200 tons; in the Bevatron 10,000 tons; in the Soviet accelerator, 35,000 tons.

The circular track of the new synchrotron is 100 meters in diameter. Protons enter it from a linear accelerator at an energy of 50 million electron volts. Thereafter they gain 54,000 electron volts on each turn, reaching their full energy after 500,000 circuits. The power required to produce each pulse is 38,000 kilowatts.

A team of Western European physicists led by John Adams of England designed and built the CERN accelerator. Through their efforts leadership in experimental high-energy physics has returned, at least temporarily, to the neighborhood in which it started.

The A.A.A.S. Meeting

A Federal department of science to establish and administer a national program of basic research was proposed by Wallace R. Brode, retiring president of the American Association for the Advancement of Science, at the annual meeting of the A.A.A.S. in Chicago. Brode, who is science advisor to the Secretary of State, pointed out that military and quasi-military agencies now exert purse-string control over 85 per cent of U. S. basic research and thus largely determine its direction. He recommended that the science department grant research funds directly to universities, rather than to investigators with specific projects (as the military now does) and that the new department take over such contract-operated laboratories as those at Brookhaven, Los Alamos and Oak Ridge, at the same time improving the status of scientists working for the Government. The department would co-ordinate the scientific activities that would remain with the military and other agencies.

Thomas Park, professor of zoology at the University of Chicago, was chosen president-elect of the A.A.A.S., to serve in 1961. Chauncey D. Leake, assistant dean of the Ohio State University College of Medicine, is president during 1960.

At a symposium on the solar system Frank D. Drake of the National Radio Astronomy Observatory reported that Jupiter may have a magnetic field at least 10 times stronger than that of the

earth. Such a field could trap enough electrons in a Van-Allen-type radiation belt to account for the three billion watts of apparently nonthermal radiation that the planet continuously emits.

New techniques for finding, dating and analyzing ancient objects were described at another symposium. George C. Kennedy and Leon Knopoff of the University of California at Los Angeles reported that pottery and other heat-treated artifacts up to 500,000 years old can be accurately dated by means of thermoluminescence. Radioactive atoms in a piece of pottery or glass produce electrons that are trapped in the material at ordinary temperatures, but are released on heating with the emission of a special glow. An analysis of this glow shows how much time has elapsed between the heating in the laboratory and in the fire where the article was made. L. S. Birks of the Naval Research Laboratory described an analytical technique in which X-rays generated within an object reveal its chemical composition without damaging it.

In another paper J. P. Scott of the Roscoe B. Jackson Memorial Laboratory in Bar Harbor, Me., told of studies indicating that destructive fighting seldom occurs in animal societies unless they are deliberately or accidentally disorganized, "as when a group of strange adults are confined together in a laboratory or zoo." Fang-and-claw behavior, he said, results from abnormal conditions and is not natural or inevitable. Scott suggested that juvenile delinquency, and perhaps even war, results from human social disorganization.

Research Money

The U. S. is currently spending $12 billion per year on research and development, according to an estimate published by the National Science Foundation. This is one billion higher than last year's rate, and more than double the level of expenditure of five years ago.

The Federal Government is footing most of the bill, budgeting $7.9 billion for research and development in 1959 and about $8.1 billion in 1960. Development costs account for 80 per cent of the Federal funds, and only 6 to 7 per cent is earmarked for basic research. Physical and engineering sciences consume 67 per cent of the total, life sciences 30 per cent and social sciences 4 per cent. The Department of Defense, the Atomic Energy Commission and the National Aeronautics and Space Administration will disburse 93 per cent of the money.

The extent to which dollar amounts

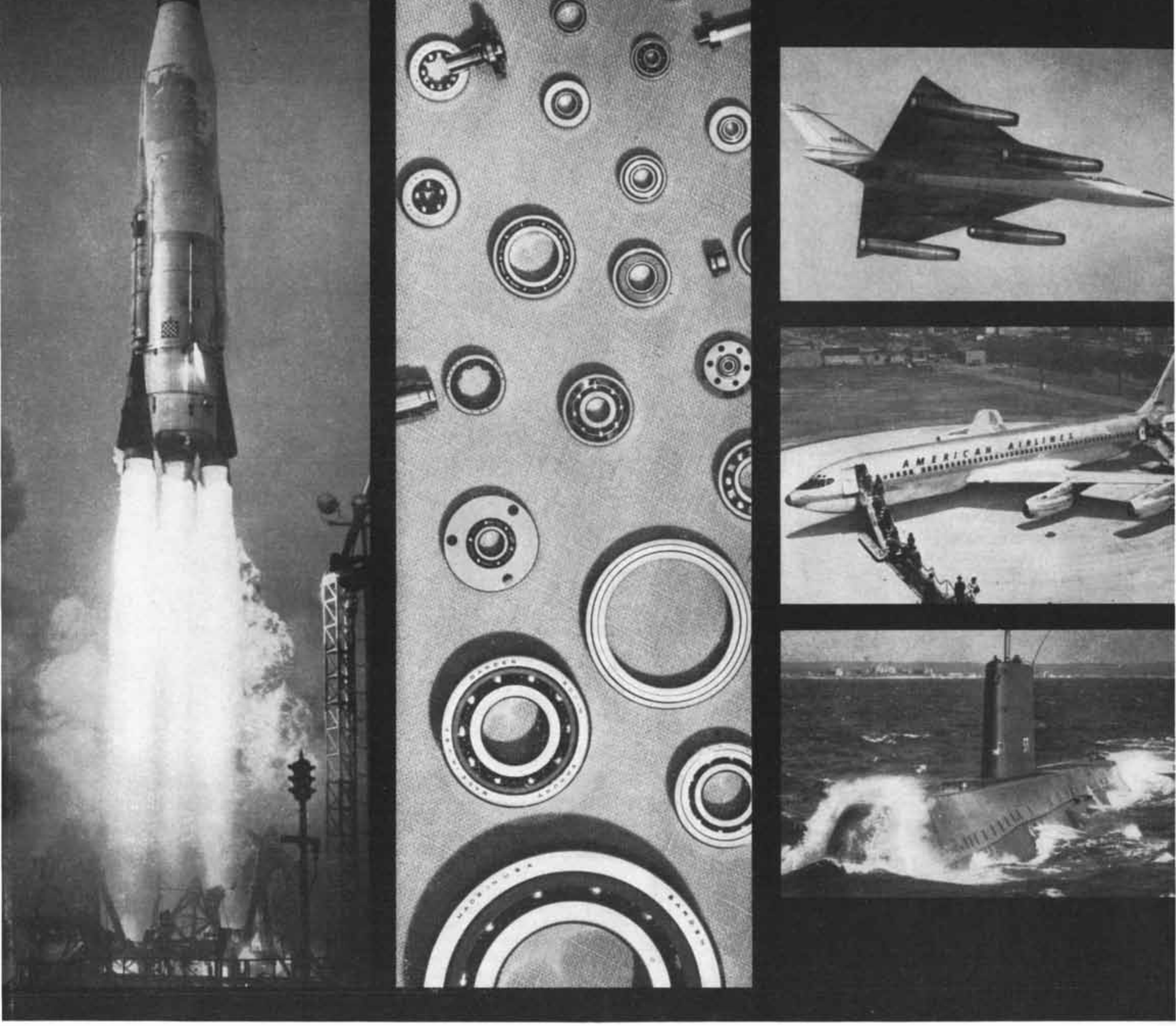
reflect the true level of scientific research and development activity has been questioned by David Novick of the Rand Corporation. Writing in the *Illinois Business Review* he points out that the "new respectability which R & D has attained" may be causing industrial firms to list under this heading expenses formerly classified under others. One large company, the author reports, broke down its $185 million research and development budget for 1959 as follows: 2 per cent for long-range research not connected with current products, 19 per cent for product development, 79 per cent for "development of equipment to customers' orders."

Thermoplastic Recording

A new method of putting information on tape, developed by W. E. Glenn of the General Electric Company, produces a record that combines many of the advantages of motion-picture film and magnetic tape. Thermoplastic tape, as it is called, is like magnetic tape in that it requires no chemical processing, can be played back immediately and can be erased and used again. Like motion-picture film, it forms a visible image that can be projected on a screen, it has high resolving power and it can easily be copied.

The recording system, described by Glenn in *Journal of Applied Physics*, consists of a fine electron-beam that sweeps across a strip of moving tape, leaving a series of parallel trails of negative charge on its surface layer. This layer is made of a thermoplastic material that can melt and solidify repeatedly. Below it is a heat-resistant layer that is positively charged. After passing under the writing beam, the tape moves through an induction heater that melts the top layer. The electrostatic attraction between the charges on the two layers pulls the molten material into a series of grooves similar to those on a long-playing record, but much narrower. The tape is then cooled, freezing the pattern into place. Since the whole process takes no more than a hundredth of a second, the tape can be viewed, scanned or edited as it is being made.

Input to the recorder—audio or video signals, or digital information from a computer—is translated into a voltage that varies the intensity of the writing beam, thus changing the amount of charge it deposits and the depth of the resulting grooves. Depending on their depth, the grooves transmit more or less light. When projected on a screen, the record forms a black-and-white image


AMERICAN AIRLINES

made up of lines of varying brightness, like the image on a television picture-tube.

To record an image in color the writing beam is split into closely spaced parts, and each line becomes a series of multiple grooves that make a tiny diffraction grating. Colors from the spectra formed in the projector by these gratings are selected by appropriately placed slots and transmitted to the screen.

Because the thermoplastic-tape system, unlike ordinary video tape, can be synchronized with a television camera, it can be combined with live action to provide special cinematic effects. As a storage system for computer information its high resolution makes possible a much denser packing of information than with magnetic tape. This would not only save space, but also reduce the time required for a computer to search its memory for desired bits of information.

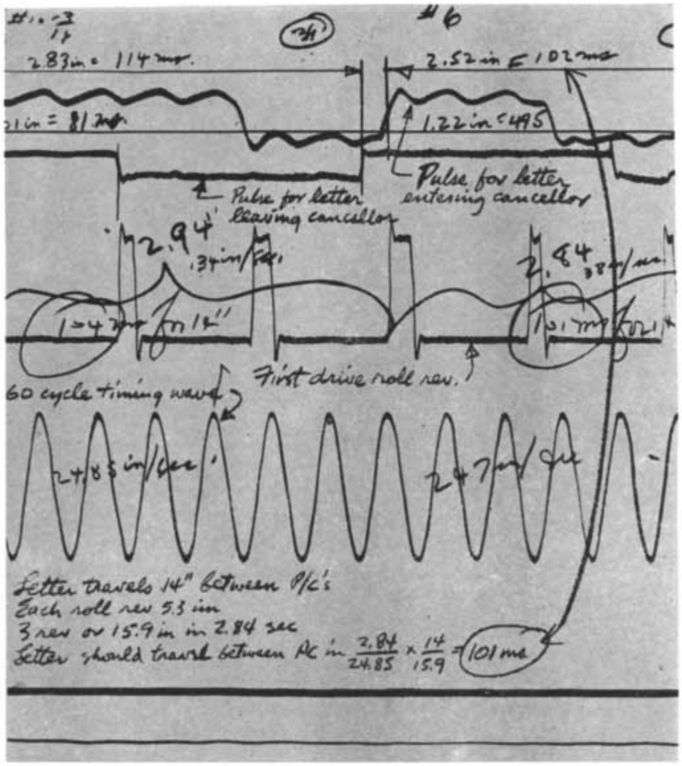
Age of the Elements

How old are the chemical elements that make up the matter of the solar system? Evidence discovered recently in a stony meteorite indicates that their manufacture was finished 4.95 billion years ago.

Using a highly sensitive mass spectrometer, John H. Reynolds of the University of California has detected traces of xenon 129 in a meteoritic sample. This isotope is the daughter element formed in the decay of iodine 129, a radioactive material. Having a half-life of 17 million years, the iodine 129 formed in the beginning has long since turned into its daughter product, which is therefore a sort of "fossil" iodine. The presence of the latter substance in the sample is evidence that some of its radioactive parent must still have been present when the meteorite was formed.

To determine how long a time had elapsed since the manufacture of the element it was necessary to know what fraction of the iodine 129 remained at the time of formation. On the assumption that iodine 129 was originally as abundant as its nonradioactive isotope iodine 127, Reynolds compared the concentrations of iodine 127 and xenon 129 in the meteorite. From this ratio he concluded that it was formed approximately 350 million years after the iodine was made. Since the meteorite itself is 4.6 billion years old (as shown by uranium-lead and potassium-argon dating), this means that the iodine is about 4.95 billion years old.

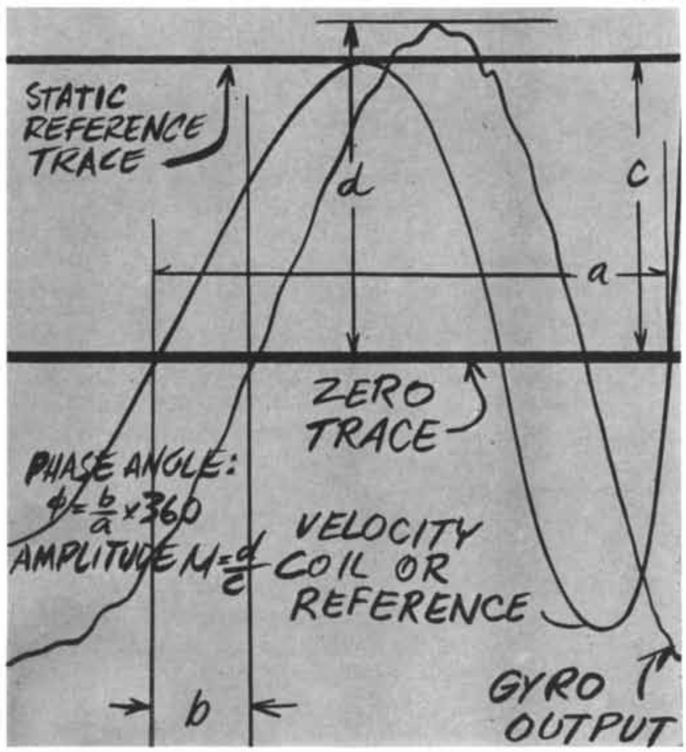
According to current theories all the elements in the solar system were manu-



In development test . . .

This directly-recorded Visicorder chart shows a canceller test of a number of letters through a new mail-handling machine developed by Emerson Research Laboratories for the U.S. Post Office Department. The Visicorder test took only 3 hours to solve a 3-week problem: Why letters changed speed as they went through the machine. Constant speed is necessary to register cancellation on the stamp every time. Motor speed variations, belt slippage, and letter slippage in the drive rollers were responsible. A synchronous drive motor, a timing-belt drive, and a better grade of rubber in the drive rollers were added to solve the problem at a vast saving in engineering time. The Emerson machine is designed to cancel 30,000 non-uniform letters per hour. It is under evaluation tests in the Post Office Department Laboratory, Washington, D.C.

these are records of leadership

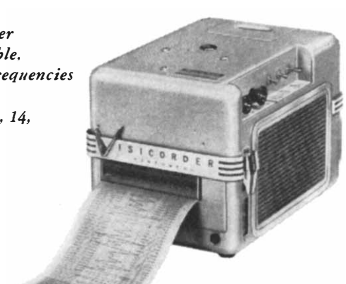


Visicorder records 2/3 actual size.

In production . . .

This comparison test of a production gyroscope was directly-recorded on a Model 906A Visicorder oscillograph by the test department of Whittaker Gyro, Van Nuys, Calif. Whittaker is a division of Telecomputing Corporation. The record shows how the Visicorder compares controlled angular velocities as a reference base to simultaneously-recorded variables, and how a dual static reference trace galvanometer simultaneously establishes a base line and a calibration line on the chart. In these and in hundreds of other scientific and industrial applications, Visicorders are bringing about new advances in product design, computing, control, rocketry, nucleonics and production.

For information on how to apply the unlimited usefulness of the Visicorder to your specific problems, phone your nearest Honeywell Industrial Sales Office.



The Honeywell Visicorder provides instantly-readable, high-sensitivity data at frequencies from DC to 5000 CPS. There are models with 8, 14, or 36-channel capacities.

Honeywell

H Industrial Products Group

Reference Data: Write for Visicorder Bulletins 906A and 1012.

Minneapolis-Honeywell Regulator Co., Industrial Products Group, Heiland Division, 5200 E. Evans Ave., Denver 22, Colorado factured over the same period in a single batch. Therefore, Reynolds concludes, they must all have finished evolving 4.95 billion years ago.

The meteorite used in the study fell in Richardton, N. D., 41 years ago and is now part of the Nininger Collection at the Meteorite Museum in Sedona, Ariz. A third of this collection was recently sold to the British Museum. Reynolds is fearful that the rest of this "national treasure" may be exported. "It seems shameful," he said, "that this priceless collection should be allowed to leave the country."

Celtic Hoard

A cache of silver objects unearthed in 1958 on the Isle of St. Ninian (in the Shetland Islands) has recently been described as "the most important single discovery in Scottish archaeology," and, except for the treasure-laden ship dug up at Sutton Hoo in 1939, "the most interesting single assemblage of Dark Age metalwork found in the British Isles."

Writing in *Antiquity*, a group of British archaeologists including R. L. S. Bruce-Mitford, Keeper of British and Medieval Antiquities of the British Museum, state that the hoard was apparently buried during the eighth century A.D. It includes seven bowls, three unidentified conical objects (thought to be ornaments for scabbard straps), the finest sword pommel of its period, the only complete hanging-bowl datable to the eighth century, 12 cast brooches, a unique one-pronged implement, and two scabbard ornaments, one carrying an important inscription. The inscription apparently contains the Pictish name of the owner, translated into Latin and written in "Insular majuscule," a large-lettered script developed in Britain in the seventh century.

It had been generally supposed that the Shetland Islands were virtually uninhabited during the eighth century. The finding of the valuables suggests that this view may be mistaken. The hoard was unearthed beneath the ruins of a 12th-century church. Perhaps, the authors suggest, an earlier church also occupied the site, and the objects represent wealth buried in a time of danger. If so, what became of the other objects in the church, such as the sacramental chalice and plate? Bruce-Mitford believes they may have been buried separately, "or else captured by the raiders whose attack led to the burial of the hoard and must have been effective enough to wipe out the knowledge that would have led to its recovery after the raid."

OPEN-HEART OPERATION at the University of Minnesota Hospital employs a helix-reservoir heart-lung machine (*upper right*) to sustain the circulation of a patient during surgery within the heart. Surgeons (*lower left*) are inserting catheter into the femoral artery to return oxygenated blood to patient from heart-lung machine. C. Walton Lillehei, senior surgeon in group, wears headlight. Behind the curtain at the patient's head (*left center*) are an anesthesiologist and instruments to monitor the patient's condition.

OPEN-HEART SURGERY

In the past five years surgeons have made large strides in correcting cardiac defect and damage. The key to this progress is the heart-lung machine, which makes it possible to by-pass the heart for some hours

by C. Walton Lillehei and Leonard Engel

Surgery, during the past decade, has penetrated its last anatomical frontier: the human heart. The surgeon today is able to open up the heart, empty it entirely of blood and, under direct vision, make unhurried repair of the valves and chambers inside. For this purpose he disengages the heart from its vital function in the body, sometimes for two hours or more; when necessary he stops its beating. "Open-heart" surgery has changed the outlook for a great many patients. Surgeons are correcting formerly hopeless congenital defects of the heart which have condemned one out of 100 children born in the U. S. to premature death. In an ever increasing number of cases surgeons are successfully repairing the injuries done by such diseases as rheumatic fever which have crippled and shortened the lives of a considerably larger number of people. There is promise that even the damage done by coronary disease (that is, the breakdown of the heart's own circulation, the major disease of the heart) may become subject to surgical relief.

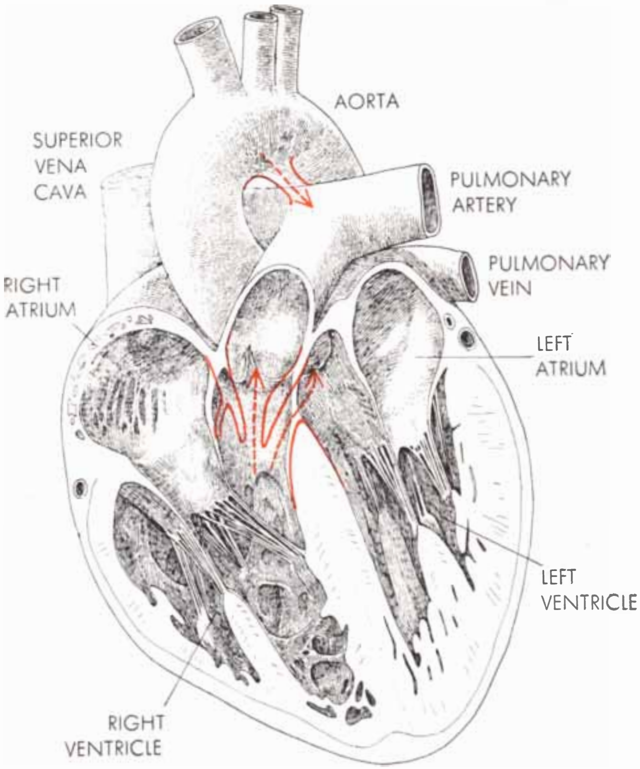
The key to this historic advance in the capability of medicine is the heart-lung machine. In order to disengage the heart, surgeons have also had to find a way to by-pass the lungs. The heart-lung machine not only does the pumping for the heart but also conducts the pulmonary exchange of oxygen and carbon dioxide; it withdraws carbon-dioxide-laden venous blood and returns oxygenated blood to the body, supplying the heart itself with "arterial" blood as needed during the period of disengagement. Without a reliable machine of this kind, interruption of the function of the heart and lungs for even a brief interval would expose to irreversible destruction such oxygen-sensitive tissues as the central nervous system and the kidneys.

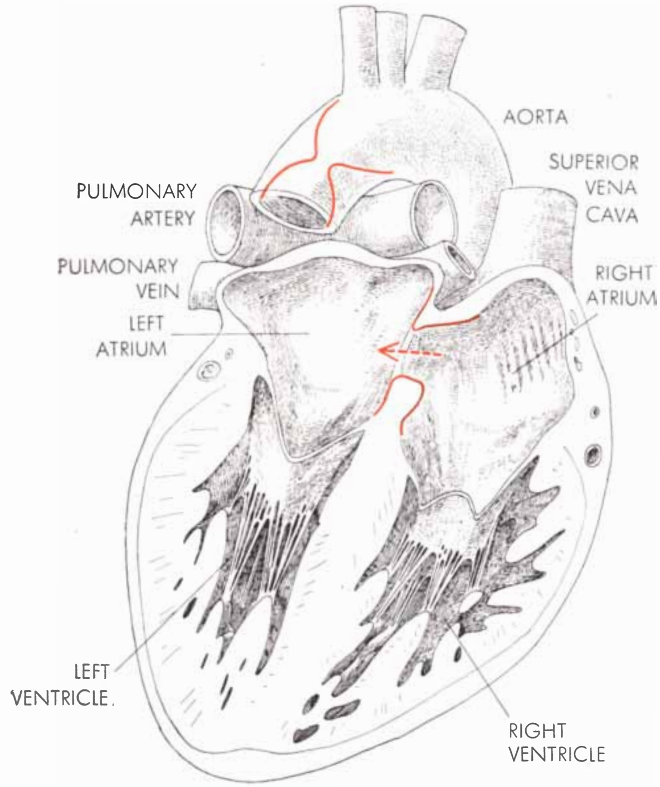
The heart tolerates the invasion by surgery well. This is in keeping with the enormous capacity for work and the formidable reserves of strength that cardiac muscle displays under stress and injury. The normal adult heart is about the size of a fist and weighs about three quarters of a pound. Yet it pumps something more than a million gallons of blood per year, at the steady rate of two ounces per stroke, 60 to 70 strokes per minute during rest and faster during periods of physical exertion; and it can continue to function with as much as a third of its muscle mass destroyed by coronary disease. The heart also has great power to recuperate from surgery. But care must of course be taken to avoid injury to its circulatory system, and the surgery must otherwise be skillfully managed. Experience has shown that postoperative care of the highest quality is also essential, particularly during the critical hours immediately after surgery, when respiratory and other complications are apt to overwhelm the patient's weakened heart without warning. Conversely, effective surgery on the heart would not be possible without such diagnostic tools as cardiac catheterization and the revealing X-ray pictures that catheterization has made possible [*see illustrations on page* 88].

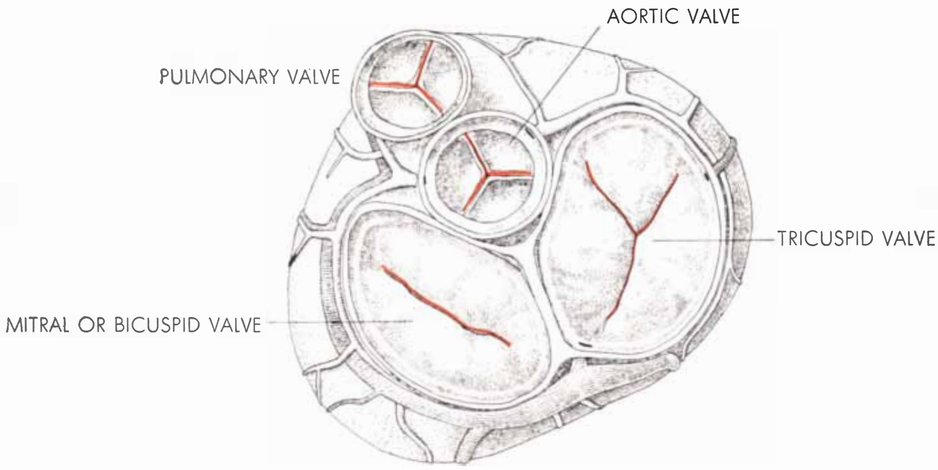
Defects in the Pump

What the surgeon is now able to repair are leaks and constructions that derange and hamper the flow of blood through the heart. Mechanically speaking the heart is a double pump, one side pumping blood through the general circulatory system, the other pumping blood through the shorter pulmonary circulatory system. Each side must deliver an equal volume of blood at each stroke under quite different pressure conditions. The right atrium, the receiving chamber of the right side of the heart, receives venous blood from the general circulation of the body; the right ventricle, or pumping chamber, drives this blood at a pressure of 20 millimeters of mercury into the pulmonary circulatory system. From the lungs, arterialized blood returns to the atrium on the left side of the heart; the left ventricle drives this blood at the much higher pressure of 120 millimeters of mercury into the general circulatory system. It is apparent that the two pumps must be well balanced to maintain their equal outputs and well insulated from each other to maintain their different pressures, and that the forward flow of blood must be smoothly sustained from chamber to chamber and out into the great vessels leading from the heart.

In the normal heart the two pumping chambers (the ventricles) are completely separated by the thick, muscular central partition of the ventricular septum. A similar, though much thinner, septum between the two atria prevents mixing of the "used" venous blood and the "purified" arterial blood. In the beating cycle the ventricular septum muscle tends to contract first; thus it provides a stiff member against which the surrounding ventricular muscles contract to squeeze the blood out of the ventricles. Simple flap valves, passively actuated by pressure change, permit the forward flow and prevent the backflow of blood throughout the cycle. The valves between the atria and the ventricles open downward to fill the ventricle with blood during the relaxation phase of the beat. In the contraction phase the leaves of these valves are brought together by the upward surge of pressure in the ventricles. As protection against the high







PRINCIPAL DEFECTS OF THE HEART are outlined in color on these views of the normal heart. Two defects are located in the drawing at top left: patent ductus arteriosus (*short circuit between aorta and pulmonary artery*) and the tetralogy of Fallot (*group of defects within heart*). Two other defects are located in the drawing at top right: coarctation (constriction) of the aorta and atrial defect, that is, a leak through the septum between the atria (auricles). At bottom the heart is shown from the top with its large vessels and atria cut away to expose its valves, the sites of defects (*suggested by colored lines*) that are caused principally by infectious disease.

pressure in the ventricles, especially in the left ventricle, the atrial-ventricular valves are restrained from everting backward into the atria by the *chordae tendineae*, the "heart strings," which tie them from underneath to the ventricle walls. The pressure surge in the ventricles forces the blood out through the three-leaved valves of the pulmonary artery and the aorta, and out into the pulmonary and general circulatory systems respectively. These valves in turn snap shut when the pumping chambers relax, and the pressure in the vessels beyond the valves exceeds the pressure in the ventricles. It is the forcible closing of these two pairs of valves that makes the audible thump of the heartbeat.

Among the most serious congenital defects of the heart are leaks across the septum between the left and right sides of the heart, especially between the left and right ventricles. Ventricular septal defects expose the pulmonary circulatory system, with its normally lower pressure, to the high pressure generated by the left ventricle. The high pressure leads to arteriosclerosis and ultimate breakdown in the pulmonary circulatory system, to heart failure and to increased susceptibility to lethal infections. Without corrective surgery only one child in 20 suffering from ventricular defects survives to be a teenager. In the so-called blue-baby disease, known medically as the tetralogy of Fallot, the ventricular defect is combined with a constriction of the passage from the right ventricle to the pulmonary artery. The constriction protects the child's pulmonary circulatory system from the high-pressure flow through the ventricular defect but puts the child on short oxygen rations; hence the victim is cyanotic, or blue.

The defects caused by rheumatic disease center principally around the valves. As an aftermath of rheumatic fever—a disease that may strike young adults as well as children—one or more of the valves may be reduced in its capacity either to permit forward flow or to prevent backflow. On the one hand the diameter of the valve may be narrowed and the leaves stiffened and calcified so that the flow of blood is severely restricted; sometimes adhesions cause the leaves to fuse. On the other hand the diameter of the valve may become enlarged and the leaves may fail to close completely, permitting leakage and backflow. In either case the derangement of the heart's hydraulics causes disorder to its structure and function. A leaky mitral valve (the atrial-ventricular valve on the left side of the heart), for example, causes the ventricle to become enlarged in the effort to offset the backflow losses, but enlargement of the ventricle may further impair the valve. As the vicious cycle continues, the ventricle may be enlarged to the point where the muscle is stretched beyond its elastic limit. Pumping efficiency then falls off drastically, and this sets in motion a complex series of reactions in many body functions, eventually leading to death.

Early Surgical Efforts

Such afflictions remained far beyond the reach of surgery until recent years. Operations on and around the heart, however, were attempted from time to time before then. In 1896 Louis Rehn of Frankfurt successfully sutured a stab wound in the right ventricle. In 1925 Sir Henry Souttar, who is still living in London, inserted a finger into the heart of a living patient to explore the mitral valve. A few years later Elliott Cutler and various associates at the Harvard Medical School attempted operations for the relief of mitral stenosis (narrowing of the mitral valve) in seven patients; six of the seven died and the seventh was unimproved.

Logically the accomplishment that initiated modern cardiac surgery was not an operation on the final fortress, the heart itself, but on the great blood vessels. During the 1930's a few physicians began to realize that serious inborn anatomical defects of the heart were not at all uncommon. One that particularly attracted notice was "patent ductus arteriosus." In this affliction a fetal blood channel that shunts blood from the pulmonary artery into the aorta, thus bypassing the lungs before birth, fails to close after birth. As a result a considerable volume of high-pressure blood is shunted from the aorta into the pulmonary artery; since aortic blood is under high pressure, the pulmonary vessels are damaged in much the same way as in ventricular defect. Progress in chest surgery encouraged the hope that this defect might be corrected. The successful attempt was finally made in August of 1938 by Robert E. Gross of Harvard, who tied off the patent ductus of a seven-year-old child at Children's Hospital in Boston. The child lived and so did others on whom Gross performed the same or similar operations.

This success awakened interest in surgery for other congenital cardiac defects. In 1944 Gross and Clarence Crafoord of Stockholm independently succeeded in correcting coarctation of the aorta, a constriction of the aorta that deprives the lower part of the body of a normal blood supply. A year later Alfred Blalock and Helen Taussig of the Johns Hopkins Medical School introduced their widely known "blue baby" operation. They increased the flow of blood through the lungs and partially relieved the cyanosis, for some years at least, by connecting a branch of the aorta—the subclavian artery—to the pulmonary artery, in effect creating an artificial patent ductus. This operation did not, of course, correct the underlying defects that lie in the interior of the heart; indeed, it added a new abnormality. But it did palliate the effects of the affliction in a significant percentage of these severely handicapped children.

The first regularly successful operations within the heart were performed in 1948 by Charles P. Bailey of the Hahnemann Medical College in Philadelphia and Dwight E. Harken of Harvard, and had as their object the relief of mitral stenosis. Both surgeons employed the finger-in-heart procedure originated by Souttar. Through an opening in the left atrium just large enough to admit the finger, the mitral valve is reopened by splitting the valve leaflets with the finger or by cutting them apart with a special knife attached to the fingertip. The finger and the knife are guided entirely by sense of touch. This ingenious procedure has been employed successfully by many surgeons in several tens of thousands of cases throughout the world. But it has been effective only because mitral stenosis is often relatively uncomplicated and because the mitral valve is located within convenient reach of the exploring finger. The "blind" or "closed" approach is not successful if the valve is leaky or its tissue is heavily scarred or calcified.

Even while such closed-heart operations were being developed, investigators in several centers were seeking ways to operate upon the open heart under direct vision. One hopeful approach was suggested in 1950 by the work of W. G. Bigelow of the University of Toronto Medical School, who showed that the circulation of the blood might be successfully interrupted for a short time without damage to the central nervous system if the body temperature were lowered and the oxygen demand of the brain and other tissues were thereby reduced [see "Hypothermia," by Raymond J. Hock and Benjamin G. Covino; Scientific American, March, 1958]. F.

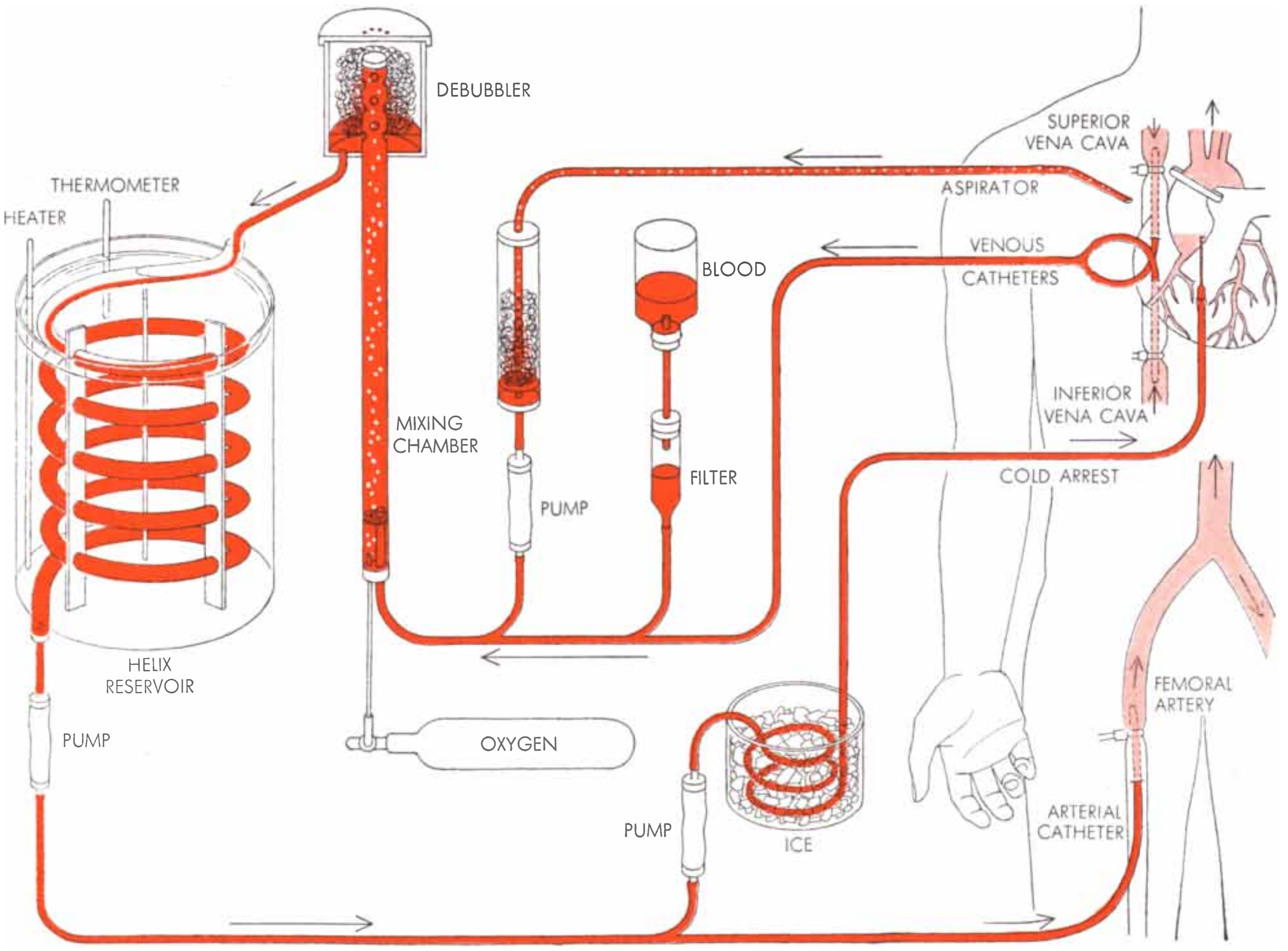
John Lewis and his associates at the University of Minnesota Medical School took advantage of Bigelow's finding to perform, in 1952, the first successful operation under direct vision inside the heart: the repair of a leak through the atrial septum in the heart of a five-year-old girl. With the patient's body temperature cooled to 82 degrees Fahrenheit, the chest was opened and the veins leading into the heart were clamped off. The heart continued to beat, and so emptied itself in a few beats. The right atrium was then opened, the defect sutured and the atrium reclosed with another set of stitches. The flow of blood into the heart —which had been cut off for a total of five and a half minutes—was restarted and the child rewarmed by immersion in a tub of hot water.

Variants of this procedure have been employed successfully in many hundreds of cardiac operations. At temperatures that are not hazardous to the patient, however, the surgeon is allowed only five or six minutes in the heart. This is not enough time to deal with complex defects or unexpected difficulties. Moreover, especially if operations upon or within the ventricles are attempted, cooling of the heart brings the risk of ventricular fibrillation, a disorganization of the heartbeat that reduces the heart to a mass of squirming muscle, utterly ineffectual as a pump.

The Heart-Lung Machine

Meanwhile a number of investigators, beginning in the 1930's, had been working on the development of a mechanical substitute for the heart. They concluded early in their effort that the machine would have to assume the function of the lungs as well; otherwise it would have to be a double pump like the heart itself and would have to be connected to the entrance and exit vessels of both sides of the heart. Apart from the inherent difficulty of incising and later repairing that many vessels—some of them singularly difficult to mend—the surgeon's vision and freedom of action would be hampered by the mass of tubing. A heart-lung machine would need only three connections to the patient's circulatory system—to the superior and inferior venae cavae, which bring venous blood to the heart, and to the aorta or a branch of the aorta.

Research experience in dogs indicated that several existing types of pump met the requirements for heart-lung machine use. The principal task for the developers of the machine was the design and construction of a device to perform the function of the lungs. In the lungs the exchange of oxygen and carbon dioxide takes place across the thin membranes of the myriad microscopic air sacs that bring air into close proximity with the blood. In an adult of average size the exchange process delivers half a pint or more of oxygen per minute to the bloodstream during normal waking activity; carbon dioxide leaves the bloodstream at an equivalent rate. But the surface area required for the exchange is large. The



CIRCUIT OF HELIX-RESERVOIR MACHINE conducts blood from two catheters inserted in venae cavae to bottom of mixing chamber. Bubbles of oxygen rising through the chamber are removed in the debubbler. Thence the blood flows into the helix reservoir and is pumped back into the femoral artery of the patient.

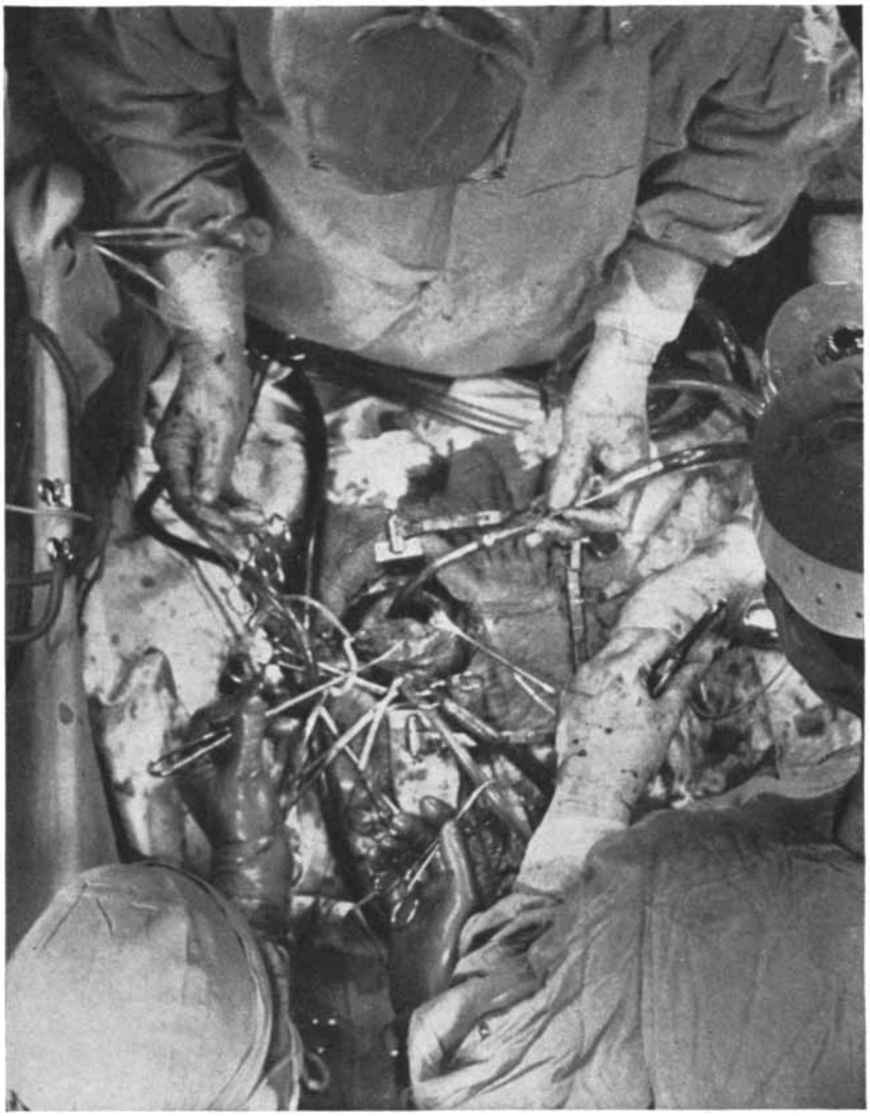
The machine can also be used to stop the heartbeat by chilling the heart. This is done by passing part of the blood through a cooling coil and returning it directly to the coronary artery. Blood flowing from the coronary circulation into the chambers of the heart is aspirated and returned to the heart-lung machine for reoxygenation.

lungs of the 150-pound adult provide some 600 square feet of surface for the two-way traffic in respiratory gases. Artificial oxygenators must likewise furnish relatively large areas of surface for the exchange of the two respiratory gases. One of the most difficult problems was that of how to expose the blood over such large surfaces outside the body without irreparably damaging the delicate blood cells.

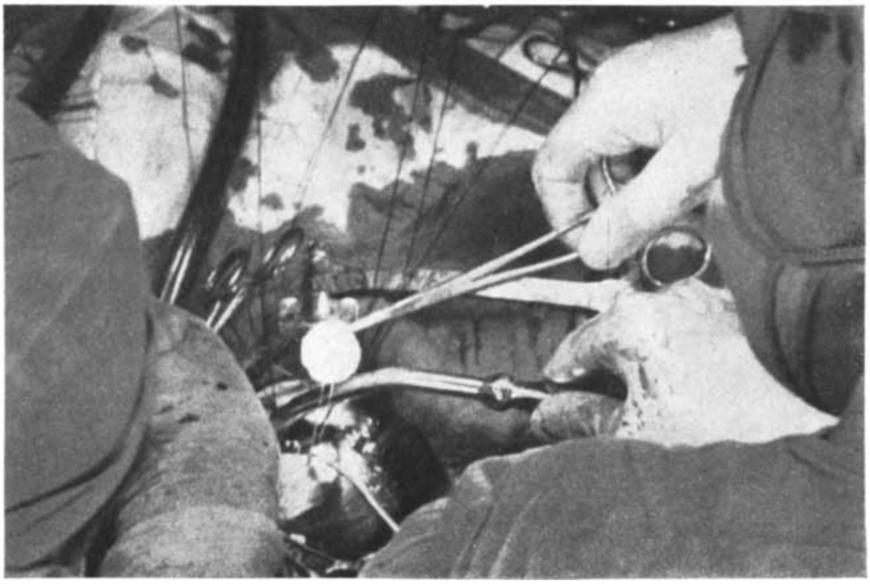
The oxygenation of blood outside the body was finally accomplished in several ways. In the system developed by one of the earliest workers in the field, John H. Gibbon of the Jefferson Medical College in Philadelphia, blood is oxygenated by filming over stainless-steel screens in an atmosphere of oxygen. In machines based on the scheme of V. O. Bjork of Stockholm, blood is picked up from a shallow trough and filmed on rotating disks in an atmosphere of oxygen. The machine developed at the University of Minnesota Medical School achieves the exchange of gases across the surface provided by oxygen bubbles rising with the blood in a vertical tube. All three types of oxygenator have now served successfully in the operating room.

Surgeons were discouraged, however, in their first efforts to employ the heart-lung machine in open-heart operations. Gibbon, in 1953, succeeded in repairing a large defect in the atrial septum of an 18-year-old girl, with the patient maintained by his machine. But all further attempts at that time failed. As a consequence the opinion began to spread that heart-lung machines, however effective in the laboratory, were bound to fail in surgery on humans. The difficulty was held to lie with the patient, not the machine. It was asserted that patients could not tolerate the triple burden of subjection to extra-corporeal circulation, the opening of the heart wall and extensive repair procedures within the heart.

This pessimism was not shared by the members of the surgery department at Minnesota. Their confidence in the ultimate feasibility of heart-lung by-pass was predicated upon the finding, in experiments on dogs, that circulation could be reduced to 10 or 15 per cent of normal for substantial periods of time without injury to the animal. This finding, made independently at Minnesota and by a group of British investigators in 1952, put the heart-lung machine in a new light. Until then it had been assumed that such a machine must provide the patient with normal or substantially normal blood-flow. If human patients could also survive on a considerably smaller blood-flow, the requirements to be met



OPEN HEART (*center*) **is aspirated of blood by tube held in hand of assistant. Two catheters in venae cavae at left of open incision conduct venous blood to heart-lung machine.**



PLASTIC PATCH, shaped to fit ventricular defect, is strung on sutures and held in forceps as surgeons prepare to anchor it. Sutures extend across the aspirator and down to the left.

by a heart-lung substitute would be eased. The "low-flow" principle made it possible to consider a wider range of schemes and to place emphasis on simplicity and infallibility in any system for by-passing the heart and lungs of a patient during surgery.

One such scheme germinated from a remark by a member of the Minnesota group. In the laboratory one day Herbert E. Warden wished out loud that "patients could be plugged into an oxygen supply the way a fetus is plugged into its mother." The group at once set out to develop the possibility of connecting the circulation of the patient to the circulation of a donor who would "breathe" for him. Such a procedure had been employed before for a variety of purposes, chiefly in animal research. At Minnesota many successive pairs of dogs were now cross-circulated, at flow rates up to 30 per cent of normal, with no detectable harm to donor or animal patient; in addition, experimental open-heart operations were successfully carried out on the animals. The results fully warranted a trial of cross-circulation in man for surgical repair of those lethal intracardiac defects which could not be corrected in any other way.

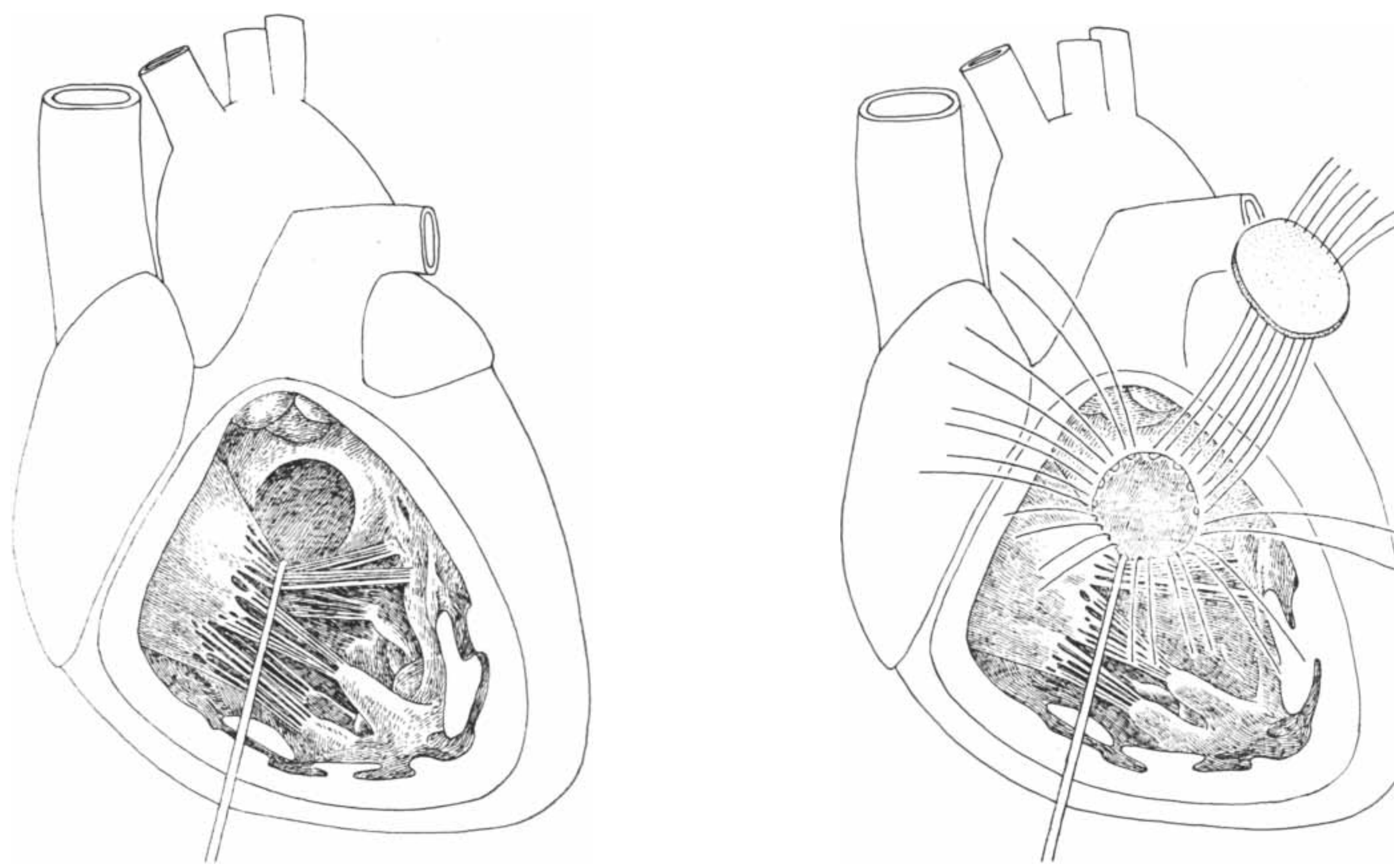
The first patient, operated on in March, 1954, was a year-old child with a ventricular septal defect, and the donor was the child's father. The participating surgeons, Warden, Richard L. Varco, the senior author of this article (Lillehei) and Morley Cohen, had all taken part in the laboratory studies. The patient survived, but died of pneumonia 11 days after the operation. During the following week two other children with ventricular septal defects were operated on by the same method with complete success. Thereafter 42 additional open-heart operations were carried out with the aid of cross-circulation, all for defects that greatly shorten life. Post-operative studies of the 19 who survived these first open-heart operations for ventricular septal defect showed that virtually all now had effective correction of their defects.

In retrospect cross-circulation played a critical role in demonstrating beyond any doubt the feasibility of heart-lung by-pass and of unhurried, direct-vision surgery in any region of the heart. Encouraged by this knowledge, the Minnesota group intensified the search for other methods of by-passing the heart and lungs. Several infants were successfully perfused from a reservoir of arterialized venous blood, that is, venous blood with nearly the oxygen content of arterial blood, obtained by drawing blood from an arm previously immersed in very hot water. This procedure was feasible because infants require a blood flow of no more than a few hundred cubic centimeters per minute.

In 15 operations the lung of a dog, dissected free of its host, served as a blood oxygenator with a mechanical pumping system carrying the blood to and from the patient. Surprising as it may seem, thoroughly washed, carefully prepared animal lungs can be utilized to oxygenate human blood without deleterious effects on the blood. But the ultimate fruit of this development program was a fully mechanical heart-lung machine, the so-called helix-reservoir system that has served in virtually all open-heart operations at Minnesota since its introduction in 1955.

The Helix-Reservoir Machine

The helix-reservoir machine embodies simple and reliable solutions to the variety of critical specifications that are set by the purpose it serves [*see illustration*

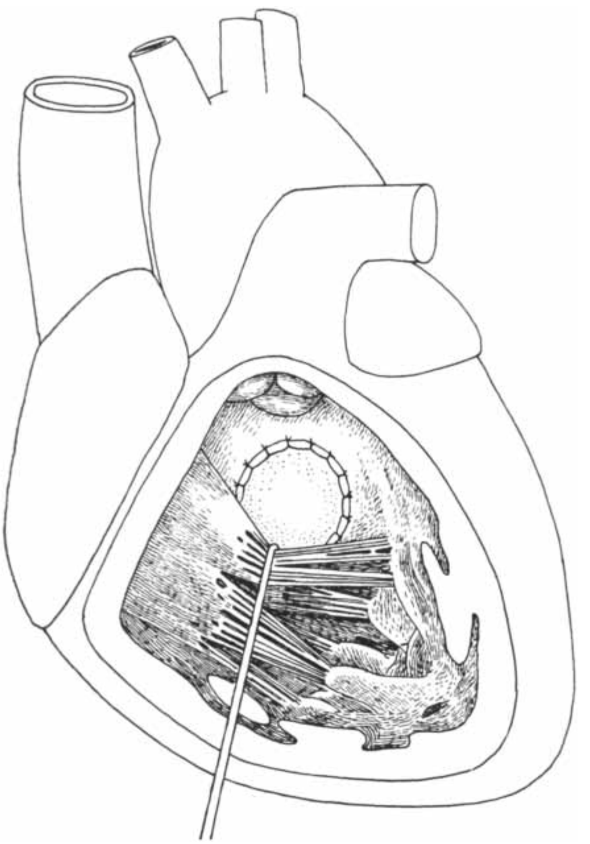


CLOSURE OF VENTRICULAR DEFECT by plastic patch is diagrammed. The defect is a round hole in the septum between the left and right ventricles (*drawing at left*). Sutures are placed around the margin of the defect and are run through the edge of the patch

on page 80]. Like other heart-lung machines it is connected to the patient's venous circulation, after the chest has been opened, by the insertion of two catheters into the venae cavae, the two large veins that empty blood from the general circulatory system into the right atrium. The blood runs by gravity to the bottom of the oxygenator tube, 18 to 24 inches below the level of the patient's heart. Entering the vertical tube through a disk that also admits oxygen through holes large enough to form large bubbles, the blood is lifted gently by the flow of oxygen to the top. Exchange of oxygen and carbon dioxide takes place at the blood-and-gas interface on the surface of the bubbles, as the blood-gas mixture rises through the tube. Thus the oxygen itself, without the help of screens or disks, supplies the huge surface area necessary for gas exchange.

The excess gas must now be completely removed to prevent embolism when the blood is returned to the patient. This is the function of the debubbler chamber atop the oxygenator tube. As the blood flows through the debubbler, it passes over stainless-steel sponges coated with a special antifoam silicone that lowers the surface tension of the blood and breaks up the bubbles, permitting the gas (which now contains carbon dioxide as well as oxygen) to escape through a screened vent in the top of the chamber. The sponges also serve as a filter to remove any clots that may have formed.

The blood then passes by gravity from the debubbler to the top of the helix reservoir, a coil of plastic tubing from which the machine gets its name. Here an added safeguard is provided by simple physical forces. If any bubbles of gas should still remain in the blood, they are forced to the surface and are held in the top turn of the coil by the denser, bubble-free blood flowing by gravity down through the helix. Enough turns are provided in the helix to hold a one-minute supply of oxygenated blood, in the event of unexpected difficulties in the flow between patient and machine. A thermostatically controlled water bath surrounding the helix-reservoir maintains the blood at body temperature. From the helix-reservoir the blood runs to a "finger" pump that squeezes the blood along a tube with cam-actuated metal fingers. This pump delivers the blood to the patient's arterial system via a catheter inserted into the large femoral artery, in the inner side of the thigh, or into the subclavian artery, which courses up through the chest to supply the arm. Through either of these major arteries the arterialized blood from the heart-lung machine perfuses the entire systemic circulatory system and returns to the heart in the venae cavae, where it is intercepted by the catheters and delivered anew to the machine.



(*drawing in center*). Sutures then secure the patch in place (*right*). Opening in wall of the heart in the drawings is not the incision made by the surgeon but a schematic cutaway.

Unless it is deliberately halted, the heart continues to beat, although its contractions are smaller than usual because its chambers are empty save for the small amount of venous blood entering from the heart muscle itself. The blood, essential to maintenance of the heart muscle, flows in through the coronary arteries, which branch off from the aorta just outside the heart proper, above the aortic valve. It makes its exit from the coronary circulatory system in the normal way, mostly through the coronary sinus into the right atrium, but to some extent directly into other chambers as well. This coronary-return blood is gently aspirated by a low vacuum and drawn into the heart-lung machine for reprocessing.

The helix-reservoir system may be set up to deliver any desired flow up to 5,000 cubic centimeters per minute. This is more than enough for safe open-heart surgery, even in the largest patients. In fact, it is now our practice to have the heart-lung machine pump an amount estimated to be equal to what the normal heart would be pumping. The knowledge derived from early experience with the oxygenation of low flows has effectively solved the problems formerly associated with the processing of larger quantities of blood. The achievement of normal flow has considerably lengthened the time that patients can be maintained on heart-lung by-pass and so has permitted more prolonged operations to correct more complex conditions. Before use the machine must be primed with two to four 500-c.c. units of fresh venous blood, obtained from compatible donors and treated with the anticlotting agent heparin. The oxygenator brings the blood up to between 95 and 98 per cent oxygen saturation. When the machine is properly operated, damage to the red cells, as measured by the concentration of free hemoglobin in the plasma at the end of the pump run, is small and not significant. A fundamental advantage of the helix-reservoir machine is that practically all of the parts of the machine that come in contact with the blood, principally plastic tubing, may be discarded after use. The only parts that are retained are the stainless-steel connectors and adapters. These are highly polished inside and out, easily cleaned and sterilized, and are designed to eliminate sharp shoulders that, by causing turbulence, might damage the cellular elements of the blood.

The Results

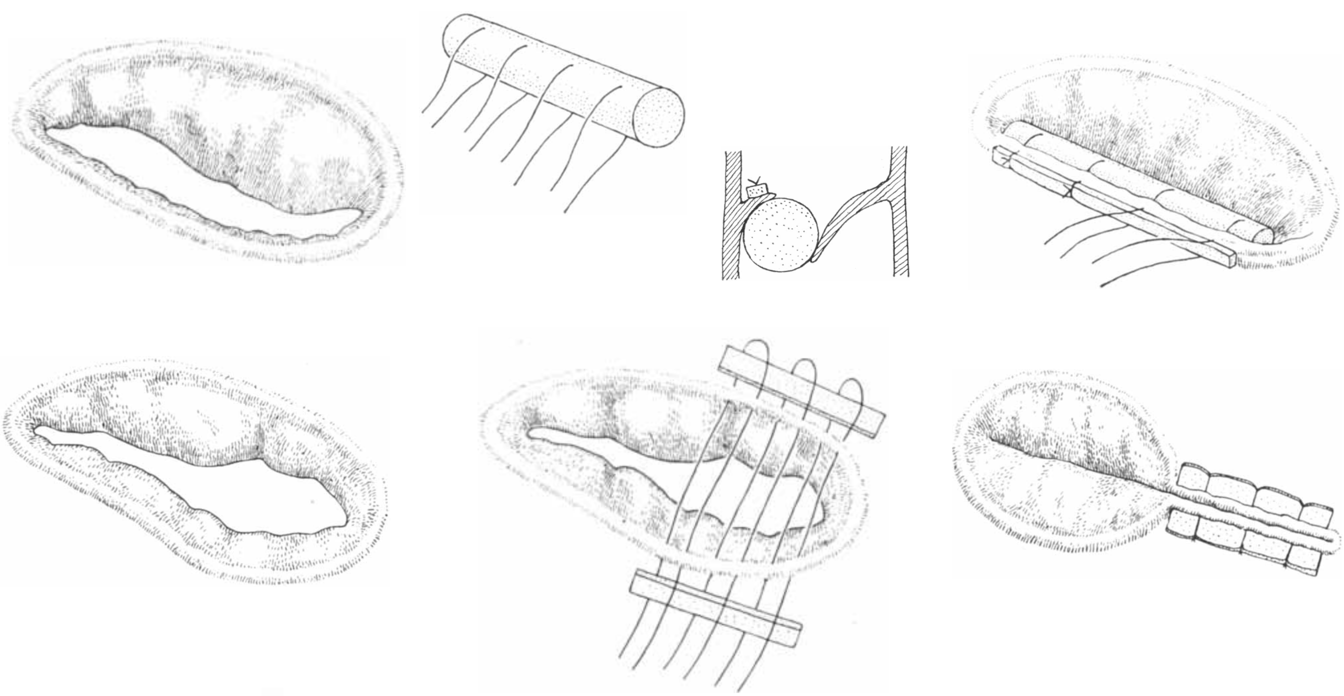
The cardiac surgery group at Minnesota has now performed nearly 1,000 open-heart operations with the aid of the heart-lung machine or other methods of by-pass. At first mortality rates for some operations were high, in part because the patients initially accepted for surgery were uniformly very ill, in part because on-the-spot improvisations were frequently necessary for dealing with malformations never before seen in living patients and with situations that could not be anticipated in the laboratory. But mortality rates showed a gratifying drop as experience was gained. Moreover, the variety of operations has widened constantly.

In the last several years the mortality in operations for defects in the ventricular septum has averaged but 2 per cent in good-risk cases, that is, patients over two years of age and without marked pulmonary blood-vessel damage. The defect in these cases may now be securely closed by suturing a patch of plastic material into the gap in the septum.

The plastics used for this and similar repairs are specially prepared sponges or felts. These materials provide myriads of interstices which are rapidly invaded with fibrous tissue once they are in place. Since the plastic thus serves only as a framework for final healing by the heart's own tissue, later reopening or rejection of the plastic patch is impossible.

Even in patients who have suffered severe pulmonary damage from ventricular defects, mortality has been reduced to 5 per cent. The problem here is that the damage to the pulmonary circulatory system raises the working pressure on the right side of the heart. A septal patch with a safety valve that gradually shuts

REPAIR OF AORTIC VALVE that leaks because of loss of leaflet tissue (*drawing at left*) involves stitching two of the leaflets together, with the stitches secured through pledgets of plastic sponge (*drawing in center*). In effect the valve now has two leaflets. The gap remaining between the leaflets is eliminated by the attachment of a shaped plastic strip to the third leaflet (*drawing at right*).



REPAIR OF MITRAL VALVE to prevent leakage can be carried out in either of two ways, depending on the nature of the damage. Leak in the valve at top left, caused by the loss of leaflet tissue, is repaired by the insertion of a plastic "spindle" (*top left center*) secured with the aid of a plastic cushion (*cross section at top right center*) to prevent cutting-out of sutures. Leak in the valve at bottom left is caused by stretching of the fibrous ring to which the leaflets are attached. Shortening of the circumference by sutures tied across one end of the valve (*bottom center*) reduces the valve opening and permits remaining leaflet tissue to close (*bottom right*).

Bendix electrically excited shock tube can be photographed by illumination from hot gases.

PLASMA PRODUCTION

. . . for magnetohydrodynamic investigations

Hypersonic flight can generate ionized shock layers with free electron densities as great as 10^{12} particles per cc. Temperature near the stagnation point can be as high as 7000°C. This is the self-generated environment of a missile or aircraft traveling at Mach 20 in the upper atmosphere.

To create these conditions in the laboratory for magnetohydrodynamic and electromagnetic propagation investigations requires a hypersonic wind tunnel. The Bendix electrically excited shock tube is such a research tool. Discharge of a capacitor bank into a conical region at one end of the tube instantly creates a shock wave which is driven down the length of the tunnel past the test body. Flow velocities up to 75,000 fps and temperatures of 20,000°C can be generated.

By passing electric and magnetic fields through the plasma in the shock tube, Bendix engineers can measure the attenuation of radio transmission through the ionized layer surrounding hypersonic vehicles. They can also investigate the acceleration of conducting gases for space propulsion, and the feasibility of direct conversion of thermal energy to electrical energy.

Plasma production is one of the projects being carried out at Bendix Systems Division to solve the technical problems which are the keys to the systems of the future. Other investigations include satellite communications systems, navigation satellites, advanced infrared reconnaissance, and the EAGLE Air-to-Air Missile System. Inquiries are invited from better engineers also looking to the future.

Bendix Systems Division
ANN ARBOR, MICHIGAN

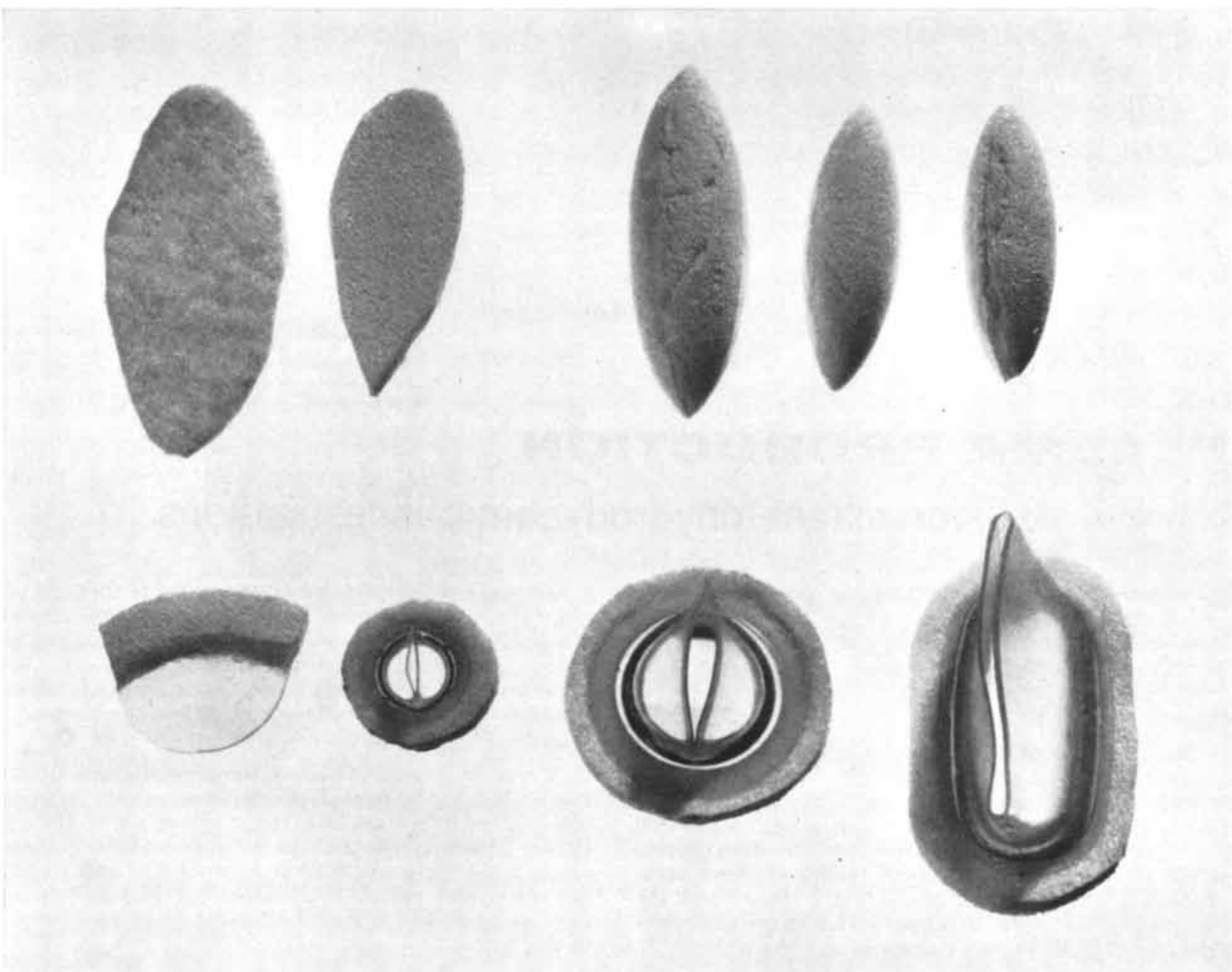
Bendix
AVIATION CORPORATION

off relieves this pressure and thereby reduces stress on the right ventricle while the ventricle is healing from surgery and the pulmonary circulatory system is returning to more normal pressure.

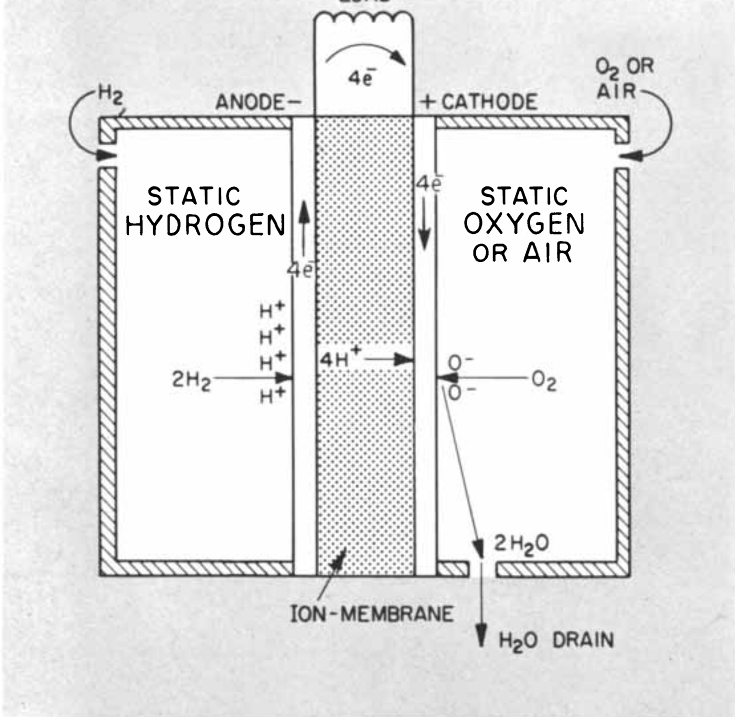
In operations for the tetralogy of Fallot, which call for closure of a septal defect and for freeing of the obstruction in the passage from the right ventricle, results have been equally gratifying. At the outset the operative mortality was 40 per cent. This was high, but no higher than the over-all failure rate for the palliative operation, which averaged an immediate mortality of about 10 per cent and another 25 to 35 per cent ultimate mortality or failure to obtain any benefit from operation. The operative mortality for the open-heart operation is now down to 10 to 12 per cent, and there should be no significant late mortality because the operation achieves an essentially normal circulation. One of the most important factors in securing complete correction even in cases of severe defect has been the introduction of an "artificial roof," a piece of plastic sewn into the outer wall of the heart, to widen the outflow junction of the right ventricle and the pulmonary artery.

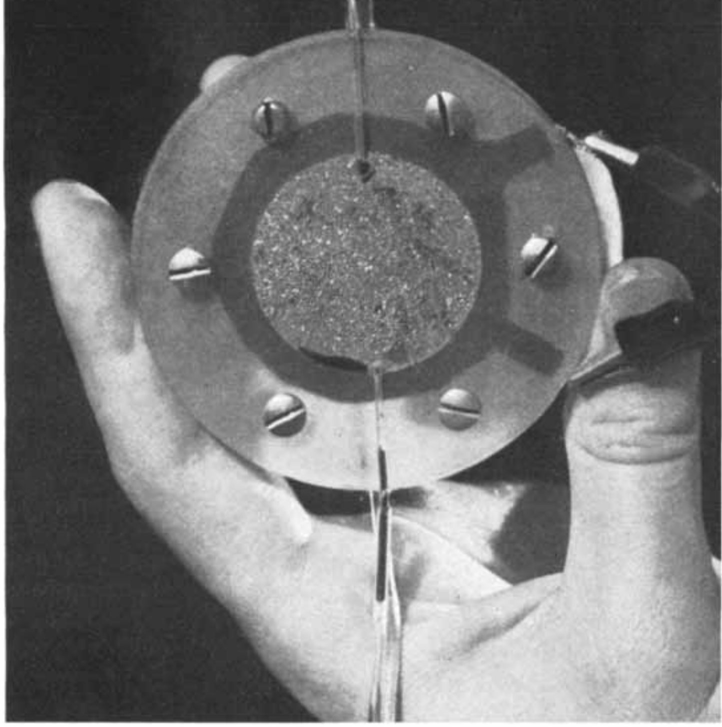
With the heart-lung machine affording ample time and enabling the surgeon to see what he is doing as he works in the open heart, it has been possible to develop routinely effective operations for many other forms of congenital malformation. Among them are congenital stenosis (narrowing) of the pulmonary artery and various heart valves; misplacement of the pulmonary veins; and even the complex defect called A-V canal (a communication between the right and left sides of the heart at the juncture of the atria and ventricles). Corrective procedures are awaited for only a few bizarre malformations, such as transposition of the great vessels, that is, the attachment of the pulmonary artery to the left ventricle and the aorta to the right ventricle, which completely deranges the circulation.

The same boons of time and direct vision have made it possible to develop solutions for many acquired defects that result from disease and chest injury, especially defects of the valves. The valves most often damaged are the mitral and aortic. Just how the surgeon proceeds depends on which valve is involved and the nature of the damage. Incompetent valves that permit the backflow of blood may be repaired by narrowing the diameter of the valve, by stitching together two of three leaves to make a three-leafed valve into a two-leafed valve and by extending a leaflet with a pledget of plastic material sewn along its lip. In the opposite condition of stenosis, or constriction of the valve, the finger-in-the-heart operation can still deal fairly well with the less complicated situations involving the mitral valve. But complex



PLASTIC PATCHES AND VALVES are proving effective in replacing missing or damaged tissues in the heart. At top left are "roofs" for repair of outflow channel from right atrium in the tetralogy of Fallot; at top right, "spindles" for repair of leaks in mitral valve. At bottom left is a plastic leaflet for insertion in the mitral valve. The three complete one-way valves at lower right are used for repair of ventricular septal defect (*left*) and for replacement of the aortic valve (*center*) and the mitral valve (*right*).





OPERATING PRINCIPLE of General Electric's fuel cell is based on hydrogen-oxygen reaction that releases useful energy . . . electricity. Schematic cross-section shows relationship and function of the two electrodes and solid ion-membrane electrolyte. Simple, compact and rugged, a single fuel cell is only one-quarter inch thick. They can be stacked in series or parallel to form fuel cell "batteries."

Story of General Electric's Ion-membrane Fuel Cell

IT'S SIMPLE, RELIABLE AND EFFICIENT!

The quarter-inch thick wafer you see above is one of General Electric's new ion-membrane fuel cells. It is silent. It has no liquid electrolyte. It has high fuel efficiency. We'd like to tell you about it; but before we do, let's start at the beginning. . .

WHAT ARE FUEL CELLS?

A fuel cell is an electrochemical device in which energy, derived from a chemical reaction maintained by the continuous supply of chemical reactants, is converted directly to electricity. This means that, like a common battery, a fuel cell converts chemical to electrical energy. But, the fuel cell has two major differences:

(1) The fuel is obtained from outside the cell, and only as needed to meet load demands. *It is not stored within the cell.*

(2) The products of the reaction are dissipated and the cell, therefore, remains invariant. That is, *no change takes place* in the electrodes and the membrane-electrolyte.

Most low-temperature fuel cells are based on a hydrogen-oxygen reaction. Our ion-membrane cell operates on this principle . . . but with a difference. It is self-regulating . . . no external controls are required.

GENERAL ELECTRIC'S FUEL CELL

Hydrogen and oxygen (or air) are supplied to opposite sides of the cell and are separated by a solid plastic membrane. Hydrogen ionizes at the anode, forming ions that enter the membrane-electrolyte. The ions migrate through the membrane to the oxygen electrode. Simultaneously, electrons travel the external circuit to the cathode where they reduce the oxygen. Over-all result: the controlled chemical combining of hydrogen and oxygen to form water, and the release of useful electrical energy.

WHAT IT WILL DO

Open circuit voltages as high as 1.08 have been obtained. Large prototype cells have produced 42.5 amps per square foot ($800 w/ft^3$) when generating maximum power. Thermal efficiency under typical load is about 60 percent, and improves under light loads. Demonstrator cells (like the one shown above) have been operated for extended periods on an experimental basis . . . one around the clock for more than 300 days.

General Electric's cell is safe, compact, rugged. It is also reversible. That is, it can be used to electrolyze water, producing hydrogen and oxygen. Thus, it can also be used to store energy . . . from a solar generator, for example.

There is no limit to fuel cell size, or the applications for it. Right now, we are producing limited quantities of practical-sized cells daily. We are also developing prototype hardware . . . a portable power pack for the U. S. Marine Corps that will put out 200 watts of 22-28 volts d-c. A hydrogen generator weighing about 5 lbs provides 14-hour operation.

For more information about fuel cells produced by G.E.'s Aircraft Accessory Turbine Dept., write for free booklet.

General Electric Company, Section C231-32, Schenectady 5, N. Y.

Yes, please send me "Some Plain Talk About Fuel Cells" (GED-7041).

For immediate project ☐

For reference ☐

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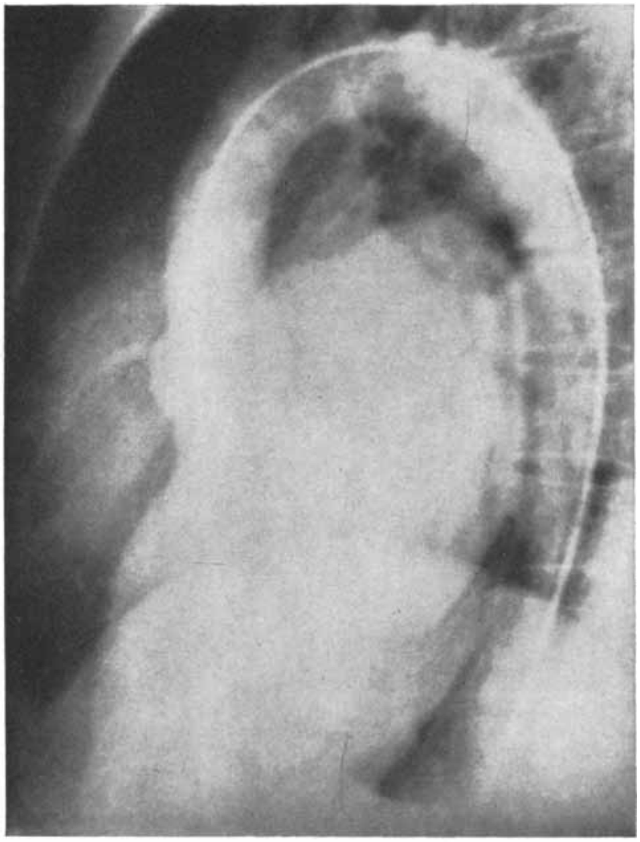
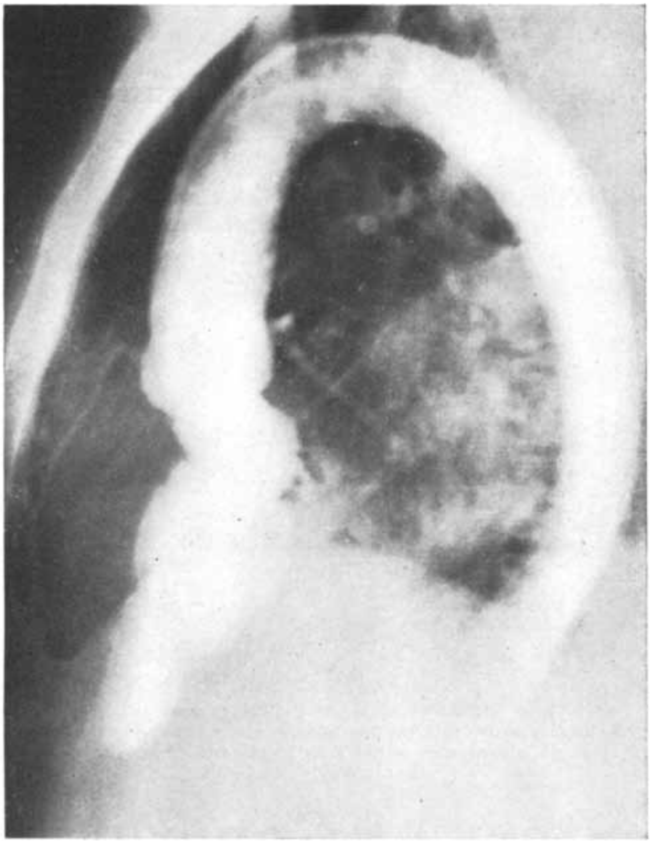
Progress Is Our Most Important Product

GENERAL ELECTRIC





MITRAL-VALVE REPAIR is demonstrated in these X-ray pictures in which heart chambers are made visible by X-ray-opaque dye introduced by catheter, the thin light line arching from the right in each picture. Upper part of large light area in picture at left indicates backflow of blood through leaking mitral valve into left atrium. Darkness in this area in picture at right shows leak is stopped.

forms of mitral stenosis are best treated by open-heart surgery, and it is quite likely that all mitral stenosis operations will eventually be performed open.

Stenosis of the aortic valve—an important contributor to mortality from heart disease—can be corrected only by open-heart surgery. In the days before the heart-lung machine many attempts were made to relieve aortic-valve constrictions by separating the valve leaflets with an instrument inserted blindly into the aorta and guided by the sense of touch. Results were poor, and aortic stenosis was thought for a time to be all but uncorrectible. The difficulty was that the damaged aortic valve is usually heavily calcified and cannot function properly even when reopened. The surgeon working blind had no way to correct the calcification. Today, under direct-vision surgery, it is possible not only to reopen the valve but also, in many cases, to cut away the calcium deposits or insert new valve leaflets of plastic.

Aside from the great problem of coronary disease, the most challenging task currently before cardiac surgeons is the development of complete artificial valves to take the place of valves so totally destroyed by disease that repair is likely to fail. What is especially needed is a valve that can be easily secured at the natural site of the aortic or the mitral valve. Here the surgeon must fit the artificial valve into a quarter-inch long segment of the aorta between the aorta's exit from the heart and the opening of the coronary arteries. Effective prosthetic valves have already been inserted successfully in a small number of patients. One patient treated at Minnesota is alive and well 15 months after replacement of her aortic valve with a plastic one.

Stopping and Starting the Heart

Under certain conditions it is desirable to stop the beating of the heart. An arrested and all-but-bloodless heart makes for more accurate repair of some defects, especially in parts of the heart that are hard to reach. Arrest may be achieved by injecting potassium citrate or acetylcholine into the coronary circulation, and it has been employed with success in a large enough number of cases to establish the advantages of elective arrest for the correction of many types of heart defect. During the interval when the heart is held motionless by these drugs, the coronary circulation must be completely shut off; as a result the heart muscle itself receives no oxygen. Such agents are therefore dangerous both to patients with advanced degrees of congenital heart disease and to virtually all patients with acquired heart disease. The heart muscle in such patients has usually been severely impaired and thus is extremely sensitive to lack of oxygen. If oxygen deprivation goes beyond the limit of tolerance, the heart may fail to restart at all, or may resume its beating only to stop in the postoperative period. During potassium citrate arrest the oxygen requirement of the heart tissue drops to quite a low level because the heart is doing very little work, but not to such a low level that it is safe to halt the flow of blood through the coronaries and so achieve one of the main purposes of elective arrest: a bloodless heart.

An alternative way to achieve arrest with no risk of depriving the heart muscle of oxygen has recently been developed at Minnesota. A small amount of cold blood is circulated through the coronary arteries, while the rest of the patient's body is kept at normal temperature. The heart is quickly and easily cooled to about 65 degrees F. At this

ANOTHER WAY RCA SERVES INDUSTRY THROUGH ELECTRONICS

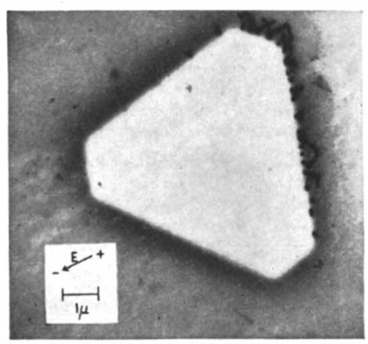
MASTERING THE MOLECULE . . . WITH ELECTRON MICROSCOPY

RCA Electron Microscope helps Eastman Kodak keep the promise of "saving all the fun in pictures!"

The quality of even the best snapshots or professional photographs can only be as good as the cameras and films they're made with, and the chemicals in which they are developed. That's why at the Kodak Research Laboratories, one of the important uses of the RCA Electron Microscope is research in connection with photographic theory. This includes investigations into the characteristics of photographic emulsions and studies of the nature of the photographic image. It's all part of the painstaking effort that assures continuing progress in picture-taking, and in the many other applications of photography.

This application of the RCA Electron Microscope by the Eastman Kodak Company is typical of the advanced research in which over 1000 of these instruments are now being used throughout the world. The EMU-3 is recognized by scientists as the "work-horse" of the laboratory because it provides extremely high electron image magnifications of up to 200,000X as well as unsurpassed ease of operation, reliability and dependable performance. Of particular value to chemical and metallurgical researchers is a new Diffraction Chamber which permits EMU microscopes to do transmission and reflection electron diffraction.

Also of importance in research and development work are the world's most versatile x-ray diffraction and spectroscopy instruments now offered by RCA. Installation supervision and contract service are available through the RCA Service Company.



In the above electron micrograph, the light hexagonal area is the imprint left in the gelatin when a large silver halide crystal from an experimental photographic emulsion was dissolved. Development centers are shown to be all along one edge of the grain.

For full particulars, write to RCA, Dept. D-111, Building 15-1, Camden, N.J. In Canada: RCA VICTOR Company Limited, Montreal.

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temperature the oxygen demand of heart muscle is so reduced that the amount of oxygen supplied by the cold blood provides effective protection against the consequences of oxygen deprivation. The heart is subject to the hazard of ventricular fibrillation as it comes out of cold arrest, but the well-oxygenated heart recovers from fibrillation easily and usually spontaneously. Cold arrest has permitted successful operations upon many patients who could certainly not have survived cardiac surgery without it, and at Minnesota has completely replaced arrest by drugs.

However, certain surgical problems call for the opposite of arrest, that is, for allowing the heart to continue beating and sometimes to fill with blood. In repairing a leaky mitral valve, for instance, the surgeon can observe the performance of the valve and see whether he has in fact stopped the leak. The blood comes from the coronary circulation, which receives blood from the heart-lung machine via the aorta and empties it into the right atrium and, in smaller amounts, directly into the other chambers.

Another development that has substantially increased the number of survivors is the direct hookup of an electric pacemaker through a wire implanted in the heart muscle. This was devised to deal with a problem that arose soon after the first operations to close defects in the ventricular septum. In suturing the patch of plastic into the defect it sometimes happens that the suture needle strikes the tract of neuromuscular fibers carrying the heart impulse from the heart's own pacemaker to the ventricles. As a result the impulse no longer reaches the ventricles, and the atria and ventricles begin beating out of synchronization. Complete heart block, as this condition is known, can be rapidly fatal. After such injury the heart is apt to come to a complete standstill at any time, because the ventricles do not beat dependably on their own. This has been a cruel outcome on occasion, when postmortem examination of the heart has shown an otherwise completely successful correction of the original defect.

Laboratory investigation showed that the heart could be stimulated to maintain an absolutely regular beat at any desired rate by a repetitive electric stimulus of as little as two to three volts at one to 40 milliamperes, delivered through a fine wire implanted directly in the ventricular muscle, and that such a wire could be left in place for protracted periods without harm. When the heart resumes a normal rhythm under the control of its own pacemaker, the wire is easily pulled out. The heart-wire pacemaker combination has been used in scores of patients, since heart block occurs in 10 to 15 per cent of operations for ventricular defect and tetralogy of Fallot. The wire is left in place until, as usually happens, healing restores the patient's ability to maintain a normal beat, or until the patient can be accommodated to a heart rate he can maintain. The pacemaker that supplies the pulses of current has now been reduced to a transistorized, battery-powered unit about the size of a cigarette package, and deaths from heart block have been reduced virtually to zero. More recently this device has been dramatically successful in the treatment of a small group of nonsurgical patients with heart block from such causes as coronary disease, infections and drug toxicity.

The Future of Heart Surgery

When operations around and within the heart first began to be performed, young surgeons were frequently advised to avoid the new field because a handful of surgical specialists in the largest medical centers would be more than enough to take care of the few patients needing cardiac surgery. Today cardiac operations are performed in almost all large hospitals, and open-heart surgery is being performed in scores of centers.

Considering that cardiovascular diseases are the largest single cause of death, the future for cardiac surgery would appear to be without limit. The one area in which progress to date may not be viewed with satisfaction is coronary heart disease. Historically surgery has been at its best in removing obstructions in various channels and vessels of the body. However, patients who have the severest symptoms of coronary disease, and who therefore are most in need of help, generally have widespread obstructions involving many small coronary vessels. These arterial vessels are singularly difficult for the surgeon to work upon effectively by presently available techniques. The effectiveness of other approaches, such as procedures for opening up new blood channels into the heart muscle, are under investigation.

Although much will probably be accomplished in the future toward the control of coronary disease by nonsurgical means, there will inevitably be many patients who will need further help. One can predict with certainty that a way will be found to improve their treatment by surgery. Numerous problems of perhaps even greater difficulty have been solved in carrying surgery into the heart.

TAKE A GIANT STEP

. . . into your future and seek out the professional opportunities awaiting creative engineers and scientists at Martin-Denver . . . For here exists the most challenging problems in space and human engineering. Join with us and communicate with N. M. Pagan, Director of Technical and Scientific Staffing (Dept. G-9), The Martin Company, P. O. Box 179, Denver 1, Colorado.

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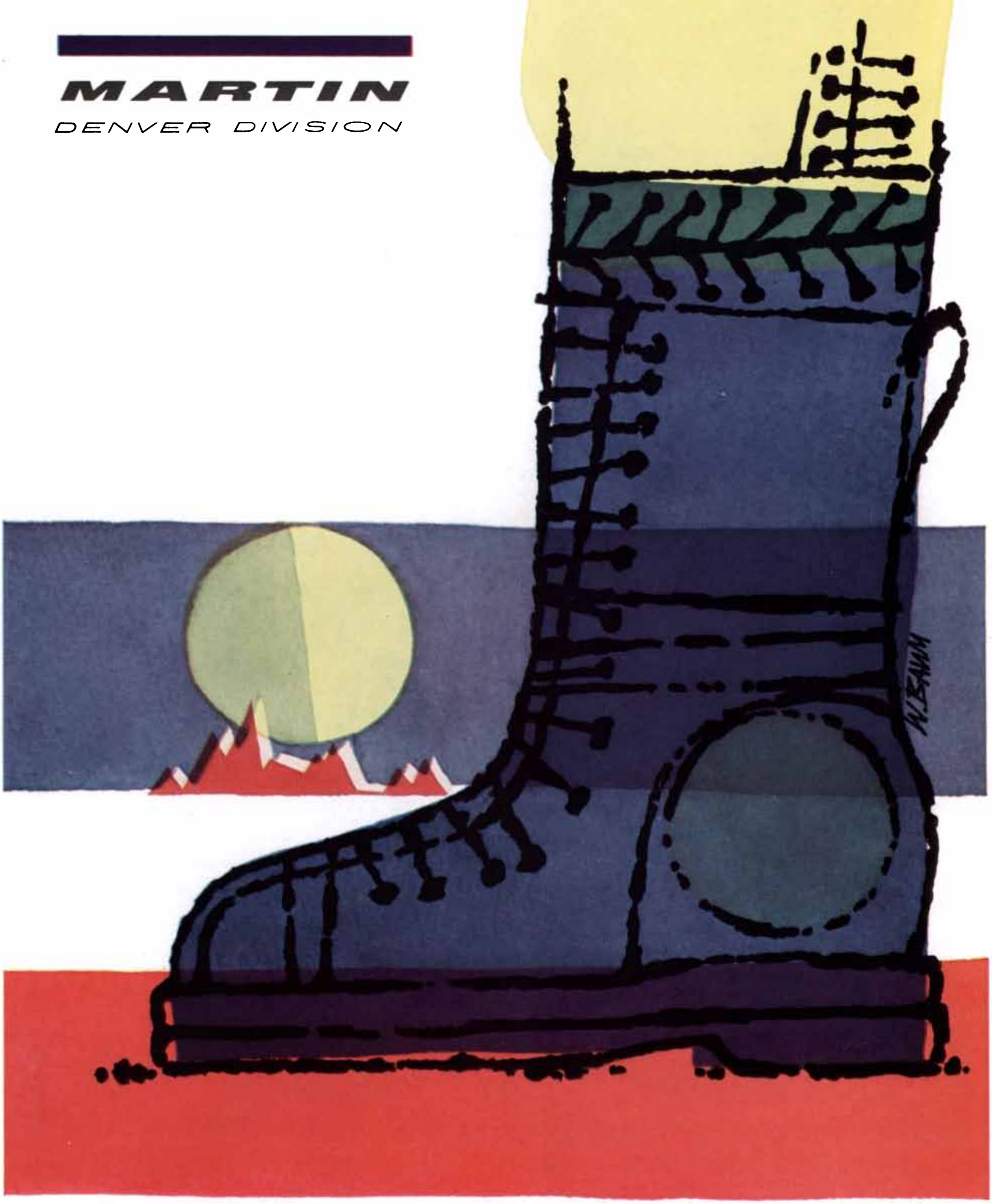
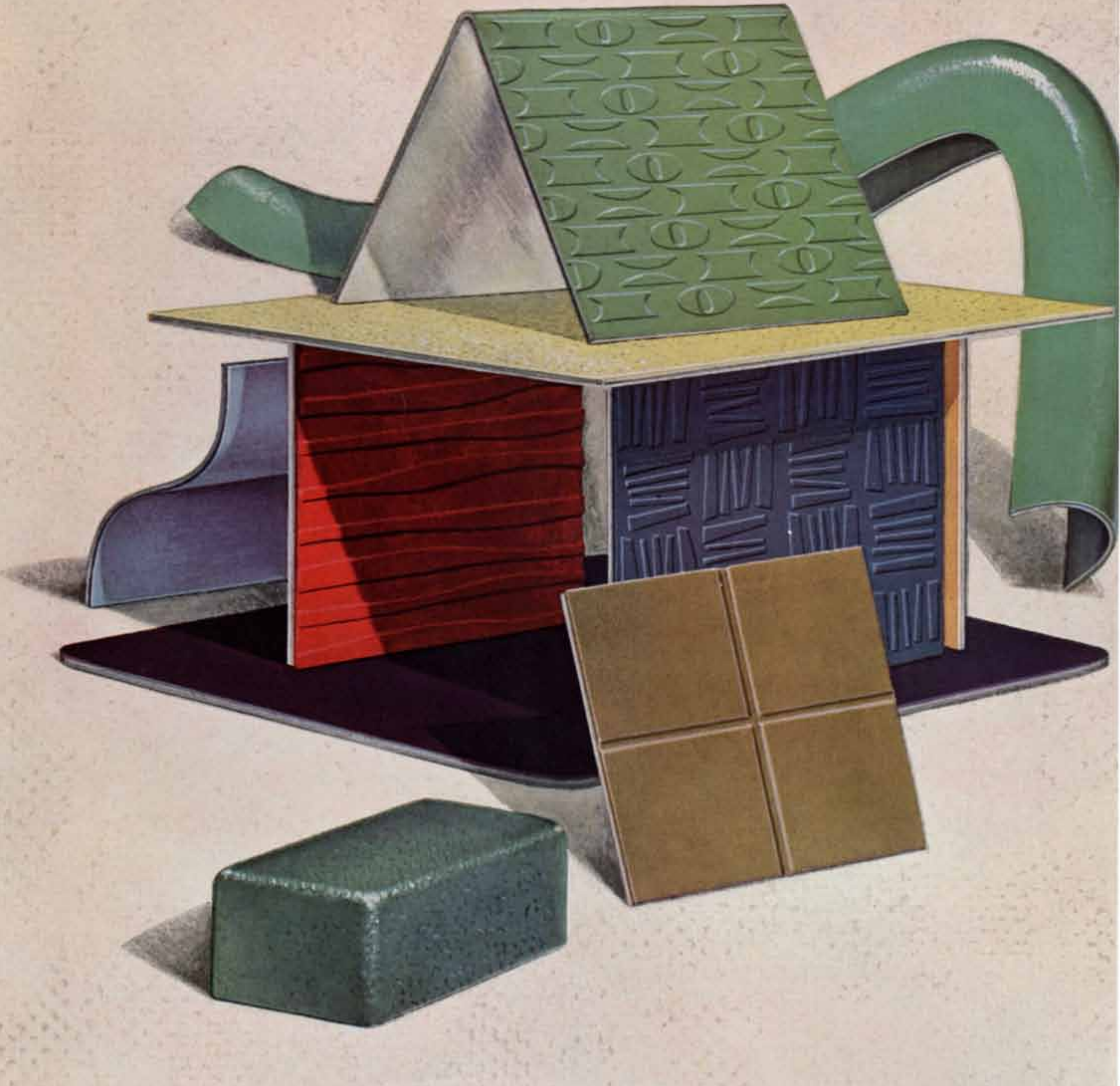
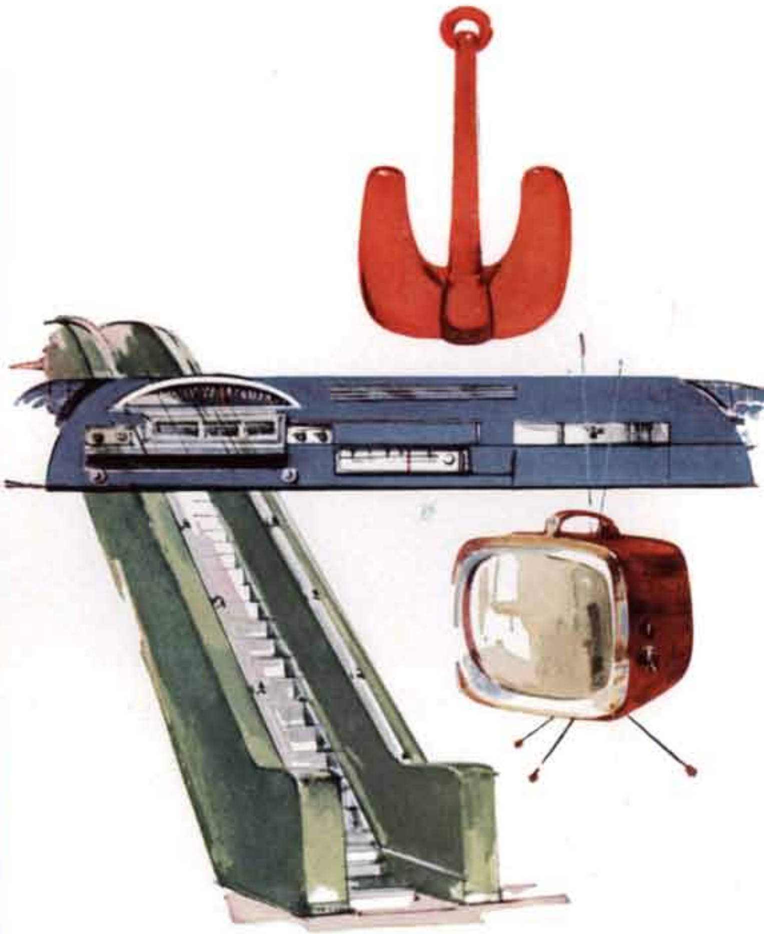
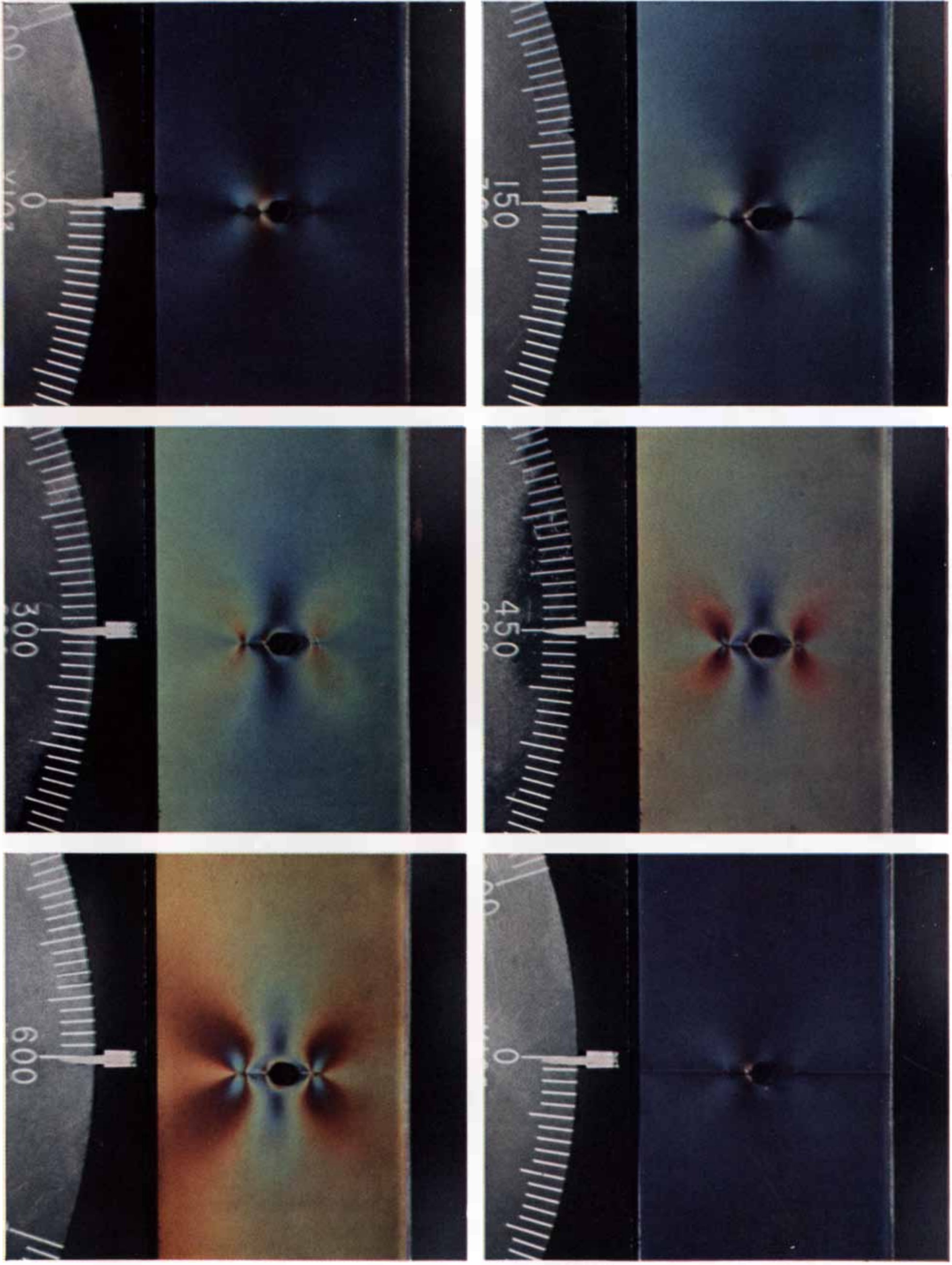


The eight divisions of the Martin Company are Activation, Baltimore, Cocoa, Denver, Nuclear, Orlando, RIAS, and Space Flight.







DISTRIBUTION OF STRESSES in a piece of plastic under increasing tension is shown in this series of polarized-light photographs. The dial at left gives the applied force in pounds. In the center of the piece is a hole, to the left and right of which is a simulated crack. The fact that the color fringes are concentrated at the ends of the crack indicates that the stress is greatest there. At bottom right piece has cracked completely. The experiment was made by George R. Irwin of Naval Research Laboratory.

Fracture in Solids

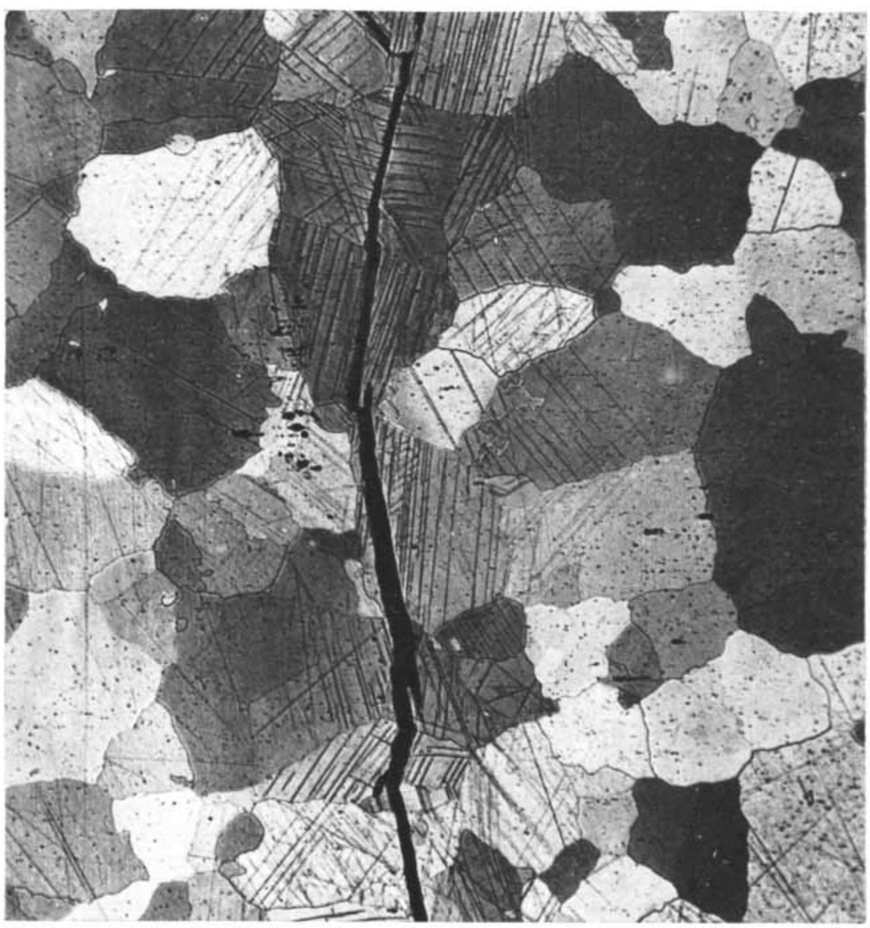
A solid is held together by the bonds between its atoms; why does it fracture under a stress that is insufficient to break the bonds? The answer lies in imperfections in the orderly arrangement of the atoms

by John J. Gilman

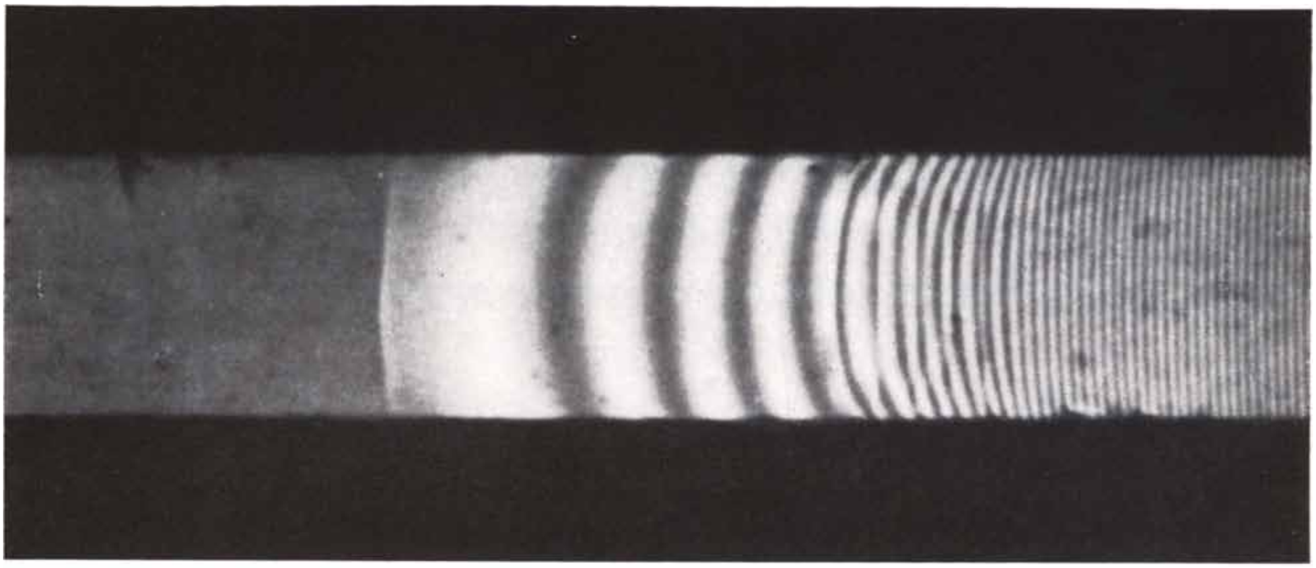
Every solid material, from the frailest eggshell china to the toughest steel, has its breaking point. It resists stress up to that point, perhaps yielding and stretching somewhat, and then suddenly it is broken by fracture. Fracture can be catastrophic: a cable snaps, whipping dangerously into its surroundings; a mile-long length of pipeline splits like a sausage skin; a pressurized aircraft fuselage bursts in flight. But fracture can also serve a useful purpose: it is easier to split things than to saw them, whether they are logs, granite or diamond. At times the event seems all out of proportion to its cause: the diamond cutter places his chisel and taps smartly with his hammer, a sharp cracking sound is heard and the solid, hard diamond cleaves into two pieces along an almost perfectly flat surface.

What happens in the instant of fracture? The speed and finality of the process seem to have discouraged investigation of it in the past. A great deal more is known about other responses of materials to stress, such as elasticity and plastic flow. For the engineer, fracture was simply the calamity to be avoided by means of careful design. The fracturing of entire ship hulls during World War II, however, brought the subject under concerted investigation at a number of research centers. It is now possible to describe the mechanisms of fracture at the atomic level and to begin the definition of their general laws.

The key to an understanding of fracture was provided some 35 years ago by a British engineer, Alan A. Griffith. He postulated that most solid materials contain small, often invisible cracks and that these cracks are extremely efficient levers for prying atoms apart [*see bottom illustration on next page*]. He calculated the amount of leverage that a crack exerts, and confirmed his calculations in a series of elegant experiments. On glass globes of a standard size and thickness he incised scratches of various measured lengths and converted these scratches into cracks by gentle tapping. Then, having coated the inner surface of a globe with a thin film to make it airtight, he gradually increased the pressure inside until it burst. The pressure required to burst each globe decreased with increasing crack length in a precise way. Griffith was thus able to show that a crack, like the arm of a lever, multiplies an ap-



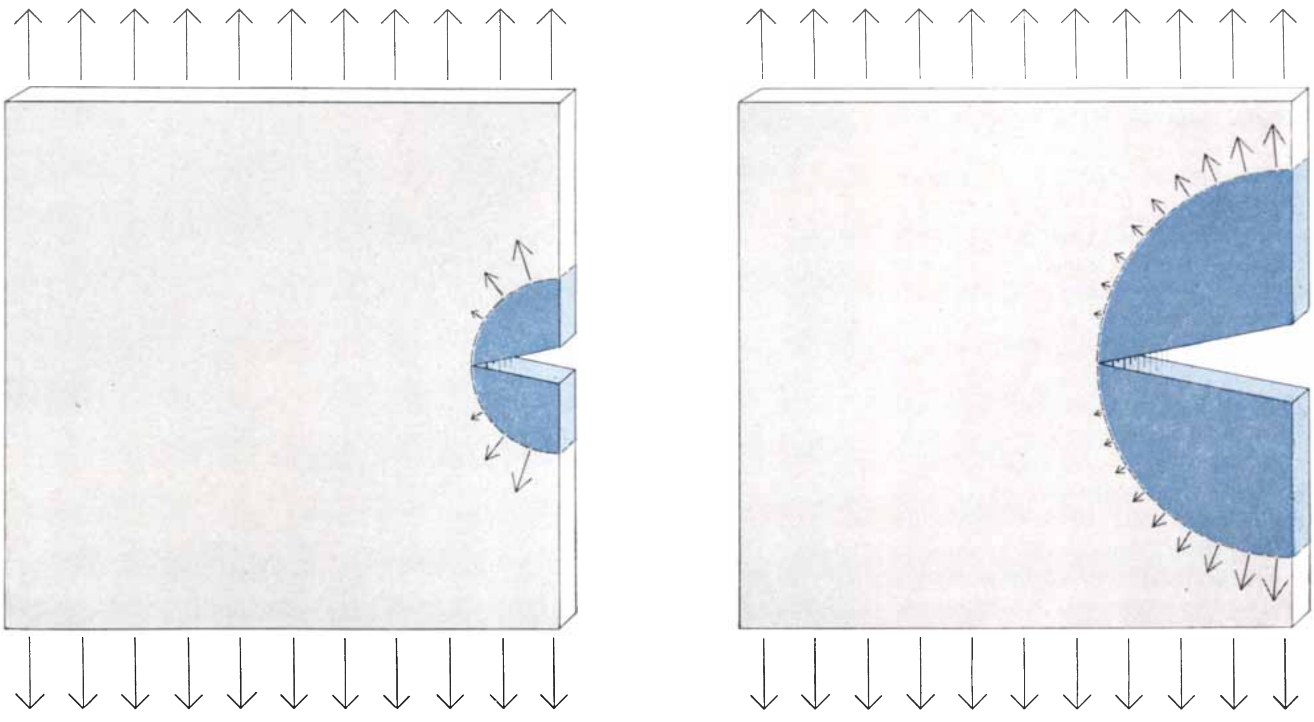
CRACK IN STEEL PLATE (polished, etched and enlarged 12 diameters) follows weak cleavage planes in randomly oriented crystals. Crystals of same shade of gray have same orientation. Thin parallel bands within crystals are "twins" caused by stresses at tip of moving crack. Photograph was made by J. R. Low of General Electric Research Laboratory.



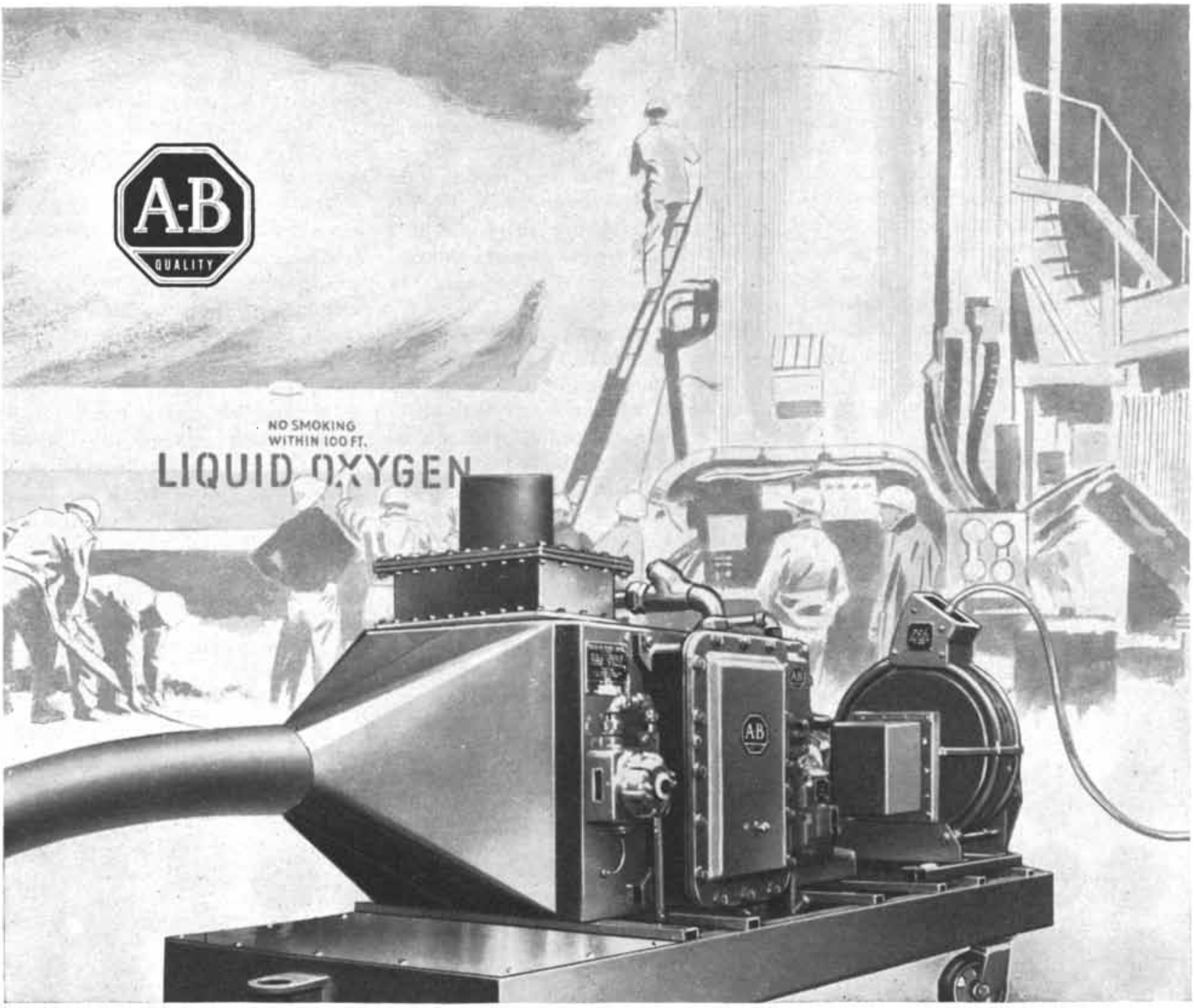
CRACK IN TRANSPARENT CRYSTAL of lithium fluoride is traced by pattern of interference fringes. Crack lies within crystal, parallel to the plane of the page. Tip of crack is marked by boundary between the darker-gray area at left and the lighter-gray area to its right. Width of crack is indicated by distance between fringes; crack opening is widest where rings are closest together.

plied force by an amount that increases with the crack length. A crack, moreover, focuses the stress onto the atomic bonds at the vertex of the crack. This concentration of stress is handsomely demonstrated by the double-refraction patterns observed in some plastics subjected to stress and viewed with polarized light. With applied stress being multiplied by a leverage factor, the concentrated stress soon reaches a high enough value to break atomic bonds and thus produce fracture.

The crack that starts a fracture may be visible to the naked eye, or it may originate in a surface scratch, or a minute fissure between crystal grains, or a defect in the atomic lattice of a crystal grain of a kind that allows it to flow plastically. Since materials in common use have such imperfections, fracture is



LEVER EFFECT OF CRACK helps explain fracture mechanism. Forces applied to top and bottom of steel plate are transmitted to vertex of crack through schematically depicted lever arms (*colored areas*). As crack grows (*right*), the effective length of lever arms increases, multiplying effective force acting at crack vertex. Lines across vertices indicate stretched bonds which are about to rupture.



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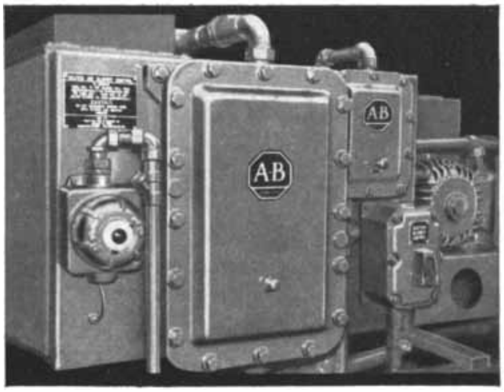
Controls by Allen-Bradley, of course

For missiles to be operational, it is vital that the liquid oxygen containers are cleaned and back in service without delay. And this blower—which cuts cleaning time from a period of hours to mere minutes—is an important part of the ground support equipment. It must be reliable, so naturally the controls are Allen-Bradley.

When hazardous locations such as this require bolted enclosures, Allen-Bradley solenoid starters eliminate the time-consuming job of cover removal for inspection and maintenance. Their famous solenoid design—with only ONE moving part—and maintenance free silver alloy contacts assure long periods of trouble free operation—with *no attention whatever!*

Insist on Allen-Bradley—the motor control that gives you bonus life and reliability with minimum maintenance.



This heated air blower, made by West-Air Fan & Blower Co. for evaporating the chemical purge solution from liquid oxygen cylinders, is equipped with three standard Allen-Bradley starters in NEMA Type 7 enclosures.

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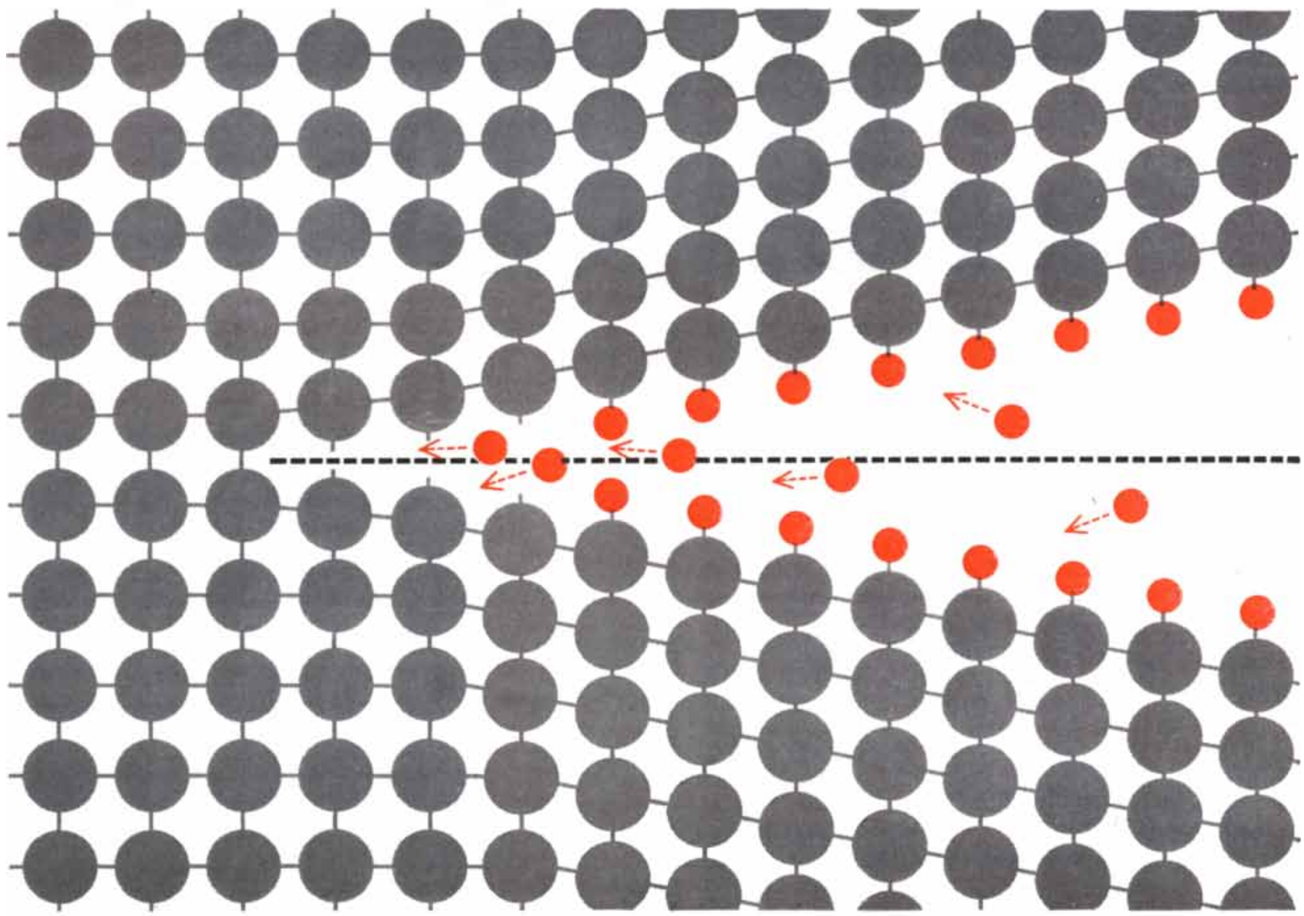
incipient in all of them. This explains why the strength of ordinary materials is so much less than the theoretical ideal suggested by the strength of their interatomic bonds. A tumbler made of ideal glass, only a 64th of an inch thick and lying on its side, could support the weight of a 200-pound man. Made of ordinary glass, the tumbler walls would have to be 16 times thicker (that is, a quarter of an inch thick) to sustain the same stress. The ideal material would withstand a stress of about a million pounds per square inch; the real material fractures under a stress of about 2,000 pounds per square inch.

The characteristics of ideal materials are now being approximated in crystals prepared by modern techniques. Many nearly perfect crystals have been obtained only in the form of fine fibers or "whiskers," but some, such as germanium and silicon, have been made in substantial sizes, as thick as a thumb. These crystals approach the ideal in strength because of the perfection of their atomic structure. As can be seen under the microscope, they have remarkably smooth surfaces. Internally their atoms are arranged in a perfectly orderly, repetitive array. When such a structure is subjected to an external force, the internal stress is distributed uniformly to all of the bonds in the lattice. No crack is present to concentrate the stress in a small area, and a crack cannot form until all of the bonds are stretched nearly to the breaking point.

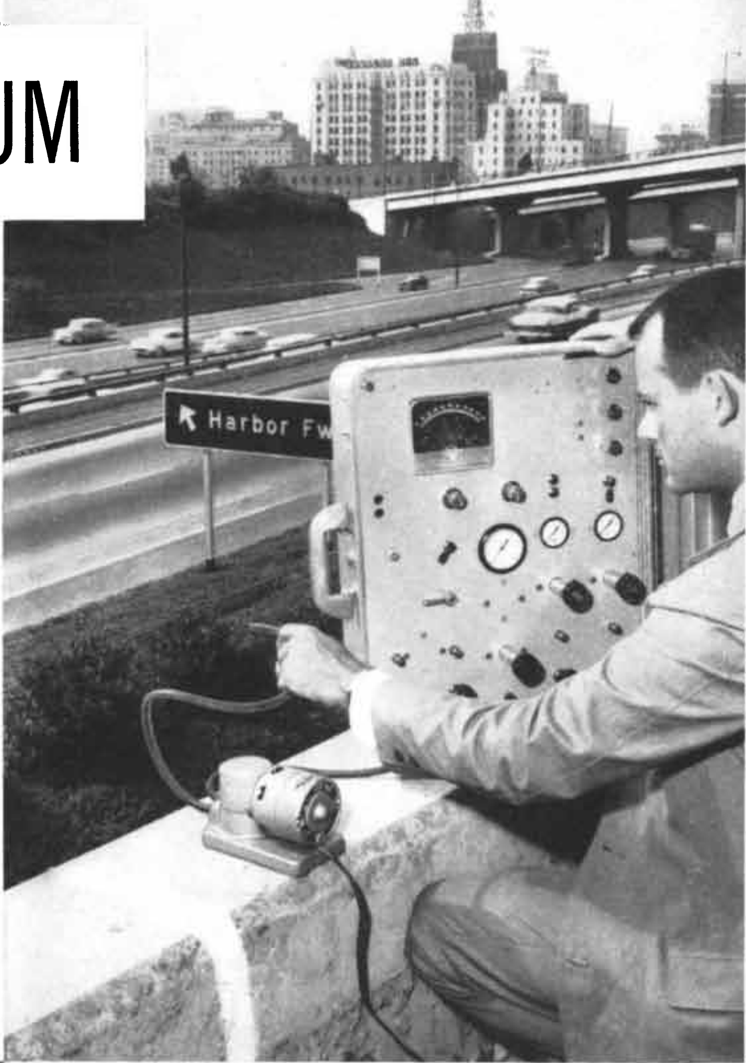
Even though most metallic crystals, and some nonmetallic crystals, may have no cracks initially, they often contain defects called dislocations which allow them to flow plastically. This makes these crystals vulnerable to crack formation through the simple mechanism illustrated on page 100. Crystals deform plastically by the sliding of one part of a crystal over the rest; rather like the sliding of the cards in a deck over one another. If the sliding occurs freely, the result is just a change in the shape of a crystal. However, if the sliding is blocked by a hard particle inside a crystal, or at the boundary between crystals, then a high concentration of stress collects at the place where the sliding is blocked. The atomic bonds at this location, now under great stress, stretch beyond their limit and rupture, forming a tiny crack.

Once a crack is well started it takes very little force to carry it through to a complete fracture. Since the force depends on the length of the crack, a specific case must be examined in order to state how much force is involved. For example, consider a plate of steel that is six inches wide and a quarter of an inch thick. Suppose that it has a two-inch crack running into one side. Then the force required to make the crack run the remaining four inches would be only about 400 pounds. Without the aid of the crack it would require a force of 500,000 pounds to pull the plate apart if it were made of the best commercially available steel, and a force of about 10 million pounds if it were made of ideal steel. It is a large leverage effect like this that makes it possible for a rela-



ENHANCED CRACK GROWTH may result when foreign atoms (*colored disks*) react with the atoms on newly exposed wall surfaces of a growing crack. In the reaction the interatomic bonds of the surface atoms break and new molecules (*linked colored and gray disks*) are formed. When new molecules are bulkier than atoms of solid, they push farther apart the walls at crack vertex.

THE P-E SPECTRUM



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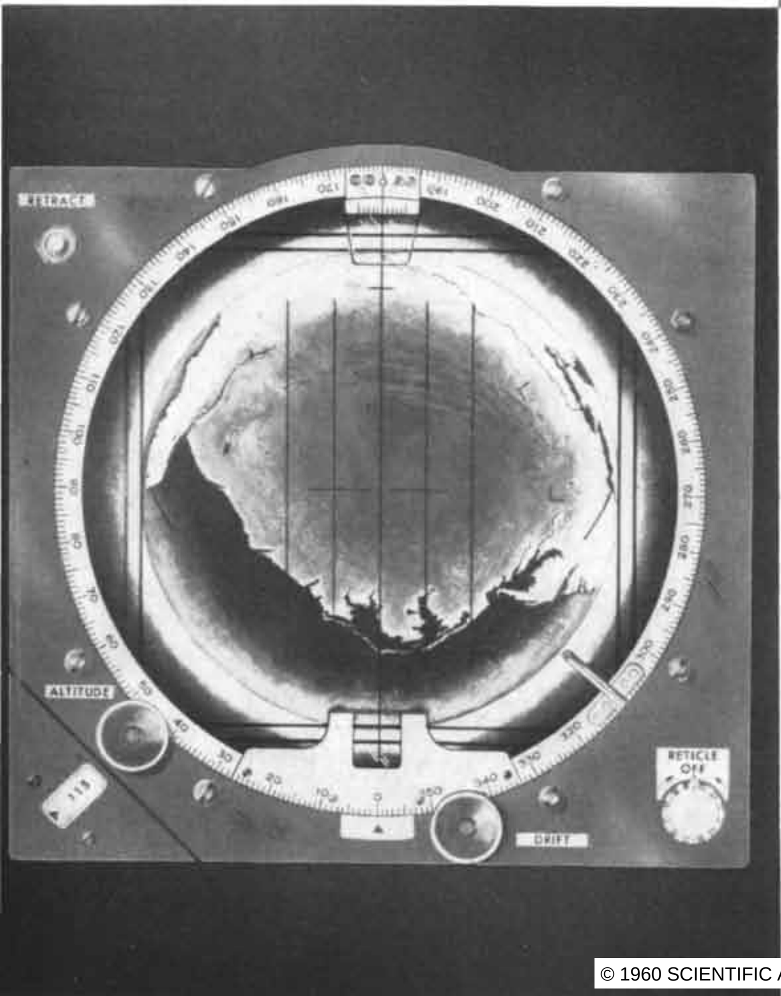
NEW PORTABLE INSTRUMENT DETECTS HYDROCARBON TRACES IN ATMOSPHERES AND GASES

Traces of hydrocarbons and many other organic vapors in the atmosphere or in gases can be detected rapidly and easily with a new instrument costing less than one-third that of conventional equipment. This Hydrocarbon Detector, developed by Perkin-Elmer, is a self-contained portable unit. It is suitable for monitoring air pollution or lower explosive limits of atmospheres, and can also serve as a leak or impurity detector in lab, field or processing systems.

Such organic compounds as hydrocarbons, aldehydes, ketones, amines and alcohols are determined when present in concentrations as low as 0.1 parts per million. There is no interference from common backgrounds — water vapor, oxygen, nitrogen, CO_2 and rare gases. Response time is less than two seconds.

Heart of the novel device is the Flame Ionization Detector, recently incorporated in Perkin-Elmer's gas chromatographic instruments. Its principle: A metered quantity of sample is exposed to a hydrogen flame in an enclosed chamber. Combustibles are ionized to effect changes in current flow in a surrounding electrical field. These changes are proportional to the sample's total organic carbon content. Results are read out on Detector's meter or an attached milliamp or millivolt recorder.



MERCURY ASTRONAUT WILL CALCULATE POSITION WITH UNIQUE PERISCOPE SYSTEM

The Mercury space capsule will bear man around the world in some 90 minutes — a far cry from Jules Verne's 80 days. To solve the difficult problem of determining his position quickly and accurately, the Astronaut will have a unique periscope system designed and built by Perkin-Elmer for the McDonnell Aircraft Corporation, prime contractor for the National Aeronautics and Space Administration's Project Mercury, Manned Orbital Space Flight Capsule.

The system will present its information on an 8″ screen showing, at orbital altitude, a 1,700-mile-diameter area of the earth. An optional altimeter which measures this diameter as displayed on the screen will give the Astronaut his altitude.

For navigational purposes, other indices will measure the angle made by the sun or moon with the longitudinal axis of the capsule, its position above the earth's surface, capsule attitude and drift angle. Thus, if the automatic reentry control system malfunctions, the Astronaut can use the periscope to determine when to fire retrograde rockets to slow the capsule to safe reentry speed.

* * * *

Perkin-Elmer has professional openings in analytical instrumentation, infrared, reconnaissance and electro-optical systems. Write Mr. Russ Byles, Perkin-Elmer Corp., 915b Main Avenue, Norwalk, Connecticut.

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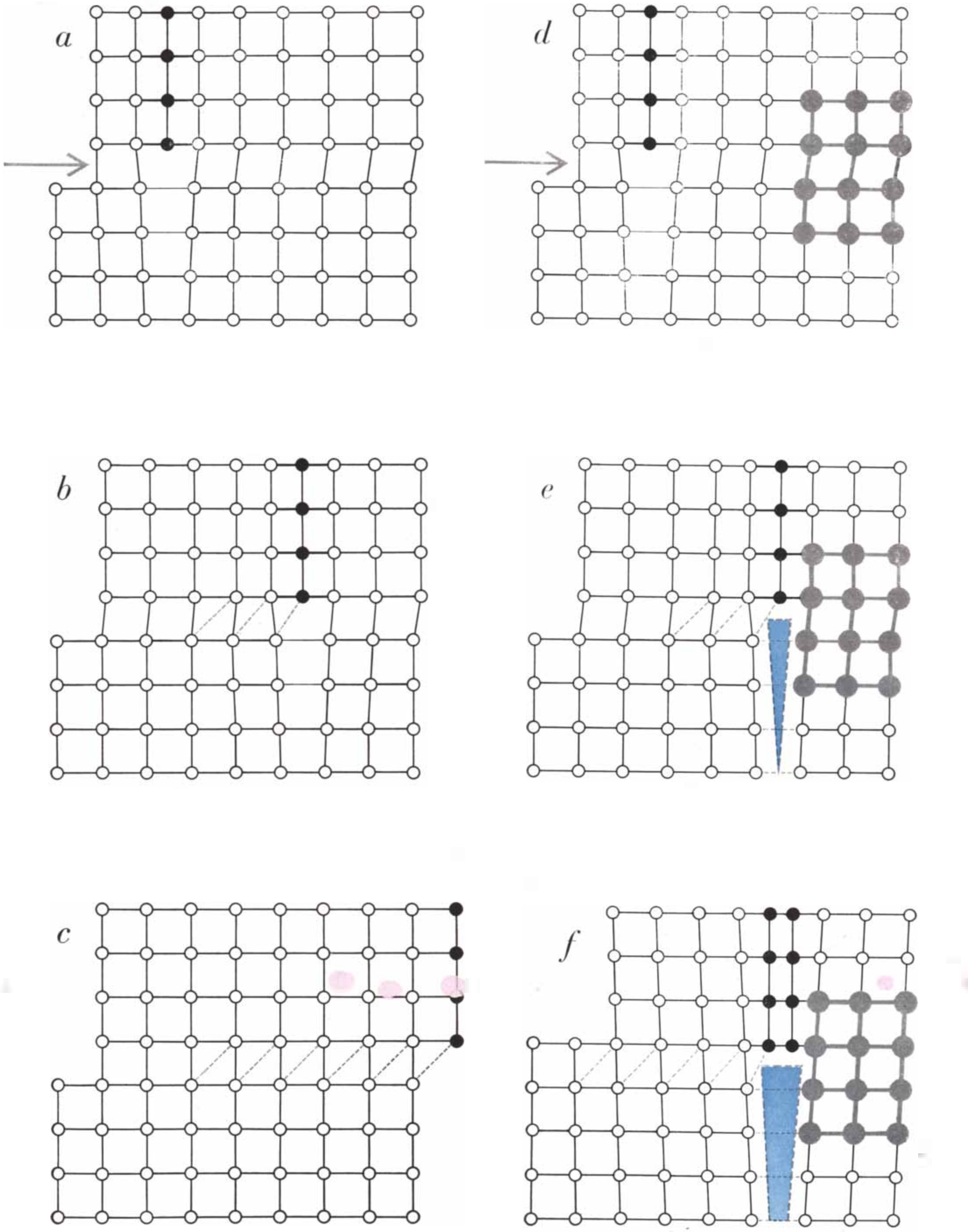
ANALYTICAL INSTRUMENTS • MILITARY SYSTEMS
FINE OPTICS • PRECISION ELECTRONIC COMPONENTS


a
d
b
e
c
f

tively small force to crack an entire ship in two.

Although plastic flow can be detrimental to the strength of a material if it is blocked and thus leads to crack formation, it can also be beneficial. By relieving the stress concentration at the tip of a crack, plastic flow can greatly increase the force required to make a crack run. But this benefit is dependent upon temperature: as the temperature decreases, the tendency to flow also decreases. When plastic flow is inhibited, unrelieved stress builds up at the vertex of the crack and more readily stretches the atomic bonds there to the breaking point. Thus as resistance to flow increases, resistance to cracking decreases [*see illustration on next page*]. Some materials, such as ordinary steel, are normally resistant to cracking, but become highly susceptible to it at low temperatures. This temperature effect caused most of the trouble with wartime ships. In southerly waters there was no problem, but during the winter in northern waters the hulls often cracked under shocks from heavy seas. Sometimes a crack ran instantly through the plates of a ship; at other times a crack remained dormant and caused serious damage later.

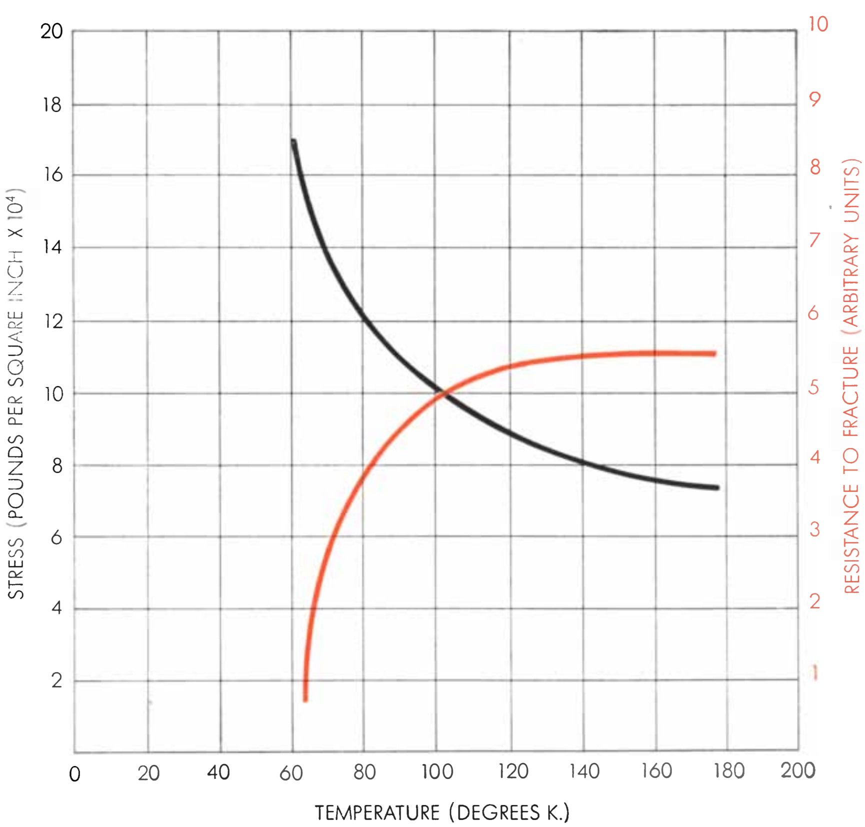
Fracture usually occurs so rapidly that the unaided eye cannot observe it. A skilled glazier, however, can make a crack creep slowly through a piece of glass by applying just the right force. If he increases the force only slightly, the crack quickly accelerates to a high velocity. During the cleaving of a diamond, five million to 50 million atomic bonds may be ruptured in a millionth of a second. One way of measuring the high velocities at which cracks can travel is to photograph them with a high-speed motion-picture camera; the dis-

PLASTIC SHEARING in crystal lattice is frequent source of fracture. Illustrations *a*, *b* and *c* on opposite page show successive displacement of atom rows induced by an applied force (*arrow*) and facilitated by a dislocation: an extra half-plane of atoms in the lattice (*black disks*). Broken lines indicate successively ruptured bonds. Illustrations *d*, *e* and *f* show same events blocked by strongly bonded group of impurity atoms (*gray disks*) in the crystal lattice. Blocking causes concentration of stresses which may open crack (*colored area in e*). Second shearing event (*f*) enlarges crack by pushing another dislocation against the obstacle. Complete fracture soon follows.

tance the crack travels in the interval between pictures gives its velocity. A second method is to make the crack itself trip timing devices. The test material is painted or plated with a grid of very thin metallic strips, each of which is part of the circuit of an electronic stop watch. As the lengthening crack successively breaks the metallic strips, interrupting the stop-watch circuits, the velocity of the crack is recorded.

Cracks have been clocked at velocities approaching that of sound: about 15,000 feet per second in solids such as glass and steel. The speed of sound is, in fact, the theoretical limit of the speed at which a crack can run, for this is the maximum speed at which the applied force can be transmitted to the crack. The velocities at which sound travels and an applied force is transmitted in a material are both limited by the elasticity of the interatomic bonds—not, as might be expected, by the magnitude of the force or the loudness of the sound. If a crack is already moving at the speed of sound, its velocity cannot be increased by a sudden increase in the applied force, because the increase in the force, transmitted at the same maximum speed, cannot overtake the crack. The crack thus never "learns" that the force has been increased, and so it cannot be driven faster than sound.

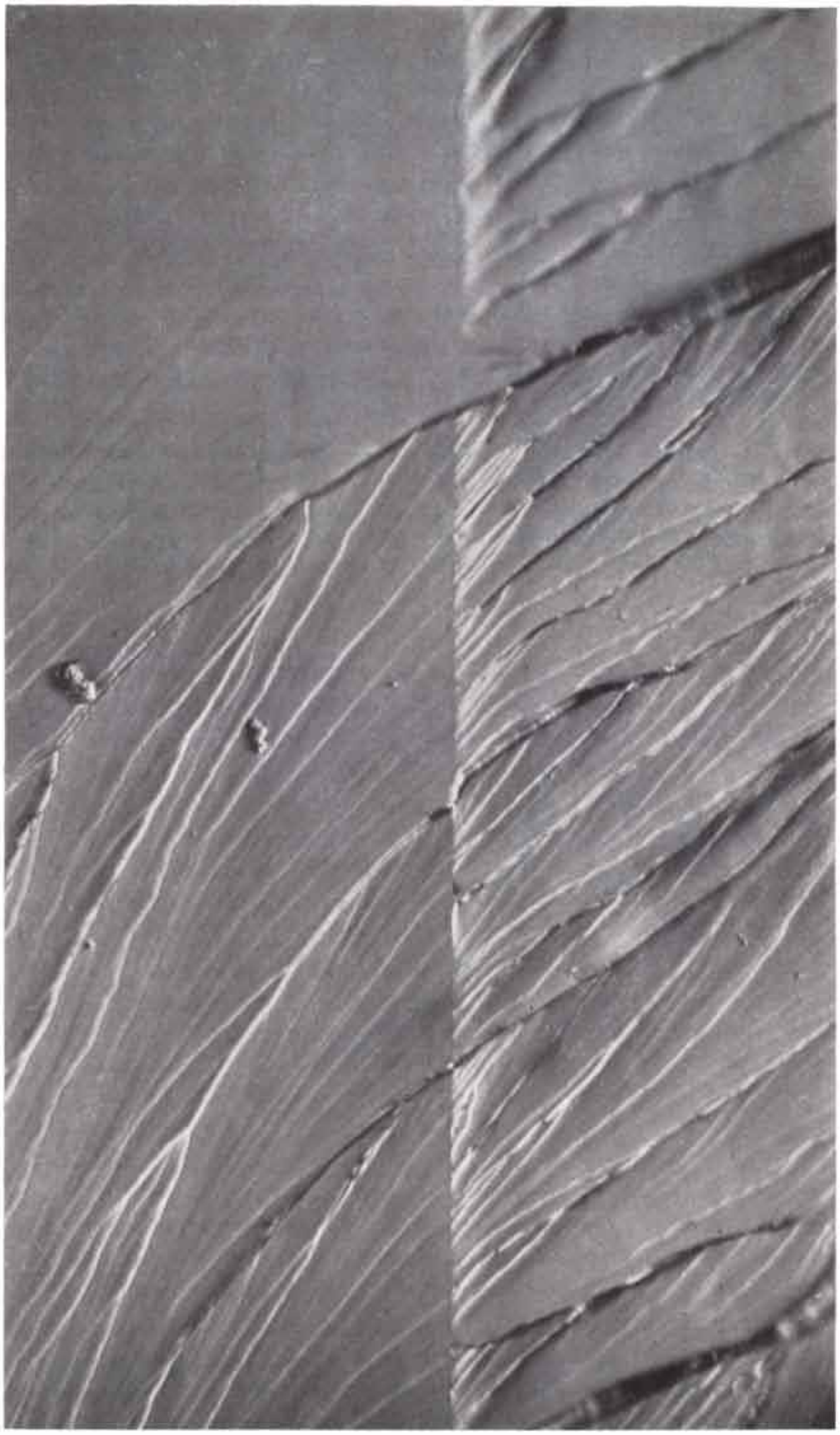
"Sudden" and seemingly inexplicable fractures are often the culmination of long series of discrete steps. A sheet of glass, for example, may support a load for a long time without apparent damage and then break without warning. In many such instances corrosion abets the fracture mechanism. The load does not exert sufficient stress to fracture the glass outright, but only exerts enough to open the invisible cracks in its surface. Then atmospheric water-vapor lays a thin film of moisture on the glass. The smooth surface resists penetration, but as the water reacts with silicon-oxygen bonds within a crack, it breaks those bonds and forms reaction products that have a larger volume than the glass. The reaction products act as a wedge, spreading the crack-faces apart. This stretches the bonds at the vertex of the crack further, encouraging the next reaction event to occur. Hence the process is both self-sustaining and self-accelerating. In time the combined effect of applied stress and increasing crack-leverage allows propagation of the crack without the aid of the



TEMPERATURE INCREASES FRACTURE RESISTANCE (*colored curve*) of steel by allowing plastic flow (*black curve*) to take place more readily. By relieving the stresses concentrated at the leading ends of cracks, plastic flow inhibits further lengthening of cracks.

wedging effect of the chemical reaction. The crack, which has been advancing a few atom-diameters at a time, now surges forward at a speed approaching that of sound, and complete fracture is the result. The same sequence of events underlies the so-called static fatigue fractures that occur in other materials.

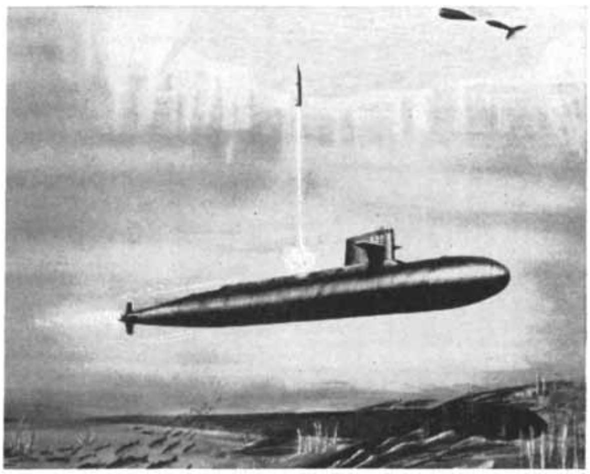
From such understanding of what makes cracks start in materials and move through them it may soon be possible to develop materials with greater resistance to fracture. This will be a rich return on a few years of fundamental research.



TEXTURE OF A CRACK WALL changes as crack crosses the boundary between two crystals of an iron-silicon alloy magnified 1,000 diameters in this photomicrograph by J. R. Low. Following cleavage plane of crystal at left, crack leaves a relatively smooth path. Unable to follow cleavage plane of differently oriented crystal at right, it leaves a jagged path.

CREW EDUCATION in operational procedure includes rundown on Navigation Control Console and NAVDAC—Sperry computer which cross-checks a dozen systems, compares references, records speeds, integrates all data for precise positioning of submarine.

POSSIBLE LAUNCH-SITE: UNDER THE ARCTIC ICE-PACK. Nuclear subs will be able to stay submerged, navigate for months without refueling, launch Polaris under water. Range places new demands on navigational resources and capabilities.



FULL-SCALE SUB SIMULATOR duplicates complex navigational equipment that will guide actual Polaris submarines. To fit systems in restricted space, everything from cabling to 62-ton Gyroscopic Stabilizer must be "engineered" into the hull.

"Dry Run" For The Missile-Launching Subs

Aiming the 1200-mile Polaris missile from a submerged nuclear sub will pose a delicate navigation problem. Engineers are solving it in a unique "underseas" laboratory.

ONE OF A SERIES:

THE STORY BEHIND THE STORY
of Sperry Marine Division

The Navy's goal of "Seapower for Peace" is nearer with each step towards operational capability of the new missile-carrying submarines. When armed with Polaris missiles, these subs will represent an unprecedented counter-punch capable of reaching targets 1200 miles away, from anywhere in the world's oceans.

The Polaris concept places critical demands on the art of navigation. A single degree of error can result in a 17-mile error in a thousand-mile range. To Sperry's Marine Division—appointed by the Navy to Navigation Systems Management of the newest class of Polaris submarines—is assigned the job of assuring highest possible system accuracy.

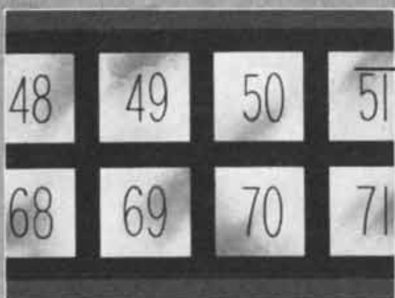
Working with the Navy's Polaris experts, Sperry engineers are installing, operating and evaluating instruments and systems for the Polaris at Sperry's "Navigation Island"—a shore-based replica of the navigation center in the Polaris submarines. Here installation and operating problems and techniques, maneuvers, emergencies, even the stars for celestial navigation, are "shot" under realistic conditions.

One system is Sperry's NAVDAC (Navigation Data Assimilation Center)—a computer which analyzes information fed to it from the navigation equipment that will eventually position the Polaris subs for missile firing. Basic to a number of the subs is Sperry SINS (Ship's Inertial Navigation System) equipment. These and other advanced systems are being evaluated and refined.

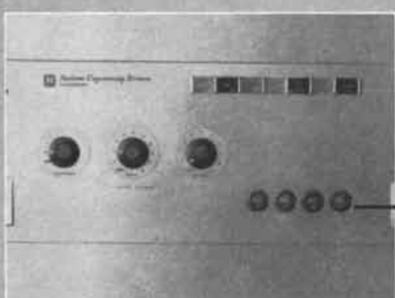
With the Navy's foresight in "interlocking" all aspects of the Polaris program . . . and with the cooperation of the many leading industries which are contributing . . . the Polaris subs will soon be operational. Marine Division, Sperry Gyroscope Company, Division of Sperry Rand Corp., Syosset, New York.

SPERRY

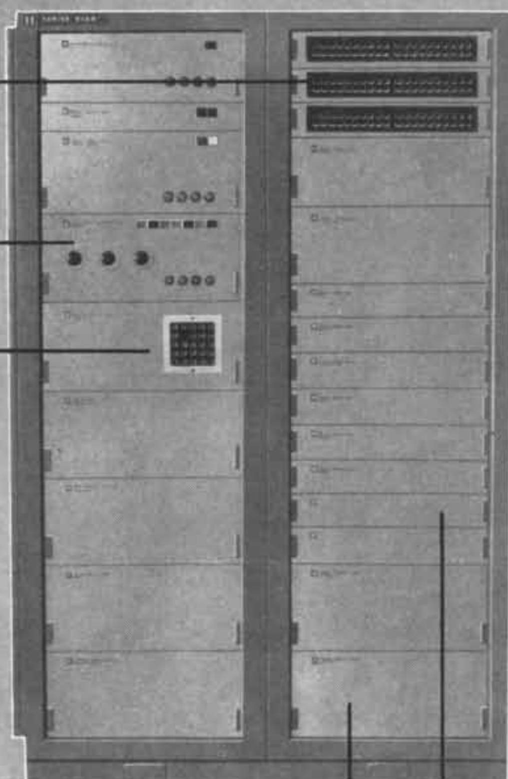
New packaged

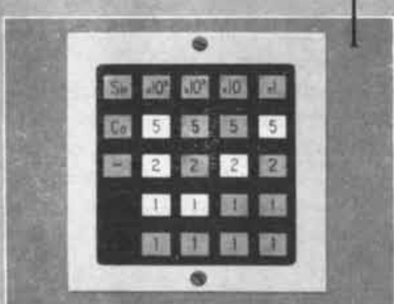


THREE 40-POINT ANNUNCIATORS make it easy for the operator to tell at a glance which variables are off-normal.

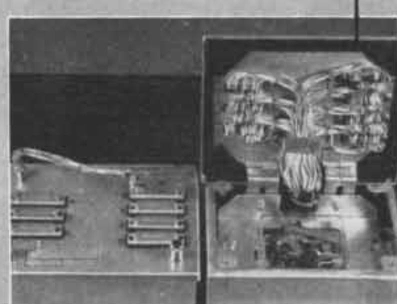


DIGITAL VISUAL DISPLAY and variable selector switches make it easy to select any single variable and watch all trends and changes continuously.





SERVICING IS SIMPLIFIED by an indicator-light panel showing the completion of each step in the analog to digital conversion. The sequence programmer can be changed from automatic to hand advance to permit operator to check each step.



UNIQUE INPUT SELECTOR is unusually dependable because of its sealed, oil-immersed construction. Servicing is normally limited to visual inspection every 6 months. Drawers pull out so voltage checks can be performed without shutting down system.

PINBOARD PROGRAMMING adds flexibility. You can change the logging or scanning sequence at will . . . substitute one type of input for another. Range, span, and zero adjustment are set by inserting pins in their proper places. No calculations are required. The pinboards are pinned in familiar units of measurements.

Honeywell logger-scanner

...*accurate within ± 0.1% of reading*

...*pinboard programming for maximum flexibility*

Here's a standard, all-purpose 120-point logger-scanner system with features formerly found only in more expensive, custom-designed equipment . . . the first of several packaged logger-scanners being introduced by Honeywell. It offers the ultimate in accuracy, flexibility, dependability and simplicity of maintenance. Wide ambient temperature operating limits—60 to 120°F—eliminate the need for special air conditioning equipment.

The Series 3120 accepts signals from primary measuring instruments—thermocouples, flow, pressure or other transducers. It measures these signals, digitizes them, and prints their values in immediately usable form. A thermocouple reference oven can be supplied to accommodate three types of thermocouple inputs—types T, J, and K—which are automatically linearized over their entire range to within 0.1% accuracy.

The operator can select either automatically or manually initiated logging cycles. He can set the system to log all variables automatically at preset intervals, or manually energize the system to operate on demand, between logging cycles.

Between logging cycles, the system can scan off-normal alarm points—high, low or both—at a rate of 7 points per second. Upon detecting an off-normal point, the system sounds an alarm, lights a point-identification light, and prints the time, point number and off-normal value on adding machine tape. During log cycles, off-normal points are printed in red on the log sheet.

Get complete details from your nearby Honeywell field engineer. Call him today . . . he's as near as your phone. MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.

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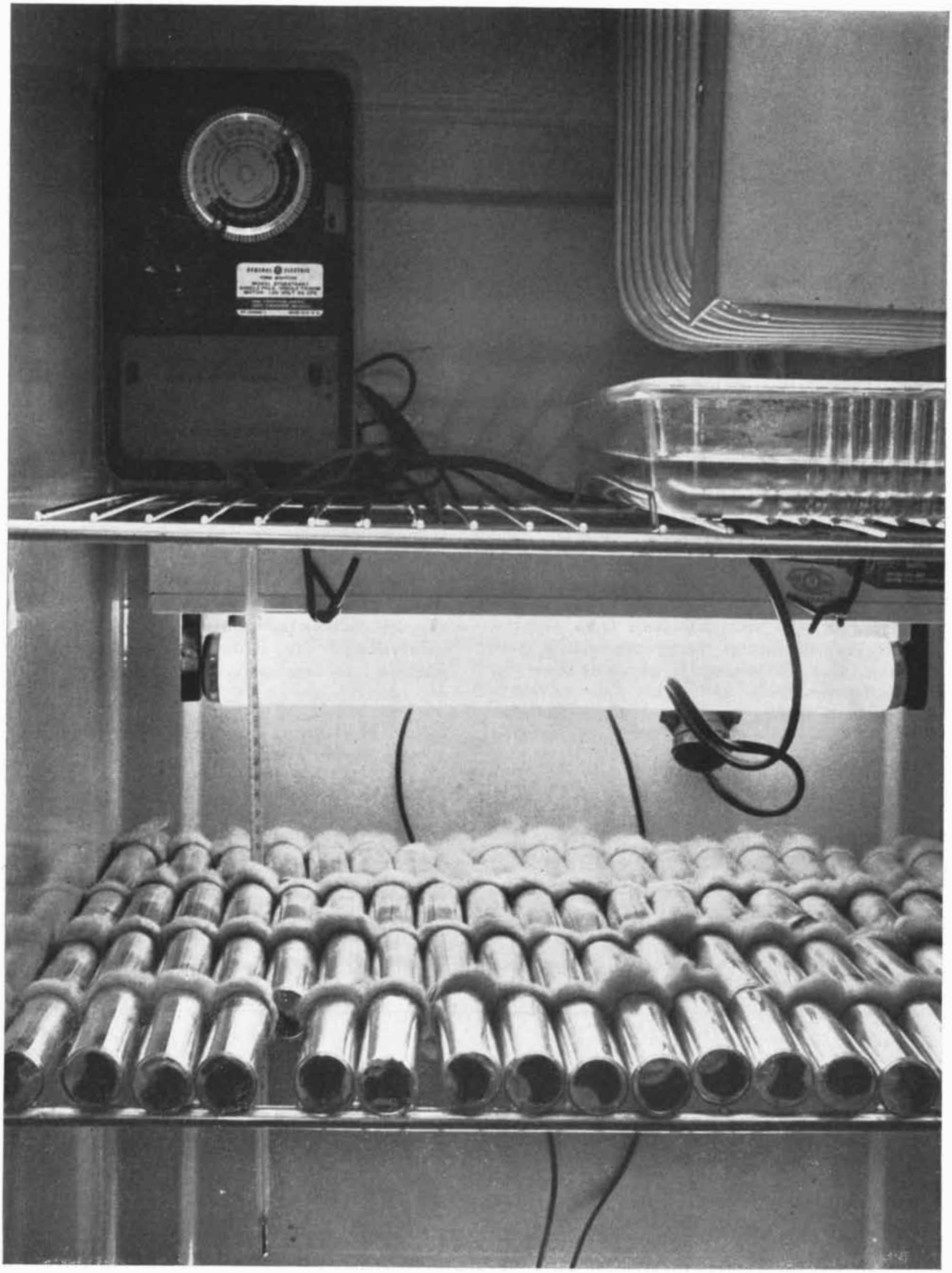
TWO TYPEWRITERS permit a single line log allowing columnar comparisons. Separate alarm printer records all off-normal variables.

STANDARD MODULAR COMPONENTS are assembled on chassis mounted as individual drawers in relay racks. All drawers are connected by plugs for easy servicing.



EFFECT OF ARTIFICIAL DAYS on the life cycles of insects can be determined by rearing them in an incubator like this one in the author's laboratory at the University of Wisconsin. Here a generation of corn borers (in glass vials) develops in a constant-temperature environment. Day length is controlled by the timer at top left, and fluorescent lamps provide the illumination.

Insects and the Length of the Day

How is it that many insects prepare for winter well before the end of summer? They do so not primarily in response to temperature change but to the seasonal variation in the cycle of daylight and darkness

by Stanley D. Beck

On the barren branches of trees and shrubs, or under the litter of fallen leaves and withered groundplants that cover the frozen soil, thousands of insect species hibernate through the winter in a dormant state called diapause. They begin to settle into this state, interrupting their busy feeding and reproductive activities, long before the end of summer. Since the weather at that time is still warm, diapause is not a reaction to unfavorable temperature. What mechanism explains this biological anticipation of the oncoming winter? Since the middle 1930's biologists have been accumulating evidence that diapause is a response to change in the length of the day as the summer wears on.

Day length, or photoperiod, affects the physiology of both animals and plants. It controls the diurnal change in the shell color of the fiddler crab and the seasonal variation in the fur color of the snowshoe hare. It sets the schedules of reproduction and migration in birds. Botanists have long recognized its important effect on plant life and speak of "long-day" and "short-day" plants; commercial florists commonly produce flowers out of season by forcing them with artificial light.

The gradual change in the photoperiod throughout the year forms the most precise basis known for the timing of biological events. At any given point on the earth's surface the length of the day depends upon the latitude, or distance from the Equator, and the time of year. It thus provides an organism with exact information on the advance of the seasons. But this information cannot by itself explain the response of animals and plants to photoperiod. Some sort of biological clock must be built into the organism itself. Photoperiod merely sets the clock.

For the study of photoperiod and internal biological clocks, insects are excellent subjects. They have exploited the possibilities of this arrangement to the full in the course of their evolution. They are small, numerous, fast-growing and, most important, dramatically sensitive to differences in day length. Research on insects has disclosed a number of promising clues to the mysterious relationship between the length of the day and the processes of growth.

The present status of investigation in this field can be illustrated by experiments on three insects: a silkworm in Japan, an aphid in England and a caterpillar in a Wisconsin cornfield. The silkworm is an example of a short-day insect. It passes the winter as an egg, which hatches into a larva in the spring, when the days are relatively short. The larva metamorphoses into a pupa and then into an adult moth, which lays eggs that hatch in the early summer, when the days are longest. The moths from these eggs lay eggs in the fall. But the late-summer eggs do not hatch immediately; they pass the winter in diapause and hatch in spring, perpetuating the cycle [*see illustration on next two pages*].

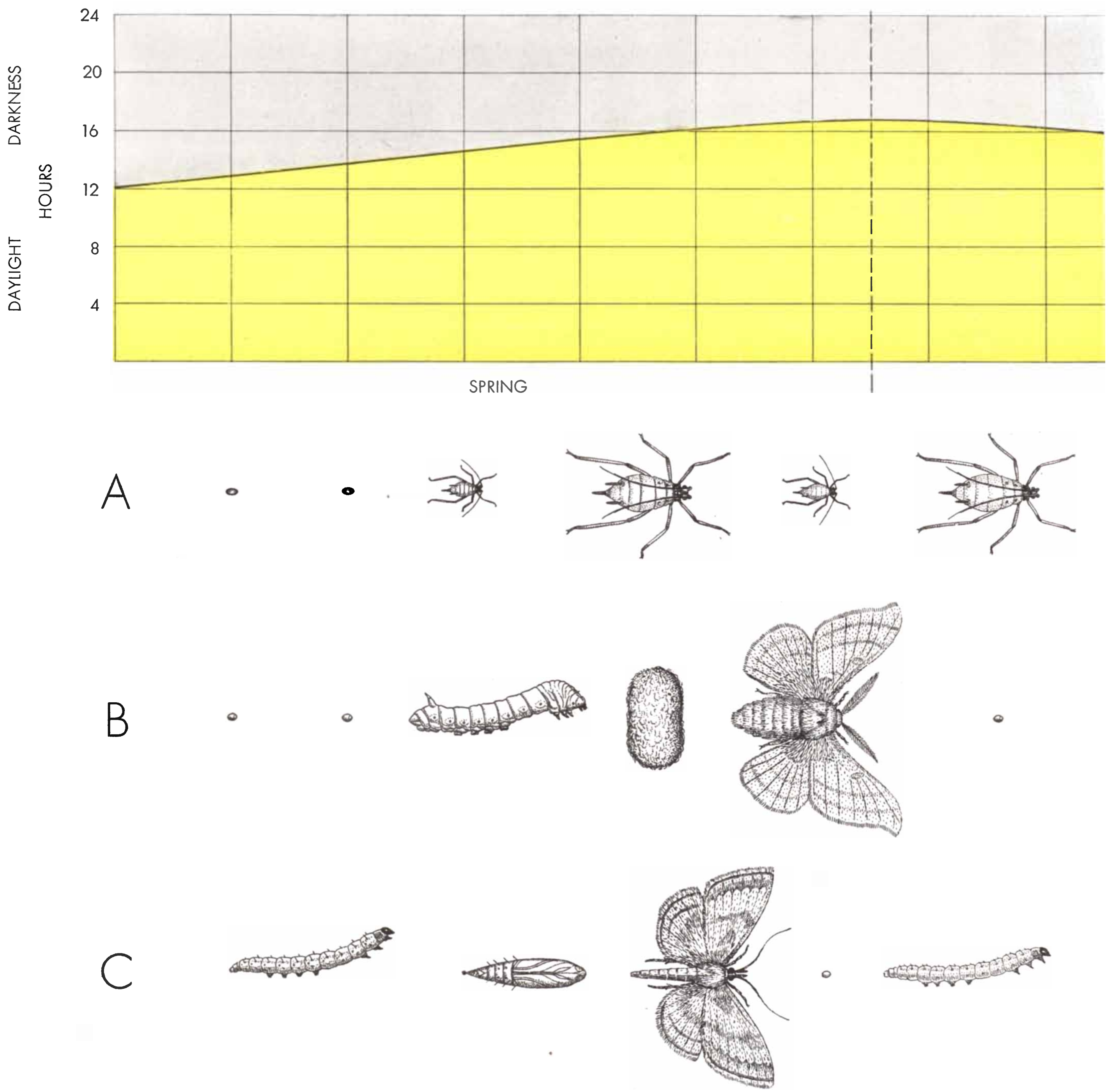
In a classic study in 1933 Makita Kogure of Kyushu University showed that the cycle could be reproduced in the laboratory by varying the photoperiods under which the insects were raised. Kogure found that silkworms reared in darkness or in short-day periods (about 12 hours of light per day) grow into moths, the eggs of which developed without interruption. So long as the eggs and larvae were kept under short-day conditions, the moths reproduced generation after generation without diapause. On the other hand, when he reared a generation of eggs and larvae under long photoperiods, the adult moths produced eggs that went into diapause, as in nature. Embryonic development began in these eggs but ceased abruptly when the embryos reached a particular stage of growth. The eggs can remain in this state of suspended development indefinitely. They resume growth and go on to hatch only if they are chilled to near the freezing point for about 40 days before being placed in an incubator. Thus the photoperiod to which the eggs and young larvae are exposed determines whether or not the eggs of the next generation will go into diapause. Photoperiod seems to have no influence on the larger larvae and the moths.

When silkworm larvae are reared under long photoperiods, an imperceptible physiological change apparently takes place in the young females. The change asserts itself when they approach maturity and begin to form egg cells. At that time some subtle influence is transferred from parent to egg, which causes the egg to go into diapause. A series of ingenious experiments by a group of Japanese biologists at Nagoya City University showed that the subtle influence is a hormone produced by a nerve ganglion in the head of the female silkworm larva. Because the hormone leads to an arrest of embryonic development, they called it the diapause hormone. While it seems to have no effect on the growth of the larva or the adult moth, its influence is passed on to the eggs.

The idea that a hormone transmits photoperiod information received further support from the studies of A. D. Lees at the University of Cambridge. Lees investigated the effects of photoperiod on the development and reproduction of a plant louse called the vetch aphid. Like the silkworm, the vetch aphid survives the winter as an egg. The eggs hatch early in the spring, developing into adults that produce many generations of young during the late spring and summer. But the young summer aphids do not hatch from eggs; they are produced asexually and are born alive. Nearly all of them are females that never mate, but each gives birth to 100 or so offspring. The offspring mature quickly and in turn give birth to 100 or more aphids, also asexually. This prolific multiplication continues until early fall, when, under the influence of photoperiod, a generation of sexual aphids is born. These aphids mate and lay eggs that remain in diapause until spring, when they hatch and begin the asexual breeding cycle anew [*see illustration below*].

The aphid's reproductive cycle is that of a long-day insect. Lees found that so long as he kept the aphid colonies under long photoperiods (16 hours of light per day) they reproduced asexually and continued to do so indefinitely; but when he shortened the photoperiod to about 12 hours of light per day, an egg-laying sexual generation was born.

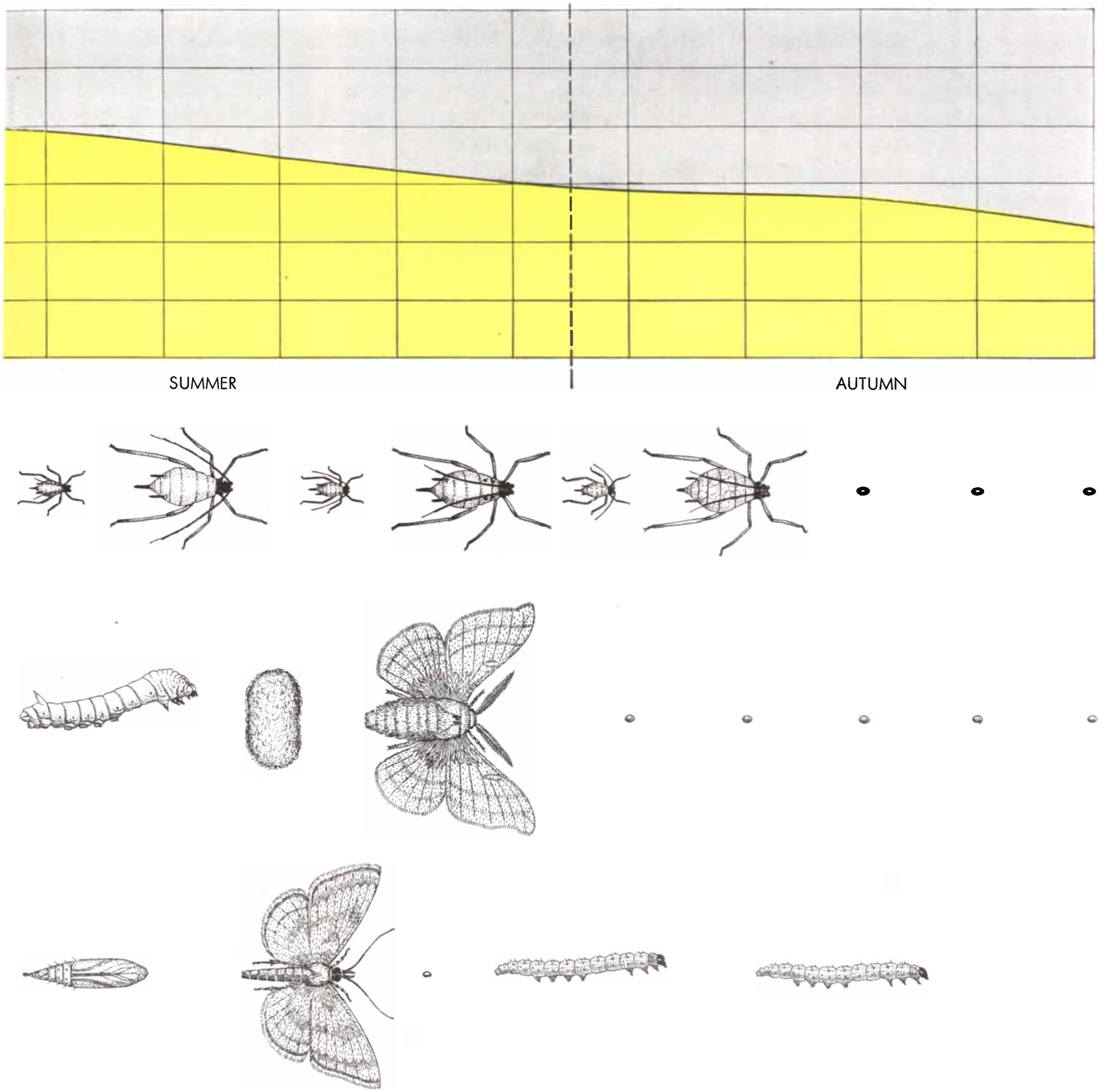
Apparently the aphid's response to photoperiod is determined early in the embryonic stages of growth. The response is already fixed in newborn aphids. This can be strikingly demon-



DAY LENGTH AFFECTS BREEDING CYCLES of three insects in different ways. The vetch aphid (A) hatches in the spring and reproduces asexually during the summer. When the days get shorter, an egg-laying sexual generation is born. The silkworm (B) also hatches in the spring, grows fat, spins a cocoon and metamorphoses into an adult moth. The moth lays eggs that develop immedi-

strated by transferring some of them from a 16-hour photoperiod to a 12-hour one. These aphids will not mature into sexual adults, but will become asexual forms that produce living offspring. The explanation for this effect lies in the fact that when an aphid is born, the embryos of the next generation are already developing within it. The offspring of the aphids transferred to the 12-hour cycle thus develop into the egg-laying sexual form. The sensitivity of the embryo to the photoperiod to which its parent is exposed can be further demonstrated by performing the same experiment on half-grown aphids. When these aphids mature, their first few dozen young will be of the asexual type, while their later offspring will be sexual forms. This effect shows clearly that the developmental pattern of the aphid is fixed only in the early stages of embryonic growth and cannot be modified by later changes in photoperiod.

Such results raise the question of whether photoperiod influences the embryo directly, or whether, as in the silkworm, the effect is to stimulate the production of a hormone in the maternal aphid. Lees answered this question by exposing aphids to an intermediate photoperiod of 14.5 hours. He expected that a photoperiod of this length would re-

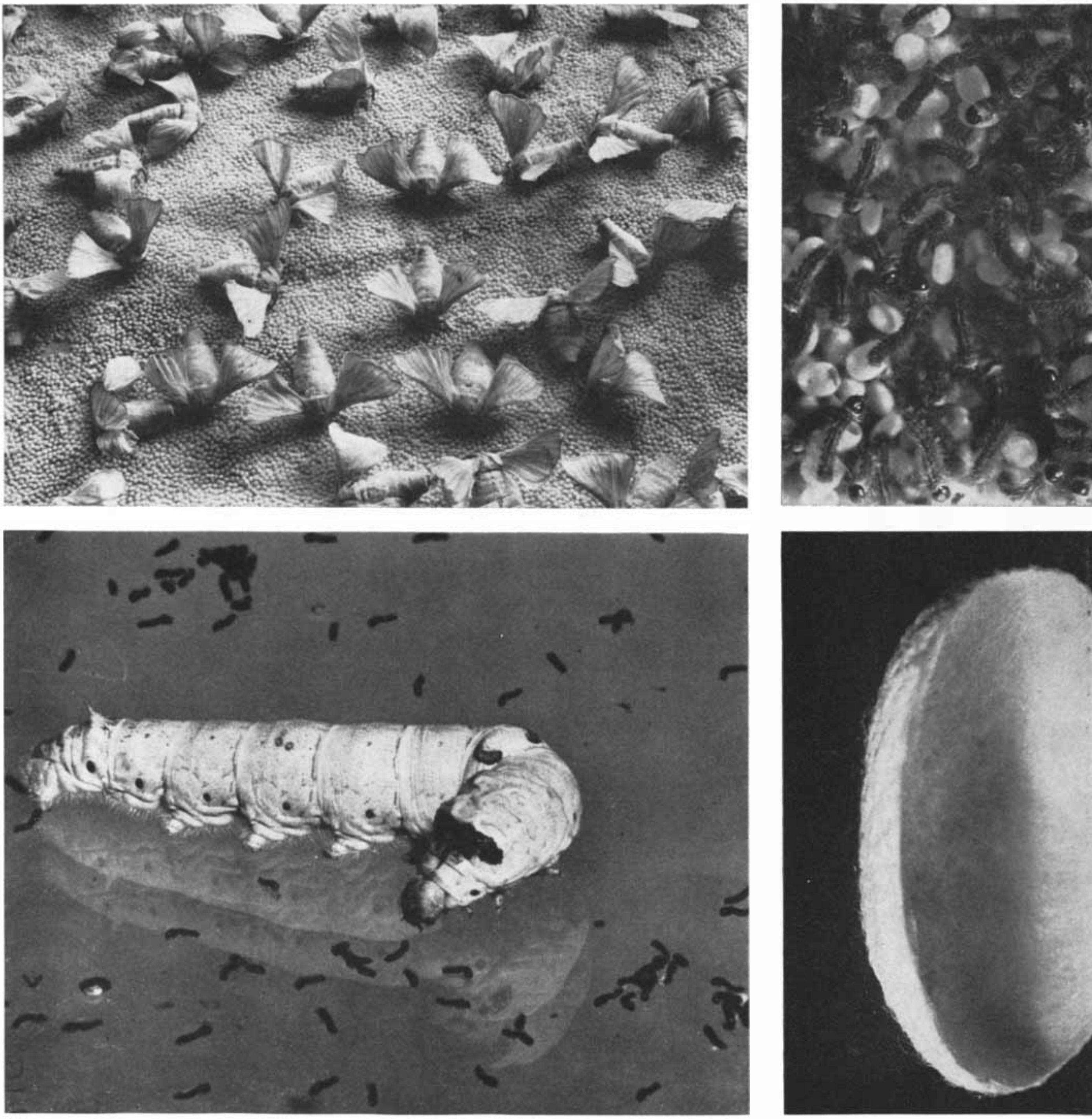


ately; the larvae hatched from these eggs become moths whose eggs do not hatch until spring. The European corn borer (C) hibernates through the winter as a mature larva; in the spring it enters the pupal stage and becomes an egg-laying moth. In early summer the moths lay eggs that develop without interruption; eggs laid in late summer, however, become larvae that hibernate until spring.

sult in the birth of a random generation in which about half the aphids would be the sexual form and half the asexual form. Although this occurred, the sex distribution was far from random: all of the offspring of any given aphid were either one form or the other. This result demonstrated quite clearly that photoperiod exerts its effect not on the embryo but upon the reproductive physiology of the maternal aphid. The outcome of the experiment also tends to support the hormone idea.

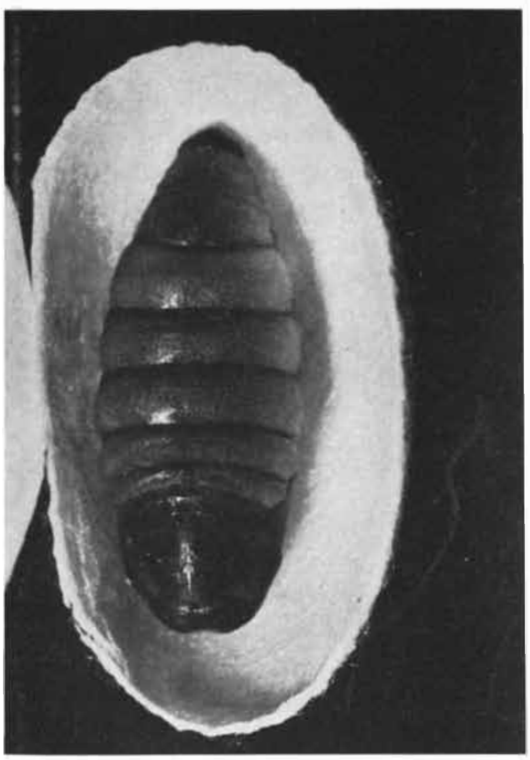
The survival value of the diapause hormones is obvious, for in both the silkworm and the aphid they stimulate the production of an egg that enables the species to endure the winter. The two insects, however, have opposite responses to photoperiod: the silkworm produces its hormone in response to long photoperiods, while the aphid produces its hormone in response to short ones. We do not yet know whether the two hormones are similar, but the fact that the reproductive organs are affected in both cases suggests that they are.

Temperature is a factor that is known to modify the photoperiod response. In my laboratory at the University of Wis-



LIFE CYCLE OF THE SILKWORM shows the effect of day length on a "short-day" insect. Eggs laid in the fall by adult moths will not hatch until spring, but those laid in early summer (*top left*) hatch immediately. The newly hatched silkworms (*top right*) eat continuously and grow to 12,000 times their original weight (*bottom left*). The giant worms then spin a cocoon and enter the pupal

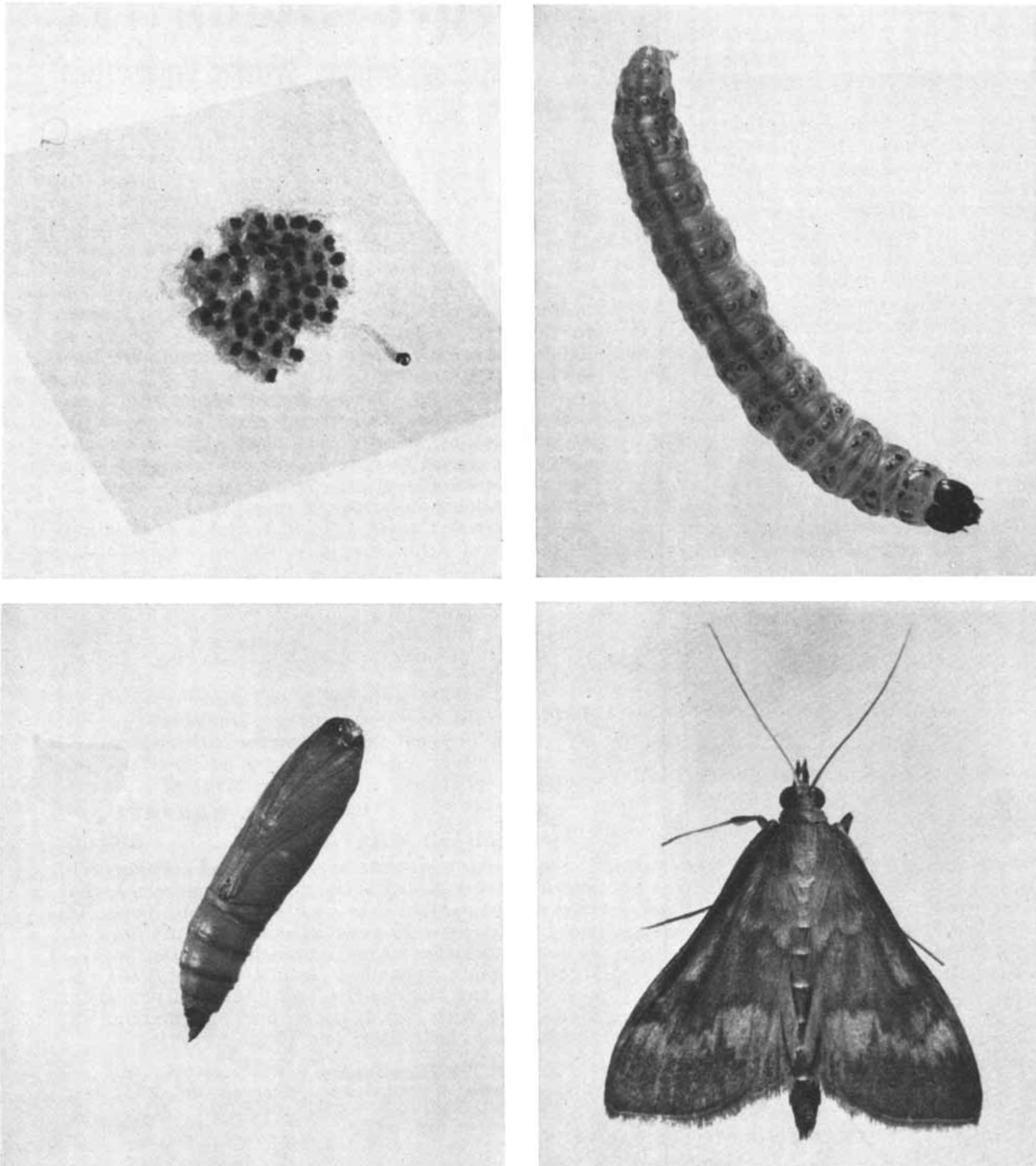
consin we have studied the effect of temperature on the hibernation of the European corn borer, a species of moth that passes the winter not as an egg, but as a mature larva. The corn borer is a long-day insect. We can rear generation after generation in the laboratory if we maintain the cultures under any of three different conditions: (1) 16 hours of light per day, (2) continuous darkness



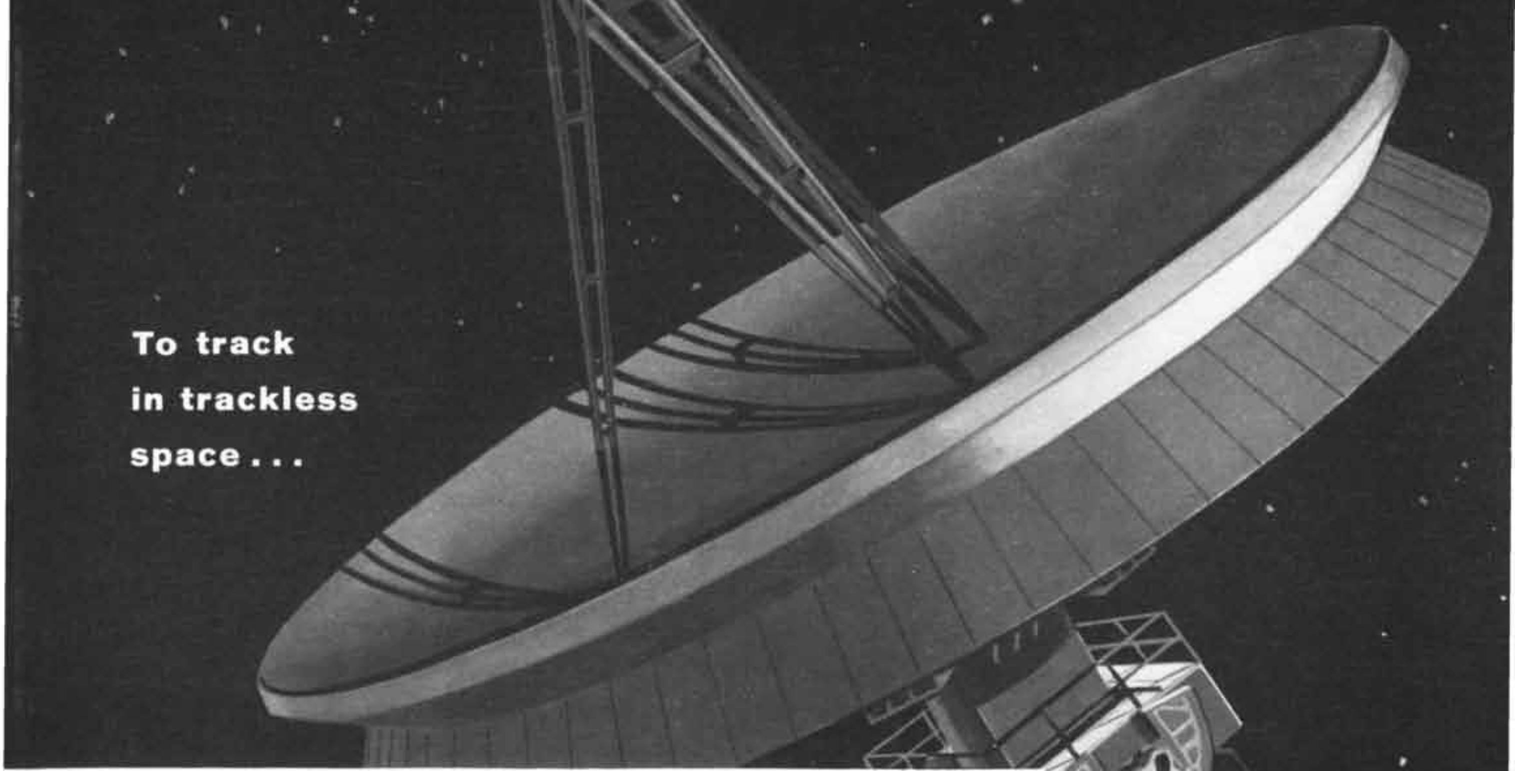
stage (*bottom right*) from which they will later emerge as adult moths. The four photographs are not reproduced to the same scale.

or (3) continuous light. In the absence of photoperiod—that is, in continuous light or darkness—temperature has only a slight effect on the incidence of hibernation. Similarly, if a batch of borer larvae are exposed to short photoperiods of from 10.5 to 13.5 hours of light per day, they will all go into diapause regardless of the temperature at which they are reared. At photoperiods of from eight to 10 hours and from 14 to 15.5 hours, however, temperature exerts a powerful influence on the incidence of hibernation: high temperatures tend to prevent it and low temperatures to increase it [*see illustration on page 116*].

This sensitivity to temperature is important in the life cycle of the borer. It explains why two generations of them are produced each season in southern corn-growing areas, while only one gen-



CORN BORER is a "long-day" insect. Eggs laid during the long days of early summer produce tiny larvae (*like the one shown with eggs at top left*) that grow to maturity (*top right*), enter the pupal stage (*bottom left*) and emerge as adult moths (*bottom right*) in a single season. Larvae hatched in late summer, however, must hibernate through the winter before entering the pupal stage. The photographs are not made to the same scale; for comparison, mature larva and adult moth are about 3/4 inch long, pupa 5/8 inch.



Philco has designed and built the world's largest 3-axis tracking antenna

The world's largest 3-axis tracking antenna was recently completed at the Philco Western Development Laboratories in Palo Alto. It will be used at one of the world-wide satellite tracking stations to receive vast amounts of scientific information from outer space. By employing the unique design feature of tri-axial mounting, this extremely accurate and complex instrument, designed and built by Philco, has complete flexibility of movement and can provide continuous coverage of telemetered information and data from satellites and missiles during any phase of flight.

At Philco you will find the skills that come from close association with the involved problems of planning, developing and implementing advanced space communications programs . . . experience that includes the design and construction of antennas of many types. Each fully meets the stringent specifications of the military and various scientific research organizations. Philco stands ready to fill your specific needs.

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This Philco 3-axis antenna stands 80 feet high and weighs over 130 tons. One of its most unique features is the 60-foot reflector—a solid aluminum skin paraboloidal structure manufactured to a tolerance of 65/1000 of an inch over its entire surface to provide maximum reception under the most severe environmental conditions. The antenna maintains its accuracy in winds up to 60 miles per hour and its mechanical efficiency in winds up to 140 miles per hour.

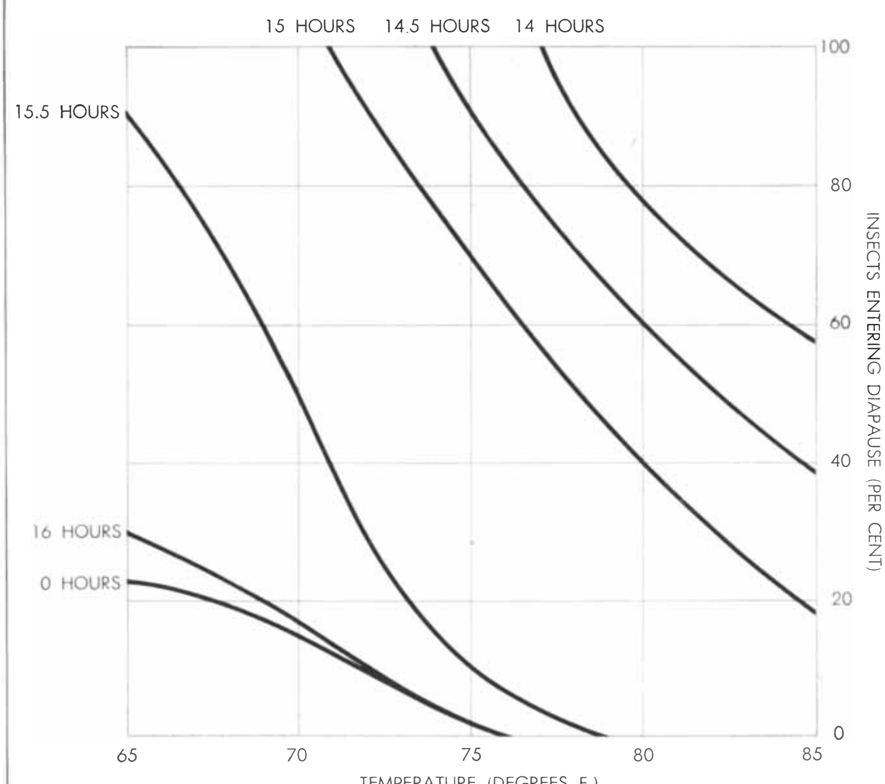
eration is produced in northern areas. If photoperiod were the only factor governing their reproduction, we would expect the opposite effect, because on any given summer day the period of daylight is shorter in the south than in the north. However, the higher temperatures of the earlier southern growing-season more than compensate for the shorter days.

In contrast to the silkworm and the aphid, which are sensitive to photoperiod only in the early stages of development, the borer remains responsive for a longer time. Present evidence indicates that it becomes sensitive in the later larval stages or is uniformly sensitive throughout the entire period of growth.

It should also be noted that photoperiod affects the members of the growing generation of corn borers, not their progeny. There is no carry-over to the next generation, as in the silkworm and the aphid. In the corn borer the earliest detectable symptom of impending diapause is a failure of the reproductive organs to develop. At a stage when the sex cells are rapidly maturing in borers reared under long photoperiod, these cells have ceased to develop in larvae reared under short photoperiods. The short-period borers still feed and grow rapidly, but the growth of their reproductive organs is arrested. Similar gonadal arrest has been observed in a number of other species of hibernating insects, including such diverse types as boll weevils and Colorado potato beetles.

In insects, as in higher animals, growth and gonadal development are controlled by hormones. Largely through the brilliant work of V. B. Wigglesworth of the University of Cambridge and Carroll M. Williams of Harvard University, the insect growth-hormone has been identified as ecdysone, which is produced by tiny glands in the insect's thoracic tissue. Insects in diapause contain no detectable amounts of ecdysone, but if they are injected with it, they soon snap out of diapause and resume normal development. It appears that the change in photoperiod somehow shuts down the production of ecdysone. How this shutdown is brought about is the question at issue. Perhaps a diapause hormone is responsible, especially in forms like the aphid and the silkworm. But if so, the insects must be sensitive to the hormone only at certain times during their lives.

Another unresolved issue is the nature of the timing mechanism that enables an insect to distinguish between a 16-hour photoperiod and one of, say,



TEMPERATURE modifies the corn borer's response to day length. The numbers at left and top indicate the length of six artificial "days" to which the borers were exposed. With days of from 14 to 15.5 hours (*top four curves*) an increase in temperature tended to prevent diapause. In continuous light or darkness (zero day length) temperature had little effect.

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12 or 13 hours. Obviously a light-receptor is required, because the insect must discriminate between light and dark to respond to photoperiod at all. Apparently the eyes are not involved, as has been demonstrated by some experiments on the Colorado potato beetle. Nor has the shielding of different parts of the insect's body located any other organ or nerve ending that is specially sensitive to photoperiod. All parts of the insect body seem equally sensitive. It now seems likely that the receptors are either numerous cells scattered over the body surface, or that they are the cells of the integument itself.

Apparently the quantity of light involved also has little to do with the photoperiod reaction, so long as the intensity is greater than a very low threshold value—usually less than one foot-candle. This suggests that no photochemical reaction is involved, for the rate of most photochemical processes increases with greater light intensity. It is possible, however, that a small-scale photochemical reaction may act as a trigger; in that case the most important cause of the photoperiod response would not be the presence or absence of light, but rather the stimulus produced by the change from light to dark, and vice versa. Each 24-hour day involves one change from light to dark and one change from dark to light, but these changes can provide no more than a series of stimuli that flip some sort of biological switch. Because different day lengths induce different responses, the switch presumably activates the biological clock. The clock measures the changing interval between stimuli and regulates the physiology of the insect accordingly.

The existence of such a clock can easily be demonstrated in the European corn borer. When we rear a batch of borers under photoperiods of 12 hours of light and 12 hours of darkness, all of them go into hibernation. The ratio of light to dark in this case is one to one. When we create an artificial 12-hour day, with a one-to-one ratio of six hours of light and six hours of darkness, none of the borers hibernates. A "day" of at least eight hours is apparently required to induce hibernation. We are now trying to identify the physiological mechanism that times this day.

Although day length exerts pronounced effects on the biology of insects as well as on other forms of life, it is not yet possible to trace a thread of coherence through the tangle of observations. But it is clear that the riddle of photoperiod conceals important clues to the physiology of insect growth.

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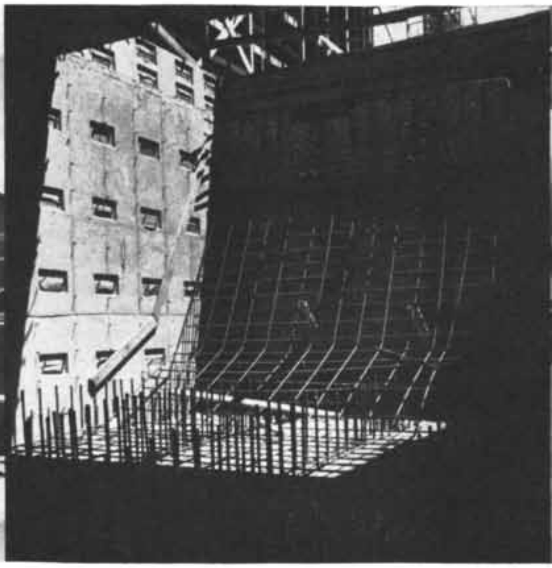
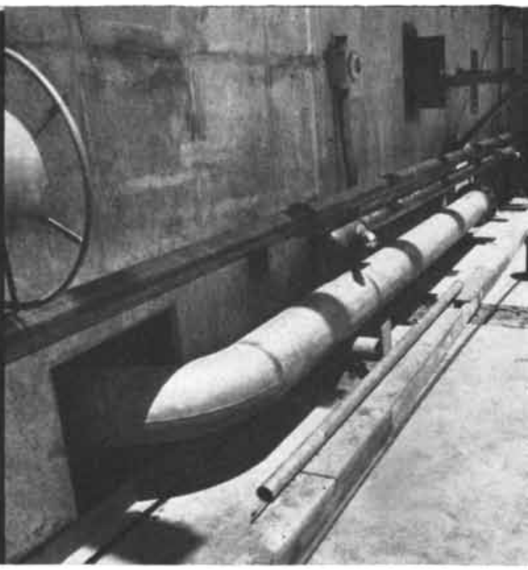
Somewhere east of Laramie, on one of Wyoming's plains, you'll find the strangest government housing project ever built. Six concrete and steel buildings are being constructed to house Atlas missiles. The site is one of the operational intercontinental missile bases to be operated by the Strategic Air Command. This base is being constructed on the surface. Follow-on bases will burrow deep into the earth. In all these systems, the Air Force puts much emphasis into ground support equipment. Virtually all steels required can be purchased from one firm—United States Steel. Whether it's carbon

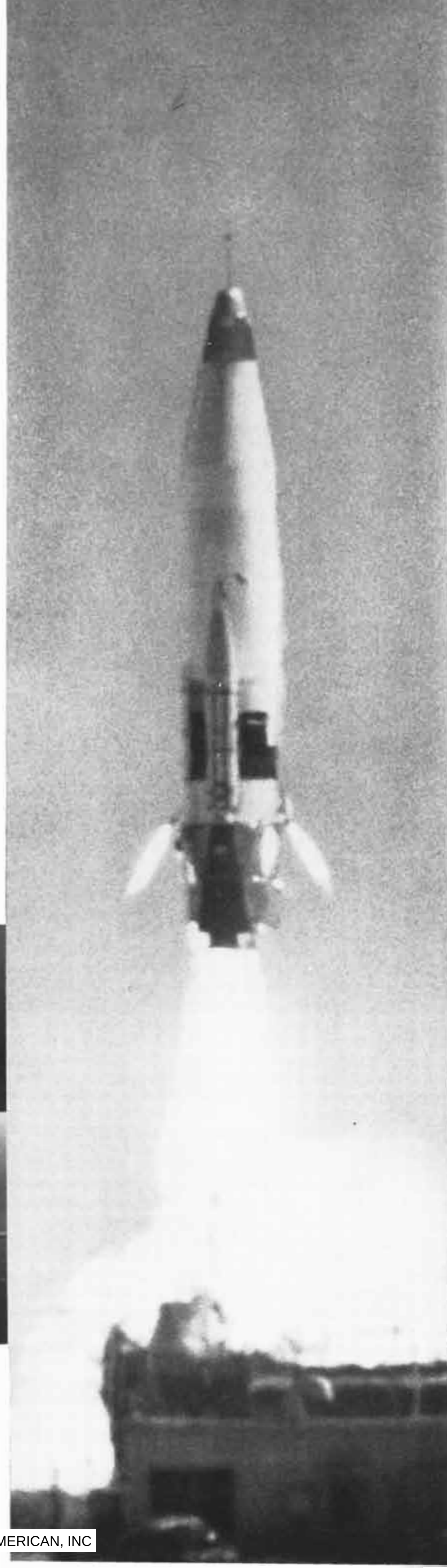
The U. S. Army Corps of Engineers is constructing this operational intercontinental missile base in Wyoming. In front of the partially completed Launch and Service Buildings are Col. Sidney T. Martin, in charge of construction, and Maurice K. Graber, a construction engineer for the Corps.

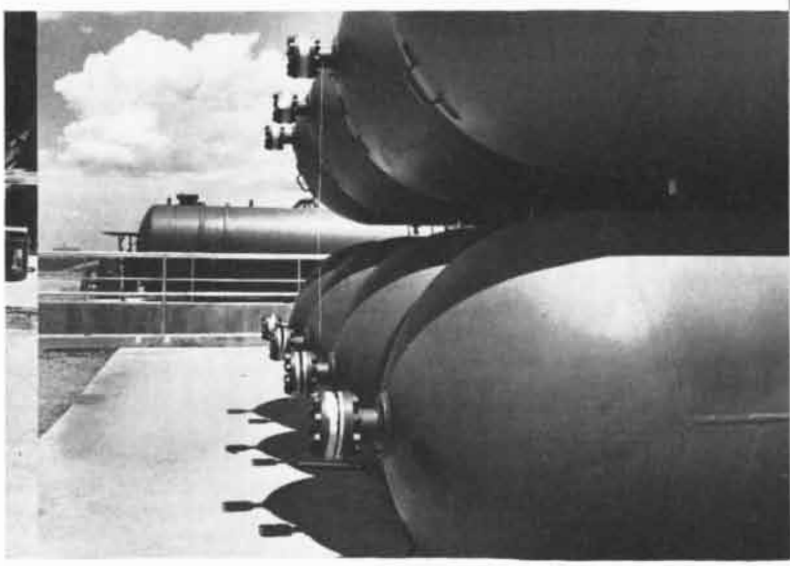


This is the inside of the blast pit of one of the launcher buildings. In all six of these buildings there are 1,040 tons of structural steel, 1,950 tons of reinforcing steel, over 48,000 tons of concrete aggregate, blocks and cement, and 8,040 tons of mechanical steel items.



Fuel lines and process piping are Stainless Steel and operate at pressures up to 15,000 psi. The pipes are kept almost surgically clean to prevent contamination of fuel and subsequent malfunction. Vapor degreasing and chemical cleaning processes are used on the pipes.





The Atlas is powered by a cluster of liquid propellant rocket engines that burn liquid oxygen and RP-1, a kerosene-like hydrocarbon fuel. 192 pressure tanks fabricated from alloy or Stainless Steel plate at this site store liquid and gases—liquid oxygen and nitrogen and helium gases which are used to inject the fuels into the missiles.

COSMIC SPHERULES AND METEORITIC DUST

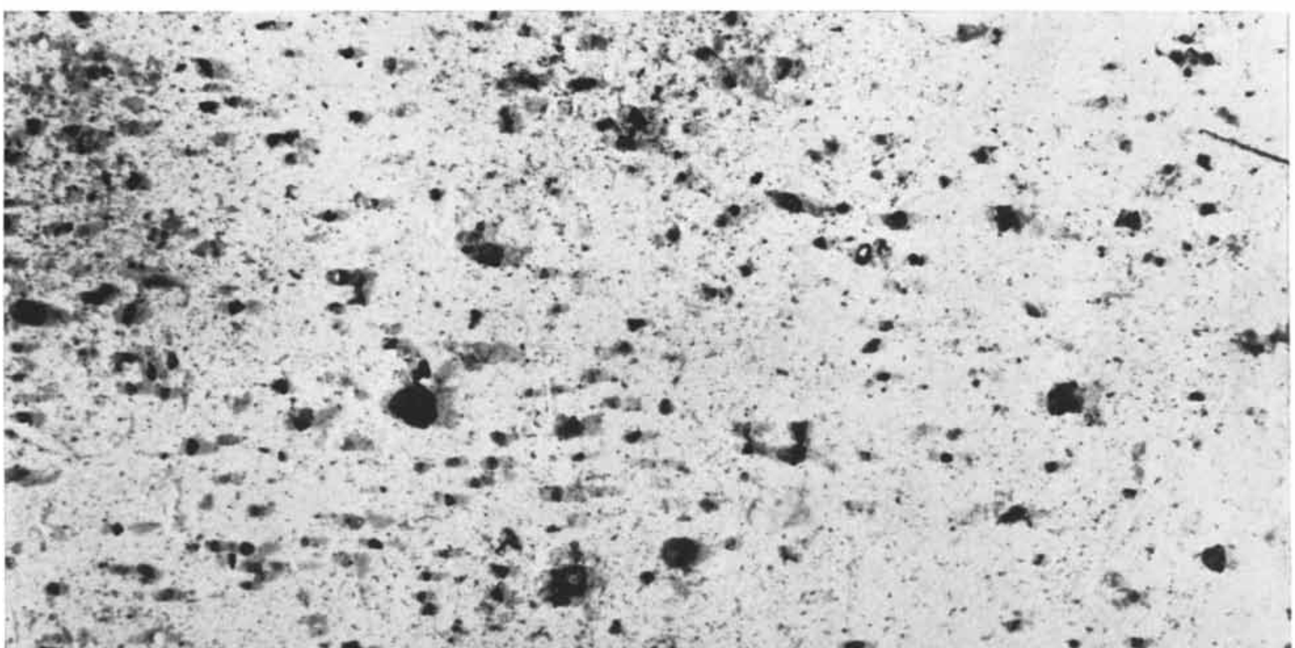
Each year perhaps five million tons of these metallic particles are released in the air by the burning of meteorites. Their occurrence in ocean sediments may be a clue to the history of the solar system

by Hans Pettersson

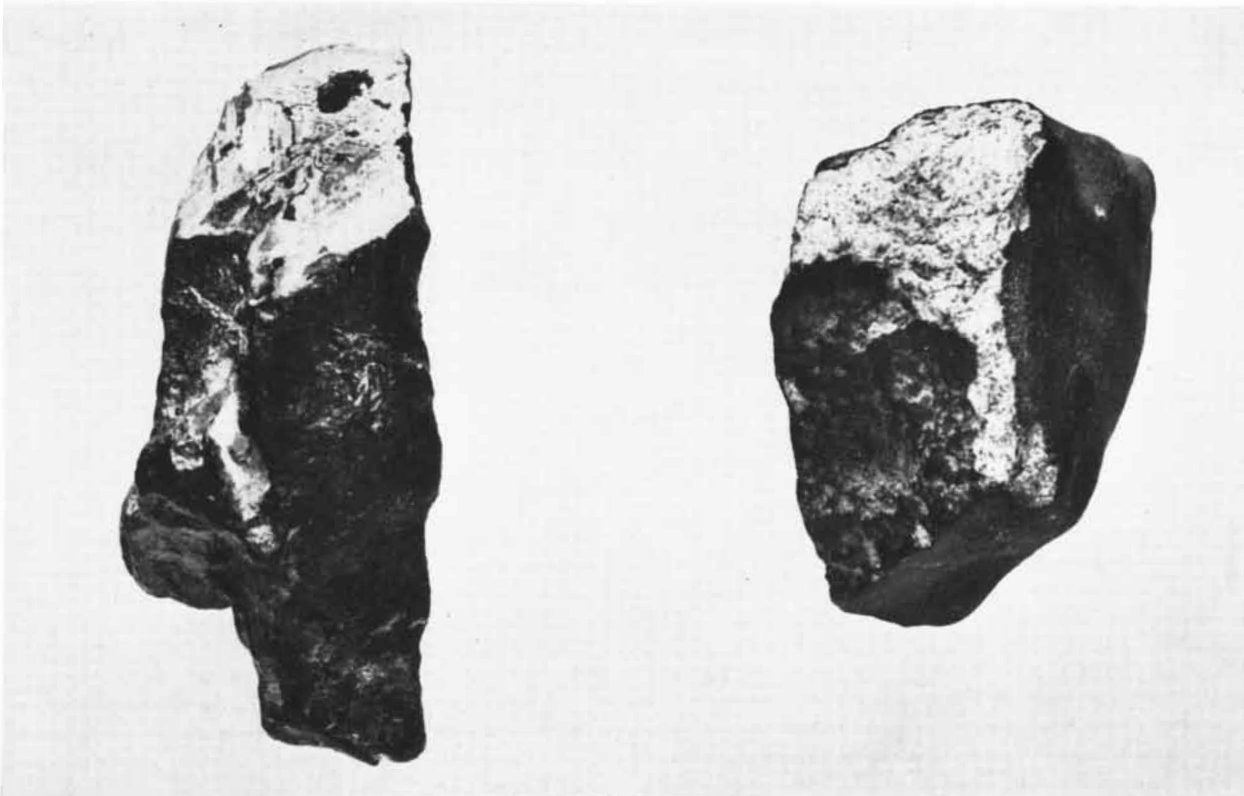
The recent extension of geophysical investigations into nearby space has given emphasis to the fact that life on earth is shielded by the earth's atmosphere. It seems doubtful that life could exist here at all were it not for the atmospheric absorption of harsh radiations from space. The present concern with radiation has, however, obscured a cosmic hazard of a more familiar kind. Every second thousands of solid projectiles, traveling at velocities of tens of kilometers per second, enter the earth's atmosphere. These bullets from the cosmos are meteorites, most of them stony but many composed of iron with an admixture of nickel. The great majority are smaller than a pinhead and weigh less than a milligram. But even a tiny meteorite could severely injure or kill a man if it reached the earth's surface with undiminished velocity. Death from "meteoritic stroke" might be a not-uncommon coroner's verdict if the protective canopy of the atmosphere were not spread above our heads.

Friction with the molecules of the atmosphere transforms the kinetic energy of a meteor to heat, light and mechanical work, and disperses its substance in a fine dust that settles slowly on the earth. A few meteorites, ranging in weight from grams to tons, are sufficiently massive to penetrate the atmosphere and plunge with impressive force into the ground. Atmospheric friction heats them only superficially. In the case of iron meteorites the surface-heating boils droplets of molten metal into the surrounding air. Instantly cooled and solidified, these droplets form tiny "cosmic spherules" that settle to the earth along with the dust of the lesser meteors.

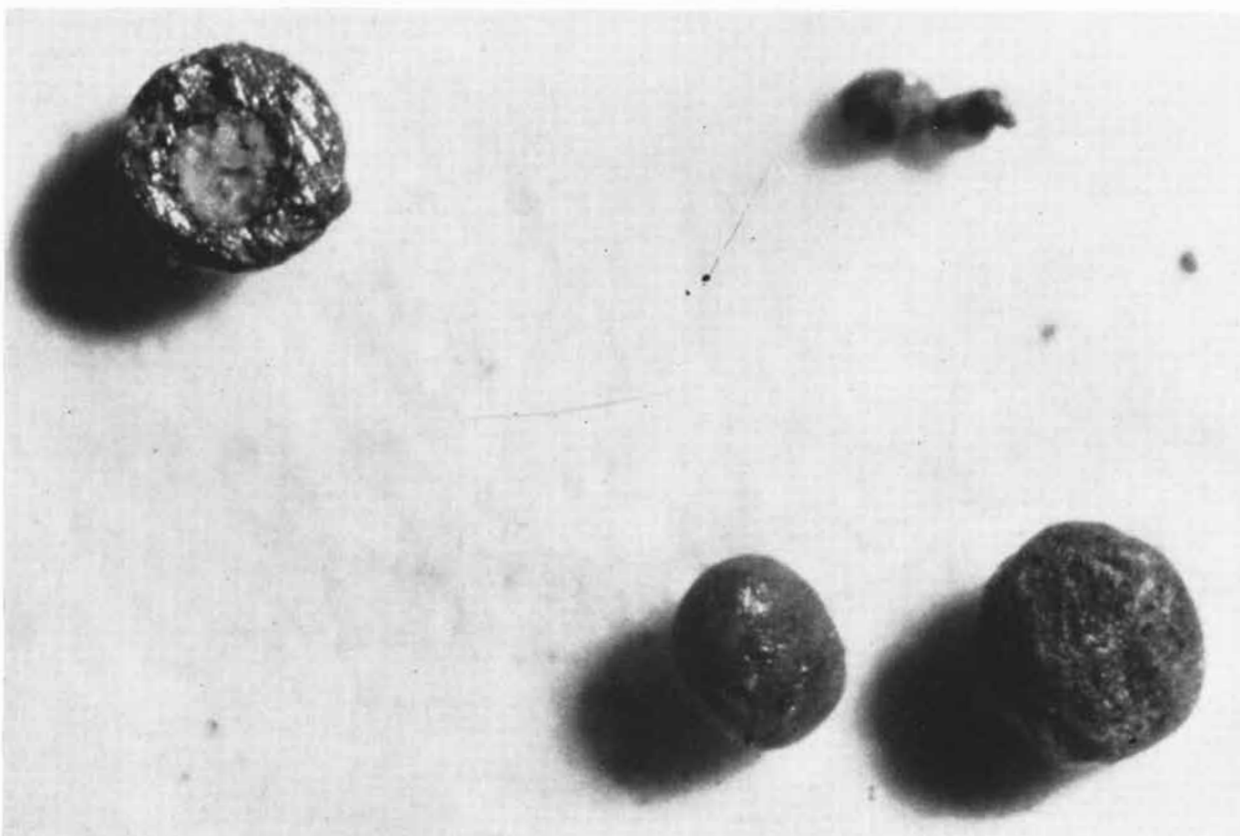
The frequency of meteors, established by visual and radio observation, indi-



MAGNETIC MATERIAL FROM OCEAN SEDIMENT is enlarged 150 diameters. The author collected these particles from a deep-ocean deposit of "red clay," brought up in a long "core." Mechanical sieves are employed to separate such particles by size, and then microscopic examination of each particle is necessary to determine which are of extraterrestrial origin and which of terrestrial origin.



RELATIVELY LARGE METEORITES that have reached the ground before burning up are of two kinds: iron (*left*) and stony (*right*). Top of iron meteorite has been cut, polished and etched. Specimens are from the American Museum of Natural History.



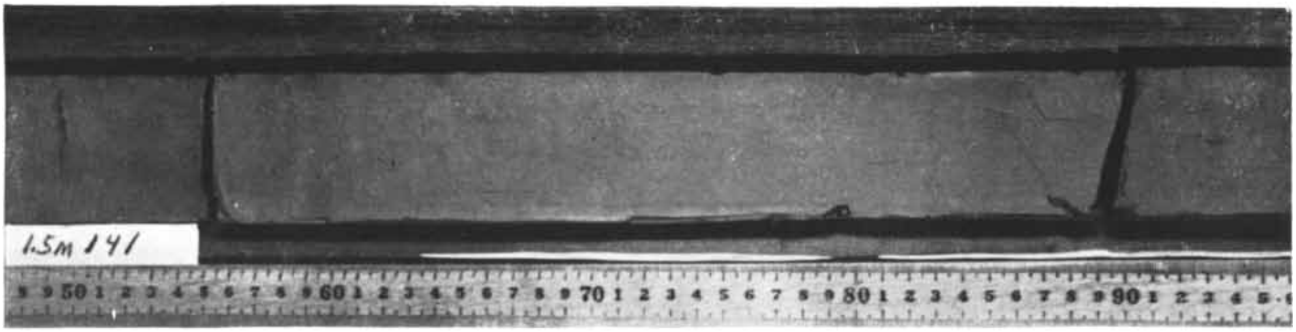
COSMIC SPHERULES appear to be droplets that have boiled out of burning meteorites. These spherules, enlarged 300 diameters, were brought up from sediments in mid-Atlantic by an expedition of Lamont Geological Observatory of Columbia University.

cates that they add a respectable tonnage of extraterrestrial matter to the total mass of the earth in the course of a year. A meteorite as small as a pinhead makes a "shooting star," and a few such evanescent streaks of light may be seen in the sky each hour on almost any clear moonless night. Shooting stars are especially numerous when the earth crosses the orbits of the several swarms of meteorites that circle the sun, notably the Perseids in the second week of August, the Orionids in late October, the Leonids around mid-November and the Geminids in the early part of December. Meteor showers vary in intensity from year to year as well as from month to month. In November, 1833, the Leonid shower produced a blizzard of shooting stars that terrified uninformed observers.

Just how much extraterrestrial material the meteor-falls contribute to the earth cannot be estimated with certainty from purely astronomical data. The atmosphere so effectively reduces this substantial quantity of matter to impalpable dust that only a tiny fraction of it, represented by the larger meteorites, has been available for scientific study. The meteoritic dust, especially that of the stony meteorites, cannot be easily distinguished from terrestrial dust. Even the larger meteorites become lost in the turnover of material on the earth's surface; there are no "fossil" meteorites, that is, none more than 25,000 years old.

During the past 13 years I have been engaged in efforts to secure direct measurements of the meteoritic fallout. My samples of meteoritic dust and cosmic spherules have come from the tops of high mountains remote from industrial civilization, and from the bottom of the ocean. Though the study is by no means complete, the data now show that meteoritic material comes down to earth in much larger quantity (about five million tons per year) than earlier estimates, based on astronomical information, had indicated. Moreover, it appears that the rate of fall has varied during the past 10 or 15 million years. These findings have relevance to a range of questions in geophysics and solar-system astronomy, from the origin of meteorites to the rate of sedimentation in the deep ocean.

It was the British oceanographer John Murray who discovered the existence of cosmic spherules and correctly deduced their origin. Upon his return in 1876 from the round-the-world cruise of *H.M.S. Challenger* he stirred a quart of "red clay," a chocolate-colored sediment from the great ocean depths, with a



TYPICAL RED-CLAY SEDIMENT was brought up from 5,350 meters in the mid-Atlantic during a research cruise from the Woods Hole Oceanographic Institution. The label and ruler below it show that this section starts (*left*) 1.5 meters from the top of the sediment.

hand magnet. The magnet picked up some 20 to 30 tiny pellets, each with a diameter of a quarter of a millimeter or less. They closely resembled iron meteorites, being pocked by atmospheric erosion. When he viewed them under a microscope, Murray decided that they were solidified drops of molten metal squirted from meteors. He suggested that only the extremely slow rate of accumulation of deep-sea sediments—one to two millimeters in 1,000 years—permitted these rare particles to collect in numbers sufficient to make extraction profitable. His view has been confirmed by the discovery that the spherules are much less numerous (sometimes apparently entirely missing) in ocean sediments that accumulate more rapidly than red clay. It is impractical even to attempt to find the spherules in continental sediments, where each one would be embedded in an enormous quantity of terrestrial material.

Cosmic spherules were so scarce and oceanographic expeditions so few that for 70 years after the voyage of the *Challenger* these meteoritic particles were scarcely studied at all. I had Murray's discovery in mind, however, during the planning of the Swedish oceanographic expedition of 1947 and 1948 [see "Exploring the Ocean Floor," by Hans Pettersson; Scientific American, August, 1950]. I particularly wanted to study the number of spherules in sediments of increasing age, or depth below the sediment surface. Using the piston-corer designed by Börje Kullenberg, we raised cores as long as 15 meters, and a few even longer, from great depths. The longest cores previously raised measured about three meters. Since red clay is deposited in the central Pacific at the rate of one to two millimeters in 10 centuries, every meter the corer sinks into this sediment brings us layers deposited 500,000 to a million years earlier. The lowest part of a 15-meter core contains sediments 7.5 million to 15 million years old.

To extract as many spherules as possible from the sediments, Kurt Fredriksson and I improved on Murray's hand magnet with an extractor that has layers of soft-iron sieves surrounding an electromagnet. Tests with a counted number of tiny artificial iron pellets placed in a

ELECTROMAGNETIC APPARATUS is used by author to collect cosmic spherules. At left is suspension of sediment, which is poured into apparatus next to it. In use the apparatus contains the electromagnet just to the right of it. Some doughnut-shaped filters are mounted on magnet; others are spread out at right. Behind them is filter setup that divides spherules according to their size.

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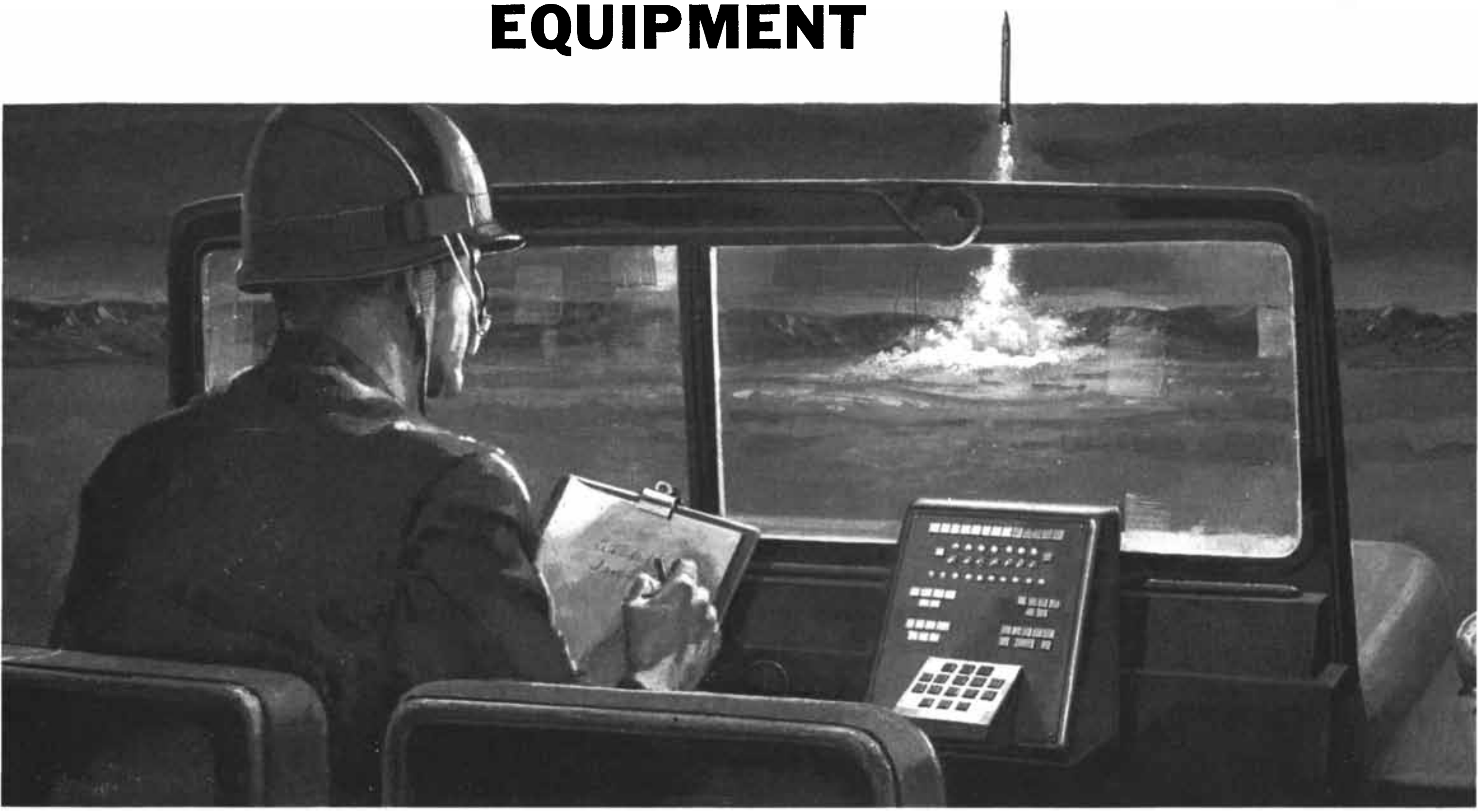

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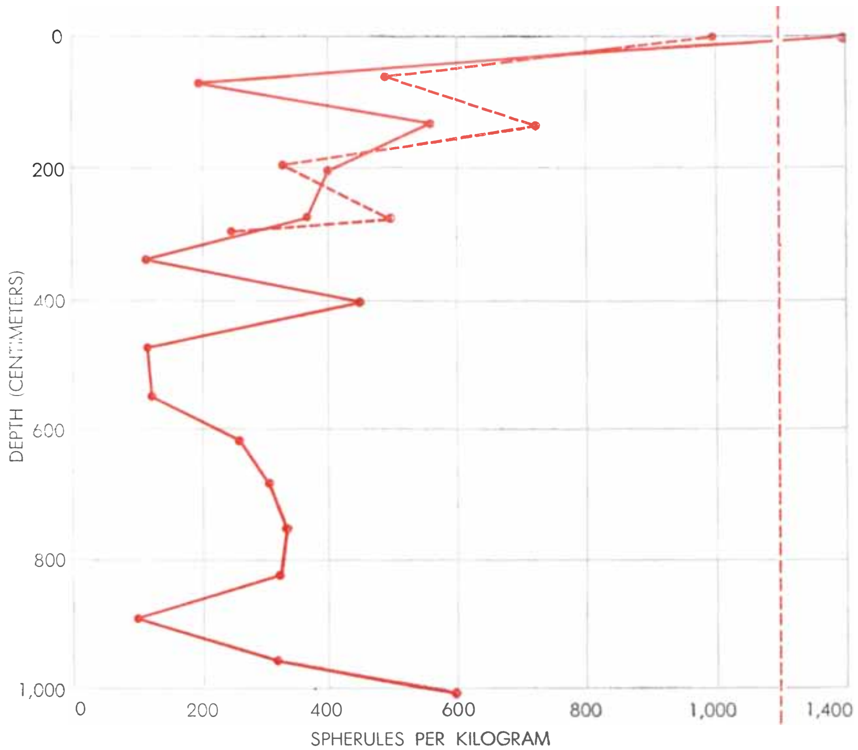

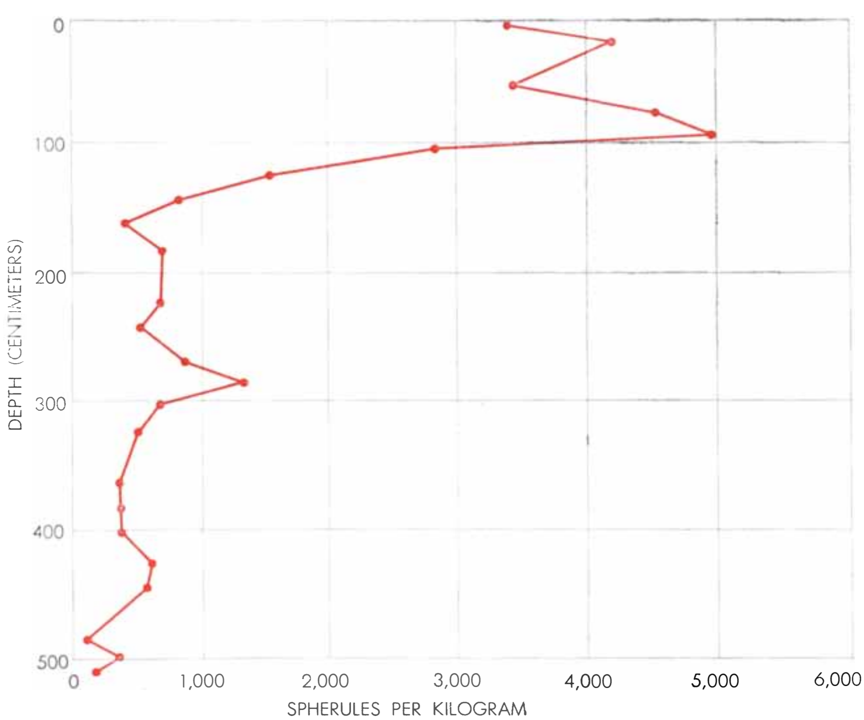

NUMBER OF SPHERULES VARIES WIDELY from top to bottom of a core, as indicated in these diagrams. Top diagram shows that a long core raised from 5,000 meters in the central Pacific (*represented by solid curve*) has 1,400 spherules per kilogram of red clay near the sediment surface, down to 100 and then back up to 600 at the bottom of the core. A shorter core from same area (*broken curve*) shows similar variations. Bottom diagram shows quantity of spherules found in a five-meter-long core from the western Pacific. Almost all cores contain a much higher number of spherules near the surface than they do lower down.

clay suspension indicated that the extractor removed 95 per cent of all magnetic particles. We stirred a weighed quantity of sediment into water and passed the resulting suspension three times through the magnetic sieves with the current on. Then we turned off the current and removed the trapped particles. Using mechanical sieves of different meshes, we separated the particles into groups with diameters of more than 250 microns, 250 to 60 microns, 60 to 30 microns (the group into which most of the spherules fell) and less than 30 microns. (A micron is a thousandth of a millimeter.) Another colleague, Marianne Nilsson, examined the particles under the microscope for shape and surface structure and counted only those of undoubted cosmic origin.

Our findings to date may be generalized in the statement that the spherule count varies from point to point on the ocean floor and from one time period to another down the length of a given core. In one core of homogeneous red clay raised from a depth of 5,000 meters in the central Pacific, the count varies from 1,400 spherules per kilogram close to the surface of the sediment, down to 100 at five meters below the surface and then up to 600 at 10 meters below the surface. In a similar core the number of spherules falls from 1,000 per kilogram at the top end down to 200 at three meters below the surface [*see top illustration at left*]. A larger number of spherules was extracted from a shorter and thicker core raised from 5,000 meters in the western Pacific, where the sediment is not so homogeneous as in the more easterly parts of the ocean. The upper layers of this core contained from 3,000 to 5,000 spherules per kilogram, whereas in levels below 1.5 meters from the surface the number of spherules was much smaller [*see bottom illustration at left*]. Cores from other oceans, where the rate of sedimentation is higher than in the central Pacific, usually contained no more than a couple of hundred spherules per kilogram; these cores, however, showed the same trend in spherule count as those taken from the bottom of the Pacific: a higher count in the upper, more recent sediments and a lower count in the ancient sediments at the bottom.

In general the cosmic spherules from the ocean floor indicate a higher rate of meteor-fall in recent times. The divergence of the count in different parts of the ocean, however, does not yet permit the computation of dependable averages

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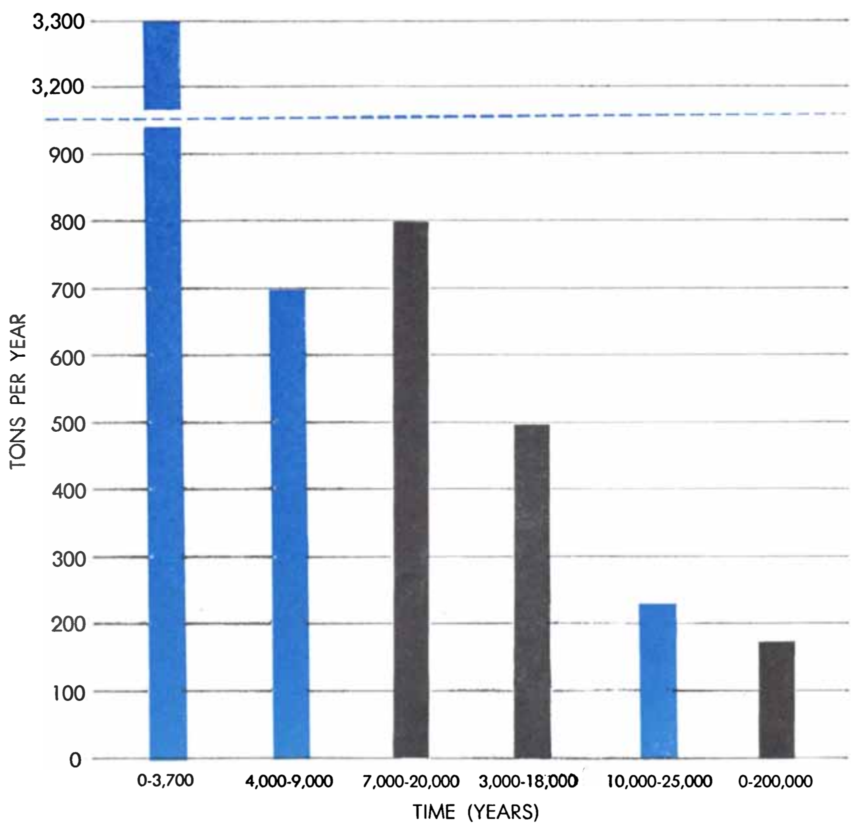
Systems, Packages and Components for: AIRCRAFT, MISSILE, ELECTRONIC, NUCLEAR AND INDUSTRIAL APPLICATIONS that would fix the variation over time. Such a curve, established by examination of a large number of different cores, might in turn furnish a time-scale for measuring the rate of sedimentation in parts of the ocean bottom yet to be explored. Deeper cores, reaching back into more remote periods of time, would also yield valuable information. Judging from the visible effects of cosmic bombardment on the face of the moon, there may be an extremely large number of cosmic spherules and other meteor fragments in the very deepest and oldest layers of ocean sediments. If the "Mohole" is drilled through the deep-ocean bed into the earth's mantle, sediments deposited since the birth of the oceans will be brought up. A count of spherules in them would produce a full record of meteoric activity through the ages.

The spherule count, even from the present shallow cores, has conclusively settled one debate. Arguing from the absence of fossil meteorites, the German geologist Robert von Schwinner advanced the idea that meteors came from outside the solar system and that they represent a sampling of interstellar debris swept into the sun's gravitational field about 25,000 years ago. Apart from the rather weak negative proof on which this hypothesis rested, astronomical observations had indicated that all meteors originate in the solar system [see "The Origin of Meteorites," by S. Fred Singer; SCIENTIFIC AMERICAN, November, 1954]. With von Schwinner's idea in mind, we carefully tested sections from the bottom end of five cores from 10 to 14 meters long. They produced from 77 to 194 spherules per kilogram of sediment. Since these particular sections must have been several million years old, the discovery of spherules in them erases any possibility that meteorites are of recent origin.

It has occurred to a number of investigators that the spherules presently drifting downward through the atmosphere might be trapped and counted by collectors exposed to rainfall and winds. From such a study one group of workers in the U. S. has estimated that several million metric tons of spherules fall annually on the earth. This estimate, however, seems improbably high. Their



SPHERULE COUNTS FROM SEVERAL DEPTHS IN TWO OCEANS are quite different. Cores from the Mediterranean (*shown in color*) indicate that during the past 3,700 years 3,300 tons of spherules were deposited on the entire earth each year. Sediments deposited in Mediterranean 4,000 to 9,000 years ago indicate that the annual average for the earth in that period was 700 tons of spherules. Cores from Pacific (*gray*) give other figures.

samples may have been contaminated with man-made spherules originating in industrial centers; pellets from welding plants, for example, can be carried by winds over great distances. Critical studies in western Germany and in Sweden have given much lower figures. My own studies on this line, made on various Pacific islands, where the risk of contamination is extremely low, show only a minute fraction of the count reported by the U. S. workers.

At present it seems more profitable to collect meteoritic dust, rather than spherules, from the air. Since relatively few meteorites are metallic and even fewer are large enough to yield spherules, the overwhelming mass of meteoritic material, whether stony or metallic, comes down as dust. In 1957, when I held the chair of geophysics at the University of Hawaii, I undertook what appears to be the first attempt to determine just how much cosmic dust is presently falling on our planet. To gather dust from the air I was fortunate enough to secure the use of the most advanced type of electrical air-pump, designed for sampling smog. One unit was installed at an altitude of 11,000 feet near the summit of Mauna Loa on the island of Hawaii. Another was set up at an observatory at 10,000 feet on Haleakala, a mountain on the island of Maui. Occasionally winds stir up lava dust from the slopes of these extinct volcanoes, but normally the air is of an almost ideal transparency, remarkably free of contamination by terrestrial dust.

It was nonetheless apparent that the dust collected in the filters would come preponderantly from terrestrial sources. To distinguish the portion contributed from space, my scheme was to rely upon the high nickel-content of meteorites. Analysis of larger meteorites had shown that the "irons" characteristically contain 7.5 per cent nickel and that even the "stones" have 1 per cent. According to Fletcher G. Watson of Harvard University, the average nickel-content of meteorites of all kinds is 2.08 to 2.8 per cent. Since nickel is a rare element in terrestrial dust, it was reasonable to expect that any nickel found in dust samples came from meteoritic sources. Taking 2.5 per cent as a fair average of Watson's estimates, I needed only to multiply the weight of the nickel by 40 to find the total weight of the dust from meteoritic sources.

Because my work was financed by the U. S. Atomic Energy Commission in connection with its study of radioactive fallout, the dust samples went first to New York, where they were tested for the presence of strontium 89 and 90 (with positive results). The material then went on to Vienna, where it was analyzed for iron, nickel and cobalt by Friedrich Hecht, an authority on microanalysis, Hans Korkisch and others.

Most of the samples contained small but measurable quantities of nickel along with a large amount of iron. The average for 30 filters was 14.3 micrograms of nickel from each 1,000 cubic meters of air. This would mean that each 1,000 cubic meters of air contains .6 milligram of meteoritic dust. If meteoritic dust descends at the same rate as the dust created by the explosion of the Indonesian volcano Krakatoa in 1883, then my data indicate that the amount of meteoritic dust landing on the earth every year is 14 million tons. From the observed frequency of meteors and from other data Watson calculates the total weight of meteoritic matter reaching the earth to be between 365,000 and 3,650,000 tons a year. His higher estimate is thus about a fourth of my estimate, based upon the Hawaiian studies. To be on the safe side, especially in view of the uncertainty as to how long it takes meteoritic dust to descend, I am inclined to find five million tons per year plausible.

The five-million-ton estimate also squares nicely with the nickel content of deep-ocean sediments. In 1950 Henri Rotschi of Paris and I analyzed 77 samples of cores raised from the Pacific during the Swedish expedition. They held an average of .044 per cent nickel. The highest nickel content in any sample was .07 per cent. This, compared to the average .008-per-cent nickel content of continental igneous rocks, clearly indicates a substantial contribution of nickel from meteoritic dust and spherules.

If five million tons of meteoritic dust fall to the earth each year, of which 2.5 per cent is nickel, the amount of nickel added to each square centimeter of ocean bottom would be .000000025 gram per year, or .017 per cent of the total red-clay sediment deposited in a year. This is well within the .044-per-cent nickel content of the deep-sea sediments and makes the five-million-ton figure seem conservative.

In order to arrive at a more reliable estimate, I am continuing the collection of samples in Hawaii. Collecting apparatus has also been installed at an observatory high on the Jungfraujoch in the Swiss Alps. Within the next few years the samples should be extensive enough to begin to produce a fairly firm indication of the total amount of meteoritic dust actually falling to the earth.

Earth-to-space ferry

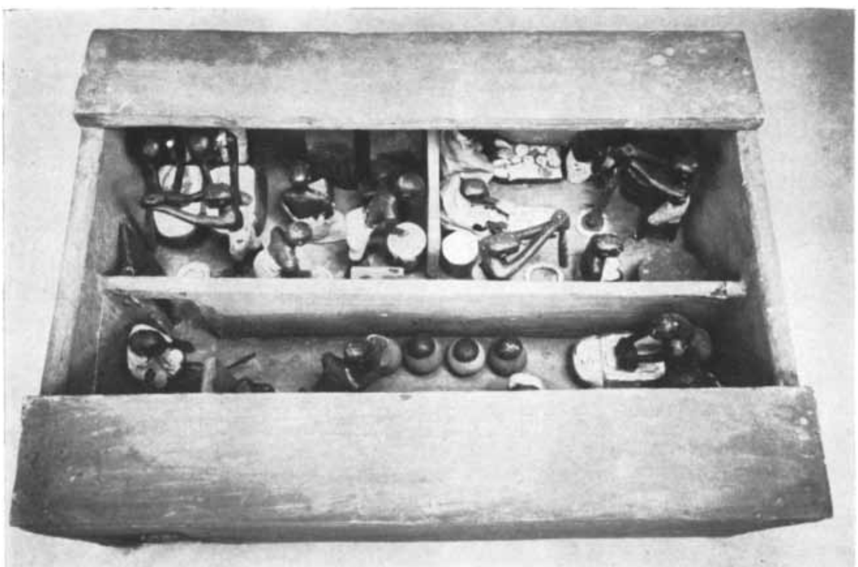
YEASTS

These single-celled fungi, essential in the making of bread and alcoholic beverages, produce enzymes and vitamins as well. They have also helped to throw light on many areas of cell physiology

by Anthony H. Rose

Yeasts have been called the oldest cultivated plants. Men may have employed these microscopic single-celled organisms to ferment wild grains even before they learned to cultivate the grains themselves. That the arts of brewing and baking were already well advanced in the early days of civilization can be gathered from the exquisitely preserved models of a brewery and a bakery found in a 4,000-year-old tomb at Thebes on the Nile [*see illustration below*]. The Book of Exodus, in its vivid account of the privations of the Jews on their flight from Egypt, takes special notice of the fact that they had to subsist on unleavened bread, having fled without yeast balm.

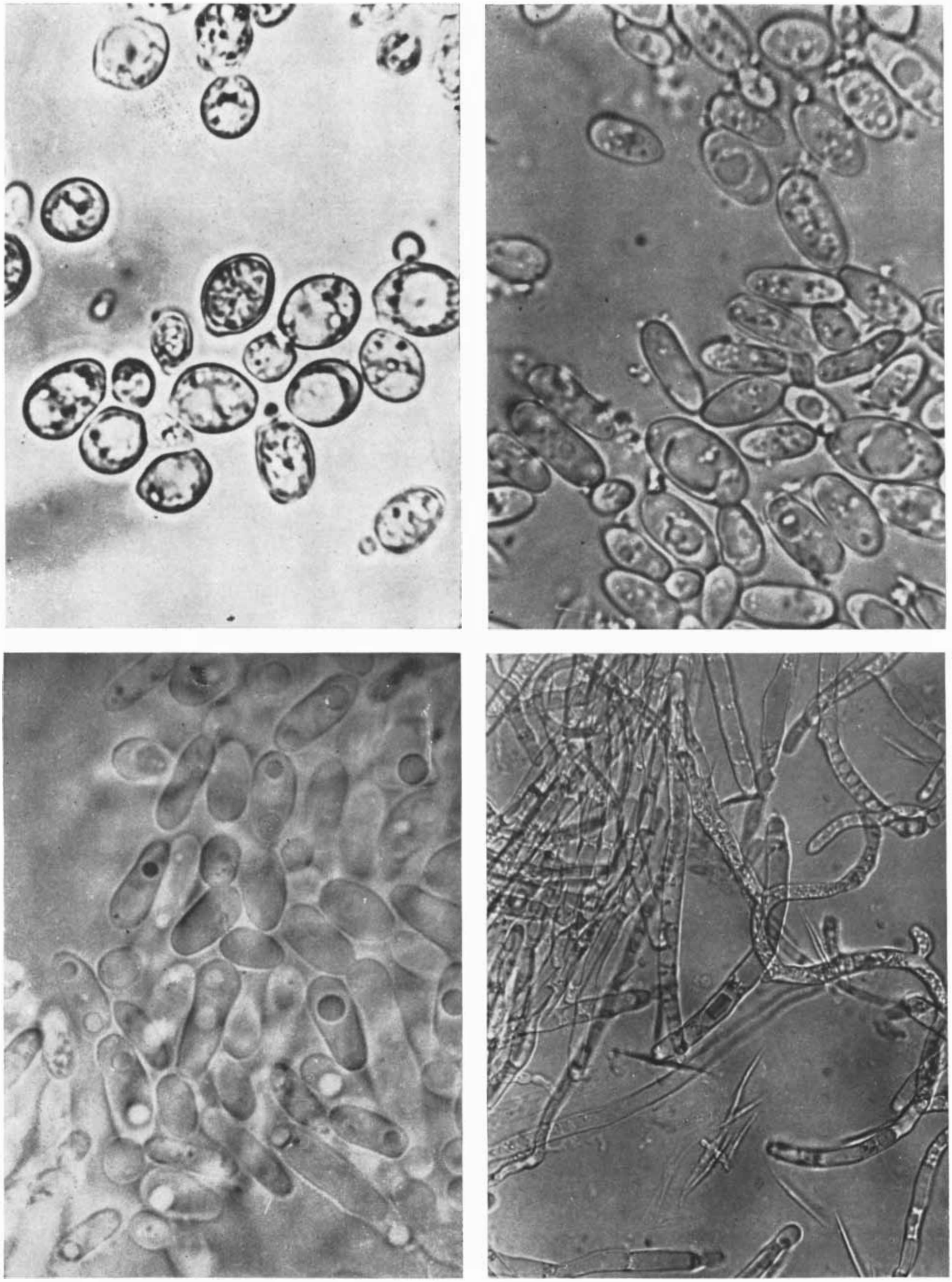
It was less than a century ago, however, that a living organism, the tiny yeast cell, was recognized as the agent of the fermentation process that yields alcohol for the brewer and carbon dioxide for the baker. The controversy that settled this question established the science of bacteriology. With the question restated to ask just how the yeast cells carry on fermentation, it was the discovery of the yeast enzymes that founded the science of biochemistry. As scientific understanding of yeasts has deepened, the technological role of these organisms has broadened. Along with bread and alcoholic beverages they now produce vitamins for human consumption and enzymes and alcohol for industry. Certain species of yeast, possessing the capacity to synthesize proteins from industrial wastes, may provide substantial relief for the world's food shortage. But the new intimacy in this ancient acquaintanceship has by no means lessened the interest that yeasts hold for the investigator. As perhaps the best known as well as the most useful microorganisms, yeasts provide the ideal laboratory subject for investigation of many fundamental questions in cell physiology.



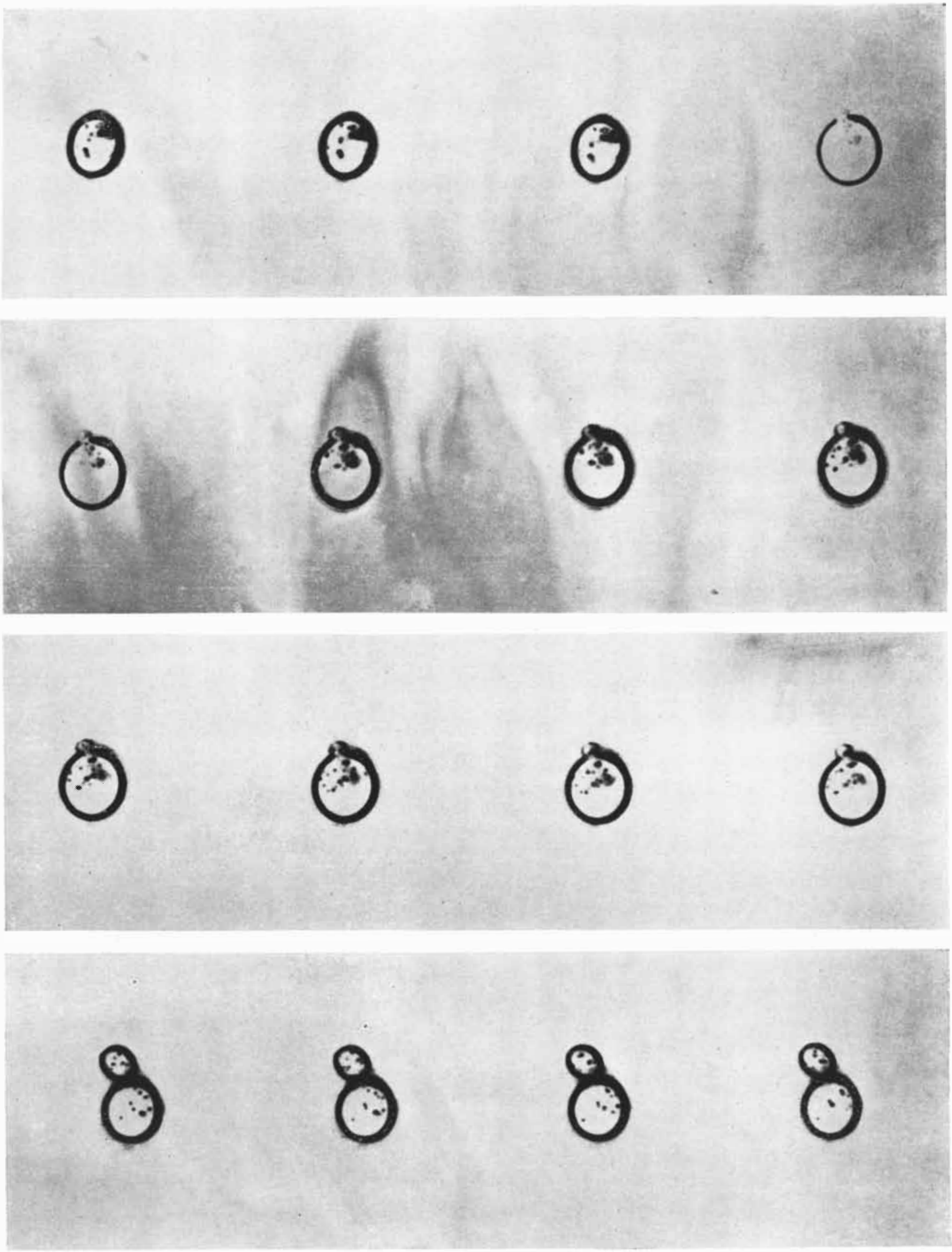
EARLY USES OF YEAST are shown in this ancient Egyptian model of a bakery and brewery. The model, found in a tomb at Thebes, dates from around 2000 B.C.; man began using yeast even earlier. The baking and brewing industries are still the largest consumers of yeast.

Yeasts are fungi—plants that lack chlorophyll and so are obliged to live a parasitic or a scavenging existence. But the word "yeast" does not have the botanical significance that is attached to such terms as bacterium or alga. In the over-all classification of fungi, yeasts appear nowhere as a separate subdivision. Rather, yeasts are fungi in a particular morphological state: the single-celled or yeast state. The true yeasts almost always occur in this state, and they include representatives of all but one of the main groups of fungi. Other fungi, including several pathogenic species, occur as multicelled, usually filamentary plants and are found in the yeast state only when they are forced into it by environmental circumstance.

The individual yeast plant is usually a spherical or ovoid cell; it measures roughly four ten thousandths of an inch in diameter (about the size of a human red-blood cell and somewhat larger than most bacteria) and weighs about a ten billionth of a gram. Structurally it resembles other plant cells. A thick cell wall encloses a mass of protoplasm that in mature cells contains granules of various shapes and sizes. Staining with an appropriate dye reveals minute particles resembling the mitochondria, which are the centers of the energy-generating oxidative reactions in most cells. In the yeast cell these mitochondrial particles play an important role in the fermentation process. Near the large central vacuole are one or two nuclear bodies that transmit



DIFFERENT TYPES OF YEAST reflect their varied uses. Brewers' and bakers' yeasts are both strains of the species *Saccharomyces cerevisiae* (*top left*); wine yeast (*top right*) is a variety of the same species. *Candida utilis* (*bottom left*) has been used for food; it converts sugars from wood-pulp wastes into protein. The species *Ashbya gossypii* (*bottom right*) is employed in the commercial production of riboflavin (vitamin B_2); the sausage-shaped cell near the center of the photograph contains an oblong crystal of the vitamin.



BUDDING OF A YEAST CELL is shown in this series of photomicrographs made at intervals of 30 seconds. The process begins with a "blowout" in the wall of the cell (*top right*) through which cell material pours to form the bud. In the next two rows the bud gradually enlarges and its wall thickens. In photomicrographs at bottom, made after a lapse of 15 minutes, bud has further enlarged and wall of the parent cell has been rebuilt. The bud will soon break away from its parent to begin an independent existence.

the hereditary characteristics of the cell—for example the efficiency with which it conducts fermentation—to its daughter cells.

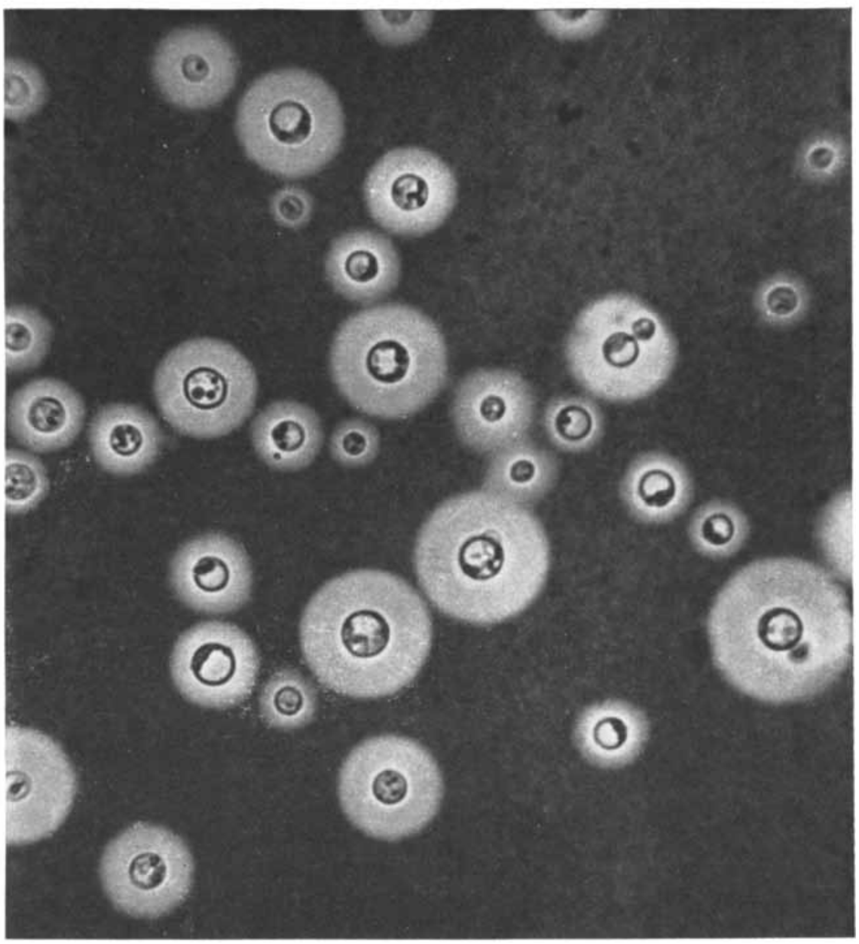
Yeasts are widely distributed in nature, being found in the soil, in the sea and even on human skin. Most species, however, grow best in sugary habitats, such as the juices of damaged plants, the nectar of flowers and the skins of sweet fruits such as grapes and apples, on which they form the familiar white film, or "bloom." Some yeasts can grow in jellies and syrups containing up to 60 per cent sugar, a concentration sufficient to inhibit the growth of most other microorganisms.

The preference of most yeasts for sugar is dictated by their metabolism. They obtain energy by breaking down sugars into simpler compounds. If oxygen is available, they convert the sugar into carbon dioxide and water. In the absence of oxygen they ferment sugar into alcohol and carbon dioxide. From the metabolic point of view fermentation must be regarded as an incomplete and inefficient process, for most of the energy originally available in the sugar remains locked up in the alcohol. It is this inefficiency, however, that makes the yeast plant useful to the brewing and baking industries, which are still the largest consumers of yeast. The brewmaster is interested mainly in the alcohol, which he obtains by fermentation of the sugars in malt wort, an infusion of germinated barley and other cereals [see "Beer," by Anthony H. Rose; SCIENTIFIC AMERICAN, June, 1959]. The baker, by contrast, is concerned only with the carbon dioxide, which softens and "raises" the dough, making it more palatable and digestible when it is baked. The alcohol, of course, evaporates during baking. Brewers' and bakers' yeasts both belong to the species *Saccharomyces cerevisiae* and differ but slightly. Indeed, only during the last century has yeast been manufactured especially for baking; bakers used to get their yeast from the brewery.

The wine-makers' yeasts belong to a different branch of the same species and are distinguished from the brewers' and bakers' yeasts by the ellipsoidal shape of their cells. Strains of this yeast predominate in the mixture of microbes that makes up the bloom on grapes. The European vintner still relies on the natural fermentation brought about by the bloom when the grapes are crushed. Indeed, he claims with some justification that the individual bouquet of a wine from a particular vineyard is largely attributable to this mixed bag of microbes. Only during bad years, when the bloom is dominated by the wrong kind of fungi, which the vintner calls "mold," does he resort to the use of a pure strain of wine yeast. North American wines, however, are invariably fermented with pure yeasts. After the grapes are crushed, the unfermented juice, or "must," is treated with sulfur dioxide to kill off the microbes in the bloom and is then inoculated with a selected yeast strain. Although this process gives the vintner greater control over the quality of his product, it makes the production of true vintage wines virtually impossible.

Spirits (whisky, rum, brandy, gin, etc.) are distilled from various juices and cereal infusions that have been fermented with yeast. Distillers also employ strains of *Saccharomyces cerevisiae*, but they select their strains for the ability to tolerate fairly high concentrations of sugar and alcohol. This tolerance enables the yeast to produce a higher-proof ferment for distillation. Similar strains ferment molasses and other sugary wastes in the manufacture of ethyl alcohol in bulk for use as an industrial solvent. The industrial demand for alcohol, however, is increasingly being met by the cheaper synthetic product made from ethylene, a petroleum by-product.

The first man to see a yeast cell was Anton van Leeuwenhoek, the founder of microscopy. It was inevitable that he should turn one of his crude lenses on a drop of fermenting beer. But his observation did not establish that the cells carry on the fermentation process. This remained to be demonstrated by Louis Pasteur in 1875, when he showed beyond all doubt that alcoholic fermentation does not arise spontaneously but is the work of living cells. Pasteur's discovery raised a new question: Was the sugar molecule decomposed inside the cell, or did the cell somehow transfer its decomposing activity to the sugar molecule? The brothers Hans and Eduard Buchner answered this question some 60 years ago in Germany. They were at-



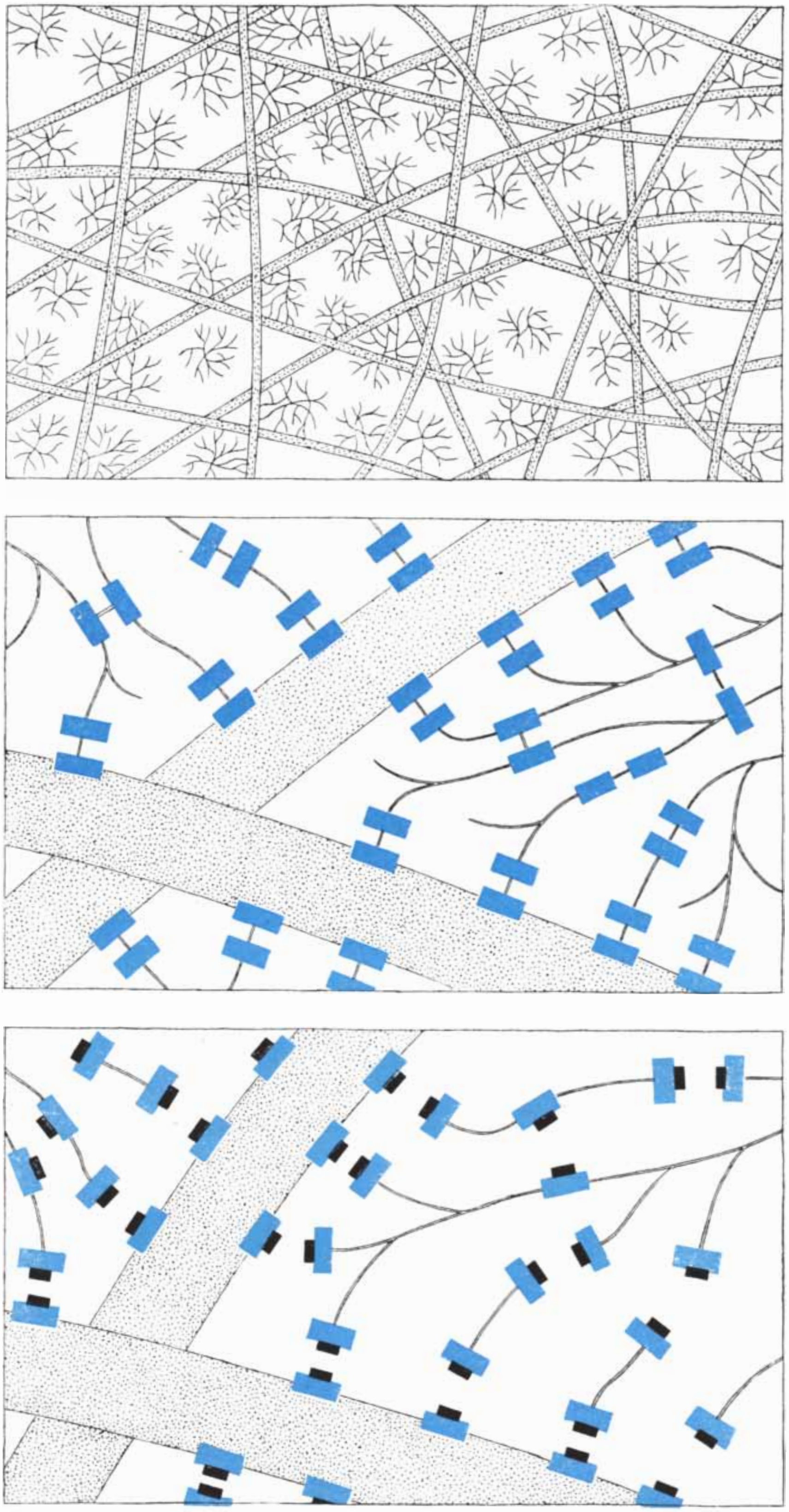
PATHOGENIC YEAST *Cryptococcus neoformans* is one of several species of yeasts and yeastlike fungi that cause disease in man. This organism attacks the central nervous system, causing a dangerous form of meningitis. The cells are enclosed in thick, gelatinous capsules.

tempting to prepare cell-free extracts of yeast for medical experimentation by grinding up yeast cells with fuller's earth and squeezing out the juice. As a preservative they added sugar to the cell-free juice and were startled to find that the juice began to bubble and froth. Clearly the machinery for alcoholic fermentation was originally housed inside the cell; the organic catalysts that comprise this machinery came to be known as enzymes (from the Greek for "in yeast").

This chance demonstration of cell-free fermentation was the first in a whole series of studies that ultimately, over the next 40 years, elucidated the entire chain of a dozen or so enzyme reactions by which the yeast organism transforms glucose into alcohol and carbon dioxide. Several eminent biochemists, including Sir Arthur Harden in England and Carl Neuberg and Otto Meyerhof in Germany, devoted the major part of their working lives to the effort. Their work acquired still greater significance with the discovery that the same series of reactions occurs in many different types of living matter, and that it represents a basic process for releasing the energy locked up in the glucose molecule.

Industrial and scientific interest in the fermentation process tends to obscure the fact that yeasts produce a great many useful substances other than alcohol and carbon dioxide. As one might expect, yeasts are a primary source of enzymes. Confectioners, for example, employ the yeast enzyme invertase to produce cream-centered chocolates. When the centers are molded and coated with chocolate, they contain a solid, crystalline sugar (sucrose). Invertase mixed into the sugar then slowly converts it into a creamy mixture of glucose and fructose. Another yeast enzyme, lactase, breaks down milk sugar (lactose); this enzyme is added to ice cream to prevent the lactose from crystallizing out. These enzymes come principally from brewers' yeast. On the other hand, most riboflavin (vitamin B_2) for human and animal consumption comes from three quite different species of yeast which, under the proper nutritional conditions, excrete large quantities of this substance.

Probably the most interesting recent development in yeast husbandry is the use of yeasts as a food for men and fodder for animals. Fungi are not, of course, a new food. Mushrooms and truffles, which are simply the spore-producing organs of certain microscopic fungi, have had their place in high and low cuisines for centuries. The idea of using yeasts as a food is credited to the German microbiologist M. Delbrück,



CHANGES IN YEAST CELL WALL during budding are depicted schematically. The wall (*top*) consists of straight fibers of a substance resembling cellulose; these are cemented together by particles of a similar but more intricately structured material. Both substances are associated with proteins containing sulfur atoms (*color*); bonds between these atoms are believed to hold the cell wall together (*center*). When the cell buds (*bottom*), an enzyme transfers hydrogen (*black rectangles*) to the sulfur atoms, breaking the bonds and thus weakening the cell wall. Internal pressure then causes the "blowout" shown on page 138.

who in 1910 delivered a lecture entitled "Yeast, a Refined Fungus." Delbrück emphasized the high-protein content of yeasts and the ease with which they can be manufactured from inexpensive raw materials. During World War II large quantities of food yeast were consumed in Germany, mainly in soups and sausages. Although brewers' yeast has been used in this way, the most useful food yeast is *Candida utilis,* an adaptable species that can convert into protein certain nutritionally worthless sugars produced as by-products in the cellulose and wood-pulp industries.

Yeasts are particularly valuable as supplements to diets low in animal proteins. Vegetable proteins are conspicuously deficient in the essential amino acid lysine. Though yeasts lack some other amino acids, they contain much lysine, and thus may provide a ready and inexpensive way to upgrade the diets of many African, Asian and Central American communities. The principal obstacle at present is that the various yeasts do not make a particularly palatable food.

Though the chemical activities of yeast are by and large well understood and have been put to good use, there are some yeasts that cause disease in man and stubbornly resist efforts to bring them under control. The yeast *Candida albicans* produces troublesome infections (moniliasis) of the fingernails and mucous membranes. A less common but more dangerous species, *Cryptococcus neoformans,* can induce a chronic and often fatal form of meningitis. Certain yeastlike fungi are responsible for histoplasmosis, a lung infection, and North American blastomycosis, an unsightly and debilitating skin disease. These microbes are "part time" yeasts that lead a single-celled existence in the body but form multicelled filaments in laboratory cultures.

As yet there is no effective therapy against these diseases. Treatment with antibiotics often aggravates them, apparently because the antibiotics kill off bacteria that normally compete with the yeast for nutrients. In fact, some public-health authorities believe that the widespread use of antibiotics has produced a significant increase in yeast infections. Fortunately several recently discovered antibiotics appear to be effective against fungi, including yeasts.

On balance and despite these few noxious exceptions, yeasts remain more allies than adversaries of research scientists. Since the days of Pasteur and the Buchners, they have provided prolific and easily cultured experimental organ-

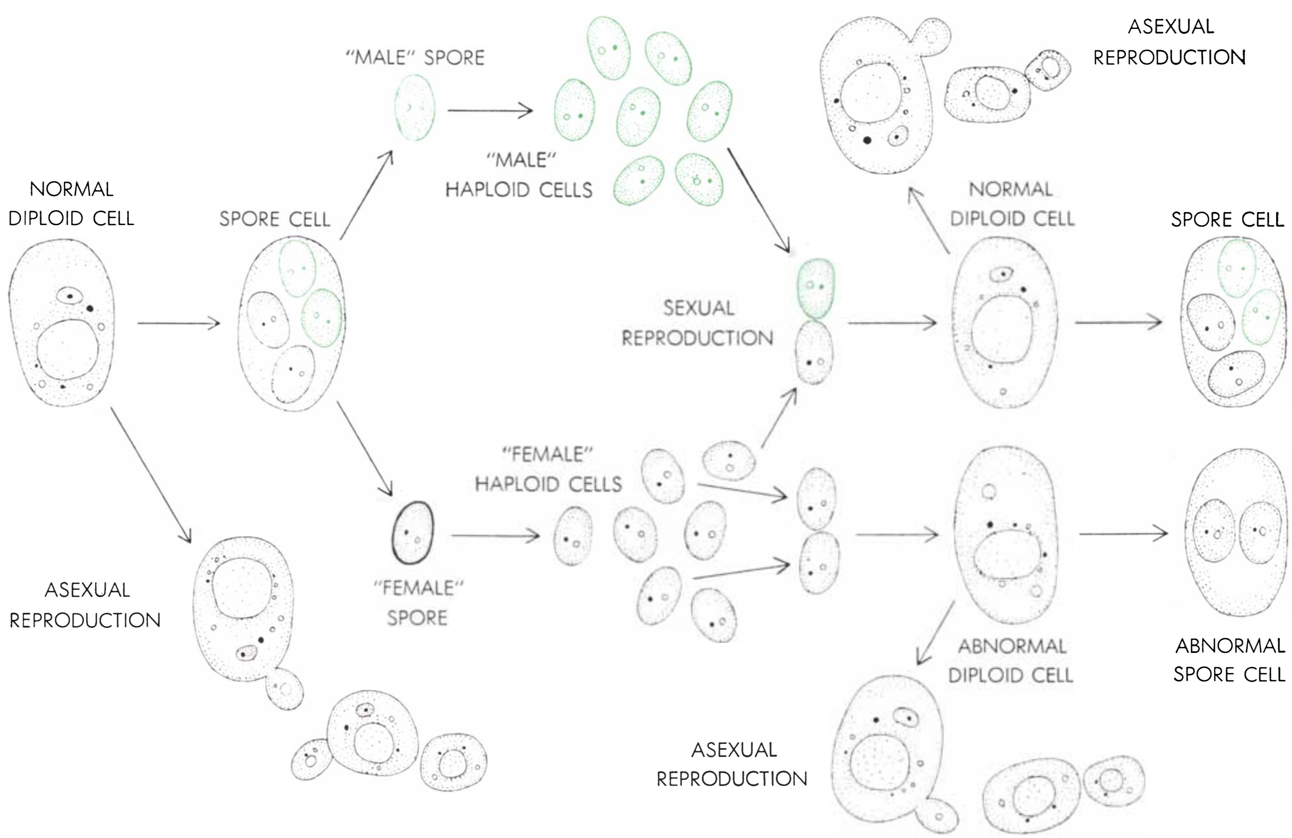
Construction of additional building in progress at RCA Moorestown—to be completed Spring, 1960 isms for use in the investigation of a host of fundamental questions. One significant research enterprise which they are now helping is the uncovering of the molecular events that take place during cell division.

When a growing cell, whether it is in a microbial culture or in living tissue, has taken up sufficient nutrient from its surroundings and has reached a certain size, a series of metabolic reactions normally comes into play that causes the cell to divide. Hardly anything is known about how these reactions are brought into operation. Among the many groups of investigators working on this question the one led by Walter J. Nickerson at the Institute of Microbiology at Rutgers University has been making impressive progress with the help of a yeast.

Most single-celled organisms, as well as the individual cells of multicelled organisms, reproduce by fission, a process in which the cell divides into approximately equal halves. Yeasts, however, reproduce by budding. Under the microscope a fully grown yeast cell is seen to develop a protuberance that gradually enlarges and within a few hours breaks away from the mother cell. Photomicrographs have revealed that the bud begins with a "blowout" in the wall of the cell, through which part of the interior material pushes to form the bud [*see illustrations on page 138*].

Nickerson and his associates sought to discover the cause of this blowout, using as their experimental organism the pathogenic yeast *Candida albicans*. Although this species normally buds, it has a mutant strain that cannot bud but instead grows into long filaments. Clearly some of the reactions that bring about cell division were not operating in the mutant. However, the first attempts to discover metabolic differences between the mutant and normal strains were not encouraging. Nutritional requirements, growth rate, fermentation rate and chemical composition all appeared to be identical. Finally it was discovered that growing cells of the mutant, but not the normal strain, could reduce a dye called red tetrazolium, that is, alter the structure of the substance by filling key bonds with hydrogen atoms. This reaction suggested that the budding process in the mutant had halted at a point at which a reducing substance was formed. For some reason this substance could not reduce the cell component that is its natural "target," though it could reduce the dye. In collaboration with Giuseppe Falcone, a visiting investigator from the University of Naples, Nickerson set about searching for the target component.

Since the first sign of cell division is the blowout in the cell wall, it seemed logical to look in the structure of the cell wall for this component. Nickerson and Falcone discovered that the wall is composed of two materials: glucan, a long-chain molecule made up of glucose units, and glucomannan, a more complex long-chain molecule composed of glucose units and those of the similar sugar mannose. Both of these polysaccharides are closely associated with proteins that somewhat resemble keratin, the kind of protein found in hair and fingernail. When keratin proteins are treated with reducing agents, they are known to become pliable. It would seem, therefore, that reduction of the cell-wall proteins temporarily softens a portion of the wall, whereupon internal pressure within the



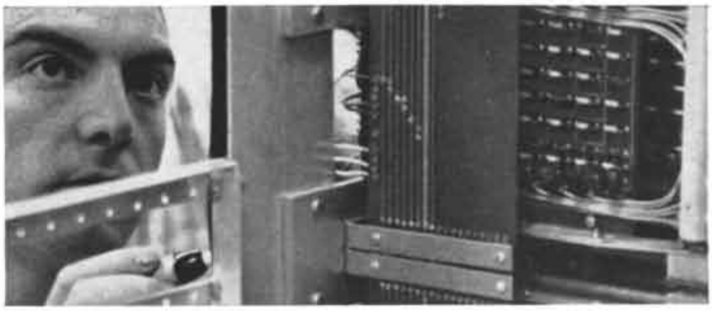
REPRODUCTIVE CYCLE IN BREWERS' YEAST indicates that asexual reproduction (budding) is not controlled by the nucleus of the cell. All yeasts multiply asexually; some species also reproduce sexually. A normal cell divides into spores of different "sexes" with nuclei containing half the normal amount of chromosomal material; the spores may multiply into haploid cells. Haploid cells of different sexes join to form a normal cell that can reproduce both asexually and sexually. If haploid cells of the same sex join, the resulting cell cannot reproduce sexually. However, its abnormal nucleus does not prevent it from budding in the usual way.

cell produces the blowout and subsequent bud.

This hypothetical scheme is now well supported by experimental results. Electron micrographs indicate that the cell wall consists of a feltlike mat of fibers composed of the glucan-protein complex. The fibers are cemented together by globules of the glucomannan-protein complex. Both of the proteins are rich in sulfur-containing amino acids, and bonds between sulfur atoms in the two substances hold the cell wall together. During budding, an enzyme reduces the sulfur atoms, thereby breaking the bond between them and weakening the cell wall. The blowout that starts the bud then takes place. In the mutant cell, however, the enzyme is apparently synthesized incorrectly, so that it cannot reduce the sulfur atom. This is the first such reaction in cell division to be worked out in biochemical detail.

It remains to be seen whether the same or similar reactions operate in other cells. The budding process is of general interest, however, because it appears to be one of the important cellular activities that is not directly controlled by the nucleus. Although almost all yeasts reproduce by budding, certain species also reproduce sexually. A cell of brewers' or bakers' yeast, for example, will sometimes divide into spores, each with a nucleus containing half the normal quantity of chromosomal material. The spores can be loosely described as male or female, depending on which portion of the chromosomes they have acquired. The fusion of a "male" and a "female" spore produces a normal cell that can bud and, under appropriate circumstances, reproduce sexually. Two spores of the same sex, "male" or "female," can also join, but the resulting cell cannot reproduce sexually. Nonetheless, its abnormal chromosomal equipment does not prevent it from budding in the ordinary way. Experiments with other organisms have confirmed the conclusion that abnormalities in the nucleus are no bar to cell division. Some cells, indeed, continue to divide even when the nucleus has been removed. Further investigation of budding in yeast promises to throw light on the universal process of cell division.

Thus man's ability to harness the activities of yeasts has given him not only food and drink but deeper insight into the chemical basis of his own existence. These microscopic organisms surely rank among the most fruitful and versatile of the domesticated plants.



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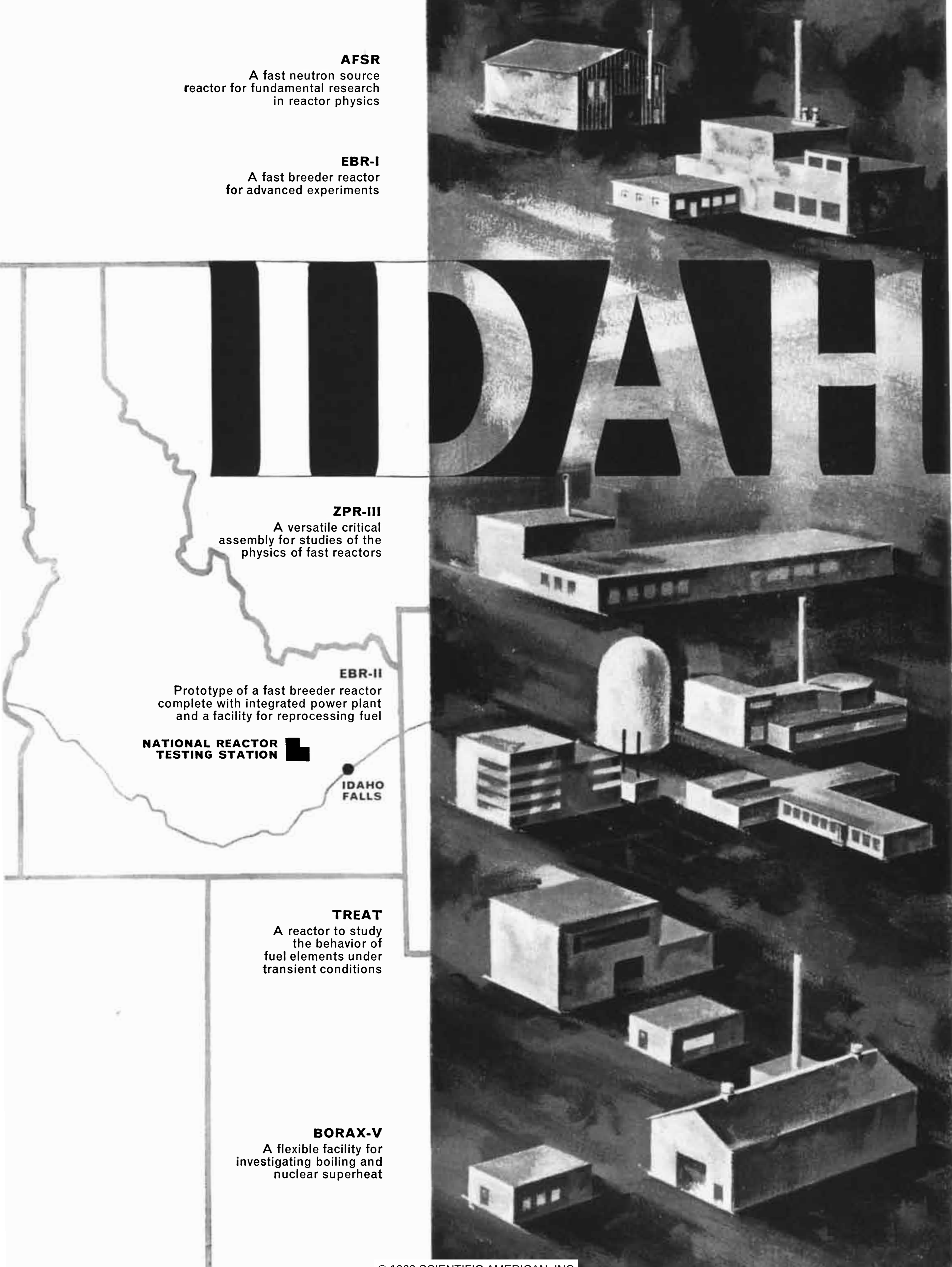
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MATHEMATICAL GAMES

A fifth collection of "brain-teasers"

by Martin Gardner

Every eight months or so this department presents an assortment of short problems drawn from various mathematical fields. This is the fifth such collection. The answers to the problems will be given here next month. I welcome letters from readers who find fault with an answer, solve a problem more elegantly, or generalize a problem in some interesting way. In the past I have tried to avoid puzzles that play verbal pranks on the reader, so I think it only fair to say that several of this month's "brain-teasers" are touched with whimsy. They must be read with care; otherwise you may find the road to a solution blocked by an unwarranted assumption.

1.

Mel Stover of Winnipeg was the first to send this amusing problem—amusing because of the ease with which even the best of geometers may fail to approach it properly. Given a triangle with one obtuse angle, is it possible to cut the triangle into smaller triangles, all of them acute? (An acute triangle is a triangle with three acute angles. A right angle is of course neither acute nor obtuse.) If this cannot be done, give a proof of impossibility. If it can be done, what is the smallest number of acute triangles into which any obtuse triangle can be dissected?

The illustration at right shows a typical attempt that leads nowhere. The triangle has been divided into three acute triangles, but the fourth is obtuse, so nothing has been gained by the preceding cuts.

This delightful problem led me to ask myself: "What is the smallest number of acute triangles into which a square can be dissected?" For days I was convinced that nine was the answer; then suddenly I saw how to reduce it to eight. I wonder how many readers can discover an eight-triangle solution, or perhaps an even better one. I am unable to prove that eight is the minimum, though I strongly suspect that it is.

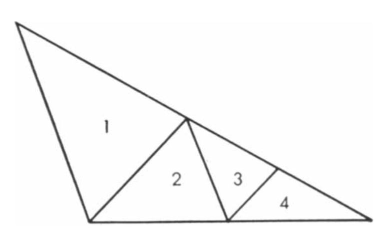
2.

In H. G. Wells's novel *The First Men in the Moon* our natural satellite is found to be inhabited by intelligent insect creatures who live in caverns below the surface. These creatures, let us assume, have a unit of distance that we shall call a "lunar." It was adopted because the moon's surface area, if expressed in square lunars, exactly equals the moon's volume in cubic lunars. The moon's diameter is 2,160 miles. How many miles long is a lunar?

3.

In 1958 John H. Fox, Jr., of the Minneapolis-Honeywell Regulator Co., and L. Gerald Marnie of the Massachusetts Institute of Technology devised an unusual betting game which they call Googol. It is played as follows: Ask someone to take as many slips of paper as he pleases, and on each slip write a different positive number. The numbers may range from small fractions of one to a number the size of a "googol" (1 followed by a hundred zeros) or even larger. These slips are turned face-down and shuffled over the top of a table. One at a time you turn the slips face-up. The aim is to stop turning when you come to the number that you guess to be the largest of the series. You cannot go back and pick a previously turned slip. If you turn over all the slips, then of course you must pick the last one turned.

Most people will suppose the odds



Can this triangle be cut into acute ones?

This common game is a sequential machine. Its input is the way you move the numbered tiles. Output is the arrangement of numbers you produce.

States in a Sequential Machine

A "sequential machine" is any device producing prescribed sequences of outputs in response to given sequences of inputs. The theoretical problem of designing a machine, satisfying certain specifications with the fewest possible number of states, is now under study by IBM scientists.

The operation of a sequential machine is not necessarily completely specified. Some states may have no specified transitions for certain inputs, and some states may have no assigned outputs. For this general case, a technique has been developed for reducing a given machine to an equivalent machine with a minimum number of states. The procedure is to construct a state diagram of the machine which describes input and output sequences. Then through the use of a transition-matrix representation, a minimum-state diagram is obtained, which is equivalent to the original machine in the sense that it will produce the same sequences of outputs for the given sequence of inputs.

Earlier reduction procedures have been applicable only to state-diagrams having known transitions for each input at each state. The extension of the procedure is important since many practical sequential machines (such as computers) require a specified operation for only a certain set of sequences of inputs.

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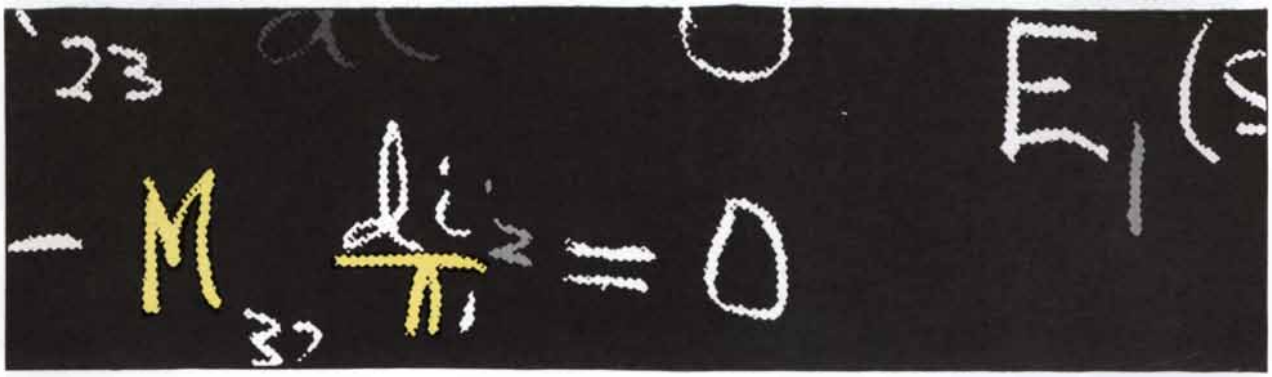

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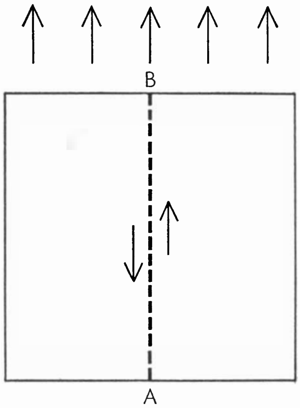


How far does the dog trot?

against your finding the highest number to be at least five to one. Actually if you adopt the best strategy, your chances are a little better than one in three. Two questions arise. First, what is the best strategy? (Note that this is not the same as asking for a strategy that will maximize the *value* of the selected number.) Second, if you follow this strategy, how can you calculate your chances of winning?

When there are only two slips, your chance of winning is obviously 1/2, regardless of which slip you pick. As the slips increase in number, the probability of winning (assuming that you use the best strategy) decreases, but the curve flattens quickly, and there is very little change beyond 10 slips. The probability never drops below 1/3. Many players will suppose that they can make the task more difficult by choosing very large numbers, but a little reflection will show that the sizes of the numbers are irrelevant. It is only necessary that the slips bear numbers that can be arranged in increasing order.

The game has many interesting applications. For example, a bachelor girl decides to marry before the end of the year. She estimates that she will meet 10 men who can be persuaded to propose, but once she has rejected a proposal, the man will not try again. What strategy should she follow to maximize her chances of accepting the top man of the 10, and what is the probability that she will succeed?

The strategy consists of rejecting a certain number of slips of paper (or proposals), then picking the next number that exceeds the highest number among the rejected slips. What is needed is a formula for determining how many slips to reject, depending on the total number of slips. This is not an easy problem, but readers who find it too difficult may enjoy playing the game with, say, 10 slips to see how close they can come by trial and error to guessing the number of slips that should be rejected to maximize the chances of success.

4.

A square formation of Army cadets, 50 feet on the side, is marching forward at a constant pace [*see illustration on this page*]. The company mascot, a small terrier, starts at the center of the rear rank [*position A in the illustration*], trots forward in a straight line to the center of the front rank [*position B*], then trots back again in a straight line to the center of the rear. At the instant he returns to position A, the cadets have advanced exactly 50 feet. Assuming that the dog trots at a constant speed and loses no time in turning, how many feet does he travel?

If you solve this problem, which calls for no more than a knowledge of elementary algebra, you may wish to tackle a much more difficult version proposed by the famous puzzlist Sam Loyd. Instead of moving forward and back through the marching cadets, the mascot trots with constant speed around the *outside* of the square, keeping as close as possible to the square at all times. (For the problem we assume that he trots along the perimeter of the square.) As before, the formation has marched 50 feet by the time the dog returns to point A. How long is the dog's path? I know of no way to solve Loyd's version without getting tangled in fifth-degree equations. The method of solution is so lengthy to describe that next month I shall give only the answer. I shall return to the problem, however, if any reader discovers a simple method of solving it.

5.

Stephen Barr of Woodstock, N.Y., writes that his dressing gown has a long cloth belt, the ends of which are cut at 45-degree angles as shown in the illustration on the next page. When he packs the belt for a trip, he likes to roll it up as neatly as possible, beginning at one end, but the slanting ends disturb his sense of symmetry. On the other hand, if he folds over an end to make it square off, then the uneven thicknesses of cloth put lumps in the roll. He experimented with more complicated folds, but try as he would, he could not achieve a rectangle of uniform thickness. For example, the fold shown in the illustration produces a rectangle with three thicknesses in section A and two in section B.

"Nothing is perfect," says one of the

Philosophers in James Stephens's *The Crock of Gold*. "There are lumps in it." Nonetheless Barr finally managed to fold his belt so that each end was straight across and part of a rectangle of uniform thickness throughout. The belt could then be folded into a neat roll, free of lumps. How did Barr fold his belt? A long strip of paper, properly cut at the ends, can be used for working on the problem.

6.

Professor Merle White of the mathematics department, Professor Leslie Black of philosophy, and Jean Brown, a young stenographer who worked in the university's office of admissions, were lunching together.

"Isn't it remarkable," observed the lady, "that our last names are Black, Brown and White and that one of us has black hair, one brown hair and one white."

"It is indeed," replied the person with black hair, "and have you noticed that not one of us has hair that matches his or her name?"

"By golly, you're right!," exclaimed Professor White.

If the lady's hair isn't brown, what color is it?

7.

An airplane, traveling with a constant engine speed, makes a large and perfect circle parallel to the ground. There is no wind. Will it complete the same circle in greater, less or the same time if there is a wind of constant speed and direction, assuming that the plane travels with the same constant engine speed that it had before?

8.

The owner of a pet shop bought a certain number of hamsters and half that many pairs of parakeets. He paid $2 each for the hamsters and $1 for each parakeet. On every pet he placed a retail price that was an advance of 10 per cent over what he paid for it.

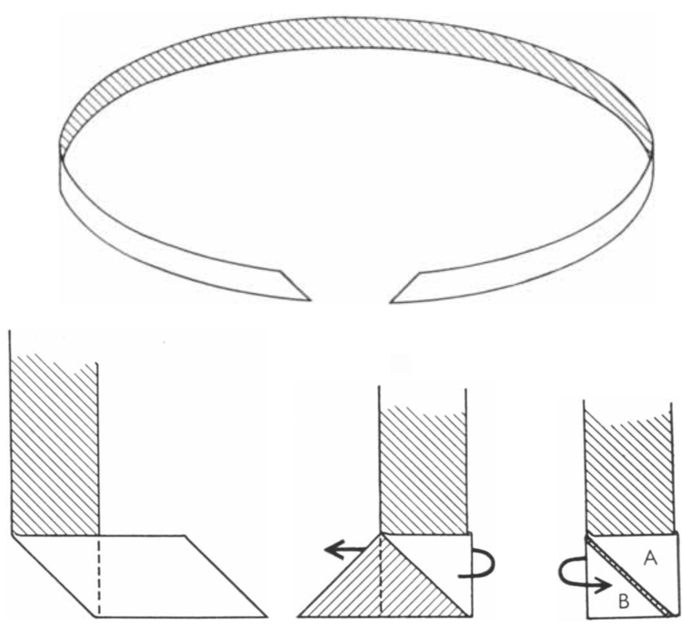
After all but seven of the creatures had been sold, the owner found that he had taken in for them an amount of money exactly equal to what he had originally paid for all of them. His profit, therefore, was represented by the combined retail value of the seven remaining animals. What was this value?

The two numerology problems posed last month by Dr. Matrix are answered as follows:

(1) The letters OTTFFSSENT are the initials of the names of the cardinal numbers from one to 10.

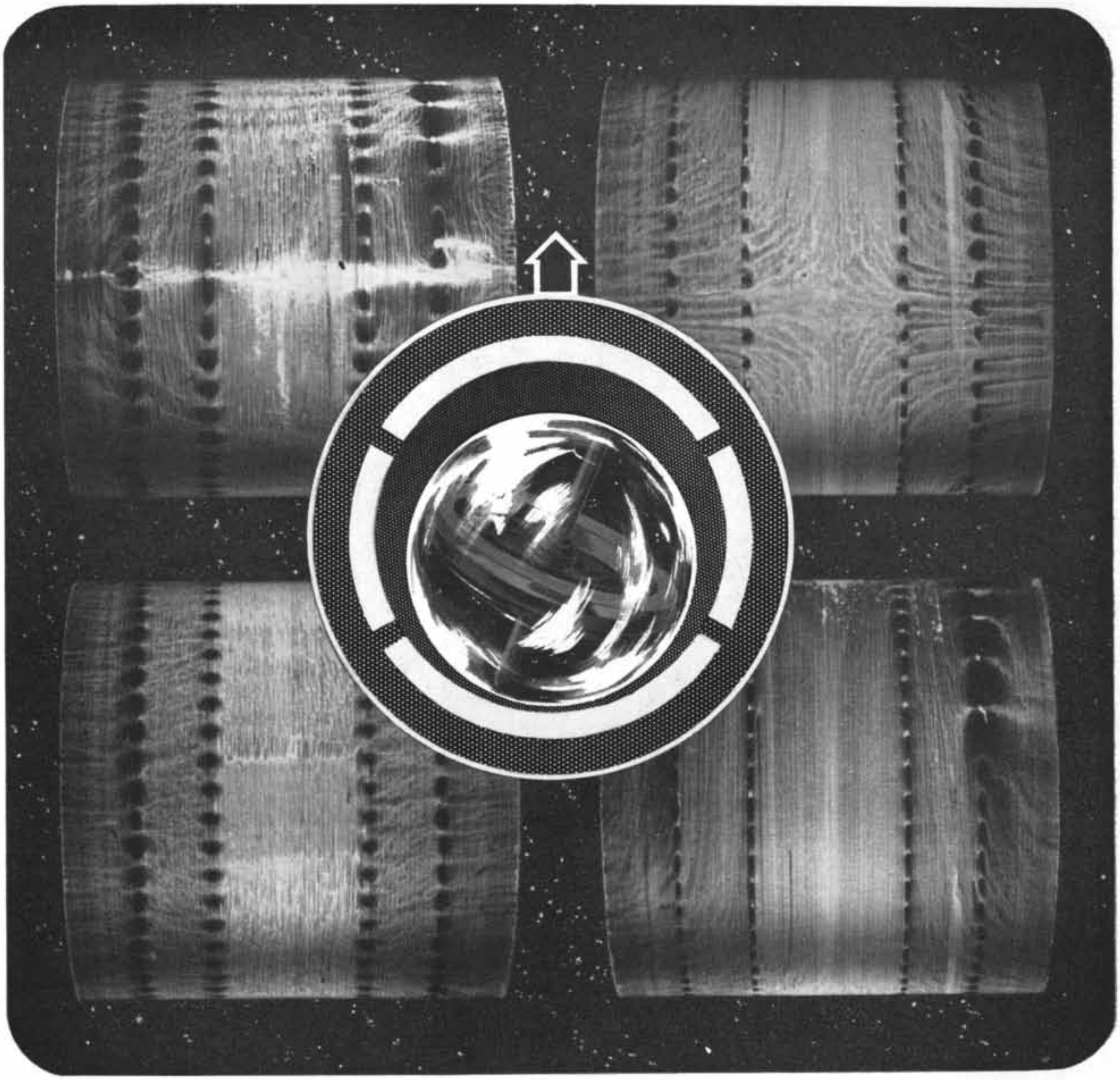
(2)

FORTY	29786
+ TEN	850
+ TEN	850
SIXTY	31486



Barr's belt (top) *and an unsatisfactory way to fold it* (bottom)

IMPORTANT DEVELOPMENTS AT JPL



GAS LUBRICATION

Research in gas lubrication and on performance and application of gas bearings is an important current activity at Jet Propulsion Laboratory.

The photographs shown are actual visualizations of gas flow patterns (obtained by an ultraviolet fluorescence technique) on a shaft under varying loads. Those on the left show pattern on an unloaded bearing — those on the right when bearing is loaded under 80 lbs. at 40 psig supply pressure.

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THE AMATEUR SCIENTIST

An amateur asks: Does a hummingbird find its way to nectar through its sense of smell?

Conducted by C. L. Stong

Walker Van Riper of Denver, Colo., is surely one of the most active amateur zoologists in the U. S. In the 14 years since his retirement from the investment-banking business he has concerned himself with, among other things, the way in which rattlesnakes strike (they do not bite; they stab) and many aspects of the behavior of hummingbirds. Accounts of his work with these animals, which has featured some remarkable high-speed photography, have appeared in SCIENTIFIC AMERICAN. Recently Van Riper has turned his attention to the question of how the hummingbird finds its way to the nectar on which it feeds; specifically, does it do so by means of the sense of smell? He writes:

"The avian sense of smell has received some notice from ornithologists, the classic experiment being one by John James Audubon on the turkey vulture. Audubon set out a stuffed deer; the vultures found it, pecked at its glass eyes and tore its skin, apparently ignoring the fact that it did not smell like food. When Audubon painted a dead deer on a large canvas and spread the canvas on the ground, the birds again sought it out. Then he hid a dead and putrid animal in a ravine over which the vultures regularly flew. They were not attracted to the bait. He concluded that these birds found their food by sight alone.

"The experiment was of considerable importance to Audubon; he reported it in Edinburgh in his maiden speech before a scientific audience. When he returned to the U. S., he found that his observations were questioned. He repeated the experiment before a group of educators and scientists, who thereupon certified that vultures used the sense of sight, and not that of smell, to find their food.

"A century later Victor Coles, a graduate student at Cornell University, repeated the experiment, with essentially the same result. In 1929 Frank M. Chapman, then the leading U. S. ornithologist, repeated one of Coles's experiments on Barro Colorado Island in the Canal Zone. Chapman hid foul-smelling food in various places; when this was found by vultures, he concluded that they must have responded to the odor. It has been noted, however, that Chapman's experiment is open to question because he did not exclude such visual clues as blowflies, beetles and similar insects that are known to find their food by smell. These could have led the keen-sighted vultures to the bait.

"A few experiments have been made on the sense of smell in other birds. Various odors have been tried as conditioning stimuli for pigeons, ducks and parakeets, mostly with negative results. In one series of experiments it was found that pigeons could not even distinguish water from a strong ammonia solution, except by dipping their beaks into the liquid.

"Similarly, in the course of extensive observations in Arizona on the behavior of the black-chinned hummingbird, the naturalist Frank Bené hid food bottles carrying an orange-scented honey solution in a flower bed. In no observed case did the birds find the food by means of its scent.

"A considerable amount of work has been done on the anatomy of the olfactory organs of birds by E. H. Craigie, R. M. Strong, C. L. Turner and others. Their findings indicate that most birds appear to have the apparatus necessary for smelling, and that it is more fully developed in some species than in others.

"The experiments so far mentioned throw some light on the question of whether or not the bird makes use of the sense of smell. But failure to observe the use of this sense under a given set of experimental conditions does not justify the conclusion that the sense is not used. Nor does the mere possession of olfactory equipment prove that an animal can or does make use of it. Considerations such as these mark important distinctions between the modern interpretation of animal behavior and older views. It must also be borne in mind that the behavior of birds differs from species to species. Pronounced variations occur even within strains of the same species. Chapman's vultures, for example, were forest-ranging birds to which the use of a sense of smell might well be more advantageous (and hence a more likely adaptation) than to the strain that inhabits open country.

"As modern students of animal behavior have made clear, what an animal *can* do does not necessarily throw light on what it *does* do. In this connection N. Tinbergen of the University of Oxford points out the following feature of instinctive behavior: An animal does not react to all the stimuli that its sense organs can perceive, but only to a small part of them. This applies to instinctive behavior, but not necessarily to learned behavior. The instinctive behavior for a given situation is thought of as a fixed, unlearned pattern of responses, the same for all individuals of the species, which is triggered or 'released' by certain definite stimuli received from the environment or induced by internal physiological changes. It is important to bear in mind that the triggering stimuli are definite, generally few in number and limited to only a small portion of the perceptions received by the animal.

"The carnivorous water beetle *Dytiscus*, for example, has highly developed compound eyes and can be trained to respond to visual stimuli. It does not react to the mere sight of moving prey such as a tadpole. When moving prey enclosed in a glass tube is displayed to Dytiscus, no pattern of behavior is released. Experiments show that the beetle's feeding response is never set off by the sense of sight but only by tactile and chemical stimuli. A dilute meat extract dripped into the water will induce the beetle to attack every solid object it touches.

"Similarly it has been found that a hen coming to the rescue of a chick in distress is reacting to the sound of the distress call, and not to the chick's movements. In one experiment the chick was tied behind a screen so that it could not be seen by the hen; the mother came to the rescue when she heard the chick's cry. But when the chick was subsequently put under a glass bell so that the hen could see it struggling but could not hear it, she remained entirely indifferent to its distress.

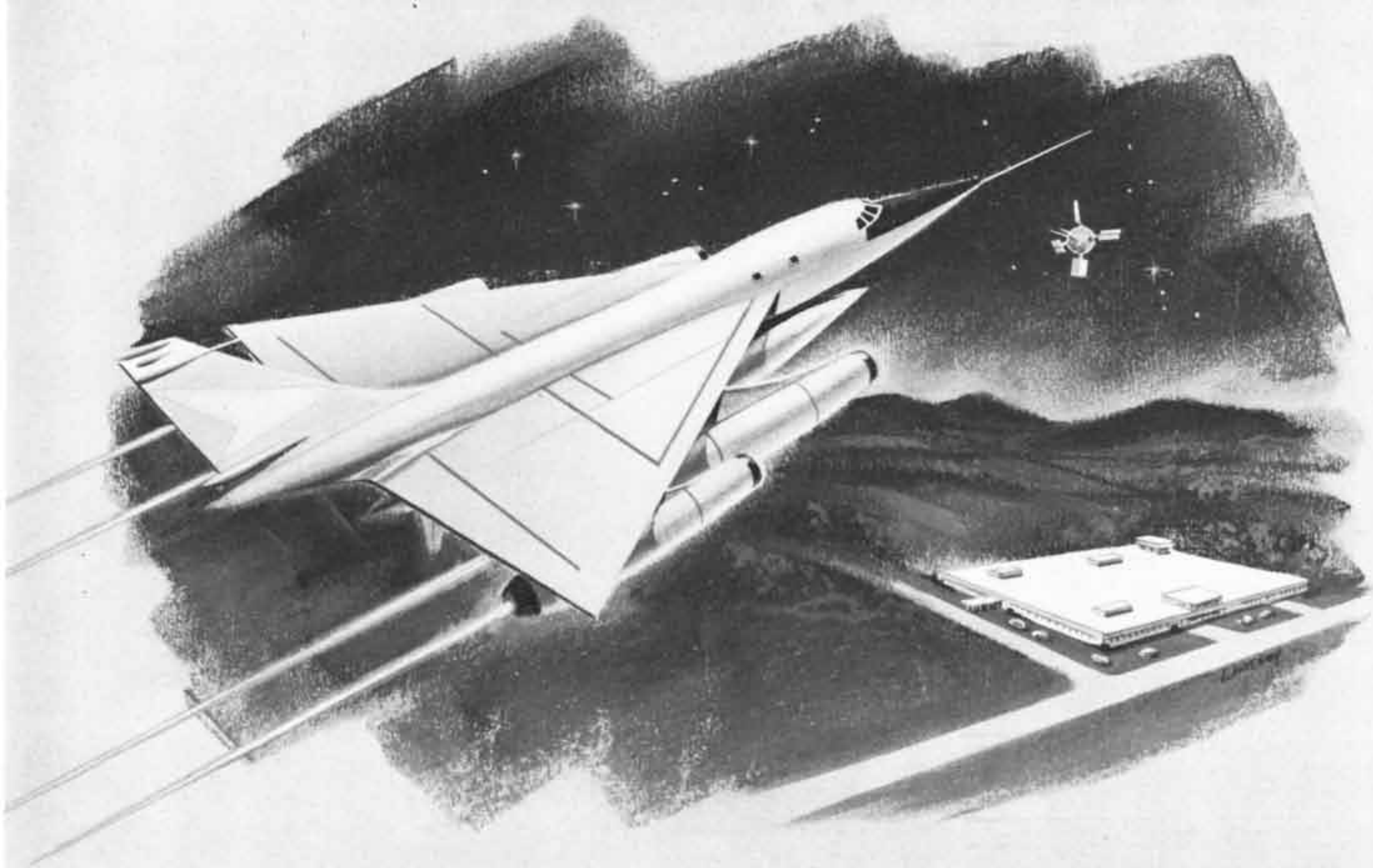
"The British ornithologist David Lack discovered that a territory-holding male robin would threaten a mere bunch of red feathers more readily than it would a complete mounted bird that showed all the characteristics of the mature male except the red breast, thus indicating the effective stimulus to be the red breast and not the complete bird. In my previous report on hummingbirds ["The Amateur Scientist," March, 1957] I showed a picture of a male broadtail furiously attacking only the head and gorget of a dead bird.

"The interesting phenomenon known as 'imprinting' is another example of the working of instinctive behavior and its releasers. The Austrian naturalist Konrad Z. Lorenz took half a clutch of eggs away from a duck and hatched them in an incubator. Subsequently he learned that if he made certain definite sounds and movements within a sharply limited period after the incubator ducklings hatched, they would adopt him as the mother and from then on follow him and react to him as their siblings did toward the real mother [see "'Imprinting' in Animals," by Eckhard H. Hess; Scientific American, March, 1958].

"When an egg falls out of the nest of a herring gull, it triggers in the brooding gull a series of maneuvers that results in the egg being moved back into the nest. Not so, however, with pigeons. I have observed them ignore eggs in plain view near the nest.

"For some years I have maintained a hummingbird feeding station in an area of rough pine and scrub oak on Cherokee

A homemade food and scent dispenser for testing the sense of smell in hummingbirds



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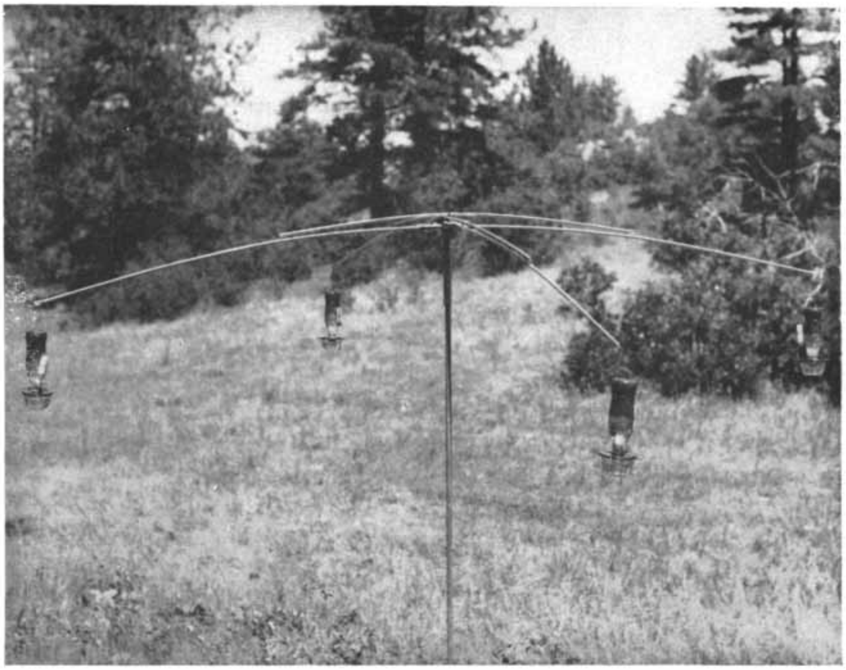


The rotary feeding station used in the experiments

Ranch, 20 miles south of Denver. The remarkable experiments of the Austrian zoologist Karl von Frisch on the senses and behavior of honeybees suggested a test of the sense of smell in hummingbirds. This sense has been shown to be useful to the bees, which, like hummers, feed on the nectar of flowers. Probably no other wild bird is so amenable to experiments of this sort as the hummingbird. Their indifference to the presence of man, together with the fact that a considerable number of them can be kept in a small area once they have learned to use artificial feeders, make them ideal subjects.

"The food dispenser I am now using is shown in the accompanying photograph [*page 158*]. It is made of a bottle inverted over a plastic container. Attached to the lid of the container is a wire perch. The birds feed through four 1/8-inch holes in the lid. This arrangement excludes honeybees, wasps and other insects, as well as other birds. The outgo of the sugar-water solution is easily measured and recorded. For this experiment I installed a new set of feeders, taking pains to make them exactly alike in every detail. An inverted half-ounce vial stuffed with cotton was attached to the side of each bottle to dispense various scents.

"On May 12 the first birds were seen, all males. Seven feeders were distributed over an area about half a mile long and 100 yards wide. Several drops of a strong flower scent, rose-geranium, were added to the scent vial of each feeder. This scent, renewed from time to time, was always associated with the feeders containing syrup. By May 25 the females had arrived; the consumption of syrup indicated that some 35 birds were using the feeders.

"On May 28 I removed all the feeders. Then I hung, on the lower branches of a large pine, six feeders, three made with syrup and scent and three with plain water and no scent. Observation gave no indication that the birds had learned to associate syrup and scent. The seven regular feeders were now replaced in their original locations for four days. Then, on June 2, I put up a feeder filled with plain water and bearing no scent 10 feet away from each of the regular feeders. The positions of these pairs were interchanged every other day.

"At this point a special testing rack was installed. It was made from parts of a television antenna and consists of four five-foot arms fastened at right angles to the top of a one-foot tube. The tube slips over and is supported by the top of a six-foot 3/8-inch pipe set in the ground as shown in the accompanying photograph [*above*]. A feeder was attached to the end of each arm. The feeder positions could be changed by pulling a rope tied to one arm. This rack and its associated feeders was substituted for all other feeders in the area. Two syrup-filled, scented feeders were hung on opposite arms of the rack and two water-filled, nonscented feeders on the other

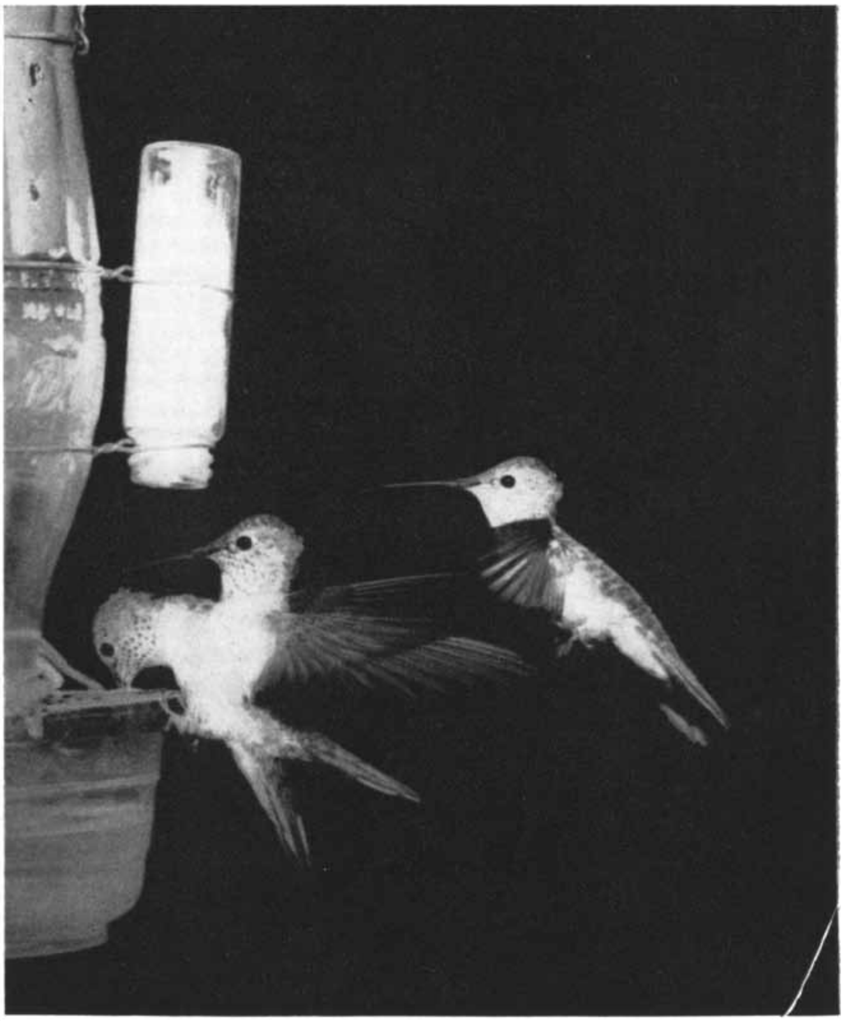
arms. Observations were made every other day, on the average, usually for a two-hour period.

"For each bird that visited the rack three things were recorded: (1) sex, (2) type of bottle visited first and (3) behavior with respect to the nonfood bottles. Birds that proceeded directly to food bottles were allowed to feed, but not to satisfy their hunger fully. After an estimated half-feeding, the bird was disturbed by revolving the rack, and a nonfood bottle was located where the food bottle had been. Most birds returned to the rack immediately. Their behavior could thus be recorded a second time.

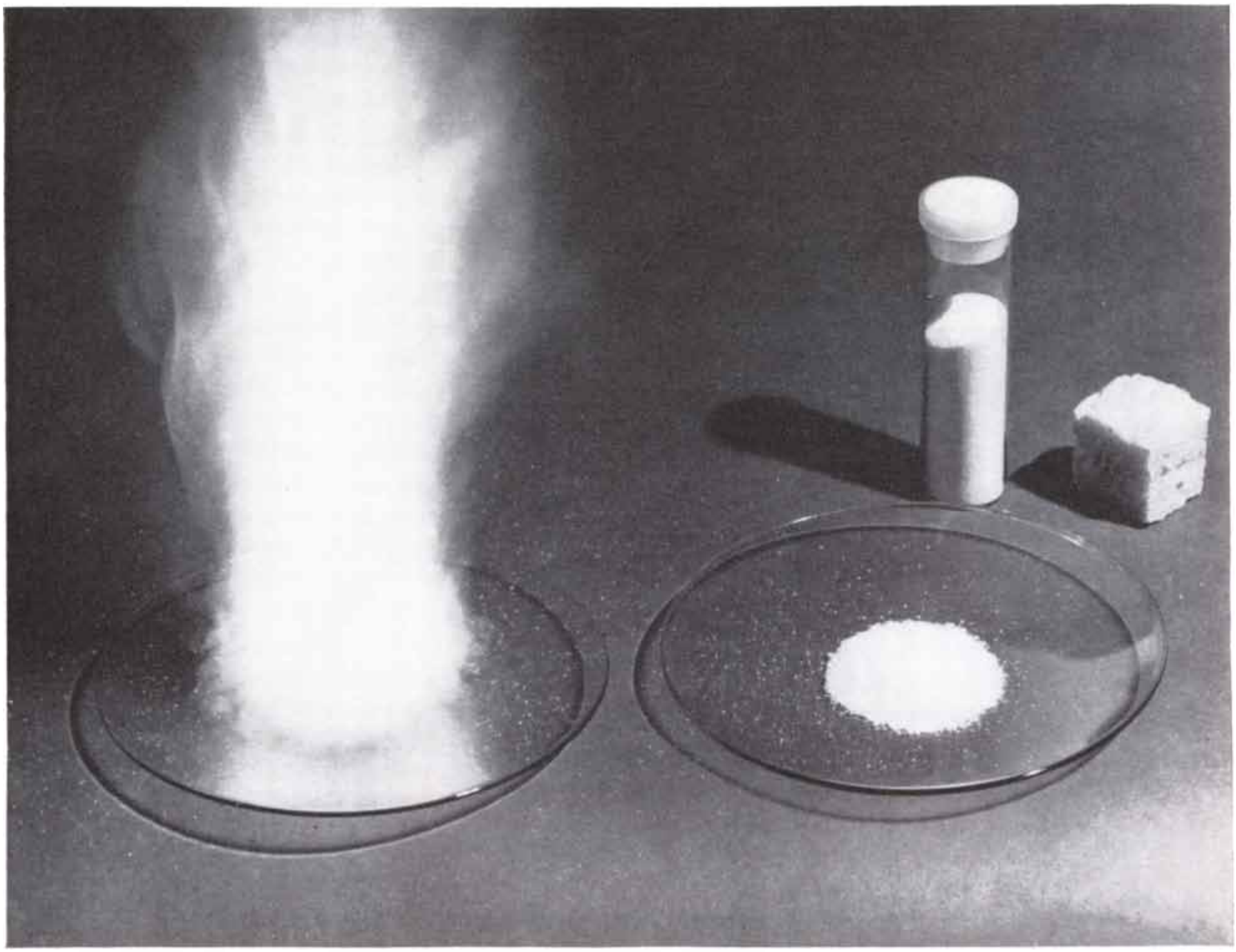
"Because all the feeders were identical, the apparatus gave the birds no visual clue to the dispensers that contained syrup. Positional clues were eliminated by frequent movements of the rack. Bees and wasps do not frequent the area because it provides no natural food for them; hence the experiment was not hampered by insect clues. The only differences between food and nonfood bottles were those detectable either by smell or by taste.

"The first question I had sought to answer by these experiments was: Did the birds learn to go directly to food bottles by scent alone? The answer was provided during the training period from May 12 to June 8, and it was 'no.' Visits to food and nonfood bottles were about equal in number.

"It became apparent with the first observations that a bird coming in search of food would normally light on the first feeder in its line of flight. When it chanced to select a feeder bearing syrup and scent, it inserted its bill in the dispenser and fed. What took place when it lit on a feeder containing no food? If it immediately left the feeder without tasting, or hovered near the feeder without perching and flew to one of the syrup and scent-carrying feeders and fed, this behavior could be interpreted as being directed by the sense of smell. If, on the other hand, the bird perched on a nonfood bottle, inserted its bill in the feed-



Repetitive flash photograph shows a hummingbird feed (left) *and back away* (right)



	NONFOOD BOTTLES				FOOD BOTTLES	
	TASTE MALE	TASTE FEMALE	NO TASTE MALE	NO TASTE FEMALE	TASTE MALE	TASTE FEMALE
	WATER AND SACCHARIN				SYRUP AND SCENT	
JUNE 13	2	7	3	0	5	5
	7	10	7	0	8	10
16	9	17	6	0	9	10
18	3	5	1	0	5	5
20	4	20	3	0	9	13
22	4	14	1	1	4	5
	IODOFORM				SYRUP AND SCENT	
23	2	13	5	9	4	11
	3	11	7	1	5	4
	9	11	2	0	8	10
26	11	10	0	0	4	10
28	1	16	0	0	1	30
30	2	14	0	0	0	14
	KEROSENE				SYRUP AND SCENT	
30	2	37	0	2	3	43
JULY 4	0	21	0	1	2	15
	AMMONIA				SYRUP AND SCENT	
4	0	8	0	1	0	8
6	1	18	0	0	7	30
8	4	9	0	1	5	4
15	3	8	2	1	2	4
20	1	1	2	0	1	0
	BUTYRIC ACID				SYRUP AND SCENT	
27	12	16	0	0	5	25
AUGUST 4	2	1	0	0	3	0
	FOUR BUTYRIC ACID BOTTLES ON RACK (NO SYRUP)					
11	15	16	0	0		
	TOTALS				TOTALS	
	97	283	39	17	90	256

Table summarizing the reaction of hummingbirds to various foods and nonfoods

ing hole, tasted and then flew away, it would appear reasonable to conclude that taste alone, and not smell, had been the determining factor.

"Throughout the experiment, syrup was always fed from the same dispensers and always carried the rose-geranium flower scent. The scent was quite strong and was renewed from time to time. A variety of scents and nonfood substances was offered in the remaining dispensers. The general scheme was to pair each syrup dispenser with a nonfood dispenser nearby, the positions being interchanged periodically. The several test combinations were observed for varying periods according to the following schedule.

"May 12 to May 28: Syrup bottles with the scent attached were available alone. No nonfood bottles.

"May 28 to June 4: Plain water was dispensed in nonfood bottles with no scent.

"June 8: Two tablets of saccharin were added to each nonfood bottle (a previous experiment having shown this solution to be unacceptable to the birds). Observations were made on June 13, June 16, June 18 and June 20.

"June 23: An eye-dropper of iodoform in alcohol was added to nonfood scent vials and the reaction of the birds observed on June 23, June 26 and June 28. On June 28 iodoform was also added to the water.

"June 30: Kerosene was placed in the feeding cups of nonfood bottles. Observations were made June 30 and July 4.

"July 4: Household ammonia was placed in nonfood bottles and scent vials. Observations were made on July 4, July 6, July 8, July 15 and July 20.

"At this point the question of whether the birds make use of the sense of smell in distinguishing between food and nonfood dispensers was clearly answered. The behavior of birds alighting on dispensers that carried water, saccharin, iodoform, kerosene or ammonia was characteristic. The bird tasted what was in the cup, promptly pulled away with a little shudder and flew in search of a syrup dispenser.

"The uniformity with which the birds reacted to the situation indicated plainly that they were responding to an instinctive or inborn behavior pattern and that any stimuli being received by the sense of smell were excluded. In my opinion this conclusion is clear-cut and sound. However, neither this response, nor the other examples of instinctive behavior cited, mean that all animals showing instinctive behavior patterns are mere automatons—that their lives are governed

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"Having reached the conclusion that my birds were not making use of a sense of smell, I next tackled a more difficult and fundamental question: Do hummingbirds have any sense of smell? I was experimenting with wild birds that were feeding on nectar and insects, their natural foods, in addition to my offerings. I did not think that there was much chance of inducing them to change their ways. But I decided to try to demonstrate the presence or absence of the olfactory sense by using another repellent odor in fixed locations for a longer period.

"On July 27 a solution of butyric acid and water (to the human nose the most repellent of the substances I used) was put in all nonfood bottles. Six of these bottles were paired with regular food bottles and left in place for nearly a month, the idea being that the birds might learn to avoid the bad odor in a longer training period. Observations were made on July 27, August 4 and August 11, with negative results. At this time I became busy with a photographic project that required the removal of all food bottles except one for attracting birds to be photographed.

"The butyric acid bottles were left in place, however, until August 20. It was interesting to observe that, although these dispensers had been in place for nearly a month, birds looking for food would light on them and invariably take the tell-tale taste.

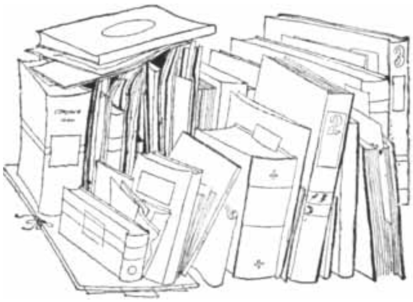
"The results are summarized in the accompanying table [*page 164*]. The two columns of the table headed Taste under Nonfood Bottles and Food Bottles list the visits by males and females that behaved in the normal manner, that is, lighting on the bottle and tasting. The columns under No Taste list visits of birds that hovered near the nonfood bottles and flew away without lighting or tasting—a pattern of behavior that might possibly indicate the use of the sense of smell. As shown by the table, these instances of apparently significant behavior were more frequent in the earlier tests than later. With continued observation an alternate explanation of 'No-Taste' behavior became obvious: 'spooking' by a guarding male. As soon as all the bottles except those on the testing rack were taken down, a male (not always the same one) would take charge of the territory and chase away or try to chase away all other birds that came to feed. The intensity of this behavior varied greatly. Sometimes a guarding male would leave the job, giving all visitors a chance to feed. Then a new guardian would take over. With close guarding, a bird coming in was easily spooked or frightened by the dominant bird and often made only one pass at a bottle. Initially this behavior seemed to indicate a rejection of the food and I accordingly noted them as No Taste.

"The table shows that more passes were recorded at the nonfood than at the food bottles. This is explained by the fact that I manipulated the rack for this result. Passes at the nonfood bottles were the significant ones. Many more observations were made of females than of males, because for a considerable portion of the period the hens were feeding their young. Their food requirement was therefore two to three times that of the other birds.

"Unfortunately the butyric acid experiment was not correctly designed to show the presence or absence of a sense of smell. Some indication of the complexity of this question and of the difficulty of devising an experimental method for answering it is given in a paper by Wolfgang J. Michelsen of Harvard University in *Science* for September 11, 1959. He used a rather complicated apparatus for studying 'olfactory discrimination' in pigeons and was able to teach the birds to use the sense of smell to obtain food. The method gives a sound and convincing result which proves that pigeons possess a sense of smell.

"In the case of hummers it seems clear that the existence of a sense of smell might be determined by the use of captive birds. With the wild birds I cannot devise a way to do it. Proving the negative—that the wild birds do not possess a sense of smell—seems to me quite impossible.

"As mentioned earlier, my experiment was suggested by the pioneering investigation of the honeybee's senses. This work shows that bees have and make use of a sense of smell. It was observed that a scout bee finds a new source of nectar, returns to the hive and by a definite pattern of behavior communicates the distance and direction of the discovery to its fellow workers. Because the scout bears the scent of the flowers, it is also able to disclose the kind of flower to be sought by the workers. Hummingbirds, being completely nonsocial, cannot use the sense of smell in this way. Moreover, the use of the sense of smell, in my opinion, would not significantly increase the efficiency of the hummingbird's normal food-seeking behavior—a possible explanation of why they have not developed this faculty."



BOOKS

A naval officer's book on the wandering albatross, the largest of all living birds

by James R. Newman

The Wandering Albatross, by William Jameson. William Morrow & Company ($3).

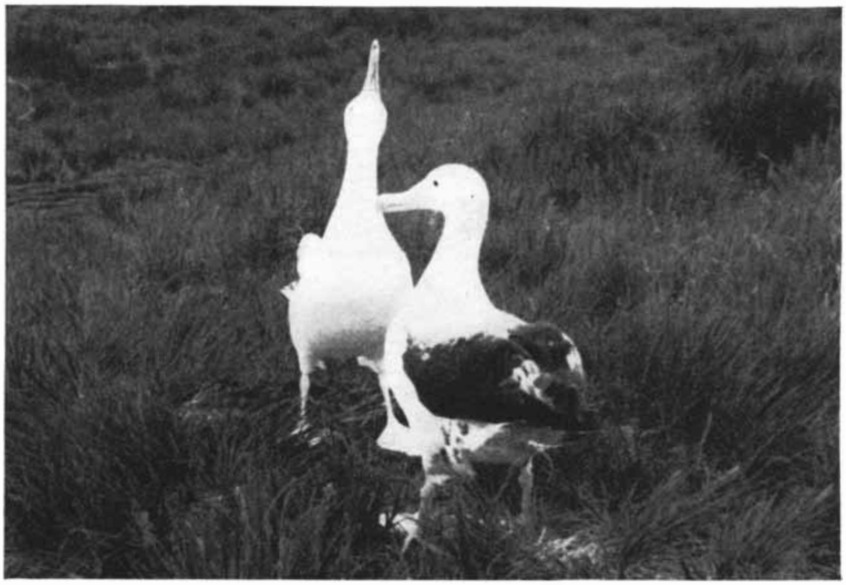
And I had done a hellish thing
And it would work 'em woe:
For all averr'd I had killed the bird
That made the breeze to blow.
Ah wretch! said they, the bird to slay,
That made the breeze to blow!

And now a mariner, neither graybeard nor ancient, has come to set things right. In November, 1939, the German warship *Graf Spee* had sunk a small merchant vessel off Madagascar and then disappeared. Immediately the British aircraft carrier *Ark Royal* was dispatched to find the raider—though where she had gone, east into the Indian Ocean or west into the trackless immensities of the South Atlantic, was not known. The Admiralty ordered the *Ark Royal* "to take up a strategic position south of the Cape [of Good Hope] to cover either eventuality, but the seas around remained empty." Among those who shared this lonely and weary vigil was a naval officer named William Jameson. For days, as the ship patrolled the horse latitudes, the sky was gray, the sea "lifeless and dull," and neither birds nor flying fish nor whales were to be seen. Then, on a fresh November afternoon a few hours after the carrier had entered the subantarctic zone, a great white form flashed into view. It was a wandering albatross, the largest of living birds. With motionless wings it skimmed the waves, turned into the wind, soared up to 40 or 50 feet, banked toward the ship and swooped down at high speed to pass across its wake. For several days the albatross, which by now had picked up companions, followed the ship. On the edge of the roaring forties the sky became overcast, the glass fell and the weather turned wild. Wind velocity rose to 60 miles per hour; 35-foot waves, 300 to 400 yards from crest to crest, made the huge ship lurch and plunge continuously. It was all a man on deck could do to wedge himself into a sheltered corner. But the albatrosses were enjoying themselves: "swooping around at high speed, banking, soaring, diving to within an inch or two of the sea; perfectly at home in their boisterous element and moving, as it seemed, in any direction they wished." Then, as suddenly as they had appeared, the birds vanished.

For Jameson the brief encounter with these superbly graceful creatures was a

Juvenile male wandering albatross was photographed by the Duke of Edinburgh. The adult bird has a wing span of 10 to 12 feet

Two wandering albatrosses stride about South Georgia Island



A male albatross (left) *struts before a female*

A male sits atop a nest. The down of the chick is visible beneath his breast

"heart-lifting and unforgettable event." He continued his naval career, became attaché at the British Embassy in Washington, was promoted to Rear Admiral and knighted. When he retired, he wrote a history of the *Ark Royal* (which, after valiant service, was destroyed by a U-boat in 1941) and then turned to a study of the wandering albatross. He searched the literature and assembled information from various other sources, and he has now written a delightful little book which summarizes all that is known about this huge, gentle, fearless creature: its habits and life history, its method of flight, its place in fable and legend.

The wandering albatross is a distinct species of albatross. It belongs to the family Diomedeidae in the order Procellariiformes, which dates from the Miocene Epoch (10 to 30 million years ago); fossil remains of an early albatross have been found in rocks dating from this period. Experts disagree on the number of different forms of albatross, but we may accept the fact that there are some 15 species. Three inhabit the Northern Hemisphere; the waved albatross is confined to the tropics. Nine species, including the royal, the sky, the black-browed and the yellow-nosed albatross, have plumage that is mostly white at maturity, and have a range which overlaps that of the two races of wanderers. The wanderer, which is the largest species of albatross, breeds on bleak, stormy, remote islands: South Georgia, Inaccessible, Kerguelen, Gough and others.

The name albatross, says the *Oxford English Dictionary*, is apparently a modification of alcatras, applied to the frigate bird, but extended through inaccurate knowledge to a still larger seafowl. (*Alcatruz* is the Portuguese word for the bucket of a water-raising wheel; whence alcatras, first applied to the pelican, which, the Arabs in Spain believed, used its great beak to carry water to its young in the desert.) The alcatras is black; perhaps to distinguish white birds the prefix albi- or albe- (with reference to the Latin *albus*: white) was substituted. Sailors have called the wandering albatross by a variety of names: cape sheep (descriptive of its immense size and color), goney (obviously a reference to the very young birds, which have an innocent and befuddled look), man-of-war bird. In 1766 Linnaeus assigned to the wanderer a more poetic name: *Diomedea exulans*. According to Jameson, two fables guided the master-classifier. An old sailors' legend says that sea captains are condemned in the hereafter to wander eternally above cold and stormy seas, as retribution for the cozy quarters in the poop they enjoyed during their lifetime while the crew dwelt in wretchedness. The other fable concerns Diomedes, a Thracian hero, who after the Trojan Wars went to Italy, was ensnared by a magician and had his companions turned into birds resembling swans. *Diomedes* means Zeus-counseled; *exulans*, an exile or banished wanderer. Thus *Diomedea exulans*.

Early books on natural history were neither very informative about *D. exulans* nor accurate. It was confused with other birds, and strange habits were attributed to it—not stranger than the truth, merely wrong. In the late 18th century, as sailing ships sought out the "albatross latitudes" (40 to 50 degrees South) information about the birds began to come in. Mariners ashore on albatross breeding-islands were more interested in eating albatross eggs—which are huge and delectable—than in compiling ornithological records, but now and then a more philosophical visitor controlled his appetite and enlarged scientific knowledge. In our century the expeditions of the *Discovery* and the *Quest*, and such ornithologists as Robert Cushman Murphy, Niall Rankin and L. E. Richdale, have provided the data from which a good picture of the life cycle of the wandering albatross can be drawn.

On tiny desolate islands, scattered high in the southern latitudes, set in the wildest seas of the world, *Diomedea exulans* builds its nest. A favorite place is South Georgia. Here, where it is bleak and treeless, where the wind always blows, where the foulest weather is the rule, where the only vegetation is coarse tussock-grass; here, where huge sea-elephants and tiny petrels, seals and penguins come to breed and raise their young, the albatrosses gather for a few months to court and mate, to produce their young and raise them to independence.

The nest is usually built in an exposed place near the shore, facing into the wind, preferably on an eminence. The bitter cold and the constant gales do not discommode the albatross; even the nestlings' feathers make a perfect coat. The main consideration is to choose a home that is also an airfield, where the birds can land and take off with the least trouble. In the air an albatross is grace itself, but on land it is a clumsy creature. It cannot perch, it walks laboriously with a waddling gait and has a hard time getting up enough speed to be airborne, and when it lands it is apt to pancake or to go over on its nose.

Spaced 20 to 50 yards apart, the nests (made of soil, moss and grass trampled into a peatlike mixture) are shaped like miniature volcanoes. They are about three feet across at the base and are built high enough—one to three feet—to keep the top above the level of the winter snows. A single egg is laid in a shallow bowl hollowed out of the top of the conical structure. Husband and wife build the nest together—an arduous task—and keep it in repair; old nests are used again.

Egg-laying begins in November and December, depending on the island, and by early January (midsummer) eggs are everywhere plentiful. In 1923 four men from the *Quest* gathered 3,500 eggs in three days from the northern end of South Georgia; as an offset to such depredations the birds' food supply has been increased by the waste products of whaling stations, and the albatross population does not seem to have decreased. An albatross egg has a coarse white shell speckled with red spots, weighs around 15 ounces and holds as much liquid as six hen's eggs. It takes roughly 10 weeks for the chick to hatch, during which period male and female alternately sit on the nest. While one partner does brooding duty, the other is at sea getting food. The sitter is patient, fearless and tame; it will fight off piratical antarctic skuas, but will permit a man to approach, provided he makes no sudden movements. *Diomedea exulans* has a great bill that can inflict serious injury, but if this is firmly grasped, the bird can be lifted from its nest and even stroked. It is fair to conclude, says Jameson, that the wandering albatross is "devoid of aggressiveness." It only attacks what it supposes to be its usual food, but like a Yosemite bear it can be "dangerous without evil intent." (Park bears should not be fed because, as a keeper once told a visitor, they don't know where the bun stops and the arm begins.)

The newly hatched albatross weighs 11 to 14 ounces, and is covered with silky pure-white down. The beak (hooked at this stage) and the feet are yellow; the eyes, very dark brown. In a week the chick almost doubles its weight, and in three weeks it is as big as a barnyard fowl. When it is a month old, it weighs more than six pounds and can frighten off any skua, so that it can do its own baby-sitting and leave both parents free to forage for it at sea. A new buffish-gray coat of luxuriant down keeps the youngster warm; autumn is now well advanced and there are frequent storms, but the bird is snug. More aggressive than its parents, it will snap at intruders;

if this doesn't work it will vomit its stomach contents, which are mixed with "a very evil smelling oil." This substance deserves a few words.

All birds of the order Procellariiformes manufacture this stomach oil, which is a gland secretion similar to the oil found in the head of the sperm whale. Its exact purpose is not known. It can be discharged for defensive purposes through the beak or nostrils; petrels are particularly adept in firing a stream of it fairly accurately and over some distance. It may also be a "supplemental food" for the young, since it is rich in vitamins. An intriguing suggestion is that ocean-going birds use it to calm the water in their vicinity when riding out a gale. Jameson says this may sound absurd, but only to those who have not seen the pacifying effects of even a small quantity of oil on a turbulent sea. It is possible that the oil is used for preening, which is very important to creatures that spend so much time in the air. The oil contains alcohol, remains fluid at low temperatures and can easily be transferred from beak to feathers. A leading ornithologist has advanced the idea that the oil of the adult is the fledgling's water supply. There may be truth in all theories.

At five months the youngster is still being fed. Although it is now fully grown, it is very fat, covered with down and cannot fly. Yet suddenly it is abandoned. Sometime in June the parents fly off to sea, apparently leaving the nest-bound fledgling to fend for itself. The ornithologist L. Harrison Matthews, visiting a snow-covered site in South Georgia in August, describes how each nest had "a young albatross the size of a small sheep sitting on it, sitting all alone and waiting; clad in a thick coat of buffish woolly down." A touching picture, almost inexplicable in biological terms, even if one recognizes that the birds can live a long time off their own fat, and that their metabolic processes during the rigorous antarctic winter probably slow down to a point closer to hibernation than can be found in any other creature of the bird world.

But this paradox of life cycle seems at last to have been solved. By piecing together observations made in storms and in winter darkness at different sites on the breeding islands, ornithologists have now concluded that the fat young goneys are not entirely abandoned by their parents. After the initial phase of daily feeding, the interval is increased, at first to two days, then to longer periods. After the parents take to the wing in June they return periodically to dispense fish and cuttlefish. This practice is continued until the young can fly. Two days before they go to sea they are given their last free meal.

The preparation for the youngster's emancipation is spread over months. All through the winter the first coat of feathers has been growing underneath the second coat of down. The goney now looks rather frowzy, with tufts of down adhering to its feathers, but in due time its dress becomes tidier. The sides of the neophyte's face are white, and there is a white bridge across its nose—"like a pair of spectacles." The feathers are a chocolate color; the beak is whitish yellow; the legs and feet, light gray. A young albatross is "a somber bird," much different from the dazzling creature it will become.

In November it begins to flap its great wings—10 to 12 feet in span—but they are still weak. It waddles around the nest, takes trials standing into the wind, springs off the ground and lurches into the air for a few seconds. André Migot observed on Kerguelen that young birds took a month practicing to fly. G. H. Wilkins of the *Quest* party watched the birds painfully clamber up a hillside (resting frequently along the way) and then, "after a prolonged rest, run a few steps downhill and launch themselves into the air for a short flight, followed by a heavy landing which probably sent them tail over beak. Getting up, with an expression of pained surprise, they would repeat the process, always toiling farther up the hill if failing to get properly airborne." When the old birds begin returning in late November, the young exhibit their prowess and begin extending their range. For several months they make trial runs over the open sea. But when the breeding birds leave, the fully fledged youngsters set out on their own and begin the "purely pelagic existence" that they will follow for several years. Some may not see land again until they return to their birthplace to mate and raise their own chicks; six or seven years may elapse before this happens. "Not for nothing has the bird been named the wandering albatross."

"It has always been a mystery to me . . . on what the albatross can subsist," wrote Darwin in *A Naturalist's Voyage around the World*. The answer is that the wanderer has the huge pastures of the Southern Ocean on which to "graze." (This apposite descriptive term was used by Anders Sparrman, who accompanied Captain Cook on his voyage around the world in the *Resolution*.) It is a large bird and a surface feeder, but the area in which it can forage is immense: some 30 million square miles, or 10 times the area of the U. S. The ways of the wandering albatross are solitary. It has its own path, it feeds and flies and rests alone, many miles away from any other of its species. But when a ship appears, the birds are drawn together. In the days of sail the ruffling of the surface water, or refuse thrown overboard, attracted birds from every quarter; the modern ship leaves a propeller wake and perhaps a trail of grease and oil that act like a powerful magnet. Albatrosses have a keen sense of smell, and their vision is such that they can see a ship eight to 10 miles away. A dozen or more birds may assemble and follow the ship for days. This brings us to the fascinating question of how they fly.

Their aerial performance is prodigious. They fly into the wind at high speed; they move up and down in a curiously curved flight path, behind, over, alongside, in front of the ship, now trailing, now overtaking, now diving, now climbing, all the while scarcely flapping their wings. They can keep up this pace for days, apparently without rest or sleep, following a vessel making 20 knots or more, and they have been known to cover a distance of at least 3,500 miles in 12 days. Neither gravity nor fatigue seems to hamper these Zeus-counseled fowl.

The explanation rests on the fact that the albatross is primarily a living sailplane. Though it is capable of powered flight, the bird's pectoral muscles are of moderate size and quite inadequate to support its sustained aerial feats. In a sailplane the force of gravity provides most of the motive power; the wings must give the required lift with the minimum drag, or resistance to forward motion. The aspect ratio (the ratio between the average width of the wing and its length) and the ratio of lift to drag must both be high. In a high-performance sailplane the aspect ratio is around 18—the same as that of the wandering albatross. The lift-drag ratio of such a wing may be as high as 40 to one, "that is to say, for every 40 pounds of lift acting upward at right angles to the wing there is a resistance to forward motion of one pound pulling to the rear."

To build a sailplane with such long and narrow wings is exceptionally difficult, but the albatross meets the specifications admirably. Its wing bones are hollow and filled with air instead of marrow; in a 20-pound bird the entire skeleton, including that of the wings, weighs well under three pounds. The living creature has other advantages over the man-made device. An albatross in flight can control its feathers and joints to change the span of its wings, their camber, sweepback and dihedral angle. The feathers can be closed or opened like a fan, thus enlarging or diminishing their total surface and achieving the optimum lift-drag ratio at any given speed.

A bird (or a sailplane) gliding through the air must overcome drag. This is done by dissipating potential energy. When the bird is high, it must slide "downhill" to pick up speed, and somewhere along the descent it must find an updraft in the air stream to regain height. Currents of this kind occur over land: on the windward side of hills, in "thermals" where warm air rises from the ground, and in "standing waves" where air passes over a hill, dips down and bounds upward. All three types of updraft also occur over the ocean. Air currents rise on the flanks of waves and rebound on the lee side of the crests. Thermals are found when the water warms cold air above it, causing the air to rise in closely packed counter-rotating cylinders; and even if the columns are blown over by the wind until they lie parallel to the surface, their counter-rotation pushes up a ridge of air along which a bird can glide. The albatross seeks out such upcurrents and makes use of them. Yet together they are too irregular and operate too near the surface to afford the bird the steady and powerful support it needs. Another source of power is thought to be available. In 1924 P. Idrac of the Paris Ecole Polytechnique carried out a careful field study that led him to what Jameson describes as the now generally accepted theory of albatross flight. Wind blowing over the sea is slowed down by friction. In Jameson's happy image, if we throw a stack of playing cards onto a table, they will spread out in different degree: the bottom cards, in contact with the table, will travel slowly over a short distance; the top cards fastest and farthest; the cards in between at intermediate speeds, each being held back by the friction of the slower-moving cards of the layer immediately underneath. So, roughly, with the winds blowing over water. For example, a wind traveling at 40 miles per hour at an altitude of 55 feet may be traveling at only 20 m.p.h. near the surface, and the layers in between will have a spread of intermediate speeds. The albatross capitalizes on this circumstance. Under the wind conditions mentioned it can start a dive from 55 feet at, say, 30 m.p.h. In still air it will accelerate to 48 m.p.h., but since the air is moving and the bird is gliding downwind, by the time it reaches the slow-moving layers of air near the surface it will have attained an air speed of 67 m.p.h. (48 m.p.h. plus 20 m.p.h, minus one m.p.h. lost to increased drag). This is more than enough to enable the albatross to soar back to its original height. Still, it would not enable the bird to follow a ship traveling into the wind, because it has lost considerable ground in its downwind dive. However, when it ascends and turns first across and then into the wind, it is constantly entering faster-moving layers of air, and the arithmetic balance of forces is in the albatross's favor, so that when it has climbed to 55 feet it is actually moving much faster (perhaps 70 m.p.h.) than when it started the dive. Just as it is possible for a sailing vessel to proceed into the wind, the albatross, making use of variations in wind-speed within a shallow layer of air, as well as of various eddies and updrafts close to a ship, executes a continuous, crudely S-shaped flight cycle that enables it to keep up for days with a vessel making 20 knots or more against the wind. It is a feat that no man-made sailplane can equal.

How long the albatross remains at sea after leaving the breeding site, how it navigates and finds its way back to the tiny home islands, how often it breeds—these are questions that are far from settled. Observers accumulate evidence but it is not decisive. The marvelous navigational ability of birds is of particular interest to missileers in our happy age. What would they not give to have their clumsy toys emulate the swallow that flies from South Africa to the barn down the road, or the albatross that circumnavigates the globe half a dozen times and then homes to a nest on Kerguelen. Indeed, what treasure has already been spilled to gain this end. But if, as Jameson says, "the results of these investigations enables a rocket to home as certainly as the swallows of Capistrano, we must pray that the secret continues to elude mankind."

Much else in this book is of compelling interest. Jameson describes the remarkable rituals of courting and mating. The returning cocks form into groups of four or five, each composing a ring with a hen in the center. Hitherto-silent suitors now begin to utter "harsh, groaning sounds, not unlike the braying of an ass and no more pleasant or musical." The female faces each male in turn and a dance ensues in which the cock shows what a splendid fellow he is. When the dance is concluded, the female, whose deportment is demure, now turns to another bird and the ritual is repeated. Everything is carried off with decorum, "in a bucolic sort of way," and while there is a hideous din and much wing-flapping and neck-stretching, there is no fighting or interfering with the other chap's dance. Occasionally, when a cock's feelings become too much for him, he strolls a short distance from the ring with his head (as Robert Cushman Murphy describes it) "swaying from side to side and hung almost to the ground. The attitude gives [the cock] a diabolical look, and it would be easy to imagine that dark and sinister thoughts were occupying [his] mind." In time, after the female has inspected all the suitors, she makes a choice, whereupon the successful male shepherds the bride-to-be to his nest. "Other females are constantly arriving from the sea and the rejected males, undaunted, waddle off to try their luck elsewhere."

The ritual after pairing is even more elaborate than that of courtship. The birds croak at each other, opening their bills wide, and then nibble at the short feathers of their partner's neck. They emit "bubbling" noises, bring their beaks together and sing screeching duets. Standing on the nest, the male spreads his wings, stretches his neck, points his bill to the sky and turns slowly through a full circle, "lifting each great foot in turn high in the air with the measured precision of a guardsman doing a slow march. All the time he lets out a high-pitched pig-like squeak." The female, though "evidently greatly flattered," is still coy, but at last comes a demonstration that is irresistible. Stretching his wings to the full, cocking his tail upward, the male "shrieks to the full capacity of his lungs. No female could ignore so fervent a declaration." Mating may now take place, though quite frequently this "ecstatic climax is followed by anticlimax," both birds seeming to tire of the whole performance and sinking exhausted to the ground to rest quietly side by side. Then the whole ceremony has to be repeated, mixed in with a little nest-building so as finally to get the show on the road. The wandering albatross, "so solitary and aloof for most of its life, is an ardent bird, and courting continues, no less fervently, while the nest is being prepared and even after the egg is laid."

For the benefit of those who demand conjugal felicity even of birds before granting their blessing, I should point out that there is evidence that wanderers are faithful to their chosen mate. But not in all cases, and at best only up to a point. Promiscuity is known among the elders, and occurs even more among the youngsters. And each time an albatross returns to breed, it selects a new mate, the older males "showing the marked preference for sprightly young females which has sometimes been noted in other walks of life."

A final word as to the fable. Jameson has made a careful search of the origins of the tale upon which Coleridge presumably based his "Rime." The results are surprising. Birds have of course always been a subject of legend and superstitious awe. Eagles, vultures, swallows, geese, magpies, crows, ravens, owls have at various times and places figured as omens, as portents, as aids to augury. Gannets, kingfishers, petrels have had special meaning for seafarers, and many have heard of the famous bird which on April 12, 1782, perched itself on the poop of Admiral Rodney's flagship and obligingly clapped its wings at every broadside poured into the French *Ville de Paris*. But of the albatross there is no record—neither of superstitions, omens, ceremonies, nor of cheering on the British Navy. If it was once believed that an albatross hovering about a ship brings bad weather, and that to kill it brings bad luck, the belief has left no trace. Moreover, there is ample evidence that sailors had not the slightest compunction about shooting an albatross or snaring it. The bird is no treat to the table, because it tastes like a stale, tough and oily fish; but catching it is sport—or what passes for sport. The albatross has also been prized for things that could be made out of it: tobacco pouches out of the webbed feet, pipestems from the hollow wing bones, a "handsome paper clip" out of the beak.

Where then did Coleridge get his notion? With the help of John Livingston Lowes's analysis in his famous *The Road to Xanadu*, and Coleridge's correspondence, Jameson clears up the mystery—or comes as close to doing it as anyone would wish. I shall leave the reader in suspense; this is but one of several excellent reasons for turning to Jameson's charming natural history.

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behavior and expansion of the cerebral cortex, all of which form part of the somatic road to culture. No less intriguing are the speculations on the effects of tool-use on human evolution. S. L. Washburn in one of these essays suggests that the form of the human hand is the result of the selective pressures on primates of at least half a million years of using tools, and that biological changes in the brain and face are due to the same cause. Tools brought about new patterns of life that included hunting, cooperation and the necessity for communication and language. Memory, foresight and originality were favored as never before; complex social systems, made possible by tools, could only be realized by domesticated individuals: "thus in a very real sense, tools created *Homo sapiens*." Certain trends and tendencies in prehuman primate behavior are of course carried over and express themselves in human behavior and culture; we are monkeys and apes in many ways. But we have also departed from the habits of our ancestors. Marshall D. Sahlins considers the emergence of cultural features that directly oppose fundamental traits of primate nature and practice. The advances of primitive man over the primates are mainly in sex and economics: the division of labor by sex and the establishment of the family on this basis, the invention of kinship, the prohibition of incest, the favoring of sharing and cooperation with regard to food, "the abolition of other primate conflicts leading to the establishment of dominance hierarchies." These, in Sahlin's words, are great triumphs of early culture. A cogent and lively little book.

THE CELL: BIOCHEMISTRY, PHYSIOLOGY, MORPHOLOGY; VOLUME I, edited by Jean Brachet and Alfred E. Mirsky. Academic Press, Inc. ($22). The third edition of E. B. Wilson's classic *The Cell in Development and Heredity* appeared in 1925; since then knowledge of the subject has increased tremendously, new specialties and techniques have arisen, and it has therefore become unlikely, if not impossible, that one person could prepare a survey as comprehensive as was Wilson's for its time. The need is great, however, for a stocktaking of what is known about the cell, a report on accomplishments, theories, methods, problems, research interests. The volume at hand is the first of a collective treatise prepared to meet this need. Part I includes an introduction and descriptions and evaluations of the most important methods for the cytologist: optical methods, fixation and staining, autoradiography, quantitative cytochemistry and histochemistry, micrurgical procedures, fractionation of cell organelles, tissue- and cell-culture. Part II deals with problems of cell biology: fertilization, sex determination, growth and differentiation, nucleocytoplasmic interaction in eggs and embryos, the acquisition of biological specificity, the effects of radiation on the cell. Two further volumes are promised which will be devoted to the study of the cell constituents and specialized cells. Evaluation of this volume is a task for specialists (therein, it should perhaps be said, lies one of the major difficulties of appraising cooperative works, for just as the subject has outgrown the single reporter, the collective survey has outgrown the single reviewer), but the scope and variety of the topics, the thoroughness of treatment by individual contributors, each of whom is a leading investigator, make it likely that this work, so promisingly begun, will when completed form a valuable addition to the literature of biology.

ELEPHANTS, by Richard Carrington. Basic Books, Inc. ($5). The perfect subject for a book, and Carrington has done well by it. The frame of this endearing and majestic freak of the animal kingdom was well described by Hilaire Belloc:

When people call this beast to mind,
They marvel more and more
At such a little tail behind,
So LARGE a trunk before.

But there is more to say. The African bull elephant may stand 11 feet six inches at the shoulder and weigh seven tons; the elephant's trunk is simply a very much elongated upper lip; the tongue is "soft to the touch as velvet"; elephants' hearing is excellent but their eyesight is poor; their eyelashes are almost incredibly long. The elephant's molars are enormous, commonly measuring a foot or more in length and weighing up to eight or nine pounds, and they renew themselves six times in a period of 60 years; then they begin to fail, which more or less fixes the elephant's life span. An elephant has a thick skin, which is nevertheless extremely sensitive, and flies and mosquitoes can drive the beast to distraction. The specialized structure of the legs, necessary to support the vast bulk of the torso, renders the elephant incapable of making the slightest jump, so that a seven-foot trench is completely impassable even though the maximum stride of a large elephant may be six and a half feet. Between the elephant's eye and ear is a slitlike orifice communicating with a gland, known as the temporal gland, lying just beneath the skin. This gland is connected with the strange emotional state, known as musth, with which all male and some female elephants are periodically afflicted. An elephant on musth is either dull and morose or violently mad and extremely dangerous. Elephants drink 30 to 50 gallons of water a day, eat 300 or 400 pounds daily of whatever is to hand (no meat) and have a singularly inefficient digestive system that utilizes less than half of what is chumped away. So much for design and function. Elephants are creatures of affection. Carrington provides entrancing details about elephants' love-life—the romantic as well as the more torrid aspects. Elephant mothers are like other mothers; they can be horrid, so-so or touchingly devoted. The most famous example of elephant mother-love is the story of Ma Shwe (Miss Gold), told by J. H. Williams in his *Elephant Bill.* Ma Shwe's efforts to save her three-month-old calf in the flooded Taungdwin River in Burma—first by keeping it afloat in the raging torrent with her trunk, then by lifting the baby out of the water and depositing it on a rocky ledge and finally, having watched over it all night from the other side of the river, swimming across and completing the rescue—is one of the supreme instances of love triumphing over the biological instinct of self-preservation. Chapters on the elephant's ancestors and living relations are full of surprises. Fifty million years ago there were 350 species of the order *Proboscidea;* only two are left. Next of kin are sea cows and hyraxes, the latter (referred to in the Old Testament by the Hebrew word meaning "the hiding one," mistranslated as "coney") being an energetic, plump, thickset little animal (about the size of a rabbit) with a pointed muzzle and small, rounded ears. An entire section of Carrington's book is devoted to the relationship between the elephant and man. Man does not come off well. He has hunted the elephant (massacred would be a better word), eaten him, used him as a military engine, worshiped him, put him to work. Atrocious cruelty and ample stupidity have been the outstanding attributes of our record. The elephant in menageries, circuses and zoos has had a better time of it. He has had peanuts offered in prodigious quantities; he has been taught ridiculous tricks; children and grownups have adored him. When the London Zoo's famous Jumbo became "unreliable" and was sold to P. T. Barnum, the public reaction of horror and dismay led to leaders in *The Times*, to indignation meetings, to elegiac melodies and music hall laments ("Why Part with Jumbo, the Pet of the Zoo" was the most affecting), to questions in Parliament. (Jumbo sailed for America on March 25, 1882, on the *Assyrian Monarch*, and might have had an inspiring career in the New World except for the fact that he was hit by a train three months later.) A final chapter on elephant preservation and control shows that, despite ivory-poaching and legalized murder by big-game hunters, the prospect is pretty encouraging. The elephant will remain. We may all be thankful, because he occupies, as Carrington says, a special place in our hearts.

WHEELS ACROSS AMERICA, by Clarence P. Hornung. A. S. Barnes & Co. ($12.50). A nostalgically entertaining graphic history of vehicular transportation. It describes and illustrates carts and barrows, corduroy roads, stagecoaches and taverns, harnesses and springs, fast mail lines and luxurious equipages, turnpikes and post roads, Conestoga wagons, Concord coaches, "accommodations," "sociables" and omnibuses, ambulances and supply trains, coachees, barouches, phaetons, runabouts, surreys, buckboards, hansom cabs, hacks, cabriolets, governess carts, buggies, traps, vis-à-vis, landaulets, victorias, broughams, game wagons, four-in-hands and farm wagons, chariot streetcars, driving for pleasure and prestige. It also goes into old and new locomotives, the growth of railroads, freight yards and rail junctions, bridges, elevated trains, tunnels; also bicycles, tricycles, hobbyhorses, tandems, velocipedes, motorcycles; and finally steam phaetons, electric coupés, petrol cars, merry Oldsmobiles, Wintons, Fords, Duryeas, Stanley Steamers, Packards, Hudsons, Popes, Peerless "18" Tourings, Pierce Great Arrow Suburbans, Cadillac "T" coupés, Locomobile "I" Limousines, Princeton Runabouts, the early automobile shows, the perils of motoring, Indianapolis races, goggles, veils and dusters, and other delicious trivia.

EVERYDAY LIFE IN EGYPT IN THE DAYS OF RAMESSES THE GREAT, by Pierre Montet. St. Martin's Press ($8). A companion volume of Georges Contenau's *Everyday Life in Babylon and Assyria*, this work by a leading French scholar, now translated into English, presents a richly detailed, lively picture of how the people of Egypt passed their days in the period of the XIX and XX dynasties, from about 1320 to 1100 B.C. Drawing on the many ancient works and modern archaeological discoveries that relate the history of this carefully studied country, Montet describes the dwelling places, the seasons and festivals, the sense of time and the hour-to-hour schedule of the day, the family institutions (from marriage to the place of servants, slaves and domestic pets), toilet, dress, cooking, games, country life, the arts and professions, travel, the life of the Pharaoh, the army and warfare, scribes and judges, the ways of the temple, the rites of burial. Many illustrations.

FALLACIES IN MATHEMATICS, by E. A. Maxwell. Cambridge University Press ($2.95). The author has gathered a number of relatively elementary fallacies in different branches of mathematics, demonstrations that lead by guile to wrong but plausible conclusions. In this category are proofs that every angle is a right angle, that every point inside a circle lies on its circumference, that every triangle is an isosceles triangle, that O is greater than zero, that all numbers are equal, that $1/x$ is independent of x, that all lengths are equal, that plus one equals minus one, that pi equals zero, and so on. Anyone, says Maxwell, who has studied a little geometry, algebra and trigonometry for a few years, "should be able to follow most of the exposition with no trouble." But the principal merit of the book, namely a somewhat deeper analysis of the sources of certain fallacies, is accessible only to the more practiced and sophisticated mathematician.

THÉORIE MATHÉMATIQUE DES PHÉNOMÈNES ÉLECTRO-DYNAMIQUES, by André-Marie Ampère. Librairie Scientifique Albert Blanchard (900 francs). A week after Hans Christian Oersted's discovery of the action of a current on a magnet was announced to the French Academy in 1820, André-Marie Ampère demonstrated to the same body that two parallel wires carrying currents repel each other if the currents are in opposite directions and attract each other if the currents are in the same direction. For several years thereafter he pursued these researches and in 1825 published his results in what Sir Edmund Whittaker has called "one of the most celebrated memoirs in the history of natural philosophy." Although certain of his major conclusions—for example, that the propagation of electrodynamic forces is instantaneous—have been proven erroneous, the mathematical theory and the principles, which he based upon his experiments, founded the science of electrodynamics. In 1827 Ampère gave the fullest account of his theory in the historic memoir which is here reprinted. A concise and helpful preface by Edmond Bauer, professor at the Sorbonne, appraises Ampère's achievement, explaining how much he contributed to the progress of electrical knowledge and in what respects his reasoning went astray.

HISTORY AND PHILOSOPHY OF SCIENCE, by L. W. H. Hull. Longmans, Green and Co. ($5). A brief survey of scientific thought from antiquity to the present day; also a few sidelong glances at philosophy. A history of science that has only two or three sentences on Ampère and Faraday, that does not mention William Rowan Hamilton, that encompasses the work of Gauss, Riemann, Bolyai and Lobachevski in 50 words or so, that has no chapter on the 18th century, is certainly a curiosity, even if the author calls his work an "introduction," "not a detailed history of science," merely an attempt to "bridge the gap between science and the humanities by considering scientific ideas in a context of history and philosophy." Disclaimers do not make a book. Why write it in the first place?

OUR SUN, by Donald H. Menzel. Harvard University Press ($7.50). The first edition of this book was published 10 years ago; the quickened pace of astronomical research has since added much to our knowledge of the sun. As Menzel points out, spectroscopes and telescopes sent aloft in rockets have provided important data; new and more powerful coronagraphs, and theoretical advances have altered our concepts of the sun and solar activity (*e.g.*, it is now known that sunspots are not storms resembling terrestrial cyclones but are "the most quiet regions of the entire solar surface, stabilized by the presence of strong magnetic fields"). The work has been completely revised to incorporate these results, newly illustrated, and the format has been enlarged. A worthy addition to the excellent series of Harvard Books on Astronomy.

CLASSIC PAPERS IN GENETICS, edited by James A. Peters. Prentice-Hall, Inc. ($3.95). This paperback, which students of genetics as well as others interested in the history of scientific ideas will be glad to have, collects the major contributions to biology of Gregor Mendel, W. Sutton ("Chromosomes in Heredity"), William Bateson ("Physiology of Heredity"), G. H. Hardy (his famous little mathematical note proving the stability of gene proportions in a population), Thomas Hunt Morgan (sex-limited inheritance in *Drosophila*), A. H. Sturtevant (linear arrangement in sex-linked factors), Sewall Wright, L. C. Dunn, H. J. Muller (two fascinating papers, on variations due to change in the individual gene, and on gene transmutation by X-rays), T. S. Painter, G. W. Beadle, E. L. Tatum, Calvin Bridges and many others.

A Diderot Pictorial Encyclopedia of Trades and Industry, edited by Charles Coulston Gillispie. Dover Publications, Inc. ($18). A selection of 485 plates from Denis Diderot's famous 18th-century *Encyclopédie, ou Dictionnaire raisonné, des arts, et des métiers,* mainly illustrating manufacturing and the technical arts. The stylish plates, well reproduced on the whole, and most of them in full size, offer a panorama of agriculture and rural arts, the art of war, iron foundries and forges, extractive industries, metalworking, glass manufacture, masonry and carpentry, the weaving of textiles, paper and printing, leather-making, gold, silver and jewelry crafts, fashion, miscellaneous trades. Introduction and notes by the editor. An attractive, enlightening and entertaining publication.

A Treatise on Language, by Alexander Bryan Johnson. University of California Press ($1.50). A soft-cover reprint of an extraordinarily original and interesting essay on semantics written in 1836 by a wholly neglected American philosopher. Johnson was born in England in 1786 and emigrated to the U. S. with his parents 11 years later. He worked for a time in his father's general store in Utica, N. Y., then opened a glass factory and joined in other business ventures with Henry R. Schoolcraft (later eminent as a traveler, ethnologist and authority on American Indians) and finally embarked on a long and successful career as a banker. He published works in economics and finance, was active in politics and was admitted, though he never practiced, to the bar. He died in 1867, aged 81, having been thrice married and having fathered 11 children. The dominant interest of this many-sided man was in intellectual pursuits, especially philosophy, in connection with which he published a number of studies. None of them attracted attention, and they remained unknown until 1938, when Stillman Drake, a historian of science (also, by agreeable coincidence, a banker), chanced upon a copy of the *Treatise* and soon recognized its philosophical worth. Drake set up and printed by hand an edition of 42 copies for his friends; later he brought the work to the attention of the present editor, David Rynin, who prepared a fresh edition (first published in 1947) which contains, in addition to the full text of the 1836 *Treatise,* passages from the first edition of 1828, a useful introduction and other critical apparatus. Johnson anticipated insights of logic, semantics and the analysis of language not attained until the 1920's and later; his attacks on metaphysics and verbalism are astonishingly modern.

Notes

Population and Progress in the Far East, by Warren S. Thompson. The University of Chicago Press ($7.50). This revision of the author's *Population and Peace in the Pacific* examines the relationship of population growth to social and economic change in China, Japan, India and Southeast Asia.

Dictionary of Guided Missiles and Space Flight, edited by Grayson Merrill. D. Van Nostrand Company, Inc. ($17.50). A 700-page compendium that explains the most commonly used terms in the guided-missile and space-flight field today. The editor's preface expresses the hope that the work will be "directed increasingly toward the betterment of man rather than his destruction."

An Essay concerning Human Understanding, by John Locke. Dover Publications, Inc. ($4.50). An unabridged reprint in soft cover of Alexander Campbell Fraser's critical edition of one of the beacons of philosophy.

Our Mineral Resources, by Charles M. Riley. John Wiley & Sons, Inc. ($6.95). An introduction to economic geology.

Radiation Hygiene Handbook, edited by Hanson Blatz. McGraw-Hill Book Company, Inc. ($27.50). A compilation of information on the industrial, medical and research uses of radiation and atomic energy.

Circumpolar Arctic Flora, by Nicholas Polunin. Oxford University Press ($20.20). A handbook, based on 20 years of field work and research, describing the vascular plants of truly arctic regions. Three companion volumes on arctic botany are to follow.

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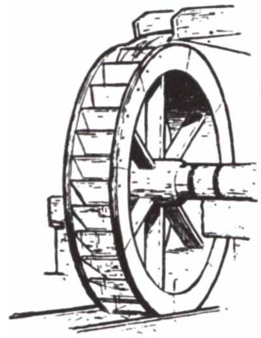

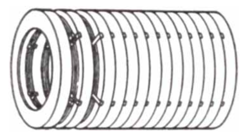

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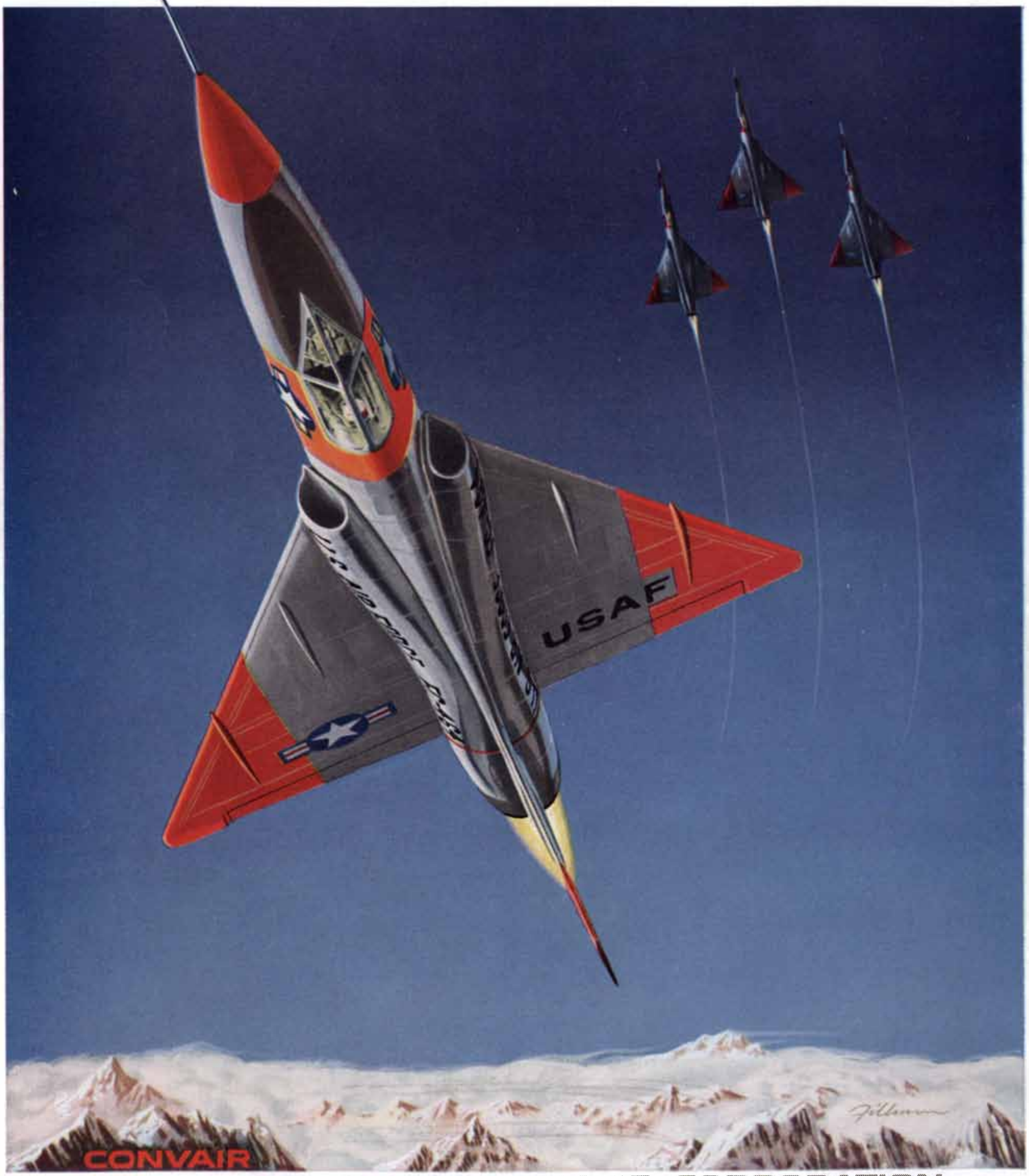

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